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Original Research Article

Response of Tomato (Solanum Lycopersicum L.) Deficit Irrigation Levels at Different Growth Stages on Yield and Water Productivity at Raya Valley, Northern Ethiopia

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Abstract: The most important biotic stress factor impacting tomato crop biophysical, biochemical, physiological, and morphological features is water stress. A field experiment was conducted to investigate the effect of water stress at different growth stage on yield and water productivity and to identify the most sensitive growth stage to deficit irrigation. The study was conducted for three non-consecutive years at Mekhoni Agricultural Research Center, Raya valley, Ethiopia. The experimental treatments were four crops growing stages (initial, development, mid and maturation stages) and three deficit irrigation levels (85% ETc, 70 % ETc and 55% ETc levels) and control irrigation of 100% ETc. The design of the experiment was split plot design with three replications.

Keywords: Tomato, Water productivity.

INTRODUCTION

Irrigated agriculture is the main user of the available water resources. About 70% of the total water withdrawals and 60-80% of total consumptive water use are consumed in irrigation (Huffaker and Hamilton, 2007).

Deficit irrigation (DI) strategies have the potential to optimize water productivity to produce higher yields per unit of irrigation water applied in horticulture (Costa *et al.*, 2007). In DI, the crop is exposed to a certain level of water stress during the whole growing season or at a particular stage of it (English and Raja, 1996). However, not all stages of crop growing season are equally sensitive to water stress. For example, water-sensitive stages occur during the yield formation stage in onion (*Allium cepa)*, during ripening growth in cabbage (*Brassica oleracea*), at the beginning of the flowering stage in pepper (*Capsicum annum*), during the late vegetative, flowering and yield formation stages of watermelon (*Citrullus vulgaris*) and at the flowering stage of tomato (Doorenbos and Kassam, 1979). Water stress level and irrigation application timing significantly affect the tomato yield and fruit quality (Wang *et al.*, 2011). It is well known that the application of DI to tomato crops can increase water use efficiency (WUE) and improve processing tomato quality (Zegbe-Dominguez *et al.*, 2003, Favati *et al.*, 2009). Conversely, DI applications may cause the development of small size fruits, lower marketable yields, early senescence of the plants and higher vulnerability to various diseases (Hanson *et al*., 2004, Favati *et al*., 2009).

In many parts of Ethiopia, agricultural production is limited by water rather than land availability due to high variability of rainfall (Bewket, 2009). Moreover, in areas where water is lifted for the irrigated land from lakes, underground water wells and rivers by using pumps, the increasing cost of fuel exacerbates the problem. Therefore, innovations are needed to increase the efficiency of water use for productivity of agricultural land in a limited water resource and by decreasing fuel cost in areas where water is lifted by pump as well.

Deficit irrigation is known to increase water productivity with insignificant or minimum yield reduction. Therefore, the objective of the study was to investigate the effect of deficit irrigation levels at different growth stages on yield and water productivity of the onion and to identify the most sensitive growth stages of onion to deficit irrigation levels.

MATERIALS AND METHODS

Description of the Experimental Site

The study was conducted at the research station of Mekhoni Agricultural Research Centre (MehARC) in the Raya Valley, Northern Ethiopia, located 668 Km from the capital Addis Ababa and about 120 Km south of Mekelle, the capital city of Tigray regional state. Geographically, the experimental site is located at 12° 51'50'' North Latitude and 39° 58'08'' East Longitude with an altitude of 1578 m.a.s.l. The site receives a mean annual rainfall of 300 mm with an average minimum and maximum temperature of 18 and 32°C, respectively. The soil textural class of the experimental area is clay with pH of 7.1 to 8.1 (MehARC, 2015).

