Effect of irrigation regime on yield and water use of tomato in western Amhara, Ethiopia

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Abstract

This study investigated the effects of different irrigation regimes on yield and yield components of Tomato at Koga and Rib irrigation schemes, western Amhara during 2012-2013. The treatments were factorial combinations five irrigation depths (50%, 75%, 100%, 125% and 150%) and two irrigation intervals (7 and 10 days interval) and laid out in a randomized complete block design with three replications. Data on yield and yield components were collected and analyzed using SAS 9 software and significant treatment means were separated using least significant difference at 5%. Application of optimum irrigation regime increased the total and marketable yield over the deficit and excess irrigation regime plot, and their interaction showed a significant effect on the average marketable, total yield and water productivity of Tomato. The highest marketable yield at Koga (61.2 t ha^{-1}) was obtained from 125%CWR at seven days interval while the highest marketable yield at Rib (45.5 t ha^{-1}) was obtained from 150%CWR at ten days interval. Therefore, for Koga and similar agro ecologies tomato can be irrigated with 125%CWR at seven days interval and at Rib and similar agro ecologies tomato can be irrigated with 150%CWR at ten days interval.

Key words: Irrigation depth, irrigation regime, schedule, tomato

Introduction

Recently precision agriculture in humid areas is already being used to increase yield and water productivity thereby making irrigation feasible (DeJonge and Kaleita, 2006). Appling optimum amount at right time as well as at critical growth stages have crucial impact (Upton, 1996; Michael, 1998). Thus, to attain stable crop yields with unpredictable storm frequency variability, irrigation scheduling is often necessary.

The national average tomato (*Lycopersicon esculentum* L.) fruit yield in Ethiopia is often low (12.5 t ha^{-1}) compared to the neighboring African countries like Kenya (16.4 t ha^{-1}) (FAO, 2004). Current productivity under farmers' condition is 9.0 t ha^{-1}, while yields up to 40.0 t ha^{-1} were recorded on research plots (Tesfaye, 2008). Several factors are responsible for this discrepancy, among which irrigation water management are the foremost factors (Fekadu and Dandena, 2006). Many investigations have been carried out worldwide regarding the effects of irrigation regime on yield of vegetables (Samson and Ketema, 2007; Pejic et al., 2011). However, most of these studies assessed the effect of reduced water stress (irrespective of appropriate irrigation scheduling to the entire growth stage on fruit yield).

Tomato plants have high water requirement throughout the growing period until fruiting occurs. The plants are resistance to moderate drought. The tomato fruit contains 90-96% water. Insufficient water during flowering and fruit development leads to flower and fruit drops, blossom end rot, physiological disorder and subsequently low fruit yield and quality. On the other hand excessive irrigation creates anaerobic soil condition and consequently causes root death, delayed flowering, and fruit disorders. Therefore, proper irrigation water management at different development stages is the most important practice to be considered for high quality fruit production.

Among the common irrigated vegetables, tomato shares the largest in both area coverage and local consumption under irrigation in Ethiopia Particularly, North West Amhara region. However, the largest production of tomato is not supported with improved water management practices to improve its productivity and fruit quality. Hence, the objectives of this study were to determine the crop water requirement and irrigation schedule of tomato and to statistically determine effect of irrigation regime on yield and water productivity in western Amhara.

Materials and methods

Site description

The experiment was conducted during 2012 and 2013 at Koga and Rib irrigation schemes, west Amhara, Ethiopia. Koga irrigation scheme is located in Mecha District; 41 kilometres from Bahir Dar on the way to Addis Ababa via Debremarkos (37°7'29.721''Easting and 11°20'57.859''Northing and at an altitude of 1953 m a.s.l). The average annual rainfall of the area was about 1118 mm. The mean maximum and minimum temperatures are 26.8 ^{0}C and 9.7 ^{0}C respectively. The soil type is Nitisols and has low available phosphorous (6.12 ppm), medium total nitrogen (0.21%), and strongly acidic soil reaction (soil pH 4.6). The field capacity (FC) and permanent wilting point of the study area were 32 (%w/w) and 18 (%w/w) respectively.

