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Evaluation of Tomato (Solanum Lycopersicum L.) Response to Deficit Irrigation at Adola District, Guji Zone, Southern Ethiopia

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Abstract: Deficit irrigation is a new innovative water-saving approach that decreases irrigation volumes while increasing water productivity in areas with limited water resources. The two-year research project was carried out to evaluate the impact of deficit irrigation levels on tomato fruit yield and water productivity in the Adola district. The experiment was designed utilizing a randomized complete block design with three replications. The treatments included three levels of irrigation deficit (50% ETc, 75% ETc, and 100% ETc). The statistical study showed significant difference in tomato fruit yield and water productivity when different deficit irrigation levels were applied at ($p<0.05$). According to the two-year data analysis, increasing deficit irrigation levels to 50% ETc of the soil before the next irrigation decreases marketable fruit yield by 15.20 and 8.7%, respectively, when compared to the highest marketable fruit yield recorded at 100 and 75% ETc. Moreover, the study found that as moisture stress increased from crop water need (100% ETc) to irrigation deficiency level of 50% ETc, water use efficiency increased. At 50% ETc, the greatest water use efficiency (20.42 kg/m^3) was obtained. In general, the two-year complete analysis result of this study directed that applying 75% ETc level saves 25% more water available to irrigate more area without having a significant effect on tomatoes fruit yield with higher values of water usage efficiency. The water saved through deficit irrigation can be used to irrigate supplementary lands with greater profitability, resulting in a more efficient and reasonable use of land and water resources. According to the partial budget analysis, the biggest net benefit was (901,065 ETB ha^{-1}) recorded from 100% ETc treatment, followed by (853,070 ETB ha^{-1}) from 75% ETc treatment. In conclusion, the current study shows that conventional furrow irrigation with 75% ETc is more economically feasible than the other treatments used in Adola District and similar agro-ecology.

Keywords: Deficit Irrigation, Crop Evapotranspiration, Water Productivity and Tomato

1. Introduction

In the semi-arid regions of Ethiopia, agricultural production is reserved by water scarcity due to poor storage and insufficient use; Rainfall varies from year to year and year on year and the demand for evaporation is high. In areas where precipitation and distribution are not sufficient to support plant growth and development, an alternative method is to use rivers and groundwater for irrigation. Satisfying crop water requirements, though it maximizes production from the land unit, does not necessarily maximize the return per unit volume of water [11]. To increase agricultural production and living standards in semi-arid area of Ethiopia, more priority must be given to improving efficiency of water collection and utilization [7, 8, 13].

Deficit irrigation is one of the irrigation water management practices which are not necessarily based on full water required by the crops. It is an optimization approach whereby net profits are maximized by reducing the amount of irrigation water and crops are purposely allowed to tolerate some degree of water scarcity with insignificant yield reduction [4]. In circumstances of scarce water supply, application of deficit irrigation could afford greater economic returns than maximizing yields per unit of water.

Deficit irrigation increases the efficiency of water in agriculture and plays a very significant role in reducing competition for scarce water resources, reducing environmental degradation and providing of food security. Nevertheless, the amount of irrigation water reduction is based on crop characteristics and usually neither accompanied by nor insignificant yield loss that rises the water productivity [1]. Deficit irrigation practices vary from traditional water supplying practices. The manager needs to know the level of transpiration deficiency allowable without significant decrease in crop yields. Before implementing a deficit irrigation programme, it is necessary to know crop yield responses to water stress, either during defined growth stages or during the entire season [10].

In the study area, no work has been done and well known on the response of tomato to the deficit irrigation. Therefore this experiment was conducted to select best deficit irrigation level which allows water saving and improve tomato production in the study area.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted in the off-season of 2019 and 2021 at Adola Rede district of Guji zone, Oromia Regional State. The study area is located between 5°44'10”- 6°12'38” N latitudes and 38°45'10”- 39°12'37” E longitudes and at an altitude of 1500-2000 meters above sea level. The district is bordered by Girja district in the northeast, Anna sora in North West, Oddo shakkiso in the south, and Wodera in the Southeast direction. The long-term (thirty years) mean annual rainfall of the study area was 1126.0 mm with a maximum and minimum temperature of 21.4°C to 28.5°C and 9.9°C to 15.0°C respectively.

