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Original Paper

Effect of Phenological Basis Deficit Irrigation on Yield and Water Use Efficiency of Tomato (*Solanum lycopersicon* L.)

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Abstract— **The availability of water is a major concern in regions with limited water resources. In such regions, the focus of irrigation management shifted from producing per unit area to producing per unit of water consumed, water productivity. An experiment was carried out, for two consecutive years(2020 and 2021) at the research farm of Shire-Maitsebri Agricultural Research Center, Tselemty district, Tigray, Ethiopia to exmine the response of tomato to deficit irrigation at various growth stages. A randomized complete block design with three replications was used. Combination of three irrigation regimes (100%, 50%, and 25% of full irrigation requirement) and four FAO-defined tomato growth stages (initial, developmental, mid, and late seasons) were considered to form a total of nine treatments. Data on agronomy and irrigation water were collected and analyzed statistically. The results revealed that reducing irrigation amount up to 75% during the development growth stage significantly decreased marketable yield by 66.5%. However, the highest water use efficiency (9.2 kg/m3) was achieved by reducing irrigation amount by 75% during the end-growth stage of tomatoes. Treatments with the lowest water use efficiency (3.5 kg/m3) were those receiving 75% less irrigation amount than the full requirement during the development growth stage. Reducing irrigation to less than 75% of the full requirement during tomato development stages can greatly impact marketable yield and water use efficiency. Therefore, the tomato crop is highly susceptible to water stress when receiving more than 50% of the full irrigation requirement during its developmental growth stage.**

Keywords— Deficit Irrigation, Marketable Yield, Tomato, Water Use Efficiency

I. INTRODUCTION

The sustainable use of water in agriculture has become a prime subject. Embracing techniques for saving irrigation water and keeping suited yields may contribute to the renovation of this ever-confined resource [1]. In areas of water shortages and long summer season droughts, maximizing water productivity can be greater beneficial to the farmer than maximizing crop yield. A latest revolutionary technique to saving agricultural water is deficit irrigation (DI). It is miles a water-saving method below which plants are exposed to a positive level of water stress either during a specific growth stage or at whole growing season [2,3 and 4]. The expectancy is that any yield discount could be insignificant as compared with the benefits of gained from the conservation of water.

The aim of deficit irrigation is to improve crop water use efficiency (WUE) via reducing the amount of water used [5,6]. The deficit irrigation approach irrigates the soil with less water than is required for evapotranspiration and uses suitable irrigation schedules, which might be commonly derived from subject trials [7,8 and 9]. Crop tolerance to deficit irrigation during the growing season changes with the phonological stage [10] and [11]. Optimum irrigation schedules are frequently primarily based on water productiveness. Deficit irrigation techniques have the capability to optimize horticultural water productivity. Nevertheless, the consequences of deficit irrigation on yield are crop-particular [12,13 and 14]. The idea for the success control of irrigation water depends on how plants address mild water stress.

Therefore, know-how of the responses of various plants to water stress is crucial to know-how the management modifications that are important for lengthy-term productivity. Enormous horticultural production areas are located in hot and dry climates because of their favorable climate situations. But,the soil water deficit is as a substitute common in those areas. Water-saving irrigation strategies including deficit irrigation may additionally permit for the optimization of water productivity in those locations by way of stabilizing yields and enhancing production [12].

Tomato (Solanum lycopersicon L) is one of the widely cultivated vegetable plants in Tigray, Ethiopia. The utility of regulated deficit irrigation (DI) techniques to this crop may considerably result in saving irrigation water [15]. Research findings confirmed contradictory on the effects of deficit irrigation techniques for tomato plants. Some researchers stated that the application of direct irrigation for the complete or partial developing season of tomatoes minimizes fruit losses and maintains excessive fruit count [16 and 17]. But, [18] found a giant reduction in dry mass yield for a glasshouse tomato cultivar using deficit irrigation. On the other hand, [19] did not find a reduction within the tomato fruit yield. Despite the fact that the outcomes of deficit irrigation (DI) on tomato fruit yield may be unique. Many investigators have confirmed that deficit irrigation saves good quantities of irrigation water and increases water use efficiency (WUE). Therefore, the aim of this subject trial became to investigate the effect of growth stage -based deficit irrigation on yield and irrigation water use efficiency in tomato.