Rib irrigation site is located in Fogera District, 60 kilometres far from Bahir Dar on the way to Gondar (37°25' to 37°58' Easting and 11°44' to 12°03' Northing and at an altitude of 1774 m.a.s.l). It receives 1400 mm mean annual rainfall. The mean daily maximum and minimum temperature of the study area was 30°c and 11.5°c. The area is characterized as mild altitude agro-ecology. The soil type of the experimental site is Fluvisols which have high available phosphorous (36.71 ppm), very low total nitrogen content (0.003), high cation exchange capacity (CEC) (33.0) and neutral soil reaction (pH = 6.7). The field capacity (FC) and permanent wilting point (PWP) of the study area were 59.25 (%w/w) and 21 (%w/w); respectively.

Methods

CROPWAT 8.0 for Windows was used to estimate daily reference crop evapotranspiration and generate the crop water requirement and the irrigation schedule for Tomato in the study areas (Table 1 and 2). Calculations of the crop water requirements and irrigation schedule were carried out taking inputs of climate, soil and crop data. In order to estimate the climatic data (wind speed, sunshine hours, relative humidity, minimum and maximum temperature) LOCCLIM, local climate estimator software (FAO, 1992) were used for both Koga and Rib where there is no class A meteorological stations. The estimator uses real mean values from the nearest neighbouring stations and it interpolated and generated climatic data values for the study site. Based on the technology we use, we assume 70% application efficiency both at Rib and Koga, and then the gross water requirement was calculated. The demand for water during the plants growing season varies from one growth stage to another. Values of potential evapotranspiration (ET_0) estimated were adjusted for actual crop ET. Table 3 and 4 shows CROPWAT 8 Windows tables for ET.

Principally, CROPWAT outputs generated by default were used to identify irrigation timing of when 100% of readily available moisture occurs and application depth where 100% of readily available moisture status is attained. To verify the CROPWAT output, field experiments were carried out for two consecutive years in both locations.

Table 1. Climate and ETo data of Koga

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	7.5	26.5	51	1	9.8	21.3	3.13
February	9.2	28	45	1	9.8	22.8	3.48
March	12	29.5	42	1	9.1	23.1	3.8
April	13.3	29.8	43	1	8.8	23.1	3.98
May	14.4	28.9	53	1	8.6	22.4	4.03
June	14	26.6	67	1	6.7	19.2	3.59
July	13.7	24	76	1	4.4	15.9	3.01
August	13.6	24	77	1	4.3	15.9	3
September	12.9	25.1	72	1	5.9	18.2	3.3
October	12.5	26.2	63	1	9	21.9	3.7
November	10.4	26.3	57	1	9.5	21.2	3.35
December	7.9	26.2	54	1	10	21	3.11
Average	11.8	26.8	58	1	8	20.5	3.46

Table 2. Climate and ETo data of Rib

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	4.6	30.5	54	2	9.2	20.3	3.12
February	6.3	33	51	2	10	22.9	3.73
March	8	33	49	2	10	24.4	4.17
April	9	32.7	51	2	8.5	22.6	4.07
May	10	31.6	65	2	6.7	19.6	3.76
June	10.4	28.5	80	2	5.4	17.4	3.41
July	9.8	25	85	1	1.6	11.8	2.39
August	10.1	25.5	86	1	6.7	19.6	3.57
September	9.8	27	82	1	9	22.9	4.08
October	7.4	29	76	2	10	23.2	3.99
November	6.7	30	69	2	10	21.6	3.55
December	5.6	30	61	1	7.4	17.3	2.81
Average	8.1						

