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Effect of Furrow Irrigation Methods and Deficit Levels on Soil Properties and Yield of Tomato (Solanum Lycopersicum L.) at Dugda District, Central Rift Valley, Ethiopia

Lemma Teklu
Oromia Agricultural Research Institute,
Bako Agricultural Research Center
P.O.Box 03 Bako, West Shoa, Ethiopia

Abstract - **Over application with high frequency irrigation are some of the major problems which reduce the land production and productivity. In recognition of these constraints, study was conducted to investigate the effect of deficit irrigation under different furrow irrigation systems on soil properties and tomato yield. A field experiment was designed as a two factors factorial in RCBD; with three time replicates. The two factors were irrigation systems and water application levels. Irrigation depth was monitored using a Parshall Flume of an opening diameter 3 inch with discharge of 3.532 l/s at a head of 8cm. Results were compared in terms of standard range for soil properties and analysis of variance for yield at (P<0.05). The mean pH value of the soil before irrigation was nearly neutral and changed to moderately alkaline for alternative furrow irrigation (AFI) system and 50% ETc water application level, while it was changed to strongly alkaline for conventional furrow irrigation (CFI) and fixed furrow irrigation (FFI) systems and water application levels of 100% ETc, 85% ETc and 70% ETc. The interaction effects of irrigation systems and water application levels showed that, there were highly significant yield difference among the three irrigation systems with 100% ETc water application level and Maximum yield was obtained from CFI system with 100% ETc. However, from economic analysis results, AFI system with 100% ETc water application level had better in marginal rate of return (2606.36%). In view of the results, AFI system is taken as promising for conservation of water (1232.9m^3/ha) and time (55:28'30" hours/ha), without negligible trade-off in yield.**

Key words: Soil, Deficit irrigation, Irrigation methods and Tomato yield

1. INTRODUCTION

Increased agricultural production has become an urgent requirement of the expanding world population (Howell, 2001; Chen *et al*., 2011). Yet, there has been a continued decrease in available fresh water that can be used by agricultural production (Cai and Rosegrant, 2003). Due to this, the sustainable use of water in agriculture has become a major concern and the adoption 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). At the same time, the quality of irrigation water has also deteriorated. As a result, both deficit irrigation and sodic water have been prevalently used in irrigated agriculture.

Deficit irrigation 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. Crop tolerance to deficit irrigation during the growing season changes with the phenological stage (Istanbulluoglu, 2009). Nevertheless, the effects of deficit irrigation on yield or harvest quality are crop specific (Costa *et al*., 2007). Information on how different crops cope with mild water deficits forms the basis for a successful application of deficit irrigation.

Irrigation water quality can affect soil fertility and irrigation system performance as well as crop yield and soil physical conditions (Al-omran *et al*., 2010). Therefore, knowledge of irrigation water quality is critical in understanding the management changes that are necessary for long-term productivity. However, the limitation in water availability and also sodicity related to over irrigation obliges to adopt alternative irrigation schedules with different frequencies of irrigation. 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).

It has been reported by FAO (2001) that 97.8% of irrigation in Ethiopia is done by surface methods of irrigation, especially by furrow system in farmer's fields and majority of the commercial farms. Furrows are particularly suitable for irrigating row crops such as vegetables, cotton, sugar beet, maize, tomatoes and potatoes planted on raised beds, which are subject to injury if water covers the crown or stems of the plants (Michael, 2008). The furrow irrigation systems were includes conventional furrow irrigation (CFI), fixed furrow irrigation (FFI) and alternative furrow irrigation (AFI). CFI is where every furrow is irrigated during consecutive watering, is known to be less efficient particularly in areas where there is shortage of irrigation water. It is usually causes excessive deep percolation at the upper part of the furrow, insufficient irrigation at the lower part and considerable runoff, resulting in low application efficiencies and distribution uniformities. The development towards optimum utilization of irrigation is to irrigate alternate furrows during each irrigation time (Zhang *et al*., 2000). By irrigating alternative furrows, half of root is exposed to wet soil condition and the other half is exposed to dry soil condition. According Hodges *et al*., 1989 and Graterol *et al*., 1993, FFI is a means of selection some furrows for irrigation while other adjacent furrows were not irrigated for the whole season.

