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Growth and physiological response of tomato to various irrigation regimes and integrated nutrient management practices

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The experiment was conducted by combining two factors namely; irrigation scheduling with three levels and nutrient management with five levels. The two factors were crossed factorially; irrigation treatments were arranged in vertical strips and integrated nutrient management arranged in horizontal–strip with strip plot design replicated three times. Field soil was sampled for physical and chemical property determinations. Equal amount of irrigation water were applied before the initiation of irrigation treatments. Once the drip system was installed, irrigation was done on the basis of daily evapotranspiration (ETo) value of the previous day. Growth and canopy characteristics such as plant height, stem diameter, lateral branch length, canopy width and canopy depth were measured and canopy cover was estimated. Additionally yield and yield components at harvest were measured from sample fruits. Physiological data such as chlorophyll content, quantum yield, and Ft were assessed. Data were subjected to analysis of variance as per the design using the SAS Software. Among irrigation levels tested, highest total yield 82.14 t ha^{-1}, was recorded from full irrigation treatment followed by 57.30 t ha^{-1} from 80% ETc irrigation levels and lowest total yield 49.30 t ha^{-1} from 60% of full irrigation depth. This finding indicated that tomato should be irrigated at full water requirement to get maximum fruit yield. From this investigation, the total fruit yield was recorded from N 185 kg ha^{-1} P 60 kg ha^{-1} combination and N 75 kg ha^{-1} P 50 kg ha^{-1} treatment combination with 67.483 and 67.31 t ha^{-1} respectively. Application of N 185 kg ha^{-1} P 60 kg ha^{-1} combination (grower's check) did not contribute to much yield difference but would encourage luxury consumption and environmental pollution. Thus combinations of full irrigation treatment with N 75 kg ha^{-1} P 50 kg ha $^{-1}$ nutrient application would be recommended for verification for tomato production around Melkassa.

Key words: Drip irrigation, N and P nutrient, evapotranspiration (ETo), ETc, tomato.

INTRODUCTION

Food security is a major concern in many parts of the world including East Africa, Rift Valley of Ethiopia where rainfall is unpredictable and unreliable (Tesfaye, 2008). The prospects for significant expansion of crop cultivation or irrigation area are limited (Edossa, 2014). To meet the rising food demand that will occur as a result of increasing population the government planned to ensure sustainable land and water productivity improvements, through integrated nutrient management over the coming decades.

The basic concept underlying the principles of integrated nutrient management is the maintenance, and possible improvement, of soil fertility for sustaining crop productivity on a long-term basis (Hegde and Srinivas, 1989). Sustained productivity may be achieved through the combined use of various sources of nutrients, and by managing these scientifically along with the growth cycle for optimum growth, yield and quality of crops, in a way adapted to local agro-ecological conditions.

Fertilizer- and water-management programs in vegetable crops production are linked; optimal management of one program requires proper management of the other; the ideal outcome should be visualized as keeping both water and nutrients in the plant root zone (Hochmuth and Hanlon, 2010). Although existing knowledge on the effects of irrigation, nutrients and other growth factors on fruit yield of field-grown tomato is appreciable (Scholberg et al., 2000) detailed studies of crop and canopy characteristics in the CRV area appear to be lacking. The detailed studies of crop and canopy characteristics are required to define crop management in the CRV areas to support field managements. Among irrigation systems, many loses encounter surface irrigation, like surface leaking conveyance canals, surface run off or deep percolation etc….from limited volumes of water compared with crop water requirements, it is economically necessary to get even more from the water. This may be done in many cases by adopting efficient irrigation methods, which can apply the scarce water more accurately; minimizing losses through different ways. Improved benefits of such systems can be derived by using efficient water application methods such as drip irrigation. The water then can be used much more efficiently for supplemental irrigation for much larger areas, or for longer seasons. The experience from many countries show that farmers who changed from furrow system to drip systems can cut their water use by 30 to 60% and crop yields often increase at the same time (Sijali, 2001). The use of such drip irrigation system permits reduction of water loss up to 50% (Hochmuth and Hanlon, 2010) and can increase the yield per unit of land by up to 100% compared with surface irrigation systems (Cowater, 2003).

In many places in Ethiopia, there are an extensive campaign of water harvesting, tapping ground water and using appropriate technologies- like treadle pump, rope and washer pumps with the realization that in many places existing water resources cannot meet the needs of the expanding population (Moges, 2006). Thus this study was conducted with the objectives to evaluate combined application of nitrogen, phosphorous, Farm Yard manure (FYM) and irrigation scheduling on growth and yield of tomato and to determine the optimal irrigation levels for maximum tomato fruit yield.

