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Response of Tomato (*Solanum lycopersicum M.)* to Water Stress on Physiology, Yield and Quality: A Review

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ABSTRACT

Tomato (Solanum lycopersicum M.) is one of the most important vegetable crops grown in Ethiopia. It is source of vitamins, minerals, antioxidants and generate income for growers, but its' physiology, yield and quality of tomato is very low mainly due to water stress problem. Therefore, this review paper is focused on the effect of water stress on physiology, yield and quality of tomato. The effect of water stress treatments on net photosynthetic rate, transpiration rate, stomatal conductance, intercellular CO2 concentration, stomatal limitation, and WUE had a significant increase with treatment 74-80% water deficit than another treatment. The highest of fruit plant-1, marketable yield and total yield were recorded at 100% ETc, but the highest yield losses were obtained at dry control. Fruit quality on fruit weight, fruit dry matter, soluble solids and pH had a significant effect, except titratable acidity. Irrigation cut at tomato veraison (irrigation cutback treatment) did not affect the yield, but enhanced fruit quality and maximized WUE, thus contributing to water saving. Through application of irrigation cutback toward the end of the tomato cycle, there is a possibility to improve tomato quality and, at the same time, save irrigation water.

Keywords: *Yield, pH, Physiology, Tomato*

INTRODUCTION

Tomato (*Solanum lycopersicum* M.) is one of the most important vegetable crops grown in Ethiopia. It is a good source of vitamins A and C, minerals, and antioxidants, which help control cancer, health disease as well as, improve the general health of man because of its rich source of lycopene (Antonio *et al*., 2004). It is consumed as either fresh fruit by themselves, in salads, as ingredients in many recipes, or in the form of various processed products such as paste, whole peeled tomatoes, diced products and various forms of juices, and soups (Kole, 2007). It is also an important cash crop grown by both small-scale farmers and commercial growers for fresh market and processing industry in Ethiopia (Lemma *et al*., 1992). Despite its' importance, the average productivity of tomato in Ethiopia is around 10 t ha^{-1} (CSA, 2015). This is very low yield compared to the world average 33.99 t ha^{-1} (FAOSTAT, 2015) due to biotic and abiotic stresses such as water stress, rainstorms, heat, and salinity (Shao *et al.*, 2015).

Among various abiotic stresses, water stress is the most prevalent abiotic constraint that causes for widespread yield reduction in agricultural production (Ghorbanli, 2013). As the plant undergoes water stress, the water pressure inside the leaves decreases and the plant wilt. Water stress affect tomato yield throughout the course of fruit growth and maturation, but quality was sensitive to water stress during the fruit ripening stage water stress has been associated with reduced yields and possible crop failure. The main consequence of water stress is decreased growth and development caused by reduced photosynthesis, a process in which plants combine water, carbon dioxide and light to make carbohydrates for energy (Sibomana *et al.*, 2013). As irrigation regimes increases, positively increased all vegetative growth parameters of tomato plants (Ibrahim, 2005). Water stress treatments (40% F.C) resulted in a significant decrease in vegetative growth of tomato plants, where plant height reduced by 24% compared to the control treatment (100% F.C). In addition, several studies have shown that a great reduction of leaf area in tomato plants and other vegetable crops was observed with deficit irrigation treatment (Mohawesh, 2016). Therefore, this review paper is focused on the effect of water stress on physiology, yield and quality of tomato.

Water Stress on Physiology, Yield and Quality of Tomato

Effect of Water Stress on Physiology of Tomato

Water stress inhibits photosynthesis by causing stomatal closure and metabolic damage. Stomata of the leaves that are slightly deficient in water opened more slowly in light and close more quickly in the dark (Nuruddin, 2001). It reduces leaf water potential, which in turn may reduce transpiration. Kirnak *et al*. (2001) have found that water stress significantly decreases in chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth; and plants grown under high water stress have less fruit yield and quality.

Chlorophyll concentration has been known as an index for evaluating source strength thus, its decrease under water stress can be regarded as a non-stoma limiting factor.

During the generative stages of processing tomato, the stomatal conductance changed depending the crop years, however, it was lower in 2015 than in 2011 under non-irrigated conditions (Table 1). During these periods, significant differences in the canopy temperature between the crop years was not detected. Chlorophyll fluorescence (Fv/Fm) and SPAD value of leaves were significantly lower under non-irrigated conditions (I0) than under irrigation in the dry year 2015 (Eszter *et al.*, 2019*)*.