Tomato (*Solanum lycopersicon L*.) is one of the most important vegetable crops and is one of the most demanding in terms of water use (Peet, 2005). The application of deficit irrigation strategies to this crop may significantly led to save irrigation water (Costa *et al*., 2007). Furthermore, studies have shown that water deficit occurs during certain stages of the growing season improves fruit quality, although water limitations may determine fruit yield losses (Patane and Cosentino, 2010). According to Patane *et al.* (2011), the adoption of deficit irrigation strategies in which a 50% reduction in ETc was applied for the whole or partial growing season to save water helped to minimize fruit losses and maintain high fruit quality. Pulupol *et al.* (1996) observed a significant reduction in dry mass yield for a glasshouse tomato cultivar using deficit irrigation, while Zegbe-Domínguez *et al*. (2006) did not find a reduction in tomato fruits yield of field-grown processing cultivar.

In the study area, poor rainfall distribution during the growing season, poor irrigation water quality and over application of irrigation water without determining the crop water requirement during a dry season were identified as the major problem of a crop failure. But, farmers pump irrigation water from ground or lake for intensive irrigation practice without considering the sustainability of precious resource. Under such existing condition, practicing of deficit irrigation and water saving methods of furrow irrigation systems could help to increase agricultural production by expanding irrigable land with the given limited amount of water. Therefore, this study aims at evaluating the effect of irrigation methods and deficit levels on soil properties and yield of tomato.

2. MATERIALS AND METHODS

2.1. Study Area Description

The experimental site is situated at Dugda district, Eastern Shewa zone, Central Ethiopia. It is located at 130 km away from Addis Ababa, the capital city of Ethiopia on the way to Ziway and at South East direction from Meki town at an altitude of 1685 masl. The site lies in 08^{0}00'-8^{0}20'N and 38^{0}30'-39^{0}00'E longitude and latitude, respectively (Fig. 1). The experimental site is characterized by sandy loam soil type, mild and warm temperate climate in which the majority of the rainfall occurs from May to September. Rainfall over the district is highly variable in temporal and spatial. The area receives an annual rainfall of 1009 mm and an average annual temperature of 18.4^{o}C (en.climate-data.org/location/ 54437/).