II. METHODS AND MATERIAL

A. Description of the Experimental Site

A field experiments were conducted in loamy sand soil at the Maitsebri Agricultural Research Farm ,Tselemty district; during the 2020 and 2021 off-seasons. The experimental site is situated on 38.15°East longitude and 13.5°North latitude and 980 m above the sea level. The long-term mean maximum and minimum temperature of the area are 42.3°C and 13.2°C respectively. The average monthly annual rainfall in the area is 340.5 mm, characterized by a mono-modal type with rainy seasons from June to mid-September. The soil of the area is characteristically well-drained, light to dark brown in color and deep in depth and continuously cultivated. The soil water contents, calculated according to gravimetrical methods (w/w %) at field capacity and permanent wilting point were 38.6% and 29.8% respectively in root zone of the soil.

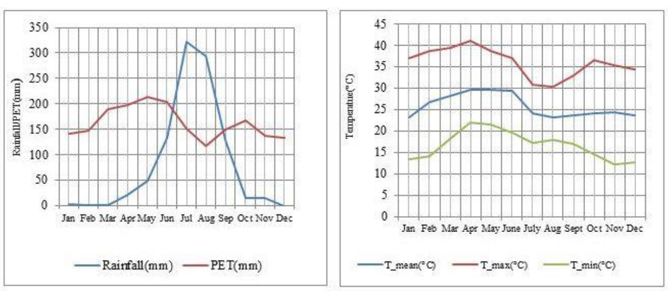

Fig. 1 Monthly mean rainfall , Potential Evapotranspiration(PET) and Temperature

B. Experimental Design and Treatment Set up

The treatments studied under this field experiment was arranged as indicated in table I below.

TABLE II. TREATMET SET-UP

Treatment Code	Treatment combination
T1	Full irrigation requirement (100%ET_c) at all the growth stages
T2	50%ETc at initial stage and full amount at other stages
T3	50%ETc at development stage and full amount at other stages
T4	50% ETc at mid stage and full amount at other stages
T5	50% ETc at maturity stage and full amount at other stages
T6	25%ETc at initial stage and full amount at other stages
T7	25%ETc at development stage and full amount at other stages
T8	25 ETc at mid stage and full amount at other stages
T9	25%ETc at maturity stage and full amount at other stages

C. Test crop Characterization

In this this study tomato-improved variety (Melkashola variety) was taken as test crop and the total growing period was four months (120-125 days) from transplanting. Based on FOA references[20 and 21) and previous research findings from our research center , the initial , developmental , mid and late/end growth stage of tomato correspond to 24days from transplanting ,36days from the end of initial stage, 40 days from the end of developmental stage and 24 days from the end of mid growth stage respectively.Tomato seedlings were transplanted in to a plot size of 9.6 m^2 after 30 days of nursery life on December 9, 2020 and December 12, 2021 of seasons. The spacing between plots and replications were 1.5m and 2m respectively. Crop data such as maximum root depth, crop coefficient and crop moisture depletion level and crop growth stages of tomato was taken from the FAO irrigation and drainage guidelines[21] to estimate the crop water requirement of tomato.

D. Estimation Crop Water Requirement

In this study, the estimation of irrigation water requirements has been based on the climatic, crop, and soil conditions of the experimental site. The FAO Penman-Monteith method [21 and 22] was used to define reference evapotranspiration and irrigation requirements with the help of a computer program called "CROPWAT version 8.0." Irrigation was applied when the water lost by ETc in the root zone reached the predetermined level (30% of the available water depletion). The irrigation volumes (Table III) were calculated by subtracting the effective rainfalls from the ETc, as calculated using Equation (1) [21]:

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

Where, the reference crop evapotranspiration (ETo) was calculated using the Penman-Monteith equation, and Kc is the crop coefficient, as taken from FAO guidelines and previous research findings in our research center for our experimental site.