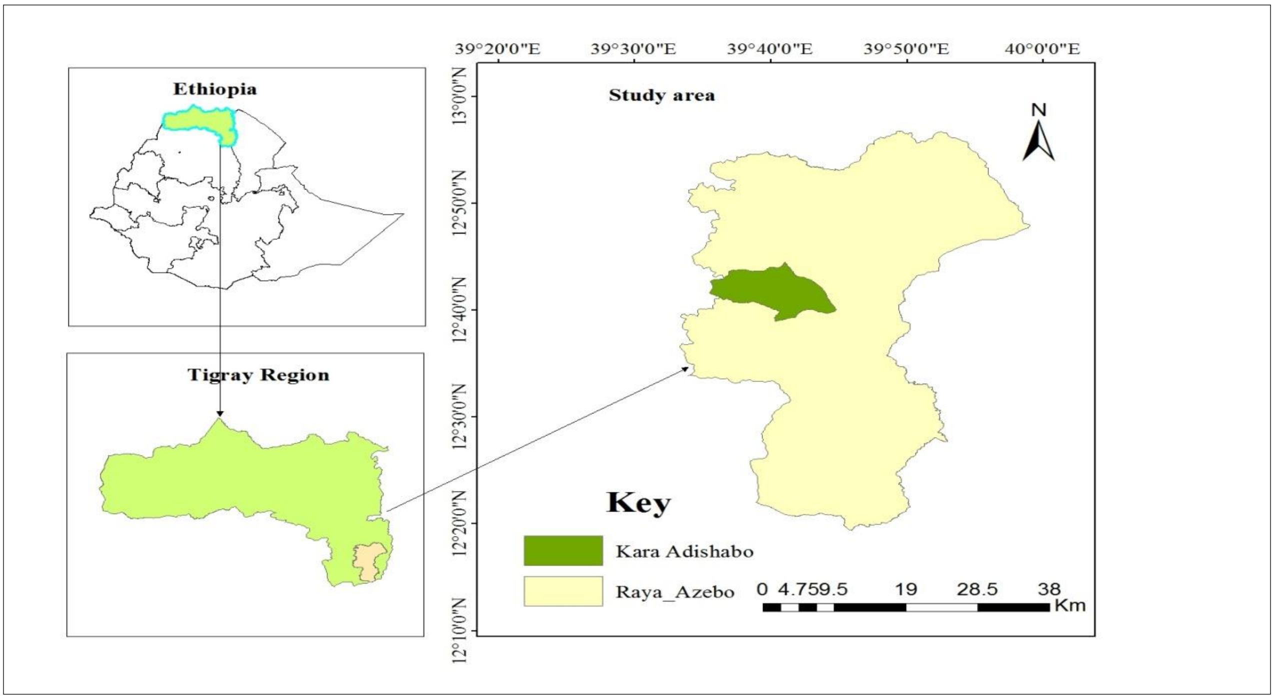

Figure 1: Map of the study area

Climatic Characteristics

The average climatic data (Maximum and minimum temperature, relative humidity, wind speed, and sun shine hours) on monthly basis of the study area were collected from the near meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software version 8.

Table 1: Long term monthly average climatic data of the experimental area

Month	T_{min}	T_{max}	RH	Wind	Sun	Rad	ETo
	°C	°C	%	km/hr	hours	MJ/m²/day	mm/day
January	11.5	27.2	73	69	7.9	18.4	3.33
February	12.8	27.1	70	86	9.4	22.0	4.02
March	13.5	29.5	68	86	8.7	22.4	4.44
April	13.8	29.7	67	95	8.7	22.9	4.65

Month	T_{min} °C	T_{max} °C	RH %	Wind km/hr	Sun hours	Rad $MJ/m^2/day$	ETo mm/day
May	15.3	32.5	58	52	9.1	23.3	4.69
June	15.8	35.0	60	43	8.6	22.2	4.70
July	15.6	31.5	90	52	6.5	19.1	4.04
August	15.0	29.7	95	43	6.5	19.3	3.89
September	14.3	30.8	74	52	6.6	19.2	3.96
October	13.1	29.8	69	86	9.2	22.0	4.36
November	12.1	28.6	67	69	9.0	20.1	3.77
December	11.3	27.1	69	69	8.8	19.0	3.4

Experimental Treatments and Design

A field experiment was carried out for three consecutive years. The experimental treatments were four crops growing stages (initial, development, mid and maturation stages) and three deficit irrigation levels (85% ETc, 70 % ETc and 55% ETc levels) and control irrigation of 100% ETc. The design of the experiment was split plot design with three replications. The growing stages were arranged as a main plot and the deficit irrigation levels as sub-plot.

Table 2: Treatment setting for field experiment

Treatment (Main plot)	Combination (Sub plot)
Initial stage	Irrigated at 100% Etc
	Irrigated at 85% Etc
	Irrigated at 70% Etc
	Irrigated at 55% Etc
Development stage	Irrigated at 100% Etc
	Irrigated at 85% Etc
	Irrigated at 70% Etc
	Irrigated at 55% Etc
Mid-season stage	Irrigated at 100% Etc
	Irrigated at 85% Etc
	Irrigated at 70% Etc
	Irrigated at 55% Etc
Late stage	Irrigated at 100 % Etc
	Irrigated at 85 % Etc
	Irrigated at 70% Etc
	Irrigated at 55 % Etc

Experimental Procedure and Management Practice

The size of each individual plots had kept at 5.4 m*4 m. The spacing between plots and blocks were 2 m and 3 m, respectively. The spacing between tomato plants and rows was kept at 50 cm and 90 cm, respectively. Each plot has 6 rows of tomato plants. All cultural practices were done to all treatments in accordance to the recommendation made for the area. Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity. The amount of irrigation water applied at each irrigation application treatments was measured using Parshall flume.