Table 3. Crop water and irrigation requirements of tomato at Koga

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	3	Initial	0.6	2.02	22.2	0	22.2
Jan	1	Initial	0.6	2.06	20.6	0	20.6
Jan	2	Development	0.6	2.11	21.1	0	21.1
Jan	3	Development	0.71	2.63	29	0.1	28.9
Feb	1	Development	0.87	3.43	34.3	1	33.3
Feb	2	Development	1.02	4.27	42.7	1.4	41.2
Feb	3	Development	1.16	5	40	1.7	38.3
Mar	1	Mid	1.21	5.39	53.9	1.9	51.9
Mar	2	Mid	1.21	5.55	55.5	2.2	53.3
Mar	3	Mid	1.21	5.67	62.4	2.8	59.7
Apr	1	Mid	1.21	5.8	58	1.3	56.7
Apr	2	Late	1.19	5.81	58.1	0.8	57.3
Apr	3	Late	1.08	5.21	52.1	9.7	42.4
May	1	Late	0.96	4.66	46.6	19.3	27.3
May	2	Late	0.88	4.25	17	10.8	3.5
					613.3	53	557.7

Table 4. Crop water and irrigation requirements of tomato at Rib

Month	Decade	Stage	Kc Coeff.	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	3	Initial	0.6	1.87	20.6	0	20.6
Jan	1	Initial	0.6	1.87	18.7	0	18.7
Jan	2	Development	0.6	1.88	18.8	0	18.8
Jan	3	Development	0.69	2.25	24.7	0	24.7
Feb	1	Development	0.83	2.79	27.9	0	27.9
Feb	2	Development	0.96	3.35	33.5	0	33.5
Feb	3	Development	1.08	3.87	31	0	31
Mar	1	Mid	1.13	4.16	41.6	0	41.6
Mar	2	Mid	1.13	4.28	42.8	0	42.8
Mar	3	Mid	1.13	4.34	47.8	0.1	47.7
Apr	1	Mid	1.13	4.41	44.1	1.8	42.4
Apr	2	Late	1.1	4.38	43.8	2.6	41.1
Apr	3	Late	0.99	3.95	39.5	3.9	35.6
May	1	Late	0.87	3.49	34.9	1.7	33.2
May	2	Late	0.78	3.17	12.7	0.5	12.1
					482.3	10.5	471.7

Treatment setup

The on-farm trial was conducted in the dry season with ten different treatments in both location at Rib and Koga. Two irrigation intervals i.e. 7 and 10 days and five irrigation depths (50, 75,100,125 and 150% CWR) of variable depths at four growth stages are selected based on CROPWAT 8.0. Thus the following treatments were set and evaluated for verification of the CROPWAT prediction with field experimentation:

1. 50%CWR at 7 day interval
2. 75%CWR at 7 day interval
3. 100%CWR at 7 day interval
4. 125%CWR at 7 day interval
5. 150%CWR at 7 day interval
6. 50%CWR at 10 day interval
7. 75%CWR at 10 day interval
8. 100%CWR at 10 day interval
9. 125%CWR at 10 day interval
10. 150%CWR at 10 day interval

The experiment was arranged with factorial RCBD with three replications and carried out from December to April. The test crop tomato, a variety of Cochero, was planted 1m x0.3m, spacing between row and plants on 4 m by 6 m plot size at Koga and 4*3 at Rib. Spacing between plot and block was 1m* 1.5m. DAP fertilizer was applied at a rate of 200 kg ha^{-1} at planting and 100 kg Urea ha^{-1} was applied half at planting and the remaining half at 45 days after planting. All the agronomic practices were equally done for each treatment. Agronomic data such as stand count, total bulb yield, marketable yield, and unmarketable yield were collected up to 5 round. In addition water productivity was calculated as the ratio of marketable yield to amount of water consumed (Arega, 2003).

Data Analysis

The means of the above parameters were subjected to analysis of variance (ANOVA) using SAS version 9 computer software. Mean comparison was done by using least significant difference test at 5% probability level.

Results and discussions

Most parameters showed significant difference for the interaction of irrigation scheduling and crop water requirement. Effect of variable irrigation regime on yield and water productivity component is presented in the following tables (Table 5 and Table 6).