The seasonal tomato water received, under the different irrigation treatments, was calculated using the soil water balance equation (2) [23].

$$ET = I + P + Cr - R - D \pm \Delta S \quad (2)$$

Where, I is the irrigation water amount (mm); P is the effective rainfall (mm); Cr is the capillary rise (mm); R is the amount of runoff (mm); D is the amount of drainage water (mm) and ΔS is the difference between soil water content values, determined gravimetrically, at planting and at harvesting (mm) in the first 0.6 m depth. In this study, Cr was considered to be zero due to the high depth of groundwater. Surface runoff was assumed to be negligible because there was no rainfall in both years to cause run-off. Drainage below the root zone was assumed negligible, since water applied was equal to water deficit in 0–0.6 m soil profile of the full irrigated treatment and rainfall amounts were not sufficient to bring the soil moisture level over the field capacity within the root zone during the growing season. Finally, the difference between soil water content values at planting and at harvesting was also negligible.

E. Data *Collection*

1) Climatic data

Before the start of the experiment, secondary data such as climatic data of 20 years on rainfall (R.F.), minimum and maximum temperature, relative humidity (RH), wind speed (WS), and sunshine hours (SH) were collected from the nearby meteorological station. Irrigation efficiency for furrow irrigation, root depth of the tomato crop, tomato crop growth stages and their respective lengths of period, and soil infiltration rate data were also collected from previous records and FAO guidelines.

2) Soil Physical Properties

Soil sampling was carried out at the experimental site to measure soil physical properties. Soil texture was determined using the pipette method [24,25 and 26] at 0–0.25, 0.25–0.5, 0.5–0.75, and 0.75–1.00 m depths for each of the three soil profiles. Bulk density was determined by the core method [27] for each depth in the three soil sampling depths. Soil water content was determined from soil samples taken at the same locations using the gravimetric method. Field capacity and permanent wilting points were considered at 0.3 and 15.0 bars, respectively[28]. The soil basic infiltration rate was determined in the field using the double-ring infiltrometer method as described by predefined approach [7].

TABLE III.SOIL PHYSICAL PROPORTIES OF THE EXPERIMENTAL SITE

Soil properties	**Soil depth (m)**				
	0-0.25	**0.25-0.5**	**0.5-0.75**	**0.75-1.0**	**Average**
Particle size distribution					
- Sand (%)	60	56	54	56	56.5
- Clay (%)	16	18	18	18	17.5
-Silt (%)	24	26	28	26	26
-Textural Class	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
Bulk density (g/cm^3)	1.38	1.34	1.33	1.31	1.34
Field capacity (weight basis %)	30.3	37.8	38.9	38.6	36.4
Permanent wilting point (weight basis %)	24.8	22.2	25.3	29.8	25.53
Total available water (mm/m)					**145.28**

F. Yield and *Yield* Components

Yield data were collected from three central furrows in a tomato planting plot. The number of fruits per plant and total fruit number were collected using five plant samples from the three central rows. Yield and other yield component parameters were collected, and the analysis was performed with Gen-Stat software.

G. Water-Use Efficiency (WUE)

The phrase water use efficiency refers to the link between growth (especially dry matter output) and water use [29 and 8]. Water use efficiency (WUE) is defined as the yield per unit of water consumed by the plant. The total seasonal amount of water consumed by the crop per treatment was recorded, and crop water use efficiency (kg/m^3) for each treatment was computed by dividing marketable yield (kg) by total seasonal irrigation water consumption (m^3).

H. Data *Analysis*

An analysis of variance was performed following the procedures of Freeman, and Gomez [230 and 31] using Gen Stat statistical software. Treatments showing significant differences were subjected to Duncan's multiple range test (DMRT) for mean separation at a 95% confidence level**.**

III. RESULTS AND DISCUSSIONS

A. Water consumption and irrigation demand

A tomato-improved variety (Melkashola variety) was planted on December 9,2020 and December 12, 2021, off-seasons. Total precipitation during the months of December to May in both years was insignificant. As a result, throughout the growing period of the crop, the only source of water was irrigation. The irrigation frequency was scheduled at four days for the initial and development growth stages ; five and six days for the mid and late-maturity growth stages, respectively. Totally, 27 irrigation events were made during the crop-growing period (124 days). The amount of net applied irrigation water according to treatments is presented in **Error! Reference source not found.**.