Table1. *Effect of water supply on physiological traits of processing tomato.*

Physiological parameters	Water	2011	2015	Average
Stomata conductance (mol m^2s^1)	Io	375.45^b	414.45^b	394.95^a
	DI	640.20^a	308.14^b	474.17^a
	WI	663.28^a	251.25^b	457.26^a
Canopy temperature (°C)	Io	27.83^a	29.51^a	28.67^a
	DI	26.16^b	24.61^b	25.38^b
	WI	25.60^b	25.59^b	25.60^b
FV/Fm	Io	0.662^b	0.729^a	0.696^b
	DI	0.753^a	0.733^a	0.743^a
	WI	0.75^a	0.73a	0.74^a
SPAD	Io	48.56^b	56.70^a	52.63^a
	DI	50.10^b	54.66^a	52.38^a
	WI	52.36^a	49.59^b	50.97^a

I0 = non-irrigation, DI = deficit irrigation, WI = regular irrigation. Means within a row following different letters are significantly different at $p < 0.05$ using Duncan's multiple range test

Source*: Eszter et al., 2019*

Changes in photosynthetic parameters under different levels of water stress are mainly caused by stomatal or non-stomatal factors, which are reflected in changes in Ci and/or Ls. When decreased PN as a result of water stress is accompanied by increased (unchanged) Ci and decreased Ls, non-stomatal factors are the main cause of reduced photosynthetic rate. In contrast, when decreased PN is accompanied by unchanged or increased Ls, while Ci is unchanged or decreased, stomatal factors are the main cause (Farquhar and Sharkey, 1982). When the RSMC was <47 to 52%, any increase in water stress and corresponding decrease in PN were associated with decreased Ci and increased Ls, suggesting that stomatal limitation was responsible for reduced PN in tomato leaves. However, when RSMC was >52%, any increase in water stress and corresponding decrease in PN were accompanied by increased Ci and decreased Ls, indicating that non-stomatal limitation was responsible for reduced PN (Table 2) (Guoting *et al*., 2020).

Effect of Water Stress on Yield of Tomato

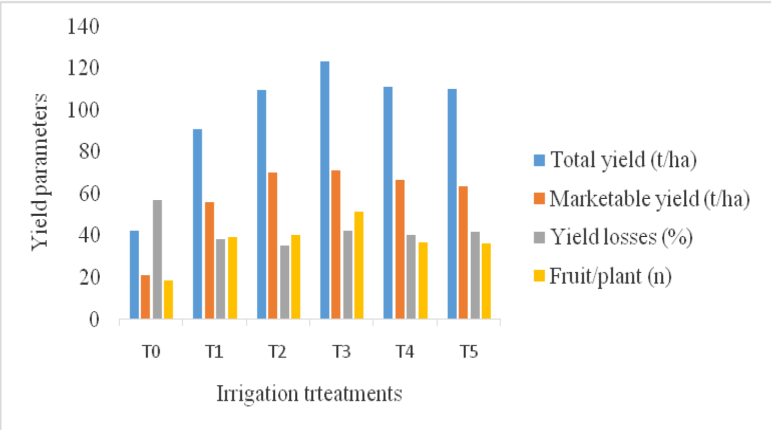
Different irrigation regimes had a significant effect on the tomato yield. The highest total yield, approx.124 t ha^{-1}, was recorded under full irrigation (T3) then 75% ETc (T2) resulted in yields (110 t ha^{-1} on average) not different from treatments with an irrigation cutback (T4 and T5). The lowest total yield (42.6 t ha^{-1}) was recorded in the dry control (T0). Marketable yield had non-significant among T2, T3, T4, and T5 treatments (67.9 t ha^{-1} on average); a lower yield in the T1 treatment (56.0 t ha^{-1}). The lowest marketable yield was obtained in the dry control (21.4 t ha^{-1}). The lowest yields corresponded to treatments T2, T1 and T0 (Figure 1). However, in percentage terms compared to total yield (yield loss), the latter parameter was higher in the dry control than the different irrigation treatments (stella *et al.*, 2017).