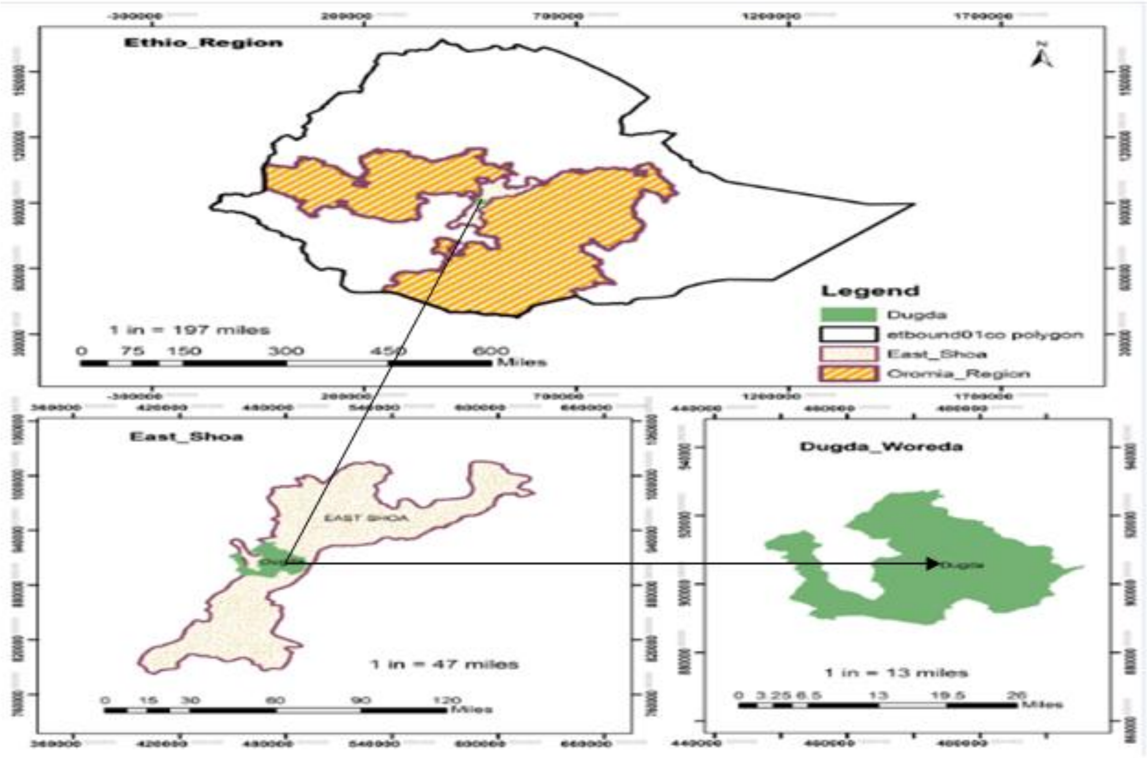

Fig.1. Location map of the study area

2.2. Experimental Design and Procedure

The experiment was implemented in two factorial combinations namely, three irrigation systems and four irrigation water levels (Table 1). The treatments combinations were arranged as completely randomized blocks design with three time replications. The depth of applied water to each treatment was measured by Parshiall Flume of 3inch throat diameter. The effective head of 8cm was calibrated and hence the resulting discharge out of the Parshall Flume was 3.532 liters per second. Each treatment has 4 m × 6 m plot size with 1m free space between plots and 2m wide spacing between blocks. Each plot contained four ridges and four furrows. Each bed had 1m width and 6m length. The trapezoidal shape furrow was prepared with an average depth of 30 cm and width of 25 cm and 15cm at the top and bottom, respectively.

The required crop water was calculated using CROPWAT version_8 computer programme considering the soil and climatic properties of the study area (Allen *et al.*, 1998). Improved tomato variety (*Galilea*) having a total growing period of 75 days after transplanting was grown in a modern green house for 21 days and transplanted on experimental plot. This crop variety was selected for its good adaptability, disease resistant and most usable in the study area. The growing period of the crop was mainly divided into four major growth periods (Brouwn *et al.*, 1989): initial, development, middle and late stages. Initial stage- runs from planting date to approximately 10% ground cover; development stage-runs from 10% ground cover to effective full cover; middle stage-runs from effective full cover to the start of maturity and late stage-runs from start of maturity to harvest, or full senescence. Percent of ground cover and phenology of the crop was considered to decide the date of growth stages (Brouwn *et al.*, 1989).

Table.1. Treatment used for the experiment

Irrigation systems	Water application levels			
	100% ETc	85% ETc	70% ETc	50% ETc
AFI	AFI100% ETc	AFI 85% ETc	AFI 70% ETc	AFI 50% ETc
FFI	FFI100% ETc	FFI 85% ETc	FFI 70% ETc	FFI 50% ETc
CFI	CFI100% ETc	CFI 85% ETc	CFI 70% ETc	CFI 50% ETc

Where: AFI100% ETc, FFI100% ETc and CFI100% ETc were alternative, fixed and conventional furrow irrigation with full irrigation respectively, AFI 85% ETc, FFI 85% ETc and CFI 85% ETc were 85% of the full irrigation (15% deficit), AFI 70% ETc, FFI 70% ETc and CFI 70% ETc were 70% of full irrigation (30% deficit) and AFI 50% ETc, FFI 50% ETc and CFI 50% ETc were 50% of full irrigation(50% deficit).

2.3. Soil Sample Collection and Analysis methods

Depending on the greatest root depth concentration which is 30cm for transplanted tomatoes, the disturbed and undisturbed composite soil sample before planting and after harvest from each treatment at a depth of 0-20 and 20-40 cm were collected and analyzed for different soil physical properties such as bulk density, texture, field capacity and permanent wilting point and also for chemical properties such as soil pH, organic matter content, total nitrogen, available phosphorus and potassium at Ethiopian Water Works Supervision and Design Enterprise, Bako and Ziway Research Center Soil Laboratory. Accordingly, the soil data used as input for CROPWAT model were summarized in Table 2.

2.3.1. Soil Physical Properties

Soil texture was determined using pipette method. This is based on direct sampling of the density of the solution. As per Stoke's law at a depth 'L' below the surface of the suspension and at time 't', all particles whose terminal velocity 'v' is greater than was passed below this level example silt passes through but clay remains.

The soil bulk density is defined as the oven dry weight of undisturbed soil in a given volume, as it occurs in the field. It was determined by core sampler method. After weighing the soil sample, it was placed in an oven dry at 105^{0}c for 24 hours. After drying, the soil was weighed again for dry mass and the bulk density was calculated by using the following formula.

$$\rho b = \frac{W_d}{V_c} \qquad (1)$$

Where

ρb= soil bulk-density, (g/cm^3)
Wd = weight of dry soil, (g)
Vc = volume of core sampler, (cm^3)

Double ring infiltrometers were used to measure infiltration rate of the soil. The tests were done at five randomly selected points in the experimental site and the average result was taken.

