

Effect of growth stage -based water stress on yield and water use efficiency of tomato at Tselemty District, Tigray, Ethiopia

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Abstract: Water availability is a strong challenge especially under water resource scarce areas. In water-scarce regions as is of Ethiopia, optimum yield and enhanced water use efficiency (WUE) of crops can be obtained if the best irrigation water management strategy is adopted. The deficit irrigation practices become the main adopting policies for water saving. A two year field experiment carried out at Maitebri Agricultural Research Center, Maitsebri experimental farm during 2019 and 2020 off seasons to find out the effect of growth stage based water stress on yield, yield parameters and WUE of tomatoes. Randomized complete block design (RCBD) with three replications was used in the field trial. Three irrigation levels (100%, 50%, and 25% crop evapotranspiration) and FAO based four growth stages of tomato (initial, developmental, mid and late seasons) were considered as treatments. Data on marketable yield, other yield parameters and crop WUE were recorded. Results showed us, that reducing the full crop water requirement up to 75% at developmental growth stage can severely reduce the marketable yield up to 66.5%. On the other hand, the highest in WUE (9.2 kg m^{-3}) was obtained by reducing the full crop water requirement by 75% at the end growth stage of tomato. The lowest in WUE (3.5 kg m^{-3}) was obtained from treatments that were irrigating 75% below the full crop-evapotranspiration at developmental growth stage. Generally, reducing irrigation water below 75%ET_c during developmental growth stage of tomato can significantly influence the marketable yield, WUE and yield parameters. Therefore, tomato crop is very sensitive to water stress beyond 50% of the full crop evapotranspiration (ET_c) at its developmental growth stage.

Keywords: growth stages, marketable yield, tomato crop, water stress, water use efficiency

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1 Introduction

The sustainable use of water in agriculture has become a major anxiety. Embracing of strategies for saving irrigation water and maintaining acceptable yields may contribute to the preservation of this ever more restricted resource (Topcu et al., 2007). In areas of water shortage and long summer droughts, maximizing water productivity may be more beneficial to the farmer than maximizing crop yield.

A recent innovative approach to save agricultural water is conventional deficit irrigation (DI). It is a water-saving strategy under which crops are exposed to a certain level of water stress either during a particular developmental stage or throughout the whole growing season (Pereira et al., 2002). The expectation is that any yield reduction will be insignificant compared with the benefits that are gained from the conservation of water.

The goal of DI is to increase crop water use efficiency (WUE) by reducing the amount of water applied (Kirda, 2002). The DI technique irrigates the root zone with less water than that is required for evapotranspiration and makes use of suitable

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irrigation schedules, which are usually derived from field trials (Oweis and Hachum, 2001). Crop tolerance to DI during the growing season changes with the phenological stage (Istanbulluoglu, 2009). Optimal irrigation schedules are often based on water productivity (Oweis and Zhang, 1998). DI strategies have the potential to optimize horticultural water productivity. Nevertheless, the effects of DI on yield or harvest quality are crop specific (Costa et al., 2007). Information on how different crops cope with mild water stress forms the basis for a successful management of irrigation water.

Therefore, knowledge on the response of different crops to water stress is critical in understanding the management changes that are necessary for long-term productivity. Most horticultural production areas are located in hot and dry climates because of their favorable weather conditions. However, the soil water deficit is rather frequent in these areas. Water-saving irrigation strategies such as DI may allow for the optimization of water productivity in these places by stabilizing yields and improving product quality (Costa et al., 2007).

Tomato (*Solanum lycopersicon* L) is one of the most widely cultivated vegetable crop in Tigray, Ethiopia. The application of regulated DI strategies to this crop may significantly lead to save irrigation water (Costa et al., 2007). Research findings showed controversial results on the adoption of DI strategies for tomato crops. Some researchers said, the application of DI for the whole or partial growing season of tomato minimize fruit losses and maintain high fruit quality (Patanè and Cosentino, 2010). However, Pulupol et al. (1996) observed a significant reduction in dry mass yield for a glasshouse tomato cultivar using DI. On the other hand, Zegbe et al. (2006) did not find a reduction in tomato fruits yield of field-grown processing cultivar. Although, the effects of DI on tomato fruits yield may be different, many investigators have demonstrated that DI saves substantial amounts of irrigation water and increases WUE. Therefore this field trial aimed to investigate

the effect of growth stage based DI on fruit yield and irrigation WUE of tomato.