MATERIALS AND METHODS

The experiment was conducted at Melkassa, combining two factors namely; irrigation scheduling with three levels and nutrient management with five levels. Irrigation treatments were arranged randomly in vertical strips in order to adjust irrigation depth uniformly along the strips. Integrated nutrient were randomly arranged in horizontal–strip plots. These two factors were crossed factorially and replicated three times. The irrigation scheduling treatments were 1) full potential evapotranspiration (ETc) [IIRI], 2) 80% ETc (= 0.80 ETc) [IRII] and 3) 60% ETc [IR III] with *Melkashola* tomato variety. The first treatment entailed optimal watering without any stress throughout the growth period; the amount of irrigation water applied to the highest irrigation water treatment was limited to the tomato consumptive use demand. In the remaining two treatments, various levels of stresses mentioned as treatment were applied starting from the start of developmental stages through mid- and late- growth stages up to harvesting stages. The second factor was five nutrient management levels with 1) NP rates obtained from field survey (smallholder farmers' rate) (N_FP_F) (N 185 kg ha^{-1} P 60 kg ha^{-1} combination) [designated as INM-I]. Based on the survey result (Edossa et al., 2013b, 2014) and information gathered from different bodies, the average amount of nitrogen and phosphorus fertilizers used by tomato growers, viz; UREA 289.51 kg ha^{-1} and DAP 286.66 kg ha^{-1} were identified and used for this field experiment as indicated as INM-I treatment, thus combined Urea and DAP were used for this treatment. The total nitrogen 133.17 kg form Urea plus 57.33 kg N from DAP summed to 190.5 N kg ha^{-1}. 2) Averages of best N and P rates found from two seasons on station experiment (N_RP_R) (N 75 kg ha^{-1} P 50 kg ha^{-1}) [INM-II] (Edossa et al., 2013a), 3) On station best N and P rates (N_RP_R) (N 75 kg ha^{-1} P 50 kg ha^{-1}) +15 tone ha^{-1} (FYM) [designated as INM- III]; 4) Use of 15 tone ha^{-1} FYM only [INM-IV] and 5) Check, no nitrogen, phosphorus and manure application [INM-V]. Both DAP and TSP fertilizers were used for the combined N and P rate treatment ($N_{75}P_{50}$), averages of findings from on station furrow and rainfed experiments [INM-II].

The low-cost gravitational drip structures were used for the experiment. A separate water meter (litter) were used to measure the amount of water quantities directly applied to each strip plots by each four separate tankers with volumes of 2000 L that installed (placed) for each irrigation regime at the head of strip plot. Four tankers were placed in the field at the height of 1.0 m frame above the field so that water is at the height necessary to provide the water pressure required for operating the system.

The laterals are 16 mm in diameter and fitted with integral drip emitters (drip emitters are welded to the inner wall of the tube and come as continuous rolls with outlets at 0.3 cm). Each plot consisted of three lateral drip lines with 5.5 m length. The emitters were prefabricated to discharge at a constant rate of 1.3 L per hour discharge rate under pressure-compensation emitters. The emitters on laterals were spaced at 0.3 m corresponding distance Of tomato plant spacing with in a row. The lateral line was laid out along each tomato row at 1.0 m spacing. The total area for each subplot was 16.50 m^2. In order to improve non-uniform-flow rate along the strip lines, 1) clean water were used directly from irrigation canal in order

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to minimize the chance of clogging the filtration system and each emitter were inspected regularly to identify clogged emitters if there was; they were unblocked by pressing with fingers because it can cause non-uniform application of waters, 4) one meter head might provide good pressure. Each tomato plants were planted under emitter so that they would benefit from the water supplied by the emitters. The field was furrow irrigated before imposing drought stress treatments, once the seedlings were well established, the irrigation treatment was commenced, at predetermined daily crop water use (ETc). Three and half meter distance buffer strip separate each plots or side flows were precluded to avoid lateral run-on and run-off (side flows) from other irrigation treatment plots.

Three sample pits were opened from each three replications for determination soil physic-chemical physical properties. Three soils samples were composted from 0 to 20, 20 to 40 and 40 to 60 cm depth accordingly from each replication. Similarly soil samples were taken for the determination of chemical properties at different depths (0 to 20, 20 to 40 and 40 to 60). All procedures and analytical methods used were a routine soil test of the sample and includes the following parameters: Textural class, soil pH, ECe, CEC, Organic Carbon, Total N, Available P, Exchangeable K, Zn, and Mn which were analyzed;

1) Soil texture: Hydrometer method was used;
2) pH measurement was made in water and in 1: 2.5 soils: water or solution suspension using a digital pH meter;
3) Electrical conductivity was measured from 1: 2.5 soils: water suspension using digital electrical conductivity meter;
4) Organic carbon was determined using Walkley-Black's method (Walkley and Black, 1934);
5) Organic matter,
6) Available phosphorus;
7) Total N,
8) C: N Ratio;
9) Exchangeable Cations; and
10) Cation Exchange Capacity.

The following general procedures and methods of analysis of the soil physico-chemical properties for experimental field was made at Deber Ziet Agricultural Research Centre Soil Laboratory. These are soil reaction, pH (1:2.5) H_2O (Water with 1:2.5), Texture (Bouycous Hydrometer Method), ECe (dS m^{-1}) (1:2.5) H_2O (Saturation Paste Extract Method), Exchangeable Cations (Neutral Ammonium Acetate methods), [CEC ($cmol_c$ Kg^{-1} soil)], organic carbon (%) (Walklay and Black, 1934), total nitrogen (%) (Micro Kjeldshl Method, 1982), available P using Olson et al. (1982); additionally, bulk density, 2) field capacity, 3) permanent wilting point of the field soils were estimated. Soil samples were tested and analyzed at Deber Ziet Agricultural Research Center.

Field plots were prepared with forty-five plots and with drip irrigation systems and independent gate valve for each strips. Seedlings were transplanted in field at 0.30 m* 1.0 m spacing. Before initiating treatments, seedlings after transplant were irrigated to the field capacity for three weeks in order to improve root development (Kirnak *et al*., 2001).

Fertilizers were applied manually; all phosphorus fertilizer quantities were added at once at the time of transplanting and Urea applied in three equal splits, 1/3 of Urea was applied at transplanting and second application 1/3 after 20 days and final third application of Urea was applied after 40 days after transplanting. Manure was mixed with 30 cm top soil and applied a month before transplanting. FYM were analyzed for available macro- and micro-nutrient elements similar to previous experiment. The pre-determined rates of FYM were estimated on air-dry weight basis where samples of FYM were taken from moisten manure heap.

The initial soil water content for top soil at time of transplanting is assumed to be close to field capacity as a result of continuous pre-furrow irrigation events. This assumption is dictated by the fact that small vegetable seedlings are extremely very sensitive to moisture stress. Then the proper amount of daily irrigation for a crop is the amount of daily ET taking place minus any daily effective rainfall (Allen et al., 1998).