The Water content field capacity (FC) and permanent wilting point (PWP) were determined using a pressure plate apparatus by applying a suction of 1/3 and 15 bars to a saturated soil sample and when water is no longer leaving the soil sample, the soil moisture was taken as FC and PWP respectively.

2.3.2. Soil Chemical Properties

pH was measured in 1:1 soil: water mixture by using a pH meter. Organic carbon content was determined according to Walkley and Black (1934) method. Total nitrogen was determined by micro Kjeldahl procedure (Kjeldahl, 1883). Available phosphorus was determined by Olsen method (Olsen *et al.*, 1954). Available potassium was determined by flame photometer method (Reed and Scott, 1961).

Meteorological data's such as minimum and maximum temperature, relative humidity, wind speed and daily sunshine hours were collected from nearby weather station to determine reference crop evapotranspiration (Table 3). The evapotranspiration was calculated using Modified FAO Penman-Monteith method (Allen et al., 1998). The rainfall received during the growing season of the crop was almost 0 mm.

Table 2. Input soil data for CROPWAT model

Depth of sample(cm)	FC(%) by vol.	PWP(%) by vol.	Bd (g/cm^3)	Sand %	Silt %	Clay %	Textural class	Basic infiltration rate (mm/hr)
0-20	23.77	12.28	1.32	71	8	21	Sandy loam	28.8
20-40	20.10	11.89	1.34	69	14	17	Sandy loam	
Average	21.94	12.09	1.33	70	11	19	Sandy loam	

Where: FC, PWP and Bd were field capacity, permanent wilting point and bulk density respectively.

Table.3. Mean monthly meteorological data and ETo value of the study area

Months	Temp. max.(^{0}C)	Temp. min.(^{0}C)	Humidity (%)	Wind speed (km/hr)	Sun shine (hr)	ETo (mm/day)
January	27.295	12.519	49	1.6	9.8	3.38
February	28.967	13.5	45.4	1.7	9.5	3.69
March	29.428	15.179	41	1.6	9.1	3.91
April	29.553	15.89	57	1.6	8.8	4.17
May	29.395	16.175	58.4	1.8	8	3.92
June	28.125	15.775	59.8	2.4	8.1	3.81
July	25.586	15.31	66.7	2.2	6.3	3.38
August	25.719	15.181	73.6	1.9	6.1	3.43
September	26.86	14.668	72.6	1.4	6.4	3.54
October	27.75	13.237	69.2	1.5	9.2	3.98
November	27.245	12.165	63	1.7	9.8	3.68
December	26.642	11.342	55.3	1.7	9.8	3.3

2.4. Determination of Crop Water and Irrigation Requirement

Crop water requirement of tomato for the growing season was determined from the reference evapotranspiration and crop coefficient using Equation (2). As there is no site specific estimated crop coefficient in the site, if not in the country, the respective crop coefficient for initial, middle and late growth stages were taken from FAO (Allen et al., 1998). To reduce the problem of over and under estimation of irrigation, farmers' experience was used to determine the numbers of days of each growing stages so as to estimate reliable Kc for the respective growing stages. For this experimental set up, a higher value of application efficiency which is 60% was adopted, because water was applied more accurately and also there was no runoff. Irrigation scheduling of the crop was computed using FAO CROPWAT program (Allen et al., 1998).

$$ETc = Kc \times ETo \qquad (2)$$

Where

ETc = crop evapotranspiration (mm/day),
Kc = crop coefficient (dimensionless), and
ETo = reference crop evapotranspiration (mm/day).

As indicated in Section 2.3, the amount of rainfall received during the experiment period was zero and hence net irrigation requirement was taken to be equal to ETc.

Crop evapotranspiration was predicted using the FAO Penman-Monteith equation and weather data, collected from the nearby of the meteorological station of experimental site and crop coefficients for standard conditions from FAO (Allen et al., 1998). ETc for the respective treatments were calculated using ETo and crop coefficient and these values were multiplied by percent of water applied at each irrigation time throughout the growth stage.