2 Methods and materials

2.1 Description of the experimental site

This experiment was conducted at Maitsebri Agricultural Research farm of Maitsebri Agricultural Research Center in 2019 and 2020 off-season time. The experimental site is located in the Northern part of Tigray, Ethiopia at about 38.15°E longitude and 13.5°N latitude and at an altitude of 1307 m above mean sea level. The long term mean monthly maximum and minimum temperature is 32.3°C and 17.2°C respectively. The average annual rainfall in the area is 678.32 mm characterized by 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, loamy sand in texture and continuously cultivated. The field capacity, permanent wilting point moisture content and available water holding capacity per meter of the soil profile in the root zone is 38.6%, 29.8% and 145.28 mm respectively.

2.2 Treatments, experimental design and management

The experiment was designed as a two-factor factorial experiment in a randomized complete block (RCBD) with three replications. The two factors were FAO based tomato growth stages and irrigation application levels. The treatments were three irrigation levels (100%, 50% and 25% of crop evapotranspiration, ETC) and FAO based four growth stages of tomato (initial, developmental, mid and late/maturity growth stages) as shown in Table 1 below. Each experimental plot had an area of 9.6 m², which consists of 5 furrows with 80 cm width and 3 m length. The recommended spacing of 30 cm between plants was employed. The spacing between blocks and experimental plots was 2 m and 1.5 m, respectively. Irrigation water was delivered to each plot using calibrated 2-inch Partial flume according to the treatments. Each experimental treatment was fertilized with an equal recommended fertilizer

application. The full dose of DAP was applied at the time of planting whereas urea was applied by splitting into two parts, half during planting and the rest just at 30 days after transplanting considering the size of the

plots. All other cultural practices were applied uniformly to all plots as per the standard recommendations of the crop.

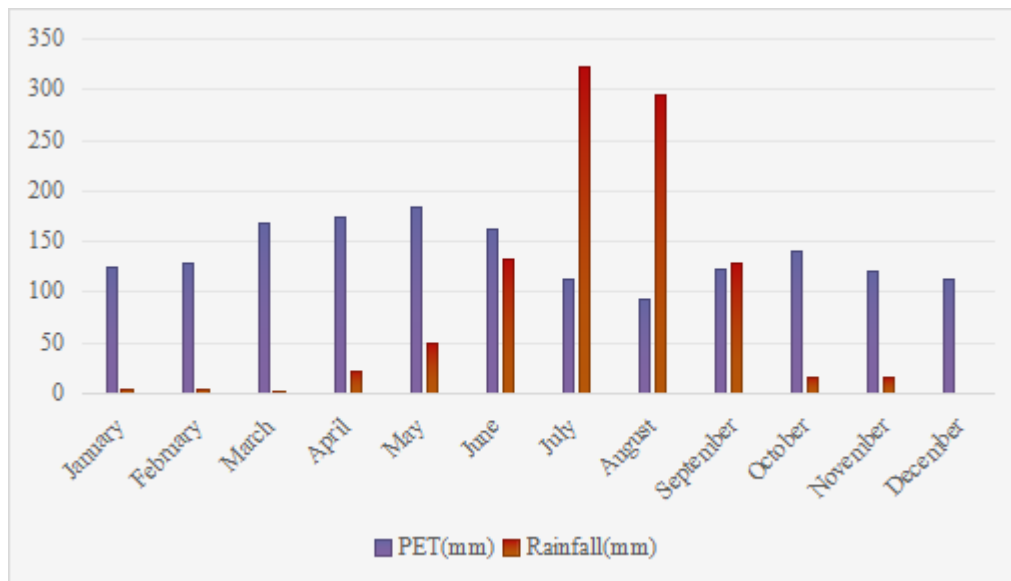


Figure 1 Monthly rainfall as compared with potential evapotranspiration (PET)