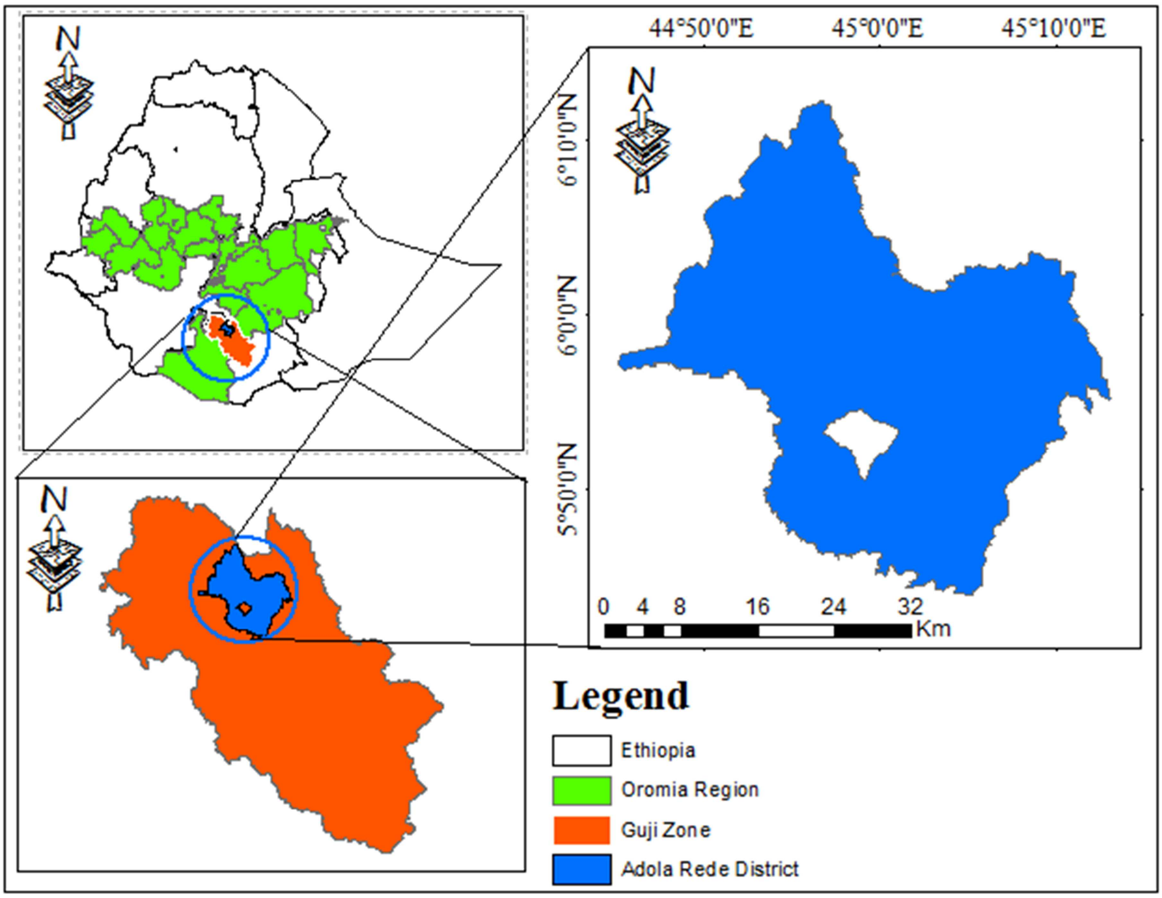

Figure 1. *Location Map of the study area.*

2.2. Climatic Characteristics

The average monthly (maximum and minimum temperature, Rainfall, relative humidity, wind speed, and sunshine hours) were collected from the neighboring meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software Table 1.