2.5. Crop Agronomy and Management

Tomato seedlings were transplanted to the experimental plots based on the recommended space of 60 cm between plants and 100 cm row spacing on 26 January, 2016. Recommended fertilizer of 200 kg/ha DAP and 150 kg/ha Urea were equally and uniformly applied to each treatments. DAP fertilizer was applied at the time of transplanting and urea was given twice, half at the time of transplanting while, half at 21 days after transplanting. The crop was cultivated and weeded four times during the growing season. The tomato was transplanted on four ridges of each plot and for further analysis the yield was harvested from the two central ridges only (2 m x 6 m plot size); this is to avoid boarder effects. The results were then converted to hectare basis using the following formula:

$$\text{Yield obtained in ton per ha} = y \times 10^4 \qquad (3)$$

Where

y = is yield obtained per square meter

2.6. Statistical Analysis

The collected soil data during field study were described on standard range while, the collected yield data was compared using GenStat15th edition, ANOVA and the mean difference was estimated using the least significance difference (LSD) comparisons.

3. RESULTS AND DISCUSSIONS

3.1. Crop water requirements and irrigation scheduling of Tomato

Crop water requirements were calculated by multiplying the reference evapotranspiration values with the tomato crop coefficient (Allen et al., 1998). The seasonal irrigation water requirement of tomato was found to be 246.58 mm. This amount of water was needed for 100% ETc with CFI, AFI, FFI (full irrigation) level treatments. Accordingly, 85%, 70% and 50% of full irrigation (100% ETc) with CFI, AFI, and FFI level were 210 mm, 173 mm and 124 mm, respectively. The depth of irrigation water required at each irrigation interval and number of irrigation events were described on Table 4. The result indicates that, the maximum depth of water was applied during mid of March which is the mid development stage of tomato. Sahasrabudhe (1996) suggested that, this is the time when the crop needs high amount of water. Maximization of crop yield and quality can be achieved through meeting crop water requirement during this critical period, given all other factors are met. Probably the high tomato water requirement during this stage of development can be accounted for development of flowers and fruit which is high energy demanding and peak physiological phase for the crop growth (Sahasrabudhe, 1996). It should be noted also that development stage is also the time during which the plants achieve higher canopy coverage and undergoing higher transpiration rate. By sufficiently supplying water to the plant, during such critical time and ensuring its uptake, it is possible to improve crop water productivity.

Table 4. Irrigation interval and depth of water applied to each treatment

Irrigation systems	Water application levels	Irrigation period and depth of applied water (mm)				
		4th February	15th February	1st March	15th March	31st March
FFI	100% ETc	21.08	27.68	63.27	67.62	66.93
	85% ETc	17.92	23.53	53.78	57.48	56.89
	70% ETc	14.78	19.34	44.29	47.33	46.85
	50% ETc	10.54	13.84	31.64	33.81	33.47
AFI	100% ETc	21.08	27.68	63.27	67.62	65.93
	85% ETc	17.92	23.53	53.78	57.48	56.89
	70% ETc	14.78	19.34	44.29	47.33	46.85
	50% ETc	10.54	13.84	31.64	33.81	33.47
CFI	100% ETc	21.08	27.68	63.27	67.62	65.93
	85% ETc	17.92	23.53	53.78	57.48	56.89
	70% ETc	14.78	19.34	44.29	47.33	46.85
	50% ETc	10.54	13.84	31.64	33.81	33.47

Where: FFI, AFI and CFI are fixed furrow irrigation, alternative furrow irrigation and conventional furrow irrigation, respectively.

3.2. Soil Properties as affected by irrigation systems and water application levels

The mean soil pH result of 7.35 before irrigation (Table 5) shows that, the soil of the experimental site is nearly neutral and suitable for crop production. However, the mean soil pH value has changed from 7.35 to 7.76, 8.06 and 8.09 for AFI, CFI and FFI systems, respectively after implementation of the irrigation. While, it was changed from 7.35 to 8.11, 7.97, 8.07 and 7.72 after application of water levels 100% ETc, 85% ETc, 70% ETc and 50% ETc, respectively.

According to Brady (2000), the pH range from 7.4-7.8 and 7.9-8.4 indicates moderately and strongly alkaline, respectively. The results of AFI system and 50% ETc of water application levels were changed from nearly neutral to moderately alkaline, while the results of FFI, CFI and water application levels of 100% ETc, 85% ETc and 70% ETc were changed from nearly neutral to strongly alkaline. Because, the lake water used for irrigation has pH (8.7), ESP (60.42%) and EC (0.64ds/m) which is categorized under sodic and with high application of irrigation water 100% ETc, 85% ETc and 70% ETc and also in CFI and FFI systems, the amount of sodium cation added to the soil from the irrigation water increases the soil pH. According to Cruz-Romero and Coleman (1975), Exchangeable sodium and calcium carbonate (Ca_2CO_3) react in low carbon dioxide and low neutral salt environments to produce high pH and appreciable concentration of sodium carbonate (Na_2CO_3). Since the soil of arid and semi-arid regions nearly always contain some Ca_2CO_3, a build up in the exchangeable sodium in the absence of an appreciable quantity of neutral soluble salts will always result in high pH.