Table2. *Response of photosynthetic parameters of tomato to different soil drought stress severities under the same photosynthetically active radiation value (1200 mmol m^{-2} s^{-1}).*

Treatments	PN (mmol m^{-2} s^{-1})	E (mmol m^{-2} s^{-1})	gs (mmol _m^{-2} s^{-1})	Ci (mmol mol^{-1})	Ls	WUE (mmol $mmol^{-1}$)
74 - 80%	7.59 ± 0.25^{a}	2.05 ± 0.05^{a}	53.42 ± 3.09^{a}	275.72 ± 2.33^{a}	0.24 ± 0.06^{c}	3.70 ± 0.04^{a}
55 - 61%	7.07 ± 0.26^{b}	1.96 ±0.06^{ab}	49.57 ± 0.45^{b}	271.00 ± 1.23^{ab}	0.25 ±0.03^{bc}	3.61 ± 0.03^{b}
47 - 52%	6.62 ± 0.24^{b}	1.87 ± 0.06^{b}	47.18 ± 2.32^{b}	260.89 ± 5.39^{c}	0.29 ± 0.14^{a}	3.55 ± 0.02^{c}
25 - 30%	5.60 ± 0.22^{c}	1.61 ± 0.06^{c}	38.28 ± 1.20^{c}	269.82 ± 1.24^{b}	0.26 ± 0.03^{b}	3.49 ± 0.01^{d}

Source: *Guoting et al., 2020*

Control relative soil water content (RSMC) = 74% to 80%, Treatment 1 (T1) RSMC = 55% to 61%, Treatment 2 (T2) RSMC = 47% to 52%, Treatment 3 (T3) RSMC = 25% to 30%, Net photosynthetic rate (PN),Transpiration rate (E), Stomatal conductance (gs), Intercellular CO_2 concentration (Ci), Stomatal limitation (Ls), Water-use efficiency (WUE).Means in column by different letters are significantly different (LSD test, $P < 0.05$)



Source: *(Stella et al., 2017)*

Figure1. *Total and marketable yield, yield losses, and fruit plant^{-1} measured in the different irrigation treatments*

0 (T0, dry control, irrigated only at transplanting time), 50 (T1), 75 (T2) and 100% (T3, fully irrigated control) of crop ET (ETc), over the whole crop cycle; T4, treatment 2 (restoration of 100-75); T5, treatment 2 (restoration of 100-50

Effect of Water Stress on Fruit Quality of Tomato

Irrigation treatments had significantly affected tomato fruit quality. The mean fruit weight was significantly higher in treatments with irrigation cutback (60.5 g on average) and in T2 one (59.1). The fruit dry matter (TS) was higher in the dry control (7.0%) and lower in T2, T3, T4 and T5 treatments (5.6% on average). The soluble solids (SS) content was higher in T0 and T5 (5.69 °Brix on average) and lower in T2 and T3 treatments (5.18 °Brix on average) (Table 3). pH was higher in T1 and T3 treatments (4.33 on average) and lower in T0 (4.2). Titratable acidity had non-significant effect by different irrigation treatments (Stella *et al.*, 2017).

Table3. *Average fruit weight, dry matter (total solids), soluble solids, pH and titratable acidity measured in the different irrigation treatments*

Irrigation trt.	Fruit weight (t/ha)	TS (%)	SS (Brix)	pH (%)	Titratable acidity (mg 100/g)
T0	38.7^{c}	7.03^{a}	5.75^{a}	4.20^{b}	0.32
T1	48.6^{b}	5.97^{b}	5.47^{bc}	4.34^{a}	0.26
T2	59.1^{a}	5.62^{c}	5.13^{d}	4.29^{ab}	0.28
T3	47.2^{b}	5.70^{c}	5.23^{cd}	4.33^{a}	0.34
T4	61.2^{a}	5.57^{c}	5.37^{bd}	4.28^{ab}	0.40
T5	59.8^{a}	5.55^{c}	5.63^{ab}	4.22^{ab}	0.34
P	***	***	**	**	Ns

0 (T0, dry control, irrigated only at transplanting time), 50 (T1), 75 (T2) and 100% (T3, fully irrigated control) of crop ET (ETc), over the whole crop cycle; T4, treatment 2 (restoration of 100-75); T5, treatment 2 (restoration of 100-50).

Conclusion and Recommendation

Tomato is the most important vegetable crop grown in Ethiopia, it is a good source of vitamins, minerals and generate income for the producers, but its' physiology, yield and quality of tomato is very low mainly due to water stress problem. Tomato quality parameters that contributed the most to the differences among deficit irrigation and full irrigation treatments, and these were the mean fruit weight, dry matter, and soluble solids. Through the application of irrigation cutback late in growing season (at the onset of fruit ripening), fruit quality may be improved in tomato and at the same time, irrigation water may be saved and water-use efficiency is improved. Therefore, this irrigation strategy may be a valid option for cultivated semi-arid areas.

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