Table 1 Treatment set-up

Treatment Code	Treatment combination
T1	100% crop evapotranspiration (ET _c) at all the growth stages
T2	50%ET _c at initial stage and full amount at other stages
T3	50%ET _c at development stage and full amount at other stages
T4	50% ET _c at mid stage and full amount at other stages
T5	50% ET _c at maturity stage and full amount at other stages
T6	25%ET _c at initial stage and full amount at other stages
T7	25%ET _c at development stage and full amount at other stages
T8	25 ET _c at mid stage and full amount at other stages
T9	25%ET _c at maturity stage and full amount at other stages

Full irrigation (100% ET_c) implies the amount of irrigation water applied as estimated by Penman Monteith method with CROPWAT computer program and 50% ET_c and 25% ET_c irrigation levels meant water stressing the test crop by 50% and 75% of the full amount required by the crop at some growth stage respectively.

2.3 Test crop characterization

The test crop used in this study was Tomato improved variety with a growing period of 120-125 days from the day of transplanting in the study area. Based on FOA references and previous research findings in our research center from many field trials, the initial growth stage was set to be 24 days from transplanting date, 36 days from the end of initial stage as development stage, 40 days from the end of development stage as mid stage of growth and 24

days from the end of mid stage as late season stage of growth. The crop was sown on 9th December 2020 and 12th December 2021 off-seasons. Tomato seedlings were transplanted in to plot size of 3 m by 3.2 m. Spacing of 1.5 m between plots within a block and 2 m between blocks were used. According to FAO irrigation and drainage paper (Allen et al., 1998), maximum root depth of 100cm; crop coefficient of 1.15 and allowed depletion level value of 0.45 were used in the determination of crop water requirement.

2.4 Crop water requirement and irrigation schedule

The estimate of the water requirement and irrigation scheduling under this study is based on the atmospheric conditions of the environment. A computer program called “CROPWAT version 8.0” was used to determine reference evapotranspiration,

crop water requirements, and irrigation schedule by utilizing metrological data as an input. For estimation of water irrigation requirements, climatic, crop and soil data have been utilized as an input. This calculation has been done by using the FAO Penman-monteith method.

2.5 Data collection

Climatic data: Before the start of the experiment, secondary data such as climatic data of 20 years on rainfall (R.F.) min and max 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 tomato crop, tomato crop growth stages and their respective length of period and soil infiltration rate data were also collected from previous records and FAO guidelines.

2.5.1 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 (Gee and Bauder, 1986) at 0-25, 25-50, 50-75 and 75-100 cm depths for each of the three soil profiles. Bulk density was determined by the core method (Blake and Hartage, 1986) for each depth in the three profiles. 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 (Klute, 1986). The soil basic infiltration rate was determined in the field using double-ring infiltrometer method in two separate sites in the experimental area as described by Bouwer (1986) (Table 2).

Table 2 Soil physical properties of the experimental site (2020/2021)

Soil properties	Soil depth (cm)				
	0-25	25-50	50-75	75-100	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 ⁻¹)					145.28

2.5.2 Yield and yield components

Yield data were collected from three central furrows of tomato planted plot. Number of fruit per plant and cluster number were collected from five plant sample of the three central rows. Yield and other yield component parameters were collected and the analysis was done using Gen-stat software.

2.6 Water-use efficiency (WUE)

WUE is used to describe the relationship between growth (particularly dry matter production) and water use (Oweis and Zhang, 1998). WUE is expressed as a yield per unit of water used by the plant. The total seasonal amount of water used by the crop per treatment was recorded and the crop WUE (kg m⁻³) for each treatment was calculated as the ratio of marketable fruit yield (kg) to total seasonal irrigation water consumption (m³).

