Response of Tomato (*Solanum lycopersicum*) to Deficit Irrigation in Raya Valley, Northern Ethiopia

Yemane Mebrahtu[1*], Ahmmed Mohammed[2] and Haftamu Tamiru[2]
1 Department Irrigation and Drainage, Ethiopian Institute of Agricultural Research (EIAR), Mehoni Agricultural Research Centre, Ethiopia; [2] Department Irrigation and Drainage, Ethiopian Institute of Agricultural Research (EIAR), Assosa Agricultural Research Centre, Ethiopia; [2] Department Irrigation and Drainage, Ethiopian Institute of Agricultural Research (EIAR), Mehoni Agricultural Research Centre, Ethiopia; *Corresponding Author: Yemane Mebrahtu, Ethiopian Institute of Agricultural Research (EIAR), Mehoni Agricultural Research Centre, Ethiopia*

Abstract

Water scarcity, erratic rainfall distribution and better management of water are a major constraint for the production of food in arid and semi-arid areas. Therefore, to cope up this problem deficit irrigation and application of irrigation systems are important concerns to achieve the goal of reducing irrigation water use and increase water productivity without significant yield loss under scarce water resources. A field experiment was carried out at Mehoni Agricultural Research Center, Raya Valley of Ethiopia, with objective of to identify the level of deficit irrigation which allow achieving optimum yield and to investigate the effect of alternate, fixed and conventional furrow irrigation method on yield and water productivity. The treatment were three deficit irrigation levels (50, 75 and 100% ETc), and three furrow irrigation methods (conventional, alternate and fixed furrow) were laid out in a random complete block design (RCBD) with three replications. The highest yield was obtained from combination of convectional furrow irrigation method with 100% ETc, convectional furrow irrigation method with 75% ETc and alternative furrow irrigation method with 100% ETc respectively without statistically difference. The highest water productivity of tomato was recorded from alternative furrow irrigation method followed by fixed furrow irrigation method, while convectional furrow irrigation method was recorded the lowest water productivity. Therefore, it can be concluded that alternative furrow irrigation method with 100% ETC of irrigation level increased water productivity which solve a problem of water shortage without significance reduction in tomato yield.

Introduction

Irrigation is one of the most important inputs for agricultural production. Limited water resources and increasing water demand for industrial and urban settlements have caused decreases in the quantity and quality of agricultural water use (Osman *et al*, 2001).

Because of the limited water and high level of competition, most irrigators in Ethiopia, especially these at tail of a scheme, allocation of irrigation water to the field is below the maximum crop water requirement for maximum yield (Lorite *et al.*, 2007).

In the semi-arid areas of Ethiopia, water is the most limiting factor for crop production. In these areas where the amount and distribution of rainfall is not sufficient to sustain crop growth and development, an alternative approach is to make use of the rivers and underground water for irrigation. Satisfying crop water requirements, although it maximizes production from the land unit, does not necessarily maximize the return per unit volume of water (Oweis *et al*, 2000). Therefore, in an effort to improving water productivity, there is an increasing interest in judicious application of irrigation water, an irrigation practice which controls the spatial and temporal supply of water so as to promote growth and yield, and to enhance the economic efficiency of crop production.

Many investigations have been conducted to gain experiences in irrigation of crops to maximize performances, efficiency and profitability. However, investigations in water saving irrigation still are continued (Sleper *et al.*, 2007). Nowadays, full irrigation is considered a luxury use of water that can be reduced with minor or no effect on profitable yield (Kang and Zhang, 2004).

Deficit irrigation is the application of less water than is required for potential ET and maximum yield, resulting in conservation of limited irrigation water (Musick, et al., 1994). Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains by maximizing yield per unit of water. Deficit irrigation as characterized by English (1990) has the fundamental goal to increase water use efficiency (WUE). Fereres and Soriano (2006) recently reviewed deficit irrigation and concluded that the level of irrigation supply should be 60-100% of full evapotranspiration (ET) needs in most cases to improve water productivity. Studies have shown that deficit irrigation significantly increased grain yield, ET and WUE as compared to rainfed winter wheat (Oweis, et al.; 2000). However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by growth stage, species and cultivars.