Calculation of Water Productivity

Water productivity (WP) is the amount of onion bulb yield per irrigation water applied.

$$WP = \frac{\text{harvested grain yield}}{\text{total water used}}$$

Where, WP is crop water productivity (kg/m^3), harvested bulb yield (kg/ha) and total water used is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Data Collection

The field data such as marketable and non-marketable yield weight were taken from each plot. The harvested yield was grouped based on its quality for market according to the size and degree of damage.

Statistical Analysis

The collected data were statistically analyzed using statistical analysis system (SAS) version 9.0 statistical package using procedure of general linear model (SAS, 2002) for the variance analysis. Mean comparisons were executed using least significant difference (LSD) at 5% probability level when treatments show significant difference to compare difference among treatments mean.

RESULTS AND DISCUSSION

Selected Soil and Water Properties of the Study Area

The result of the soil analysis from the experimental site showed that the average composition of sand, silt and clay percentages were 15, 27 and 58%, respectively. Thus, according to the USDA soil textural classification, the percent particle size determination for experimental site revealed that the soil texture could be classified as clay soil (Table 3).

Moreover, the pH value of the experimental site was 7.3. According to (Tekalign 1991), soils having pH value in the range of 6.73 to 7.3 are considered neutral soils. And this value falls in the pH range that is very conducive for most vegetables and tomato production.

The analysis of the irrigation water showed that pH value of 7.7 and ECw value of 0.46 dS m $^{-1}$ were obtained. According to (FAO 1999), water salinity has classification the irrigation water quality of the study area was classified at medium.

The pH of irrigation water is not a problem by itself, but it is an indicator of other problems such as sodium and carbonates. According to (Bryan *et al., (*2007), the irrigation water was classified in the study area slight to moderate (7- 8) in terms of pH (Table 3).

The total available water (TAW) that is the amount of water that a crop can extract from its root zone is directly related to variation in FC and PWP and its root depth. Tomato root depth extends to 60 cm and hence the TAW of tomato is 103.2 mm. TAW of the experimental site soil was found to be 172.04mm per meter depth (Table 4).

Table 3: Major soil and water characteristics of the experimental field

Soil parameters	Unit	Value
Particle soil distribution		
Sand	%	15
Silt	%	27
Clay	%	58
Textural class		Clay
pH	-	7.3
ECe (by 25°C)	dS m $^{-1}$	0.12
Irrigation Water		
pH	-	7.7
ECw	dS m $^{-1}$	0.46

Table 4: Physical characteristics of soil at the experimental site

Soil texture	Bulk density (g/cm^3)	Field capacity (%)	Permanent wilting point (%)	Total water holding capacity (mm)
Clay	1.1	44.34	28.7	172.04

Marketable Yield, MY (Kg ha^{-1})

The statistical results of three consecutive years shown that there was no significance difference in effect of water deficit at different growth stages on marketable yield of tomato at $p \leq 0.05$ except significant difference that was seen at MS stage for 2nd and 3rd year trials. However, there was significant difference in effect of water deficit on marketable yield of tomato without considering tomato's growth stages. Though there was no significant difference between the results nominated with the same letters along a column.

The highest marketable yield of tomato was recorded with 100%ETc (control) and decreased gradient was seen as water level decreased that the lowest value of marketable yield was recorded at 55%ETc for all trials period. Similarly, Hashem M S, *et al*., 2018 stated that the marketable yield under the Full Irrigation treatment yielded the highest values as compared to deficit treatments.

Unmarketable Yield, UMY (Kg ha^{-1})

The statistical results of three consecutive years shown that there was no significance difference in effect of water deficit with and without considering growth stages on unmarketable yield of tomato at $p \leq 0.05$ except significant difference seen for 1st year trial.

The result shown that the percentage of unmarketable yield out of total yield increased as water deficit increased thus less percentage was recorded with control as compared to water deficit treatments.

Total Yield, TY (Kg ha^{-1})

The statistical results of three consecutive years shown that there was no significance difference in effect of water deficit at different growth stages on total yield of tomato at p ≤ 0.05 except significant difference that was seen at MS stage for 2nd and 3rd year trials. However, there was significant difference in effect of water deficit on total yield of tomato without considering tomato's growth stages though there was no significant difference between the results nominated with the same letters along a column.

The highest total yield of tomato was recorded with 100%ETc (control) and decreasing gradient was seen as water deficit increases that the lowest total yield of tomato was recorded at 55%ETc for all trials period. The result also shown that there was a positive correlation between marketable and total yield of tomato that both responded the same to water deficit level.