2.3. Soil Sampling and Analysis

The soil samples were collected from trial site with depth of 0-30cm and 30-60cm to determine bulk density, soil moisture, field capacity, permanent wilting point, soil texture, soil pH, Electrical conductivity (EC), Soil organic matter and soil organic carbon (OC) following standard laboratory technique. The particle size distributions in the soil profiles were determined using hydrometric method [15]. Soil pH was measured in 1: 2.5 soil: water mixture by using a pH meter. The electrical conductivity of the soil of the study area was measured by calculating the conductivity of saturated soil extract using an Electrical conductivity meter. Organic carbon content was determined by titration method using chromic acid (potassium dichromate + H_2SO_4) digestion [18]. Bulk density of the soil was computed using core sampler. Field capacity and permanent wilting point of the soil were analysed through pressure plate apparatus in the laboratory with a pressure of 1/3 bar (for field capacity) and 15 bars (for permanent wilting point). The soil was also measured for infiltration using the Double Ring Infiltrometers.

Table 1. *Long-term (2004-2018) monthly climatic data of the experimental area.*

Month	T_{min} (°C)	T_{max} (°C)	RH (%)	Wind speed (m/s)	Sunshine hour (hr)	ETo (mm/day)
January	9.5	29.5	49.1	0.4	7.9	3.17
February	11.0	30.4	47.1	0.5	7.6	3.4
March	13.7	30.0	52.1	0.4	7.0	3.6
April	15.5	27.5	61.4	0.3	5.6	3.36
May	16.2	25.8	73.0	0.3	5.1	3.18
June	14.4	24.0	71.1	6.2	3.3	2.63
July	14.0	22.9	71.1	0.5	2.3	2.34
August	13.9	24.0	72.9	0.4	3.8	2.74
September	14.1	26.0	70.5	0.4	4.8	3.08
October	14.2	25.5	73.6	0.5	4.3	2.9
November	12.4	26.2	68.5	0.5	6.5	3.12
December	10.4	27.0	59.4	0.3	7.6	3.08
Average	13.3	26.6	64.2	0.9	5.5	3.05

Source: National meteorological station (Tmin= Minimum temperature, Tmax= Maximum temperature, RH= Relative humidity, ETo = Reference Evapotranspiration)

2.4. Experimental Design and Treatments

The treatments included of three levels of water application (100%ETc, 75%ETc and 50%ETc) and by using one tomato variety as a testing crop. Full irrigation (100% ETc) shows that, the amount of irrigation water applied as estimated by Penman Monteith with CROPWAT computer program and 75% (ETc) and 50% (ETc) irrigation level meant 25% and 50% less of full irrigation requirement, respectively. The experiment was laid out in randomized complete block design with three replications. The amount of irrigation to fulfill the crop water requirement was computed with CROPWAT model using long term climatic data, soil and crop data. The amount of irrigation water to be applied at every irrigation application time measured by parshall flume. The total number of plots were 12 and each plot has 2.1 m length by 3 m width (6.3 m^2) in size consisting of four rows. Each row was accommodating 7 plants, and 28 plant per plot at the spacing of 0.75 m and 0.30 m between rows and plants, respectively. The net harvested area was 3.15 m^2 (2.1 rows x 1.5 m) from the two central rows. The spacing between plots and adjacent blocks were 1.5 m and 2 m, respectively.

2.5. Seedling Preparation, Transplanting and Crop Management

Tomato (Lycopersicon esculentum Mill.) seed Koshoro variety was sown at nursery prepared on farm land. The vigorous, strong, and healthy seedlings were grown in seedbed and transplanted to prepare area six weeks after germination on the first week. Treatment applications were started one week after transplanting for well establishment of the seedlings. The recommendation rate of fertilizer consisting of 200 kg ha^{-1} of urea and 242kg ha^{-1} of NPS were applied. NPS was applied at transplanting time in one application while urea was applied in split application 50% of urea was applied during transplanting and 50 % of the urea applied six weeks after transplanting. Additionally, significant agronomic practices were applied uniformly for all experimental plots as often as necessary.