The objective of the study was to identify the level of deficit irrigation which allow achieving optimum yield and to investigate the effect of alternate, fixed and conventional furrow irrigation systems on yield and water productivity.

Materials and Methods

Description of the experimental site

This study was conducted at the research station of Mehoni 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° 68'08" 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).

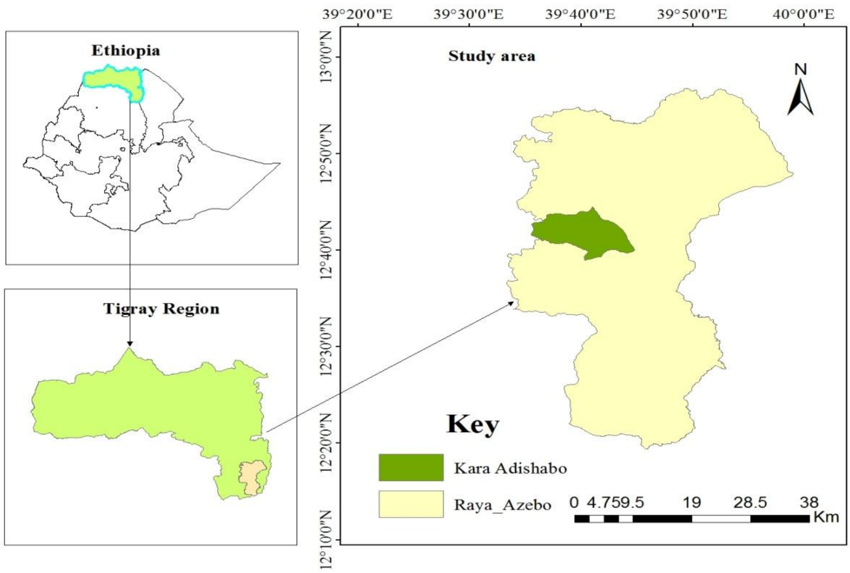

Figure 1. Map of the study area

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.

Experimental treatments and design

A fieldexperiment was carried out for three non-consecutive years. This experiment was laid out in RCBD with three replications. The treatments were included three furrow irrigation methods i.e alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) and three levels of irrigation applications levels (100%,75% and 50% ETc) combination of each other. Treatment having 100 % ETc irrigation level and conventional furrow irrigation was considered as a control. All cultural practices were done in accordance to the recommendation made for the tomato. The optimal irrigation schedule (ETc) was computed with the aid of CROPWAT model. The amount of irrigation water applied at each irrigation application was measured using Parshall flume.

Table 1. Treatment used in the experiment

Treatment	Combinations
T1	Convectional furrow irrigated with 100% ETc
T2	Convectional furrow irrigated with 75% ETc
T3	Convectional furrow irrigated with 50% ETc
T4	Alternative furrow irrigated with 100% ETc
T5	Alternative furrow irrigated with 75% ETc
T6	Alternative furrow irrigated with 50% ETc
T7	Fixed furrow irrigated with 100% ETc
T8	Fixed furrow irrigated with

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.

Table 2. 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 3. 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	170.04

Data collection

Yield data were collected from the four central rows out of six rows per plot to avoid border effect. Plant height, number of fruit per plant and cluster number were collected from selected eight plant sample of the four central rows.

Water Productivity (WP)

Water productivity was estimated as a ratio of fruit yield to the total ETc through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$WP = \frac{Y}{ETc}$$

Where, WP is water productivity (kg/m^3), Y crop yield (kg/ha) and ETc is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Statistical analysis

The three years yield and yield component data collected were subjected to ANOVA test using SAS software. The overall variability and effects of the treatment on yield and yield component parameters were considered as significant when $p < 0.05$. Least significant difference (LSD) test was applied for statistically significant parameters to compare means among the treatments.