2.7 Data analysis

Analysis of variance was performed following the procedures of Gomez et al., (1984), 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.

3 Results and discussions

3.1 Water consumption and irrigation demand

Tomato improved variety (Melkashola variety) was planted on 9th December 2019 and 12th December 2020 off-season time. Total precipitation during December to May in both years was insignificant. As a result throughout the growing period of the test crop, the only source of water was irrigation. The irrigation frequency was scheduled as 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 Table 3.

Table 3 Total seasonal net irrigation depth applied to treatments

Treatment combination	Net depth of irrigation(mm)	Water saving(m ³ ha ⁻¹)
100% Crop evapotranspiration (ET _c) at all the growth stages(T1)	678.1	-
50%ET _c at initial stage and full amount at other stages(T2)	644.8	333.4
50%ET _c at development stage and full amount at other stages(T3)	601.0	770.9
50% ET _c at mid stage and full amount at other stages(T4)	536.4	1416.7
50% ET _c at maturity stage and full amount at other stages(T5)	592.7	854.2
25%ET _c at initial stage and full amount at other stages(T6)	628.1	500.0
25%ET _c at development stage and full amount at other stages(T7)	561.4	1166.7
25 %ET _c at mid stage and full amount at other stages(T8)	464.5	2135.5
25%ET _c at maturity stage and full amount at other stages(T9)	550.0	1281.3

Based on the output of the CROPWAT 8 model, the optimum/full seasonal irrigation requirement in the area for Tomato vegetable was found to be 678.13 mm (6781.3 m³ ha⁻¹) for non-stressed condition as indicated in Table 3. The approximate value of seasonal crop water requirement of Tomato for maximum yields is 400 to 700 mm depending on climate (Critchley et al., 1991). The amount of water applied for non-stressed irrigation treatments (100% Crop evapotranspiration at all growth stages) agreed with the range of water requirements stated above. The amount of water applied to the water- stressed treatments and the water savings as compared to the indicator treatment (100% Crop evapotranspiration at all growth stages) indicated in Table 3. Maximum water savings (2135.5 m³ ha⁻¹ and 1416.7 m³ ha⁻¹) was found by reducing the amount of irrigation 75% and 50% of the full requirement at the mid growth stage of tomato respectively. As shown in Table 5 there is no statistically significant yield reduction by applying irrigation water 75% and 50% less than the full amount.

3.2 Fruit length and fruit Circumference

The two years combined statistical analysis showed that plant fruit length and fruit circumference of tomato had affected by the application of different irrigation levels ($p < 0.01$). However, we have not observed significant effects on days to 50% flowering, days to 50% fruit setting and fruit number per plant among treatments as indicated in Table 4. Similar

research findings as in the case of Rosadi et al. (2005) discovered that a small difference in moisture deficit levels did not affect plant growth parameters. In this experiment, we observed significant influence on the yield parameters (fruit length, fruit circumference, marketable yield) and WUE (Table 4).

The highest in fruit length (7.47 cm) and fruit circumference (12.12 cm) were obtained from treatments irrigating full amount of irrigation water at all growth stages of tomato. Whereas the lowest in fruit length (3.48 cm) and fruit circumference (6.42 cm) was obtained from treatments applied 25% of full crop water requirement at development growth stage (Table 5).

3.3 Marketable and unmarketable yield

Marketable yield of tomato was significantly influenced ($p < 0.5$) due to the adoption of different irrigation levels at different growth stages of the crop (Table 4). The unmarketable yield was also highly significantly influenced ($p < 0.1\%$). The result revealed that the lowest marketable yield (144.3 q ha⁻¹) and the highest unmarketable yield (101.88 q ha⁻¹) was recorded at treatments irrigated 75% less than the full amount of water required at the development growth stage of the crop (Table 5). Reducing the amount of irrigation water required up to 75% at development growth stage of tomato results 66.5% yield loss as compared to the fully irrigated treatments at all growth stages. As shown in Table 5, there is no statistically significant difference among treatments

irrigated with different amount of irrigation at different growth stages except reducing the amount of water up to 75% at development growth stage of tomato. The major finding here is that reducing the amount of irrigation water at developmental growth stage up to 75% of the full amount results in a significant yield loss (66.5% loss) and high unmarketable yield. On the other hand, we observe that reducing the amount of irrigation water up 75% any growth stage rather than the developmental

growth stage has not significant yield loss (Table 5) in this study.