2.6. Crop Water Requirement

Crop water requirement refers to the volume of water that needs to be supplied, while crop evapotranspiration refers to the volume of water that is lost through evapotranspiration [2]. For the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference crop evapotranspiration (ETo) and the effect of crop characteristics (Kc) are important [6]. The long term and daily climate data such as maximum and minimum air temperature, relative humidity, wind speed, sunshine hours, and rainfall data of the study area were collected to determine reference evapotranspiration, crop data like crop coefficient, growing season and development stage, effective root depth, critical depletion factor of tomato and maximum infiltration rate and total available water of the soil were determined to calculate crop water requirement using CROPWAT model using the following equation.

$$ETc = ETo \times Kc \quad (1)$$

Where, ETc = crop evapotranspiration, Kc = crop coefficient, ETo = reference evapotranspiration.

2.7. Irrigation Water Management

The total available water (TAW), stored in a unit volume of soil was determined by the expression:

$$TAW = 1000\sum(\theta FC - \theta PWP) * BD * Zr \quad (2)$$

Where: TAW: volumetric total available water in the root zone (mm/m) FC: volumetric moisture content at field capacity (m^3/m^3) and PWP: volumetric moisture content at permanent wilting point (m^3 /m^3). BD: bulk density (gm. /cm^3): Zr= maximum effective root zone depth (mm)

Net Irrigation Water Requirement obtained from the expression below

$$I_{net}(mm)= ETc(mm)- Peff(mm) \quad (3)$$

Where: I net= Net irrigation requirement

ETc=Crop water requirement

Peff= Effective rainfall

The depth of irrigation supplied at any time was obtained from the equation below

The gross irrigation requirement was obtained from the expression below

$$Ig = \frac{In}{Ea} \quad (4)$$

Where: Ig= Net irrigation

In= Net irrigation requirement

Ea= Application efficiency

The field water application efficiency for surface furrow irrigation is normally taken as (60%).

The time required to deliver the desired depth of water in to each furrow was calculated using equation

$$T=\frac{Dap\times w\times l}{360\times q} \quad (5)$$

Where; Dap is depth of water applied (cm), t is application time (hr), l is flow length (m) q is flow rate ($l\ s^{-1}$) and w is furrow spacing (m).

2.8. Water Productivity

Water productivity was estimated as a ratio of fruit yield of tomato to the total crop water consumption by evapotranspiration (Etc) through the growing season and it was calculated using the following equation [19].

$$CWP = \frac{Y}{ET} \quad (6)$$

Where, CWP is crop water productivity (kg/m^3), Y tomato fruit yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

2.9. Data Collection and Analysis

Yield data were collected from the two central rows out of four plant row per plot to avoid border effect. Plant height, number of fruit per plant and cluster number were collected from selected five plant sample of the two central rows.

The two years yield and yield component data were collected and subjected to ANOVA test using Genstat 18th edition software. The overall variability and effects of the treatment on yield and yield component parameters were considered as significant when $p< 0.05$. Least significant difference (LSD) test was applied for statistically significant parameters to compare means among the treatments.

2.10. Economic Analysis

To measure the costs and benefits associated with fuel, labor, management and irrigation water, the partial budget technique as described by CIMMYT was applied [5]. The net income (NI) was calculated by subtracting total variable cost (TVC) from total Return (TR) as follows:

$$NI = TR - TVC \quad (7)$$

3. Results and Discussion

3.1. Analysis of Selected Soil Physicochemical Properties

The soil physicochemical properties of the trial site was analyzed and the Summary result is given in Table 2. Accordingly, the particle size distribution revealed that the soil textural class of the study area was loam. The experimental site has the average field capacity (FC) of 29.3% and permanent wilting point (PWP) 21.6% in weight base. The average total available water (TAW) by volume percentage is also estimated as 106.26 mm/m. The basic infiltration rate of the soil was 16 mm/hr.