Results and Discussion

Crop water requirement of tomato

The water requirement of tomato was computed for the growing season using the CROPWAT 8 computer program with climate, soil and crop input data from the study area. The values of ETo estimated using CROPWAT model based on climate parameters need to be adjusted for actual crop ET. The crop water requirement of the tested crop is calculated by multiplying the ETc with crop coefficient (Kc).

Pre-irrigation and common irrigation were applied for all plots uniformly without considering the treatments variation for transplanting and enhance better establishment of transplanted onion. Pre-irrigation was done before one day of transplanting. Two common irrigation after transplanting was applied to refill the moisture to field capacitynTmhe effective root depth.

According the seasonal irrigation water requirement of tomato was in the studyn area 529.9 mm. This amount of water was needed for 100% ,75% and 50% ETc of irrigation level with convectional furrow irrigation method were 529.9 mm, 397.7 mm, and 265.2 mm respectively. The amount of water was needed for 100% ,75% and 50% ETc of irrigation level with fixed and alternative furrow irrigation method were 3055.2 mm, 239 mm, 172.8 mm respectively.

Effect of irrigation levels and furrow method on yield and yield component

Effect of irrigation levels and furrow method on plant height

Plant height of tomato was high significant ($P < 0.01$) affected by the main effects of furrow irrigation methods and irrigation level, but not significantly ($P < 0.05$) affected by the interaction effectsnTmhe treatments (Table4).

Significantly higher plant height of tomato 43.04 and 42.9 cm was recorded for 100% ETc (full irrigation) and 75% ETc of irrigation depth of water applied respectively. 50% ETc of irrigation level of water applied recorded the lowest plant height Tm40.6 cm.

The highest plant height was 45.1 cm recorded by conventional furrow irrigation method followed by alternative furrow irrigation systems with the value of 40.7 cm. The lowest plant height was observed from the treatment of fixed furrow irrigation method with value of 40.6cm. Among the treatment of Alternative and fixed furrow irrigation method there were no significances difference. This result was in line with the findings of (J.C Paul, et al., 2013) and S.K Biswas et al, (2014). The highest increase in vegetative growth might be due to the availability of soil moisture.

The results of this study are reliable with those finding of (Zinabu. 2019) who found that deficit irrigation reduces plant height of tomato, which in turn affects yield. The finding of this study is also in agreement with those of (Yemane et al. 2018), who reported that water deficit significantly reduced plant height.

Effect of irrigation levels and furrow method on number of fruit per plant

The analysis of variance the interaction of furrow irrigation methods and irrigation level has shown that, there was not significant difference ($P < 0.05$) on number of fruit per plant, but the main effect of furrow irrigation methods and irrigation levels was shown significances differences (Table 4).

As shown in Table 4, the higher number of fruit per plant of tomato 51.4 was recorded for 100% ETc of irrigation level and followed by 75% ETc. The lowest number of fruit plant was observed from 50% ETc of irrigation level with the value of 45.8. Statically the was no significant differences between 100% and 75% ETc of irrigation level.

The higher number of fruit per plant was observed from the treatment convectional furrow irrigation method 52.4 and alternative and fixed furrow irrigation method were recorded the lowest number of fruit per plant. The result might be because of the reason that high irrigation levels increased photosynthetic area of the plant (height of plants and number of leaves), which increased the number of fruit per plant and increased fruit yield. The reduction of number of fruit under deficit irrigation was mainly attributed to reduction of water rather than to reduction of assimilates imported into the (fruit Ho JC 1996). Similar finding was obtained (Selamawit 2017), who reported that deficit irrigation significantly reduced number of fruit per plant height.

Effect of irrigation levels and furrow method on unmarketable and total yield of tomato

Significantly higher unmarketable and total yield of tomato were recorded when 50% ETc and 100% ETc irrigation level applied with the value 6.0 and 39.91

tone/ha respectively. In the other hand, the lowest unmarketable and total yield of tomato were observed from the treatment of 100% and 50% ETc of irrigation level with the result of 5.02 and 35.72 ton/ha respectively. Unmarketable yield of 100% and 75% ETc irrigation level was not have significant differences.