Water Productivity, WP (Kg m^{-3})

The statistical results of three consecutive years shown that there was no significance difference in effect of water deficit at different growth stages on water productivity of tomato at p ≤ 0.05 except significant difference that was seen for 1st year trial. However, there was significant difference in effect of water deficit on water productivity of tomato without considering tomato's growth stages though an effect was no significantly different for the 1st year trial and between the results nominated with the same letters along a column for 2nd and 3rd year trials.

The highest water productivity of tomato was recorded with 55%ETc and decreasing gradient was seen as water deficit level increased to full irrigation level and the lowest water productivity of tomato was recorded at 100%ETc for all trials period though not significant for 1st year trial. The result also agreed with Hashem M S, *et al.*, 2018 that stated most of the minimum Water Productivity values were associated with Full Irrigation treatment. In other word, the result shown water productivity had a positive correlation to deficit irrigation.

Table 5: Analysis of variance (ANOVA) for Marketable Yield (kg/ha), Unmarketable yield, Total Biomass Yield (kg/ha) and water productivity (kg/m^3) of stage and deficit irrigation

Treatments	Mean Squares											
	1st year				2nd year				3rd year			
	MY (kg/ha)	UMY (kg/ha)	TY (kg/ha)	WP (kg/m^3)	MY (kg/ha)	UMY (kg/ha)	TY (kg/ha)	WP (kg/m^3)	MY (kg/ha)	UMY (kg/ha)	TY (kg/ha)	WP (kg/m^3)
Growth Stages												
IS	36583.3	10153.2^{b}	46736.4	7.3^{b}	43095^{a}	2485.3	45580^{a}	8.32	46420^{a}	3920	50330^{ba}	8.47
DS	35806.4	10451.4^{ab}	46577.5	7.5^{ab}	42259^{a}	2335.6	44594^{ab}	8.40	46500^{a}	4080	50580^{a}	8.78
MS	36126.1	10342^{ab}	46148.4	7.8^{a}	39827^{b}	2523.6	42350^{b}	8.33	44750^{b}	4420	49170^{b}	8.94

Mean Squares		Treatments: LS	LSD (p=0.05)	Deficit Irrigation	55%ETc	70%ETC	85%ETC	100%Etc	LSD (p=0.05)	CV
1st year	MY (kg/ha)	36316.9	Ns		34303.1^{c}	35892.6^{bc}	36111.9^{b}	38525^{a}	1659.9	5.5
	UMY (kg/ha)	10573.2^{a}	322.3		10838.8^{a}	10587.3^{a}	10238.7^{b}	9855.0^{c}	322.3	3.7
	TY (kg/ha)	46890.1	Ns		45141.9^{b}	46479.9^{b}	46350.6^{b}	48380.1^{a}	1686.8	4.4
	WP (kg/m^{3})	7.4^{b}	0.4		7.6	7.59	7.3	7.51	Ns	5.9
2nd year	MY (kg/ha)	42911^{a}	2299.7		40622^{b}	41241^{b}	42626^{ab}	43602^{a}	2299.7	6.5
	UMY (kg/ha)	2359.7	Ns		2494.3	2418.7	2486.5	2304.8	Ns	12.3
	TY (kg/ha)	45271^{a}	2269.9		43117^{b}	43660^{ab}	45113^{ab}	45906^{a}	2269.9	6.1
	WP (kg/m^{3})	8.45	Ns		8.6^{a}	8.4^{ab}	8.3^{ab}	8.2^{b}	0.4	6.3
3rd year	MY (kg/ha)	47000^{a}	820		40660^{d}	44120^{c}	47750^{b}	51830^{a}	820	2.1
	UMY (kg/ha)	4330	Ns		3930	3920	4420	4500	Ns	27.9
	TY (kg/ha)	51330^{a}	1290		44580^{d}	48330^{c}	52170^{b}	56330^{a}	1290	3
	WP (kg/m^{3})	8.78	Ns		9.36^{a}	8.85^{b}	8.54^{b}	8.14^{c}	0.4	5.4

CONCLUSION

Deficit irrigation is an important practice to wisely use the scarce water resource, avoid the risk of water table increase in irrigated agricultural land and to minimize competition and conflict between different water users with limited water resource. The amount of water saved by deficit irrigation will help to irrigate additional crop land in water resource scarce areas which now a day is common problems due to climate change and other related natural resource degradation with acceptable crop yield reduction per a given area.

Based on the objective, tomato responds irrigated at all growth stages that 100%ETc is better for higher marketable yield except in water use efficiency which is least so it is promising for hither tomato yield if there is no water scarcity. While, it can be concluded 55%ETc deficit irrigation level that can give higher water productivity of tomato for areas where water scarcity is an issue.

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Conflict of Interests: The authors have not declared any conflict of interests.

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