3.2. Effect of Deficit Irrigation on Yield Component, Yield and Water Productivity

3.2.1. Effect of Deficit Irrigation on Plant Height

There is significance difference in plant height between experimental treatments at ($P<0.05$) level Table 3. The maximum plant height (81.72 cm) was perceived at 100% ETc followed by 75% ETc (76.35 cm). But, statistically there is no significance difference between the two treatments. On the other hand the minimum plant height (73.02 cm) was recorded at 50% ETc. The highest value obtained in vegetative growth under treatment 100% ETc might be due to the availability of soil moisture at optimum level [12]. The present result is in agreement with the results of Selamawit, K. who reported that the maximum plant height was obtained at 100% ETc [14].

Table 2. *Result of selected soil physico-chemical properties.*

Soil characteristic parameters	Results
Basic Infiltration rate (mm/hr)	16
Sand (%)	38
Silt (%)	41
Clay (%)	21
Texture	loam
Soil pH	7.0
Electrical conductivity (dS/m)	0.474
Organic carbon (%)	3.6
Bulk density (g/cm^3)	1.38
Field capacity vol. (%)	29.3
Permanent wilting point vol. (%)	21.6
TAW (mm/m)	106.26

3.2.2. Effect of Deficit Irrigation on Fruit Number per Cluster

Different levels of deficit irrigation treatment significantly ($p<0.05$) affected fruit number per cluster of tomato. A declining trend was observed in fruit number per cluster of tomato of due to increasing levels of deficit irrigation level. The maximum fruit number per cluster (84.75) was recorded at irrigation treatment of 100% ETc (Table 3) which is statistically non-significant with deficit irrigation at 75% ETc. The minimum fruit number per cluster (58.09) was recorded at a 50% ETc deficit irrigation treatment (Table 3). Increasing soil moisture deficit level to 50% ETc leads to a reducing of 24.43 and 31.46% as compared with the maximum fruit number per cluster recorded at 75 and 100% ETc, respectively.

Table 3. *Effect deficit irrigation on yield, yield component and water productivity.*

Deficit Levels	PH (cm)	FNPC	MFY (t/ha)	UMFY (t/ha)	WUE (Kg m^{-3})
50 % ETc	73.02^{b}	58.09^{b}	38.81^{b}	5.210	20.42^{a}
75 % ETc	76.35^{a}	76.87^{a}	42.79^{ab}	5.916	15.01^{b}
100 % ETc	81.72^{a}	84.75^{a}	45.77^{a}	5.704	12.04^{c}
LSD (5%)	5.98	14.87	4.77	1.145	1.91
CV (%)	6.3	16.1	8.9	16.2	9.6

Where; PH: plant height, FNPP: fruit number per plant, FNPC: fruit number per cluster, MFY: marketable fruit yield, UMFY: unmarketable fruit yield, CV: coefficient of variation and WUE: water use efficiency

3.2.3. Effect of Deficit Irrigation on Marketable Fruit Yield

The average means of the two year study revealed that different levels of deficit irrigation significantly ($p<0.05$) affected marketable fruit yield of tomato in the study area. Marketable fruit yield of tomato revealed a decreasing trend as the moisture stress increased from 100% ETc to 50% ETc. The maximum marketable fruit yield (45.77 t/ha) was recorded at 100% ETc or full irrigation (Table 3) which was statistically similar to that of 75% ETc. On the other hand, the minimum marketable fruit yield (58.09 t/ha) was recorded at 50% ETc. The present finding revealed that increasing deficit irrigation levels to 50% ETc of the soil before the next irrigation leads to a decrease of marketable fruit yield by 15.20 and 8.7% as compared with the maximum marketable fruit yield gained at 100 and 75% ETc, respectively. Similar findings were also described that tomato is sensitive to water deficit that affects growth and yield of the crop [16]. The current finding is also in agreement with the findings of Selamawit K., who stated that increasing irrigation deficit level which leads to a longer irrigation interval significantly affected marketable fruit yield of tomato [14].