The highest total yield of tomato was obtained from the treatment of convectional furrow irrigation method (39.13 ton/ha) followed by alternative furrow irrigation method (37.51 ton/ha). Statistically higher unmarketable yield was recorded from fixed and alternative furrow irrigation method with the value of 62.68 and 59.3 ton/ha respectively. The lowest unmarketable yield of tomato was observed from convection furrow irrigation method (Table 4).

The increased total yield by applying full (no deficit) irrigation could have better performance on vegetative growth like plant height, number of fruit and cluster per plant which increase photosynthetic capacity of the plant, which in turn can improve to increment in total bulb yield.
The results of this study was agreed with the finding of (Kebede, 2003) who reported that stressed onion plants may bulb too early, produce small-sized bulbs and bulb splits and, thus, produce high amount of unmarketable yield. This could be due to low rate of transpiration caused by stomata closer under moisture stress condition which brought about reduced photosynthesis and poor bulb growth and developments.

As the irrigation level increased, the total yield increased. This result was also in agreement with the findings of (Ferreira and carr, 2002).

Table 4. Effect of furrow irrigation methods and irrigation levels on plant height(cm), Number of fruits per plant, Unmarketable yield (ton/ha) and Total yield (ton/ha) of tomato

Furrow methods	PH	NFPP	UMY	TY
CFI	45.1^{a}	52.4^{a}	4.32^{b}	39.13^{a}
AFI	40.7^{b}	48.1^{b}	5.93^{a}	37.51^{b}
FFI	40.6^{b}	46^{b}	6.27^{a}	35.91^{c}
LSD (P=0.05)	2.1	3.7	0.56	13.97
Irrigation level				
100%	43.04^{a}	51.4^{a}	5.02^{b}	39.91^{a}
75%	42.9^{a}	49.2^{ab}	5.51^{ab}	38.15^{b}
50%	40.6^{b}	45.8^{b}	6.00^{a}	35.72^{c}
LSD (P=0.05)	**2.1**	**3.7**	**0.57**	**13.9**
CV (%)	**5.06**	**7.7**	**10.3**	**5.7**

*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at P < 0.05; LSD= least significant difference; CV = Coefficient of variation.

Effect of irrigation levels and furrow methods on marketable yield

Marketable yield of tomato was highly significantly affected (*$P < 0.01$*) by the furrow irrigation methods and irrigation level (Table 5). Similarly, interaction effect of furrow irrigation methods and irrigation level was observed significant differences on the marketable yield of tomato.

The maximum marketable yield of tomato was observed at 100% ETc with convectional furrow irrigation method (37.82 ton/ha) and the minimum yield recorded at 50% ETc with fixed furrow irrigation method (28.35 ton/ha). Statistically there was no significance differences between the interaction of 100% ETc with convectional furrow irrigation method, 75% ETc with convectional furrow irrigation method and 100% ETc with alternative furrow irrigation method. Higher marketable yield of tomato was recorded from 100% ETc followed by 75% ETc irrigation level with the value of 35.25 and 32.71 ton/ha respectively. Significantly lower bulb yield of 29.72 ton/ha was recorded with 50% of irrigation level.

Among the furrow irrigation method treatments, conventional furrow irrigation method produced the highest yield of 34.86 ton/ha, alternate furrow irrigation method (32.05 ton/ha) while fixed furrow irrigation method gave the lowest yield of tomato with the value 30.77 ton/ha.

This result was in lined with the finding of (Sepaskhah and Ghasemi 2008), who reported that small amount of applied water reduced yield in every other furrow irrigation (AFI and FFI) as compared to CFI due to water stress, when the same irrigation frequency was applied which supported the result of this research.
This result is supported by finding of (Selamawit 2017) and (Tamirneh 2018), who reported that deficit irrigation reduced marketable yield of tomato as compare 100% crop water requirement.

Table 5.

Effect of irrigation levels and furrow methods on water productivity

The analysis of variance indicated that irrigation levels and furrow method was high significant ($p < 0.01$) affected by the interaction and main effect of each treatment on water productivity of tomato (Table 6).