The organic matter content of the soil of the experimental site before and after irrigation was less than 2% which is very low (Landon, 2014). But, after implementation of the experiment the organic matter content of the soil increases from 1.15% to 1.22%, 1.29% and 1.34% for FFI, AFI and CFI systems and from 1.15% to 1.28%, 1.43%, 1.37% and 1.24% for water application levels of 100% ETc, 85% ETc, 70% ETc and 50% ETc, respectively (Table 5). In arid and semi-arid area, moisture is a limiting factor for the decomposition and availability of soil organic matter. That is why the soil organic matter content after irrigation was increased for both irrigation systems and water application levels. This is consistent with the report of an increased trend in soil organic matter content was observed as the water deficit level of 85% ETc which further decreasing consistently (Abu and Malgwi, 2012).

The mean results of total nitrogen content of the soil before and after irrigation were less than 0.15% which is low (Havelin *et al*., 2013). However, the total nitrogen content in the soil increases after irrigation from 0.08% to 0.108%, 0.113% and 0.108% for FFI, AFI and CFI systems and from 0.08% to 0.11%, 0.117%, 0.11% and 0.10% for irrigation water application levels of 100% ETc, 85% ETc, 70% ETc and 50% ETc, respectively (Table 5). Under CFI and FFI systems, the total nitrogen is less as compared to AFI system due to leaching effect. According to Richard and Michael (2012), a conversion factor of 4.43 multiplied with the results of total nitrogen before and after irrigation, the results were changed to nitrate (NO_3^-) form which is the water soluble form of nitrogen. This helps us to judge how the solubility and availability of the nitrogen increases after it gets moisture through irrigation.

The mean results of available phosphorus before and after irrigation were between 30-80mg/kg of soil which is optimum (Karltun et al., 2013). After irrigation, it was increased from 44.19 mg/kg of soil to 46.89, 46.02 and 46.96 mg/kg of soil and 46.45, 45.95, 47.07 and 47.03 mg/kg of soil for FFI, AFI, CFI and 100% ETc, 85% ETc, 70% ETc and 50% ETc, respectively (Table 5). This shows that, as pH results of CFI and FFI systems increased to strongly alkaline, phosphorus fixation also increased.

As the result indicates, the available potassium content of the soil was decreased to some extent after irrigation on both irrigation systems and water application levels (Table 5). As a result, it was decreases from 306.29 mg/kg of soil to 257.87, 274.88 and 304.61 mg/kg of soil for FFI, AFI and CFI systems, while it was decreased from 306.29 mg/kg of soil to 254.25, 284.15, 284.81 and 293.26 mg/kg of soil for 100% ETc, 85% ETc, 70% ETc and 50% ETc, respectively. These results show that, when the soil gets enough moisture from irrigation, the plant uptake rate of the potassium is increased, while its content in the soil decreases. In addition to uptake, it is well established that potassium is liable to leaching and thus, this might have also decrease its content in the soil. This situation was mostly pronounced in moisture stress area where soil moisture is a limiting factor. Experiment undertaken in the middle Awash reported by Haider (1986) is in agreement with the results obtained in the present study.

Table 5. Mean value of soil parameters of irrigation systems and water application levels

Soil parameters	Irrigation systems			Water application levels				Composite soil sample
	FFI	AFI	CFI	100% ETc	85% ETc	70% ETc	50%ETc	
pH in water	8.09	7.76	8.06	8.11	7.97	8.07	7.72	7.35
OM (%)	1.22	1.29	1.34	1.28	1.43	1.37	1.24	1.15
Total N (%)	0.108	0.113	0.108	0.11	0.117	0.11	0.10	0.08
Available P_2O_5(mg/kg of soil)	46.89	46.02	46.96	46.45	45.95	47.07	47.03	44.19
Available K_2O (mg/kg of soil)	257.87	274.88	304.61	254.25	284.15	284.81	293.26	306.29

Where: OM, P_2O_5 and K_2O are organic matter, phosphorus pent oxide and potassium dioxide, respectively.