3.4 Water use efficiency

As indicated in Table 4, there was highly significant difference due to the application of different irrigation amounts at different growth stages at 0.1% significant level. The highest and the lowest WUE values were 9.2 kg m⁻³ and 3.5 kg m⁻³ obtained from plots that were irrigating 25% ETc at maturity and development growth stages with full amount at the other stages respectively.

Table 4 Analysis of variance on important agronomic parameters of Tomato

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

Note: NS=not significant; *, **, *** indicates significant at 0.05, <0.01 and <0.001 levels respectively; DFI, 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 5 Statistical comparison of the mean values of relevant parameters of Tomato (2020/2021)

Trts	50%DFI(days)	50%DFS(days)	FNPP	FL(cm)	FCir(cm)	Myld (Q ha ⁻¹)	UnMyld (Q ha ⁻¹)	WUE(kg m ⁻³)
T1	57.83 ^a	67.83 ^a	14.21 ^a	7.47 ^a	12.12 ^a	431.9 ^a	44.10 ^a	6.9 ^a
T2	54.83 ^a	67.17 ^a	15.42 ^a	5.61 ^{bcd}	10.59 ^{ab}	413.9 ^a	17.31 ^a	7.6 ^a
T3	57.17 ^a	68.00 ^a	14.10 ^a	4.65 ^d	8.48 ^c	394.1 ^a	16.53 ^a	7.8 ^a
T4	57.17 ^a	67.50 ^a	16.93 ^a	6.75 ^{ab}	11.53 ^a	419.1 ^a	18.0 ^a	9.01 ^a
T5	57.50 ^a	69.17 ^a	15.94 ^a	5.86 ^{bcd}	11.27 ^a	386.4 ^a	18.53 ^a	7.7 ^a
T6	59.17 ^a	65.60 ^a	14.01 ^a	6.07 ^{bc}	10.77 ^{ab}	386.1 ^a	14.48 ^a	7.3 ^a
T7	55.00 ^a	68.17 ^a	12.86 ^a	3.48 ^e	6.42 ^d	144.3 ^b	101.88 ^b	3.5 ^b
T8	56.17 ^a	67.33 ^a	13.82 ^a	5.09 ^{cd}	9.04 ^{bc}	365.2 ^a	17.92 ^a	9.1 ^a
T9	54.83 ^a	68.00 ^a	16.86 ^a	5.88 ^{bcd}	11.79 ^a	427.3 ^a	25.52 ^a	9.2 ^a
Mean	56.63	67.85	14.91	5.65	10.22	382.7	21.0	7.56
LSD	ns	ns	ns	1.136	1.756	142	32.11	3.82
C.V	6.3	4.6	39.2	17.1	14.6	32.7	30.50	30

Note: columns assigned with the same letter have not significant difference. Trts, treatments, DFI, 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

4 Conclusions

In the study area, the depth of rainfall is low and its distribution is uneven and highly erratic to meet the daily ETc requirement. Under this condition, the need to use the available water economically and efficiently is indubitable. This study emphasizes the comparison of irrigation management strategies which could contribute to water-saving, and increase WUE with no or minimum yield reduction in the semi-arid climate of northern Ethiopia particularly in

the study area. Results confirmed that different irrigation treatments significantly influenced yield, WUE and other parameters of tomatoes. The highest marketable yield obtained from applying 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 growth 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 yield (by 66.5%) and WUE. In terms of marketable yield and WUE, we have not seen a significant difference among treatments except the 25% of irrigation amount applied at development growth stage of the crop. Therefore, the results in 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 substantial amount of water in the case of limited water availability conditions.

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