The highest value of water productivity was recorded from the interaction of 50% ETc with alternative and fixed furrow irrigation method with the result of (22.4 and 21.4 kg/m^3). On the other hand, the lowest water productivity was obtained from the interaction of 100% ETc of irrigation level with convectional furrow irrigation method (7.2m^3/ha).

Irrigation level, in its main effect, increased water productivity from 50% ETc to 100% ETc irrigation level. Higher water productivity of tomato was obtained from 50% ETc followed by 75% ETc of irrigation level with the value of 18.57 and 13.53 kg/m^3 respectively. As compare the other treatment, full irrigation (100% ETc) of irrigation level was recorded the lowest water productivity (10.83 kg/m^3). Significantly higher water productivity of tomato was recorded when alternative furrow irrigation method applied with 17.06 kg/ha^3 and followed by fixed furrow irrigation method with 16.52 m^3/ha, while the lowest water productivity was recorded when convection furrow irrigation applied with the value of 9.34 kg/m^3. The results of this research are in agreement with (Yemane et al. 2018), who reported that water productivity values decreased with increasing irrigation level. In line with this result, (Samson and Ketema 2007) reported that deficit irrigations increased the water use efficiency.

Table 6. Interaction effects of furrow irrigation system and irrigation levels on water productivity (kg/m^3) of tomato

Furrow methods	Irrigation level			
	100%	**75%**	**50%**	**Mean**
CFI	7.2^e	8.9^d	11.92^c	**9.34**
AFI	15.8^b	14.99^c	22.4^a	**17.06**
FFI	12.49^c	15.7^b	21.39^a	**16.52**
Mean	**10.83**	**13.53**	**18.57**	
LSD (0.5)		**1.32**		
CV (%)		**5.37**		

*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $P < 0.05$; LSD= least significant difference; CV = Coefficient of variation.

Table 7: Marketable yield, Water used, Water saved, Yield reduction, Rank on yield reduction and water saved under the different deficit irrigation treatments

Treatment	MY (tone/ha)	WU (m^3/ha)	WS (m^3/ha)	YR (%)	YR (ton/ha)	Rank on WS	Rank on YR
Convectional furrow irrigated with 100% ETc	37.82	52599	0	0.0	0	9	1
Convectional furrow irrigated with 75% ETc	35.36	3977	1322	6.5	2.46	8	2
Convectional furrow irrigated with 50% ETc	31.39	2652	2647	17.0	6.43	3	6
Alternative furrow irrigated with 100% ETc	35.16	3052	2247	7.0	2.66	6	3
Alternative furrow irrigated with 75% ETc	31.57	2390	2909	16.5	6.25	4	4
Alternative furrow irrigated with 50% ETc	29.41	1728	3571	22.2	8.41	1	8
Fixed furrow irrigated with 100% ETc	32.76	3052	2247	13.4	5.06	6	5
Fixed furrow irrigated with 75% ETc	31.21	2390	2909	17.5	6.61	4	7
Fixed furrow irrigated with 50% ETc	28.35	1728	3571	25.0	9.47	1	9

MY= Marketable yield (ton/ha), WU= Water Used (m^3/ha), Water saved (m^3/ha), Yield reduction (%), Yield reduction (ton/ha)

Conclusion

It could be concluded that, In the study areas water is a limiting factor and a combination of alternative furrow irrigation method with 100% ETc irrigation level gave higher water productivity without significance tomato yield reduction, while the applied water in alternative furrow irrigation was reduced the amount of irrigation water and increasing the irrigated land by 50% than the convectional furrow irrigation method.

Acknowledgments

The authors are grateful to Ethiopian Institute of Agricultural Research, for providing funds for the experiment and technical support. The authors also very grateful to Mehoni Agricultural research centre for all staff of Natural Resources Management Research core process for giving us support in field management, suggestion and technical guidance during the course of the study experiment.

References

Bryan G, Donald A and Robert G. 2007. Managing irrigation water quality for crop production, Washington state university.