Based on the CROPWAT 8 model output, the whole seasonal irrigation need in the area for tomato crop was found to be

678.13 mm (6781.3 m^3/ha) for the non-stressed treatment(100%ETc at all groth stages), as shown in Table III. Tomato crop requires 400 - 700 mm of irrigation water for optimum yields, depending on climate [32 and 33]. **Error! Reference source not found.** shows the amount of water applied to water-stressed treatments and the water-savings as compared to the controlled treatment (100% crop evapotranspiration at all growth stages). The amount of water applied to non-stressed irrigation treatments (100% crop evapotranspiration at all growth stages) was agreed with the range of tomato crop water requirement stated above[32 and 33].

TABLE IV. SEASONAL NET IRRIGATION DEPTH APPLIED TO TREATMENTS

Treatment combination	Net depth ofirrigation(mm)
100% Crop evapotranspitation (ET_c) at all the growth stages(T1)	678.1
50%ETc at initial stage and full amount at other stages(T2)	644.8
50%ETc at development stage and full amount at other stages(T3)	601.0
50% ETc at mid stage and full amount at other stages(T4)	536.4
50% ETc at maturity stage and full amount at other stages(T5)	592.7
25%ETc at initial stage and full amount at other stages(T6)	628.1
25%ETc at development stage and full amount at other stages(T7)	561.4
25 %ETc at mid stage and full amount at other stages(T8)	464.5
25%ETc at maturity stage and full amount at other stages(T9)	550.0

TABLE V. ANALYSIS OF VARIANCE ON YIELD AND YIELD PARAMETERS OF TOMATO

Source of Variation	50%DFl	50%DFS	FNPP	FL	FC	Myld	UnMyld	WUE
Treatments	NS	NS	NS	***	**	*	***	***

NS=Not significant**; *, **, ***** indicates significant at 0.05, <0.01 and <0.001levels respectively; DFl, Days to flowering, DFS, Days to fruit setting, FL, Fruit length, FC, Fruit circumference ,FNPP, fruit number per plant , Myld, Marketable yield, UnMyld, Unmarketable yield, WUE, Water use Efficiency

TABLE VI. TREATMENTS MEAN COMPARISON OF RELEVANT PARAMETERS OF TOMATO

Trts	50%DFl(days)	50%DFS(days)	FNPP	FL(cm)	FCir(cm)	Myld(Q/ha)	UnMyld(Q/ha)
T1	57.83[a]	67.83[a]	14.21[a]	7.47[a]	12.12[a]	431.9[a]	44.10[a]
T2	54.83[a]	67.17[a]	15.42[a]	5.61[bcd]	10.59[ab]	413.9[a]	17.31[a]
T3	57.17[a]	68.00[a]	14.10[a]	4.65[d]	8.48[c]	394.1[a]	16.53[a]
T4	57.17[a]	67.50[a]	16.93[a]	6.75[ab]	11.53[a]	419.1[a]	18.0[a]
T5	57.50[a]	69.17[a]	15.94[a]	5.86[bcd]	11.27[a]	386.4[a]	18.53[a]
T6	59.17[a]	65.60[a]	14.01[a]	6.07[bc]	10.77[ab]	386.1[a]	14.48[a]
T7	55.00[a]	68.17[a]	12.86[a]	3.48[e]	6.42[d]	144.3[b]	101.88[b]
T8	56.17[a]	67.33[a]	13.82[a]	5.09[cd]	9.04[bc]	365.2[a]	17.92[a]
T9	54.83[a]	68.00[a]	16.86[a]	5.88[bcd]	11.79[a]	427.3[a]	25.52[a]
Mean	56.63	67.85	14.91	5.65	10.22	382.7	21.0
LSD	Ns	ns	ns	1.136	1.756	142	32.11
C.V	6.3	4.6	39.2	17.1	14.6	32.7	30.50