Equal amount of irrigation water were applied to each treatment before the initiation of irrigation treatments (sum of daily ETc). Once the drip system is installed, the drip irrigation was done on the basis of ETo value of the previous day. The amount of irrigation water applied, ETm, was determined from the calculated water requirement for tomato as determined from the crop coefficient (Kc) and the daily reference evapotranspiration (ETo) using ETc = ETo * Kc. Irrigation scheduling was based on check book of soil water balance budget method (ETc = ETo*Kc) where simple accounting approach for estimating how much soil-water remains in the effective root zone based on water inputs and outputs. Irrigation was scheduled when the soil-water content in the effective root zone is near the predetermined allowable depletion volume through keeping track of rainfall, evapotranspiration and irrigation amounts. Daily irrigation treatments were applied until the estimated required volume of water is completely gone from the tanker.

Tomato average Kc would be taken after many adjustments have been made for initial, mid and late season stages to be 0.6, 1.15 and 0.8, respectively (Allen et al., 1998). The drip irrigation efficiency was assumed to be 0.85 for lesser quality of laterals and gravity pressure head that are available in the local markets. The daily ETo data used in this research were calculated with the software program EToCalc developed by Raes (2006) on basis of the FAO Penman Monteith equation with standard coefficients for the Angstrom formula and a standard albedo value of 0.23 from Melkassa Weather Station were used. The net irrigation, that is, the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity (Michael, 2008) is calculated as net irrigation requirement. Daily net irrigation water applied at each growth stages were determined by the following field water balance equation, [Net irrigation, ETc = Kc *ETo].

The daily effective rainfalls were calculated based on the procedures developed by USDA (1997). However, rainfall event occurring during harvesting would be excluded since it is not useful for the yield formation (*Anon*.). The estimated effective rainfalls were summed over the tomato growing period. The total amount of irrigation water applied to each treatment was calculated as the sum of water applied during the crop establishment period and the ETc of the remaining period and finally the total water supplied to the crop equals to the amount of irrigations and total effective rainy precipitations recorded along the crop growth period.

Daily irrigation amount were adjusted according to existing reference *ET* and *Kc*. The irrigation treatments were differentiated by their two meters arrangement for strip, irrigation events would be controlled manually by using valve and water meter at the water tanker. The valve was put on and off after calculating net irrigation and adding losses (gross depending on amount of water to be applied at desired level for each strip separately). Records of daily applied water were kept from the start of treatment application up to final harvest date for each treatment and was summed up for each treatment. Soil moisture was monitored periodically using gravimetrically in order to apply estimated amount of water for replenishing the root zone to field capacity.

Soil samples were collected regularly for soil moisture estimation using gravimetric method (Home et al., 2002). Helical auger was used to collect soil samples. Before irrigation water application, the profile water content was determined. Irrigations were adjusted and initiated at predetermined depletion of available soil water. Samples were taken to the office work room, weighed (wet weight), oven dried, and weighed again (dry weight). Cares were taken to protect soil samples from drying before they were weighed. An electric oven takes 24 h at 105°C to adequately remove soil water (USDA, 1997). Percentage of total soil-water content on a dry weight basis was then computed.

The values of Kc of tomato used (0.6, 1.15 and 0.80 respectively, in the initial, mid and late season stages) is represented with 25 days for the initial, 34 days for the development, 20 days for mid and 41 days for late growing stage; making a total of 120 days as recommended by Allen et al. (1998). The daily Kc development coefficient for tomato for any day in the growing season were adjusted by considering that during the initial and mid-season stages Kc is constant and equal to the Kc value of the growth stage under consideration (Allen et al., 1998). During the crop development and late season stage, Kc varies linearly between the Kc at the end of the previous stage (Kc prev) and the Kc at the beginning of the next stage (Kc next), which is Kc end in the case of the late season stage. The partial wetting for wetting patterns of the drip emitters was measured from sample drippers and adjusted to 0.3 ratios.

Some of growth and canopy characteristics data such as plant height- measured using rulers; stem diameter- measured using digital calipers just at above the surface (≈5 cm), lateral branch length-measured using rulers. Canopy cover (CC) was estimated by multiplying mean canopy width with mean canopy depth and dividing the products by the area covered by the plant (spacing between rows multiplied with spacing between plants). Additionally yield and yield components at harvest, fruit size, average fruit length (longitudinal) and equatorial diameter at harvest using digital calipers and average fruit mass at harvest, total yield (includes both marketable and unmarketable fruit yield) were measured.

Finally the following physiological data such as chlorophyll content, quantum yield, and Ft were assessed from sample plants and leaves. The leaf chlorophyll content was estimated non-destructively using a portable hand held Chlorophyll Meter (Minolta SPAD-502, Konica Minolta Sensing, Inc. Japan). An average of one leaf per plant and five leaves per plot were measured. The SPAD readings were measured at 90 DAT on fully expanded leaves from 5 plants per plot. The quantum yield: [expressed as number of molecules of CO_2 fixed or O_2 evolved per photon absorbed. The quantum yield measurements were taken using same SPAD readings similar to leaf chlorophyll content measurement from 9:00 to 11:00 at 90 DAT on fully expanded leaves from 5 plants per plot. The leaf chlorophyll fluorescence (Ft) was also taken at same time as quantum yield using hand held SPAD readings instrument. Samples of five matured top leaves from many branches were taken from compound leaf, from third to fourth compound leaf single leaf plot were composited. Additionally, leaf stomatal conductance was measured at 70 DAT using Porometer (Model Sc-1; Steady State Diffusion Porometer, Decagon Devices) (mmol/m^{2}s) were used. Leaf stomatal conductance was measured from five sample leaves per plot and the measurement was taken before noon 9:00 to 11:00 pm (Taiz and Zeiger, 2003). Daily rainfall data were also used for the manipulation of growing season daily weather conditions. EToCal (Raes, 2009) was used for the estimation of daily reference evapotranspiration to identify each day into either dry or wet days. Data from this experiment were subjected to analysis of variance as strip plot design using the SAS Analytical Software (2003). When the F-value was significant, a multiple means comparisons were performed using DMRT at P < 0.05 probability level.