FAO (Food and Agricu[redacted]ral Organization), 1999. Soil salinity assessment methods and interpretation of ele[redacted]ical conductivity measurements. US salinity laboratory united states department of agric[redacted]ure, riverside, California, USA.

B (([redacted] 2002. Response of potatoes (Solanum tuberasum L.) to irrigation and nitro[redacted]n in a hot, dry climate: I. water use. Field Crops Research, Vol. 78, p. 51-64.

Ho JC. 1996. The mecha[redacted]sm of assimilate partitioning and carbohydrate compartmentation in fruit in relation to th[redacted] quality and yield of tomato. J. Exp. Bot. 1996; 47:1239-1243.

JC Paul, Mishra JN, Pradhan PL and Panigrahi B. 2013. Effect of drip and surface irrigation on yield, Water-Use-efficiency and economics of capsicum (capsicum annuml). Grown under mulch and non-mulch conditions in eastern coastal India. European Journal of Sustainable Development 2, 1, 99-108.

Kang, SZ and Zhang JH. 2004. Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency. Jour. of Experimental Botany, 55: 2437-2446.

Kebede Woldetsadik. 2003. Shallot (Allium cepa var. ascalonicum) responses to plant nutrient and soil moisture in a sub- humid tropical climate. Journal of Horticultural sciences and Biotechnology, 78(4):549-555.

Lorite IJ, Mateos L, Orgaz F, Fresses E. 2007. Assessing deficit irrigation strategies at the level of an irrigation district. Agricultural Water Management 91:51-60. http://dx.doi.org/10.1016/ j.Agwat. 2007.04.005.

MehARC. (Mehoni Agricultural Research Center, Land and water research process). 2015. Annual research report, Maichew, Tigray, Ethiopia.

Osman Y, Oner C, Demet U and Hasan B. 2001. Irrigation scheduling of Drip-irrigated Tomato using A pan evaporation, Turkey Journal of Agriculture, 26(2002)171-178.

Oweis T, Zhang H and Pala M. 2000. Water use efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. Agronomy Journal 92: 231-238.

Samson and Tilahun. 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia, Agricultural Water Management, vol. 89.

Selamawit Bekele. 2017. Response of Tomato to Deficit Irrigation at Ambo, Ethiopia. Journal of Natural Sciences Research. Vol.7 No.23 2017.

Biswas SK, Akanda AR., Rahman MS and Hossain MA. 2014. Effect of drip irrigation and mulching on yield, water-use efficiency and economics of tomato. Bangladesh Agricultural Research Institute, Gazipur, Bangladesh. Vol. 61, 2015, No. 3: 97 102.

Sleper DA, Fales SL, and Collins ME. 2007. Foreword. In: Irrigation of agricultural crops (R.J. Lascano and R.E. Sojka, eds.), 2nd edition, Agronomy MonograpH no. 30. ASA-CSSA-SSSA publishing, 664p.

Sepaskhah AR and Ghasemi M. 2008. Every-other-furrow irrigation with different intervals for sorghum. Pak. J. Biol. Sci. 11(9): 1234-1239.

Tamirneh Kifle. 2018. Evaluation of Tomato Response to Deficit Irrigation at Humbon Woreda, Ethiopia. Journal of Natural Sciences Research. Vol.8, No.15, 2018.

Tekalingn Mamo, I.Haque and Aduayi EA. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis manual. Plant science division working document 13, ILCA, Addis Ababa, Ethiopia

Yemane Mebrahtu., Abraham W/micheal. and Solomon Haftu. 2018. Response of onion (Allium cepa l.) to deficit irrigation under different furrow irrigation water management techniques in Raya Valley, Northern Ethiopia. African Journal of Plant Science. Vol. 12(5), pp. 105-113.

Zinabu A. 2019. Evaluation of Alternate, Fixed and Conventional Furrow Irrigation Systems with Different Water Application Level on Onion Yield in Dubti, Afar, Ethiopia. Industrial Engineering Letters. Vol.9, No.5, 2019.