Columns assigned with the same letter have not significant difference. Trts, Treatments, DFl, Days to flowering, DFS, Days to fruit setting, FL, Fruit length, FCir, Fruit circumference, FNPP, Fruit number per plant, Myld, Marketable yield, UnMyld, Unmarketable yield, WUE, Water use Efficiency ,LSD,least significance difference,C.V, Coefficient of variance

B. Yield *and* Growth Parameters

1) Fruit length and fruit circumference

The two-years combined statistical analysis revealed that varying irrigation levels had a significant impact on tomato plant fruit length and fruit circumference (p<1%). However, we found no significant effects among treatments on days to 50% flowering, days to 50% fruit setting, or fruit number per plant, as shown in **Error! Reference source not found.**. In this experiment, we discovered that fruit length, fruit circumference, marketable yield) and water use efficiency was affected by irrigation tratmenrs applied at different growth stages of tomato (**Error! Reference source not found.**).

Treatments that irrigated with full amounts of irrigation water at all growth stages produced the longest fruit (7.47 cm) and largest fruit circumference (12.12 cm). The treatments that applied 25% of the full crop water demand/irrigation requirement at the development growth stage produced the shortest fruit length (3.48 cm) and fruit circumference (6.42 cm) (**Error! Reference source not found.**).

C. Marketable and unmarketable yields

Error! Reference source not found. shows that various irrigation amounts at different growth stages had a significant effect (p<0.5) on tomato marketable yields. The unmarketable yield was also considerably affected (p < 0.1%). The results revealed that the lowest marketable yield (14,430 kg/ha) and the largest unmarketable yield (101,88 kg/ha) were obtained at treatments irrigated with 75% less water than the full water requirement during development growth stage (**Error! Reference source not found.**). Reducing the amount of full irrigation water required by up to 75% during the developing growth stage of tomatoes results in a 66.5% yield loss when compared to fully irrigated treatments at all growth stages.As demonstrated in **Error! Reference source not found.**, there is no statistically significant difference between treatments irrigated with varying levels of irrigation amounts at different growth phases, with the exception of reducing the amount of water by up to 75% during the tomato development growth stage. The main finding is that lowering irrigation water at the developmental growth stage by up to 75% of the full irrigation requirement resulted in a large yield loss (66.5% loss) and a high unmarketable yield output. In contrast, we find that lowering irrigation water by 75% at any growth stage other than the developmental growth stage results in no substantial yield loss (**Error! Reference source not found.**).

D. Irrigation Water Savings

1) Water Use Efficiency (WUE)

Table VII shows that, the application of varied irrigation volumes at different growth stages resulted in a very significant difference ($p \leq 0.1\%$)level. The highest and lowest water usage efficiency values were 9.2 kg/m^3 and 3.5 kg/m^3 obtained from plots that were irrigated with 25% ETc at maturity and development growth stages, with the full amount at all other stages, respectively.

IV. CONCLUSION

Rainfall depth in the research area is low, and its distribution is uneven and inconsistent, making it difficult to achieve the daily crop evapotranspiration demand. Under these circumstances, the need to use available water efficiently is undeniable. This study focuses on comparing irrigation management options that can help save water and boost water use efficiency with no or minimal production loss in northern Ethiopia's semi-arid climate, notably in the study area-Tselemty district, Tigray.Results confirmed that different irrigation treatments significantly influenced tomato yield, water use efficiency, and other parameters. The highest marketable yield obtained from applying a full amount of irrigation at all growth stages of tomato has no significant difference compared to applying less water at different growth stages except at the development stage. In this study, we have found that the developmental growth stage of tomatoes is the most sensitive growth stage to water stress. Reducing the amount of irrigation water required up to 75% of the full amount at this growth stage can adversely affect marketable yields (by 66.5%) and water use efficiency. In terms of marketable yield and water use efficiency, we have not seen a significant difference among treatments except for the 25% irrigation amount applied at the development growth stages of the crop. Therefore, the results of this study verified that we can reduce the amount of irrigation water up to 75% of the full amount required at any growth stage, except the developmental growth stage, to save a substantial amount of water in the case of limited water availability conditions.

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