Marketable yield and fruit weight

The interaction effect of irrigation frequency and depth showed a highly significant difference in marketable yield of tomato ($P < 0.001$, Table 5). At Koga, the highest (61.2 t ha^{-1}) tomato marketable yield was obtained from 125%CWR at 7 day irrigation interval while the lowest (27.5 t ha^{-1}) was obtained from 125%CWR at 10 day irrigation interval, (Table 5). The result is in line with the finding of Solomon et al (2014), who reported the application of 14mm depth, of irrigation (i.e. 75% of Cropwat generated depth) at 11 days interval gave the highest marketable yield 55.73 t ha^{-1} around Jari, eastern Amhara. The reduction in marketable yield of tomato with an increased amount of water stress level of this test was consistent with previous work conducted on tomato as reported by Schoolberg et al. (2000). The results indicated that, the marketable fruit yield of tomato is influenced by irrigation frequency while not irrigation regime. Marketable yield of tomato increased with an increment of irrigation depth from 50-125%CWR at 7 day irrigation interval while not at 10 day interval. However, further increase in irrigation level did not bring significant effect on marketable yield of tomato, reductions in marketable yield of tomato at irrigation depth beyond 125%CWR at 7 days irrigation interval and beyond 7 days irrigation interval may be due to the fact that much higher irrigation depth and interval can adversely affect marketable yield through the development of physiological disorder such as aeration and also creating favorable environment for diseases.

The marketable bulb yield of tomato at Rib had a positive response for irrigation frequency and depth as well as for interaction ($p<0.05$) (Table 6). The highest (45.51 t ha^{-1}) and lowest (32.01 t ha^{-1}) tomato marketable yields were obtained from 150%CWR at 10 day and 50%CWR at 7 day irrigation interval, respectively (Table 6). Marketable yield of tomato increased with an increment of irrigation depth from 50-150%CWR at 10 day irrigation interval while not at 7 day interval. Similarly the highest non marketable yield (5.44 t ha^{-1}) was observed from the application of 100%CWR at 7 days interval. The source of un marketability was insect damage, disease and crack; but insect damage took the lion’s share. The tomato yield obtained from this is by far higher than the yield obtained from the convectional production as well as from the yield reported by Hanibal et al. (2014) at Megech, Ethiopia.

Table 5. Effect of irrigation depth and frequency on marketable, unmarketable and total yields and water productivity at Koga

Frequency	Depth	Marketable yield (t ha^{-1})	Un marketable yield (t ha^{-1})	Total yield (t ha^{-1})	Water Productivity (kg m^{-3})
7	50	41	5.9	46.9	7.55
7	75	39	5.3	44.3	6.85
7	100	46.6	6.1	52.7	7.64
7	125	61.2	7	68.2	6.39
7	150	50.3	8.1	58.4	3.85
10	50	41.6	17.5	59.1	7.69
10	75	34.2	14.6	48.8	6.02
10	100	35.1	12.1	47.2	5.9
10	125	27.5	12.4	39.9	3.27
10	150	31.1	12.7	43.8	2.86
CV (%)		40.8	10.2	51	5.8
	Depth	0.9	0.11	1.02	0.34
	Frequency	28.06	6.13	5.97	2.5
LSD (5%)	Frequency*Depth	5.38	0.26	7.56	0.8

Table 6. Effect of irrigation depth and frequency on fruit weight, marketable yield unmarketable yield, total yield and water productivity at Rib

F	D	MY (t ha^{-1})	UMY	TY	WP	Treatment		FW weight
7	50	32.01	5.03	34.96	8.2	F	7	43.44
7	75	38.75	3.94	42.76	6.6		10	41.35
7	100	35.8	5.44	41.19	4.58			
7	125	36.53	4.52	40.48	3.7		50	43.82
7	150	36.45	3.6	40.02	3.1		75	40.45
10	50	34.73	4.62	39.33	8.9	Depth	100	42.36
10	75	35.72	3.6	39.46	6.1			

of tomato were reduced under deficit irrigation level. Generally, total yield of tomato at Koga and Rib showed a similar trend with marketable yield.