RESULTS AND DISCUSSION

Soil analysis

The results of soil textural analysis showed that sand, silt and clay has relatively similar proportions. The soil textural analysis at this site has indicated that it is predominantly clay loam throughout its profile. The bulk density of top soil 0 to 20 cm depth range from 1.015 to 1.035 g·cm^{-3}, and range from 0.957 to 1.069 g·cm^{-3} for the sub surface 30 to 40 cm soil depth and finally range from 1.001 to 1.055 g·cm^{-3} for the lowest depth (40 to 60 cm depth). The analysis of all soil samples indicated that the soil has same pH values of an average 7.61 at all layers which are mildly alkaline rating. The average field capacity (FC) was found to be 0.335 m^3 m^{-3}, and average wilting point (WP) of the soil sample were found to be 0.205 m^3 m^{-3}.

The field plot has higher OC in the surface soil 2.76% (g/100 g) (high rating - good structural condition with high structural stability) and 2.03% (g/100 g) in the middle (20 to 40 cm depth) (high rating - good structural condition with high structural stability) and the bottom (40 to 60 cm) with 1.26% (g/100 g) content rated as moderate with both average structural condition and average structural stability. The analysis indicate that the OM of the top soil (0 to 20 cm depth) found to be 4.73% (g/100 g) rated as high described as good structural condition with high structural stability. In the second layer (20 to 40 cm depth) the OM was found to be 3.50% and rated as high and described as good structural condition with high structural stability. However, the bottom layer (40 to 60 cm), the OM was found to be 2.20% indicating the layer has moderate rating, average structural condition with average structural stability. Both the top soil layer (0 to 20 cm) and following layer (20 to 40) cm depth has similar total N 0.139%, rated as low status (Hazelton and Murphy, 2007). While the last layer (40 to 60 cm depth) has 0.086% total N again rated as low N status. The C: N ratio of the top soil was found to be 16.91 while 14.89 for the bottom soil layer. The available P content of top soil (0 to 20 cm depth) is found to be 36.50 ppm which is rated as very high P status; while 26.76 ppm P content in the second layer (20 to 40 cm depth), still rated as very high P level. However 11.62 ppm P content was measured in the bottom layer (40 to 60 cm depth), and rated as moderate.

Results of soil analysis indicated that the Ca content of all soil layers have greater than 40.32 cmol (+) kg^{-1}, rated as very high rating values while Mg content analysis indicated that the overall soil layers have higher than 4.67 cmol (+) kg^{-1}, rated as high. The K^+ content of the top soil layer (0 to 20 cm depth) was found to be 4.20 cmol (+) kg^{-1}, and rated as very high, while 3.32 cmol (+) kg^{-1} were recorded from the second soil layer (20 to 40 cm depth), and still rated as very high. Finally 2.82 cmol (+) kg^{-1} were recorded from bottom soil layer (40 to 60 cm depth) which is rated as very high. The results of high K^+ contents of various soil samples of the experimental plots including previous experimental fields have high K^+ content. These high K^+ content is in line with the recent findings of Murphy (1959), who reported that most Ethiopian soils in the 1950th had high K^+ content. The Ca: Mg cationic balance of soil samples derived from sample soil analysis and range from 7.404 to 9.146 (low Mg rating) for the upper soil (0 to 20 cm depth) and 6.316 to 10.033 (low

Table 1. Analysis of variance table showing mean square values of vegetative growth yield and yield components parameters of tomato as influenced by integrated nutrient managements and application of various moisture regimes.

Source of variations	df	Mean square values								
		Plant height (cm)	Canopy diameter (cm)	Canopy width (cm)	Stem diameter (mm)	Leaf Ft	Leaf quantum yield	Leaf chlorophyll content	Stomatal conductance	Total yield (t/ha)
Replication	2	13.726	65.4847	41.0891	6.26460	1049.76	0.00221	216.895	1231.1	1695.8
INM	4	28.651**	51.7305*	45.2294**	3.97776	2008.72	0.00801	56.367	396.5	2060.9*
Error (a)	8	12.810	5.3407	8.4087	1.30895	1165.02	0.00138	26.384	1814.1	991.3
Irrigation Levels (IR)	2	204.644**	7.2842	66.8408**	6.31708	2025.41	0.00153	466.172**	22349.2**	43979.1**
Error (b)	4	12.803	9.0678	3.4260	4.00823	1367.90	0.00783	3.216	403.4	315.0
NM x IR	8	12.713*	14.5756	5.9727	1.47473	857.51	0.00395	26.387	1427.2	2434.7*
Error (c)	16	4.816	7.6629	6.8035	1.82010	1818.15	0.00471	47.024	699.3	637.5
Total	44									
Grand Mean		59.426	34.967	47.745	14.763	229.24	0.5340	51.737	132.80	62.916
CV (%)		3.693	7.91653	5.463031	9.138399	18.60080	12.85726	13.25450	19.91227	12.69
R^2		0.912	0.817187	0.828409	0.731594	0.551956	0.600687	0.729260	0.872104	0.926333
Root RME		2.194	7.91653	2.608343	1.349112	42.63974	0.068658	6.857437	26.4435	79.84406

Figures without asterisk indicates non significant at $P > 0.05$; * and significant at $0.05 < P \geq 0.01$ and ** significant at $P < 0.01$ probability levels, respectively.