3.3. Tomato Yield Performance

As depicted from analysis of variance (Table 5), there were highly significant yield difference at (P<0.01) between irrigation systems. As indicated on (Table 6), the yield obtained from CFI (25.194 ton/ha) and AFI (24.021 ton/ha) systems were significantly different from FFI (20.00 ton/ha) system. But, there was no significant difference between the yield obtained from CFI and AFI systems. The reason why the yield result is well performing as compared to CFI system is probably because of a better application efficiency and physiological response associated with AFI (Franandez, 1994; Kang, 2000; Zhang *et al*., 2000) and less evapotranspiration associated with AFI (Stone *et al*., 1979).

In addition to the above advantages, as pH results after irrigation shows the soil changed from nearly neutral to moderately alkaline in AFI while, it changed from nearly neutral to strong alkaline in both CFI and FFI systems as a water used for irrigation was sodic.

As shown on (ANOVA Table 5 and Table 6), there were highly significant yield difference among the water application levels (P<0.01). This is consistent with the report of continuous water stress during the period of fruit set and fruit development can results significantly reduced fresh fruit yield and blossom-end rot (Sahasrabudhe, 1996).

Table 5. Analysis of variance (ANOVA) for yield

Source of variation	SS	df	MS	F computed	F-tab	
					(0.05)	(0.01)
Blocks	22.85	2	11.43	2.85	3.44	5.72
Treatments	684872.10	11				
Irrigation systems	178.07	2	89.04	22.18	3.44	5.72**
Water application levels	1345.99	3	448.66	111.79	3.05	4.82**
Irr. System x water appl. Levels	158.33	6	26.39	6.58	2.55	3.76**
Error	88.30	22	4.01			
Total	1793.54	35				

Where:*-significant **-highly significant, SS- is sum square, df- is degree of freedom, MS- mean square

Table 6. Effects of irrigation systems and water application levels on tomato yield performance

Irrigation systems	Yields (ton/ha)	water application levels	yields (ton/ha)
CFI	25.194^{a}	100% ETc	31.879^{a}
AFI	24.021^{a}	85% ETc	24.574^{b}
FFI	20.00^{c}	70% ETc	20.794^{c}
		50% ETc	15.038^{d}
Mean	23.072		23.072
CV	8.7%		8.7%
$LSD_{0.05}$	1.696		1.959
SE±	0.578		0.668

Where: yield results with the same letter are not significantly different at P = 0.01 according to LSD.

3.3.1 Interaction Effect of Irrigation Systems and Water Application Levels on yield

Another inference from analysis of variance (Table 5) was the interaction effects between irrigation systems and water application levels which is highly significant at (P<0.01) on yield. From (fig. 2), the yields obtained were significantly different for the three irrigation systems at 100% ETc water application levels. Maximum yield was obtained from CFI with100% ETc which is significantly different from both FFI and AFI with 100% ETc, while minimum yield were obtained from both FFI and CFI with 50% ETc. This shows that, yield was highly affected by irrigation systems at 100% ETc water application level and in area where water availability and quality is not a problem CFI with 100% ETc was a promising. However, from economic analysis results (Table 7), AFI with 100% ETc is better in marginal rate of return and more advantageous to irrigators. Net benefit of 50928.59 birr/ha is obtained while changing from AFI system with 85% ETc to AFI system with 100% ETc. As already known, there was a significant reduction (50%) in the volume of water applied to the AFI treatments. This means 2465.8 m^3 volume of water is needed to irrigate 1 hectare area in CFI system which is enough to irrigate 2 hectare area of land in AFI system. So, when the area to be irrigated becomes double in AFI system using the saved volume of water, the yield obtained also becomes double.