Water productivity

Interaction effects between irrigation schedule and depth had significantly influence on water productivity of tomato ($P \leq 0.05$, Table 5&6). Irrigation regimes have positive and highly significant effect on water productivity of tomato. The lowest (2.86 kg m^{-3}) and the highest (7.69 kg/ m3) water productivity of tomato were obtained for 150% and 50%CWR at 10 day irrigation interval, respectively at Koga. The result is in line with the finding of Solomon et al (2014), who reported Application of 14mm depth of irrigation (i.e. 75% of Cropwat generated depth) at 11 days interval gave the highest water productivity of 6.18 kg m-3 around Jari, eastern Amhara. The lowest (3.9 kg m^{-3}) and the highest (8.9 kg m^{-3}) water productivity of tomato were obtained for 150% and 50%CWR at 10 day irrigation interval, respectively at Rib. The water productivity, however, decreased with increasing irrigations depth both at 7 and 10 days irrigation interval.

Conclusion and recommendations

The effects of irrigation regime were assessed by examining their effects on yield and water productivity of tomato. The result of current study revealed that irrigation scheduling and depth had a significant effect on total fruit yield and water productivity in both irrigation schemes. Marketable and total fruit yield of tomato increased with increase in irrigation depth at 7 and 10 day interval at Koga and Rib irrigation scheme respectively. At Koga, 68.2 and t ha^{-1} and 6.38 kg m^{-3}, maximum yield and water productivity was achieved at 125% CWR at 7 day interval. In Koga area, a total of 18 irrigations were applied during the growing season. Application of 150%CWR at 10 days interval gave significantly better marketable yield, total yield, water productivity and bulb weight as compared to the optimum level. In Rib area a total of 12 irrigations afterwards were applied during the growing season. Hence from the foregoing statistical analysis results, if irrigation regime is aimed at maximizing yields per unit of irrigated area, 150%CWR at 10 day interval is recommended for Rib and similar agro ecology and 125%CWR at 7 day interval is recommended for Koga and similar agro ecology.

References

Al-Jamal, M. S., T. W. Sammis, S. Ball, and D. Smeal. 1999. Yield-Based, Irrigated Onion Crop Coefficients. Applied Engineering in Agriculture 15(6): 659-668.

Clements, B., and McGowen, I., 1994. Strategic fertilizer use on pastures. NSW Agriculture. Agnote Reg. 4/57, Orange, NSW.

DeJonge, K. and A. Kaleita. 2006. Simulation of Spatially Variable Precision Irrigation and Its Effects on Corn Growth Using CERES-Maize. No 062119. St. Joseph, Mich.:ASABE.

Gizaw Desta and Menelik Getaneh. (eds.) 2014. Achievements and Experiences of Agricultural Water Management Research and Development in Amhara Region. Proceedings of the First Workshop on Agricultural Water Management Research and Development in Amhara Region 28-30 March 2012, Bahir Dar, Ethiopia. Amhara Regional Agricultural Research Institute (ARARI). Pp119-129.

Enciso J, Wiedenfeld B, Jifon J, Nelson S (2009). Onion yield and quality response to two irrigation scheduling strategies.ScientiaHorticulturae. 120: 301-305.

FAO, 1992. Cropwat a computer program for irrigation planning and management. Irrigation and drainage paper, No. 46.

Fekadu M, Dandena G (2006). Review of the status of vegetable crops production and marketing in Ethiopia. Uganda J. Agric. Sci. 12 (2): 26-30.

Michael Abebe, 2001. Irrigation Research technologies recommended for sustaining crop production in some irrigated areas of Ethiopia. Norwegian university of science and technology, Norway

Muchovej RM, Hanlon EA, McAvoy E, Ozores-Hampton M, Roka FM, et al. (2008) Management of Soil and Water for Vegetable Production in Southwest Florida. Institute of Food and Agricultural Sciences.

Richard, G., Allen, L., and S. Pereira, 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage Paper 56, Rome.

Rockstrom, J. 2001. On Food and Nature in Water Scarce Tropical Countries. Journal of Land and Water International Series 99. pp 4-6.

Samson B and Ketema T (2007). Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia.Agric. Water Manag. 89: 148-152.

Scholberg J, Brian L, McNeal, Jones JW, Boote KJ, et al. (2000) Field-Grown Tomato: Growth and CanopyCharacteristics of Field-Grown Tomato. Agron J 92: 152-159.

Upton, M. 1996. The Economics of Tropical Farming System. Cambridge University Press,UK.