Mg rating) for the sub surface 20 to 40 cm depth and 7.379 to 11.196 (low to Mg deficit rating) for the last bottom 40 to 60 cm soil depth indicating that the experimental field has low Mg content. There is an overall trend that the Ca: Mg cation balance ratio increases depth-wise; the estimated values indicates more Mg deficit in the last depth. Similarly Mg^{2+} content is higher in the upper and tends to decreases in the lower.

Mean square, main and interaction effect of growth, physiological responses and yield components of tomato as influenced by irrigation regimes and integrated nutrient management (INM) practices

Analysis of variance indicated that application of various irrigation regimes combined with integrated nutrient management showed significant interaction effect on some of the variables and variable effects on some other measurements recorded from tomato plant (Table 1). Application of various irrigation regimes combined with INM did not show interaction effect on any one of tomato growth and development characteristics with this experiment.

However interactions of irrigation regimes and integrated nutrient management were observed on total fruit yield and WUE of *Melkashola* variety. Highest yield of 82.1 t ha^{-1} fresh fruit was obtained from full irrigation and lowest yield of 49.3 t ha^{-1} obtained from 60% irrigation water with saving 40% of irrigation water (Table 2).

As irrigation depths decrease there is direct relationship with total fruit yield reduction in tomato. This supports the statement by Muchovej et al. (2008) that vegetables are nothing but nicely packaged water; it is quite profound and points to the fact that high quality and yield are directly associated with proper water management. Similar findings were reported by Kirnak et al. (2001) where egg plants grown under high water stress had less fruit yield and quality than those in the control treatment. Reviewing the yield obtained from various N and P study, Jones (2008) explained that referring report of FAO, a good commercial yield of tomato under irrigation ranges between 450 q and 65.0 t ha^{-1}. Similar findings were obtained by Sezen et al. (2010) and Tuzel et al. (1994) where increasing irrigation, full irrigation increased total tomato fruit yield. Kirnak et al. (2001) generalized that the decrease in fruit yield and plant growth induced by water deficit in egg plants was a consequence of a reduction in transpiration.

Similar results were found by Birhanu and

Table 2. Mean values of various irrigation regimes and integrated nutrient management on vegetative growth, fruit yield and yield components of tomato grown under drip irrigated condition.

Irrigation regimes	Plant height (cm)	Canopy diameter (cm)	Canopy width (cm)	Stem diameter (mm)	Leaf Ft	Leaf quantum yield
IR I	63.55^{A}	35.75	49.678^{A}	15.50^{A}	215.89	0.52267
IR II	58.27^{B}	34.85	48.065^{A}	14.46^{B}	234.73	0.53733
IR III	56.44^{C}	34.33	45.492^{B}	14.32^{B}	237.09	0.54200
Mean	59.426	34.69	47.5218	14.76	229.23	0.534
LSD (0.05)	3.6275	NS	1.8765	3.6275	NS	NS
Integrated NM						
[$N_{185}P_{60}$] [INM-I]	62.51^{A}	38.79	51.27^{A}	15.63^{A}	237.26	0.54333^{AB}
[N_RP_R] ($N_{75}P_{50}$) [INM-II]	59.40^{B}	35.56	48.21^{B}	15.16^{AB}	247.18	0.57667^{A}
[INM- III]	58.62^{B}	33.91	46.92^{BC}	14.68^{AB}	233.44	0.52556^{AB}
[INM-IV]	58.38^{B}	34.06	47.09^{BC}	13.91^{B}	218.22	0.49444^{B}
[INM-V]	58.38^{B}	32.50	45.23^{C}	14.42^{AB}	210.07	0.5300^{AB}
Mean	59.45	34.96	47.744	14.76	229.23	0.534
LSD (0.05)	3.890	NS	3.152	1.2437	NS	0.040

Irrigation regimes	Leaf chlorophyll content	Stomatal conductance	Marketable fruit (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total fruit yield (t ha^{-1})	WUE[1] (kg fruit yield ha^{-1} m^{-3})
IR I	55.02^{A}	176.74^{A}	63.63^{A}	18.267	81.902^{A}	28.96^{A}
IR II	54.88^{A}	117.29^{B}	33.83^{B}	22.413	56.250^{B}	24.23^{B}
IR III	45.30^{B}	104.36^{B}	27.82^{B}	23.062	50.868^{C}	28.95^{A}
Mean	51.737	132.80	41.765	20.813	62.916	27.72
LSD (0.05)	1.818	20.362	9.712	NS	5.689	2.311
Integrated nutrient management						
[$N_{185}P_{60}$] [INM-I]	54.12	130.41	41.765	26.223	67.988^{A}	29.57
[N_RP_R] ($N_{75}P_{50}$) [INM-II]	52.64	133.87	43.27	22.772	66.050^{A}	29.57
[INM- III]	50.07	130.00	38.048	21.705	59.752^{AB}	28.52
[INM-IV]	53.61	143.61	38.746	19.384	58.130^{AB}	26.72
[INM-V]	48.24	126.11	46.990	16.154	63.144^{B}	24.78
Mean	51.733	132.80	41.765	21.713	62.916	27.720
LSD (0.05)	NS	NS	NS	NS	4.98	NS

*= Average of three replications. Means within each column with different letters are significantly different at LSD at *P* = 0.05 level of significance. [1] = WUE was estimated by dividing the total fruit yield production per ha per m^3 of water used by the plant.