3.2.4. Effect of Deficit Irrigation on Unmarketable Fruit Yield

The result revealed that deficit irrigation treatment had no significant effect on unmarketable yield of tomato. Numerically the unmarketable fruit yield (5.9 t/ha) was recorded at a 75% ETc (Table 3) and followed by (5.7 t/ha) under treatment of 100% ETc. On the other hand, the minimum unmarketable fruit yield (5.2 t/ha) was recorded at deficit irrigation treatment of 50% ETc (Table 3).

3.2.5. Effect of Deficit Irrigation on Water Use Efficiency

Pooled means of two-year results revealed that different levels of deficit irrigation significantly ($p<0.05$) affected the water use efficiency of tomato in the study area. The study revealed that water use efficiency shown an increase trend as the moisture stress increased from crop water requirement (100% ETc) to irrigation deficit level of 50% ETc. The maximum water use efficiency (20.42 kg/m^3) was recorded at a 50% ETc (Table 3). On the other hand, the minimum water use efficiency (12.04 kg/m^3) was recorded at treatment of 100% ETc which is statistically similar to that of 75% ETc (Table 2). Although, the effects of deficit irrigation on tomato fruits yield may be different and many investigators such as [9, 17] have demonstrated that deficit irrigation saves substantial amounts of irrigation water and increases in water productivity. These indicated that part of the water used under 100% ETc leads to inefficient utilization of the irrigation water by the crop [3].

3.3. Economic Comparison of Treatments

As shown in the table 4, the maximum net benefit value of 901065 birr/ha was obtained from 100% ETc followed by 853070 birr ha^{-1} from 75% ETc treatment. The lowest net benefit 765880 birr ha^{-1} was obtained from 50% ETc treatment. The highest benefit to cost ratio was obtained under treatment 75% ETc (10.7). This result revealed that applying furrow irrigation with 75% ETc is economically feasible for tomato production in Adola area of the Guji zone.

Table 4. *Economic analysis of tomato under different treatments.*

Treatments	Marketable fruit yield (Kg ha^{-1})	Total Return (ETB /ha)	Total cost (ETB /ha)	Net Income (ETB /ha)	Benefit-cost ratio
50 % ETc	38810	853820	87940	765880	9.7
75 % ETc	42790	941380	88310	853070	10.7
100 % ETc	45770	1006940	105875	901065	9.5

ETB = Ethiopian Birr

Note: - The price of tomato taken was 22 ETB Kg^{-1}.

4. Conclusion and Recommendation

Most of the farmers in Adola rede District depend on rain-fed agriculture. But rainfall of the study area is very erratic, and drought occurs very commonly. Hence, effective use of irrigation water using appropriate irrigation system and management is an important attention in the moisture stress areas of the region to increase water productivity and reduce the environmental impacts of irrigation.

Based on the result of this experiment the maximum marketable fruit yield (45.77 t/ ha) was recorded at 100% ETc or full irrigation which was statistically similar to that of 75% ETc. Conversely, the minimum marketable fruit yield (38.81 t/ha) was recorded at 50% ETc. The present study revealed that tomato yield and yield components shown a decreasing trend when deficit irrigation increased from 100% ETc to 50% ETc. The yield and yield components were statistically similar when irrigated at 75 and 100% ETc. However, water use efficiency shown an increase tendency as the moisture stress increased from crop water requirement (100% ETc) to irrigation deficit level of 50% ETc.

In general the two years overall analysis result of this study shown an Application of 75 % ETc level save 25 % more water being available to irrigate additional land without a significant effect on fruit yield of tomato with greater values of water use efficiency. Under limited water resource conditions, the main goal is to improve water productivity through minimizing water wastage and enhancing the crop water productivity through different practices. Based on the partial budget analysis, the highest net benefit of 901,065 ETB ha^{-1} was recorded from 100% ETc treatment and followed by 853,070 ETB ha^{-1} with 75% ETc.

In conclusion, the present study points out that convectional furrow irrigation application with 75% ETc is economically and more profitable than other treatments around Adola Rede district and similar areas.

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