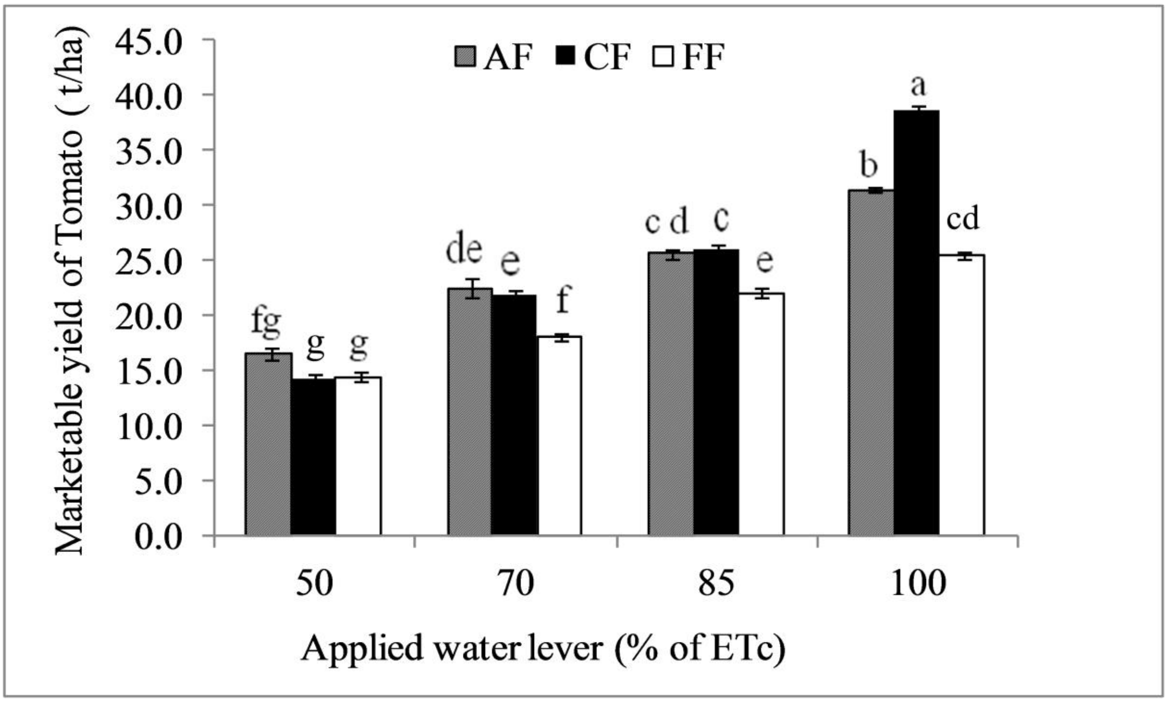

Figure 2. Interaction effects of irrigation systems and water application levels on tomato yield

Table.6.Irrigation water & time of irrigation saved and cost- benefit analysis of the interaction effects of irrigation systems and water application levels

Treatments	Time saved (hr/ha)	Water saved (m^3/ha)	sum of cost that varies (birr/ha)	Total yield (ton/ha)	Adjusted yield (10%) (ton/ha)	Total revenue (birr/ha)	Net benefits (birr)	DA	MRR= $\frac{\Delta TR*100\%}{\Delta MC}$
AF with 50% ETc	173.21'55"	1849.35	10238	15.94	14.35	129150	118911.97	D	-
FF with 50% ETc	173.21'55"	1849.35	10338	15.28	13.75	123750	113411.97	D	-
AF with 70% ETc	153.56'13"	1602.77	14333.2	21.69	19.53	175725	161391.76		1200.94
FF with 70%ETc	153.56'13"	1602.77	14533.1	20.78	18.7	168300	153766.86	D	-
AF with 85% ETc	139.22'37"	1417.83	17404.65	24.78	22.3	200700	183295.35		1028.31
FF with 85% ETc	139.22'37"	1417.83	17704.95	22.53	20.28	182475	164770.05	D	-
AF with 100% ETc	55.28'30"	1232.9	20476.1	31.44	28.3	254700	234223.94		2506.32
FF with 100% ETc	55.28'30"	1232.9	20686	25.50	22.95	206550	185864	D	-
CF with 50% ETc	124.50'50"	1232.9	40976.1	15.56	14	126000	85023.94	D	-
CF with 70% ETc	85.58'26"	739.74	57366.48	21.86	19.675	177075	119708.52		211.62
CF with 85% ETc	56.51'14"	369.87	69659.30	25.5	22.95	206550	136890.70		139.77
CF with 100% ETc	0	0	81952.1	38.69	34.83	313425	231472.88		769.41

Where: D, DA, MRR, ΔMR and ΔMC were marginal rate of return, dominance analysis, dominance, change in marginal revenue and change in marginal cost, respectively.

4. CONCLUSION

Maximum depth of irrigation water was applied during the mid developmental stage of a crop at the time when the crop needs high amount of water, the mean pH value of the soil before irrigation was nearly neutral and changed to moderately alkaline for AFI system and 50% ETc water application level, while it was changed to strongly alkaline for CFI and FFI systems and water application levels of 100% ETc, 85% ETc and 70% ETc. Soil organic matter, total nitrogen and available phosphorus contents were increases after irrigation while it was decreases for available potassium. From economic analysis results, AFI system is better in marginal rate of return and is the best technology among the tested technologies to be recommended for the communities of the study area, because of its yield performance, reduction of the problem of sodicity, in addition to time, labour and irrigation cost saving.

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