Tilahun (2010) that their irrigation was positively influenced tomato productivity; the result was due both to the increase in number of berries per plant and the fruit average weight as irrigation increased. Their study concluded that the total yield and marketable tomato yields were

Table 3. Total fruit yield (t ha^{-1}) of tomato as affected by interaction of application of various irrigation regimes and integrated nutrient management (INM) under drip irrigated growing condition.

Irrigation level	INM*					Mean (t ha^{-1})
	INM I	INM II	INM III	INM IV	INM V	
IRR I	99.886	89.195	75.290	74.446	71.880	82.1394^{A}
IRR II	57.498	60.940	61.101	47.328	59.683	57.309^{B}
IRR III	45.069	51.815	54.650	56.302	38.660	49.300^{C}
Mean	67.483^{A}	67.317^{A}	63.681^{AB}	59.359^{AB}	56.741^{B}	62.9162

* Mean of three replications.

Table 4. Average plant height (cm) of tomato as affected by interaction of application of various irrigation regimes and integrated nutrient management under drip irrigated growing condition.

Irrigation level	Integrated nutrient management (INM)*					Mean
	INM I	INM II	INM III	INM IV	INM V	
IRR I	67.613	65.120	60.360	61.203	63.493	63.558^{A}
IRR II	61.136	55.203	58.553	57.370	59.113	58.275^{B}
IRR III	58.7866	57.880	55.726	56.570	53.260	56.444^{C}
Mean	62.512^{A}	59.401^{B}	58.213^{B}	58.381^{B}	58.622^{B}	***59.426***

* Mean of three replications.

significantly decreasing as the deficit level was increased. At the same time, they found that the marketable yield decreased with stress levels. The reduction of total yield of tomato with an increased amount of water stress level of this test was consistent

with previous work conducted on tomato and other crops such as cotton (Candido et al., 2001; and Yaza et al., 2002).

Among integrated nutrient tested, INM I and INM II gave similar fruit yield 67.48 t ha^{-1} and 67.31 t ha^{-1} and lowest fruit yield was obtained from check plot (INM V) 56.74 t ha^{-1} (Table 3). This indicates that the experimental field is relatively fertile probably due to residual P available from previous year's applications in the soil.

The grand mean plant height measured was 59.42 cm, with the highest values measured from IRR-I with 63.55 cm and the last values was measured from IRR III 56.44 cm (Table 4). It is observed from correlation analysis that plant height was significantly, strongly and positively correlated with fresh fruit yield of tomato with $r^2 = 0.691$. Thus the higher plant height, the more flowers and fruits would be produced from the plants that contribute to yield.

Irrigation levels brought highly significant effect on plant height, canopy width, leaf chlorophyll content, stomatal conductance and total yield at $P < 0.01$ levels (Table 1). As irrigation depth decreased, plant height decreased, highest for full irrigation was 63.558 cm, and lowest for lowest irrigation depth (60% ETo) with 56.44 cm in height (Table 2). Irregular and inadequate water supply reduced growth, yield, and quality of different tomato cultivars (Tan, 1990). Kirnak et al. (2001) found that severe water stress reduced plant height by 46%, stem diameter of egg plant by 51%. Similarly as irrigation depth increased the canopy width increased, measuring highest 49.6780 cm and lowest 45.4927 cm (Table 3). Similar to plant height and canopy width, highest irrigation level increased leaf chlorophyll content 55.02 unit and lowest irrigation depth reduced leaf chlorophyll content to 45.30 unit. Similarly, stomatal conductance of tomato was highest 176.74 for highest irrigation depth, while, lowest 104.36 for lowest irrigation depths (Table 3). This indicates that under low moisture conditions, tomato leaves has low stomatal conductance that contributed to low CO_2 assimilation and further low dry matter production and corresponding fruit yield.

Management of INM practices brought highly significant effect on plant height and canopy width at $P < 0.01$ probability levels; whereas significant effect on canopy diameter, total yield and water use efficiency at $0.05 < P > 0.01$ probability level (Table 1).

Table 2 shows some of the growth and vegetative response of tomato to integrated nutrient management; there are increments of most growth parameters towards integrated nutrient managements (INM-I), while there is reduction of these growth parameters towards the check. Highest plant height was recorded from INM-I, with 62.51 cm, while similar heights were recorded from all other integrated nutrient managements (Table 2). Similarly highest canopy width, 51.277 cm was recorded from INM-I while last 45.234 cm was recorded from check. Highest canopy diameters with 38.793 cm from INM I and

Table 5. Estimation of Pearson correlations coefficients (r^2) between growth characteristics of tomato as influenced by fertility management practices and irrigation regimes under drip irrigated condition.

Growth characteristics	PH	CD	CW	SD	Stomatal conductance	QuaYield	LeChloFluo	LeChloCon
CD	0.294*							
CW	0.555**	0.796**						
SD	0.336*	0.562**	0.594**					
Stomatal conductance	0.498**	0.084	0.350*	0.234				
QuaYield	0.219	0.302*	0.235	0.233	-0.203			
LeChloFluo	0.029	-0.005	0.046	0.038	-0.215	0.692		
LeChloCon	-0.247	-0.223	-0.346*	-0.3789*	-0.434	-0.048	0.200	
Total fruit yield	0.691**	0.464	0.697**	0.534**	0.587**	0.133	0.003	-0.556**

** indicates significant correlation at $P < 0.01$, * significant correlation at $P < 0.05$. The decimal numbers without any asterisk are non-significant at $P < 0.05$ level of significance. PH: Plant height, CD: Canopy diameter, CW: Canopy width, SD: Stem diameter, QuaYield: Quantum yield, LeChloCon: Chlorophyll content, LeChloFluo: Chlorophyll Fluorescence.

lowest 32.50 cm from check were recorded. Similar highest total fruit yield , 67.483 t ha^{-1}, was obtained from INM-I and INM-II, while lowest total fruit yield was recorded from check with 56.741 t ha^{-1} (Table 2); this most probably due to the fact that water deficit also inhibited the uptake of nitrogen, phosphorus and other nutrients within the plant. Although there is no much yield variations, as application of FYM would improve soil physical properties and would sustain the soil fertility and plant productivity eco-friendly.

Correlations among and within growth and yield characteristics of tomato under various irrigation regimes and INM practices

Some plant growth characteristics have very strong positive and significant associations with total fruit yield such as total fruit yield with plant height (r^2 = 0.69), total fruit yield with canopy width (r^2 = 0.69), total fruit yield with stem diameter (r^2 = 0.53), total fruit yield with stomatal conductance of tomato under various irrigation depths and integrated nutrient applications (r^2 = 0.58) (Table 5). While the analysis indicated that the associations between total fruit yield with leaf chlorophyll has extremes negative and strong significant association (r^2 =-0.55). The analysis further showed that there is no significant association or direct relationships between total fruit yield with canopy diameter, total fruit yield with quantum yield, total fruit yield with ChloFt of tomato under this experiment.

Regression analyses of growth and yield characteristics of tomato under application of various irrigation regimes and INM practices

Regressions analyses were used to relate growth parameter with irrigation depth, with the equation representing the relationship between the two parameters, among plant height and stem diameter has equations and coefficient of determination (R^2) were put on each figure. As irrigation depth decrease there is direct plant height and stem diameter reduction with R^2= 0.92, and R^2 = 0.839 (Figure 1).

The results of chlorophyll fluorescence measurement indicated that as irrigation depth increased the chlorophyll fluorescence yield was reduced (Figure 2). Based on the review of Maxwell and Johnson (2000), light energy absorbed by chlorophyll molecules in a leaf can undergo one of three fates: it can be used to drive photosynthesis (photochemistry), excess energy can be dissipated as heat or it can be re-emitted as light—chlorophyll fluorescence. These three processes occur in competition, such that any increase in the efficiency of one will result in a decrease in the yield of the other two. Hence, by measuring the yield of chlorophyll fluorescence, information about changes in the efficiency of photochemistry and heat dissipation can be gained. The results from the experiment showed that as irrigation depth increased, the portion of light energy absorbed by chlorophyll molecules in a leaf can undergo to drive photosynthesis (photochemistry) performance would be increased so that yield of the tomato plant increased. On the other hand, deficit irrigation increased leaf chlorophyll fluorescence of tomato probably suggesting much light is not used in the photosynthesis performance.

Figure 2 indicates that at higher irrigation regimes, there would be higher stomatal conductance with R^2 = 90%, relationship. Low stomatal conductance indicates significant stomatal closure associated with reduced transpiration (Taiz and Zeiger, 2003). Low stomatal conductance is related to low water supply to the tomato plant, which implies relatively dried conditions in the rizospher.

The regression function analysis indicated that as irrigation depth increases, the leaf chlorophylls fluoresce linearly decreased at R^2= 83%. As irrigation depth

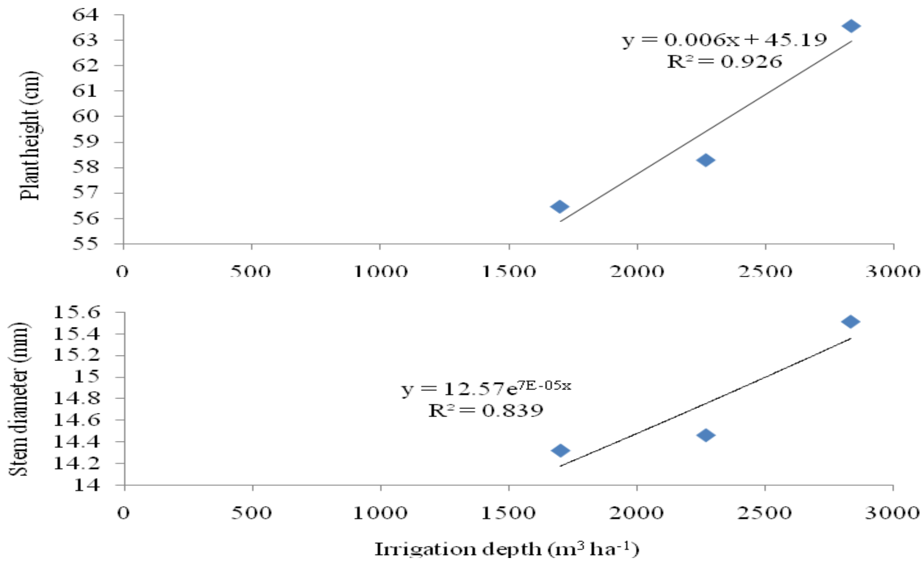

Figure 1. Graphical relationship of regression of growth characteristics, yield and yield component responses of tomato as a function of irrigation water use.

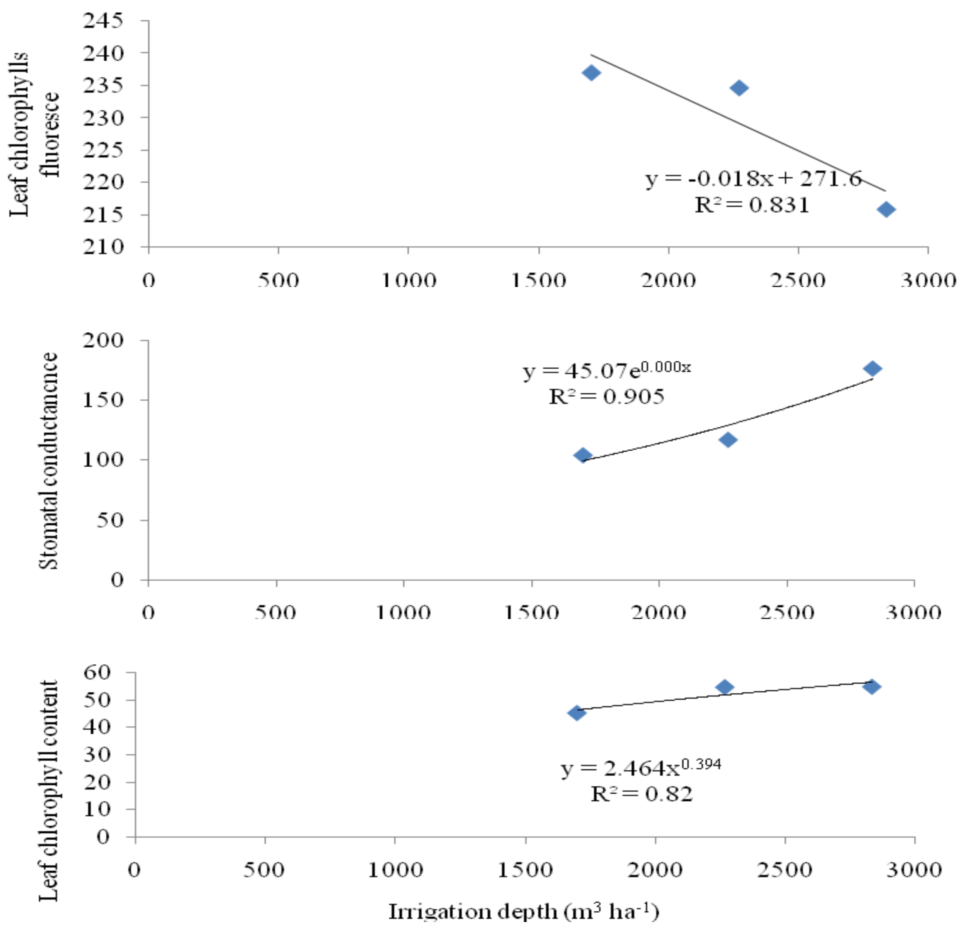

Figure 2. Graphical relationship of regression of leaf chlorophyll content, stomatal conductance and leaf chlorophylls fluorescence responses of tomato as a function of irrigation regimes.

increases, the leaf chlorophyll content was found to be increasing in power function R^2 = 82%. Similar findings were reported by Kirnak et al. (2001) where water stress resulted in significant decreases in chlorophyll content of egg plants

It also showed positive relationship with yield at R^2 = 0.587 with fresh fruit yield. The stomatal conductance is much more closely related to soil water status, and the only plant part that can be directly affected by soil water status is the root system. Mild water stress does usually affect both leaf photosynthesis and stomatal conductance (Taiz and Zeiger, 2003).

Conclusions

Among irrigation levels tested for tomato, highest total yield 82.140 t ha^{-1}, was recorded from full irrigation treatment and followed by 57.30 t ha^{-1} from 80% ETc irrigation levels and lowest total yield 49.30 t ha^{-1} from 60% of full irrigation depth, this finding indicated that tomato crop should be irrigated at full water requirement to get maximum fruit yield. The highest mean plant height was measured from IRR-I (full) and the last value was measured from IRR III (60% of full irrigation). The correlation analysis indicated that plant height was significantly, strongly and positively correlated with fresh fruit yield of tomato. Thus the higher the plant height, the more flowers and fruits would be produced from the plants that contribute to yield. Similarly, highest irrigation level increased leaf chlorophyll content and lowest irrigation depth reduced leaf chlorophyll content; stomatal conductance of tomato was also highest for highest irrigation depth, while lowest for lowest irrigation depths indicating that under low moisture conditions tomato leaves have low stomatal conductance that contributed to low CO_2 assimilation and further low dry matter production and corresponding fruit yield. Water deficit probably inhibited the uptake of nitrogen, phosphorus and other nutrients within the plant. This study showed that there is increments of most tomato vegetative growth parameters towards integrated nutrient managements (INM-I), while there is reduction of these growth parameters towards the check.

This investigation showed that high tomato fruit yield was recorded from INM-I and NM-II treatments with 67.483 and 67.317 t ha^{-1} respectively. However use of high dose of N from treatment INM-I (farmer's N application rate) did not increase tomato fruit yield higher than INM-II indicating application of extra N by growers, did not contribute to yield but may be to various N losses. Although, the exact nutrient (N and P) requirements depend on fertility status of the soil including the cation balances in which the crop is being taken; from this experiment combination of full irrigation treatment with INM-II N and P nutrient application would be recommended for verification. However, addition of fully decomposed farmyard manure did not contribute to yield and requires further research, but might help for the maintenance of good soil conditions.

The results of chlorophyll fluorescence measurement indicated that as irrigation depth increased the chlorophyll fluorescence yield was reduced. The results from this experiment showed that as irrigation depth increased, the portion of light energy absorbed by chlorophyll molecules in a leaf can undergo to drive photosynthesis (photochemistry) performance would be increased so that yield of the tomato plant increased. On the other hand, deficit irrigation increased leaf chlorophyll fluorescence of tomato probably suggesting much light is not used in the photosynthesis performance. From this experiment, it is observed that at higher irrigation regimes, there would be higher stomatal. Low stomatal conductance indicates significant stomatal closure associated with reduced transpiration; low stomatal conductance is related to low water supply to the tomato plant, which implies relatively dried conditions in the rizosphere. As irrigation depth increased the leaf chlorophyll fluorescence linearly decreased; however the leaf chlorophyll content found to be increased.

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