Ethiop. J. Agric. Sci.23:57-77 (2013)

Growth and Yield Components of Tomato as Influenced by Nitrogen and Phosphorus Fertilizer Applications in Different Growing Seasons

Edossa Etissa[1], Nigussie Dechassa[2], Tena Alamirew[3], Yibekal Alemayehu[2] and Lemma Desalegn[1]

[1]Melkassa Research Center, EIAR, eetissa@yahoo.com, lemmades@yahoo.com,

[2]Haramaya University, ndechassa@yahoo.com, yibekal_2007@yahoo.com

[3]Ethiopian Water Resources Institute, alamirew2004@yahoo.com

Abstract

Tomato is an important cash crop in Central Rift Valley of Ethiopia. However, the yield is constrained by poor soil fertility management and lack of appropriate/adequate fertilizers rates recommendation. Experiments were conducted at Melkassa on station with the objectives of evaluating effect of N and P fertilizer applications on growth and yield, and determining optimal requirements for tomato. The experiments were conducted under both cool season furrow irrigated and rain-fed conditions with variable fertility status of the fields. The treatments consisted of four rates of nitrogen (0, 50, 100 and 150 kg N ha^{-1}) and four rates of P (0, 46, 92 and 138 kg ha^{-1}). The experiments were laid out in a CRBD in a factorial arrangement and replicated three times using Melkashola variety. Data on growth and canopy characteristics such as plant height and stem diameter, main lateral branch length, canopy width and depth were measured from selected plants. Some of the growth and yield components such plant height, canopy diameter, canopy width, stem diameter, lateral branch length, total dry mass above the ground per plot, shoot fresh and dry weight, marketable and unmarketable fruit yield and total yield at harvest were measured were assessed. Maximum fruit yield was estimated from regression lines of applying 105 kg N ha^{-1} and 85 kg P ha^{-1} under furrow irrigated experiment (continuously cultivated field). However, the highest fruit yield was from application of 40 kg N ha^{-1} and 10 kg ha^{-1} for the rainfed experiment (relatively fertile field). Thus, results of both experiments were averaged to propose on farm verification of N and P requirement of tomato, N 73 kg ha^{-1} and P 48 kg ha^{-1} around Melkassa and similar soil types.

Key words: furrow irrigated, rain-fed, season, tomato, inorganic N and P fertilizer

Introduction

Tomato is cultivated in Ethiopia in most parts of the country throughout the year. However, incidences of pests and diseases, moisture stress, improper rates of fertilizer application and too high and/or too low temperatures significantly constrain production and productivity of the crop (Getachew and Mohammed, 2012, unpublished).

Various reports such as Edossa *et al*., (2013b) indicated that tomato is grown during various seasons such as cool-dry season, hot-dry season and during the rainfed season, although some production is observed throughout the year for continuous supply in the country. There is a need of specific technological packages development such as N and P requirement for main production seasons and areas.

It is well documented that application of N promotes vegetative growth and fruit yield of tomato, and later application in the growing stages favours fruit development, thus nitrogen has a dramatic effect on tomato growth and development in soils with limited N supplies such as sandy soils (Hokam *et al*., 2011). Similarly, application of phosphorus is an important nutrient for tomato plant growth and development, a deficiency of P leads to reduced growth and reduced yields (Hochmuth *et al.,* 2009). Tomatoes have the greatest demand for phosphorus at the early stages of development (Csizinszky, 2005). However the availability of P is largely dependent on the soil pH (Brady and Weil, 2002), thus there might be low P availability due to P-precipitation in the semi-arid Rift Valley area of Ethiopia due to higher soil pH.

Among the field management practices, applications of Urea and DAP fertilizers have significant and positive relationship with fruit yield. However, tomato growers in the CRV area apply variable rates of N and P fertilizers, probably in excess of the crop requirements (Taha, 2007); thus determination of optimum mineral N and P fertilizer application rates for tomato production is required so that maximum yield and quality would be obtained. Therefore, these experiments were conducted with the objectives of evaluating the effect of mineral N and P fertilizer applications on growth and yield and determine the optimal mineral N and P fertilizer levels under furrow irrigated and rain fed field growing conditions at Melkassa.

Materials and Methods

The experiments were conducted at Melkassa Agriculture Research Centre, one during cool-dry season transplanted on 15 Nov. 2010 using furrow irrigation and another during rainy season from July to September 2011. Semi-determinate *Melkasholla* tomato variety was used. The treatments consisted of four rates of N (0, 50, 100 and 150 kg N ha^{-1}) and four rates of P (0, 46, 92 and 138 kg P ha^{-1}). The experiments were laid out as a completely randomized block design in a factorial arrangement and replicated three times. All nursery management practices were made as recommended by Lemma, (2002). Watering was made in the interval of three days throughout the growth period of the seedlings in the nursery.

One meter ridges distances between rows were prepared using a tractor mounted rigger, and seedlings were transplanted to the permanent experimental field at the spacing of 0.30 m *1.0 as recommended by Lemma, (2002). The transplanting was made on 17 November 2010 for field experiment. The tomato field was irrigated at the interval of five to six days depending on the prevailing weather conditions throughout the crop cycle.

Full dose of given phosphorus fertilizer treatment was added at the time of transplanting and Urea was applied in three equal splits, 1/3 at transplanting and 1/3 at 20 days after transplanting, and the remaining 1/3rd was applied 40 days after transplanting. Both Urea and phosphate fertilizers were placed alongside the ridge in the plating rows about 5 cm away from the transplanted to ensure that there would be no direct contact with the soil particles below the plant and to reduce P fixation and N leaching. No staking was made during the dry season with the furrow-irrigated experiment since the plant was short; however staking was made during additional rainfed experiment conducted during the rainy seasons on relatively fertile soil because the plant is very tall.

Data on growth and canopy characteristics such as plant height, stem diameter, main lateral branch length, canopy width, canopy depth (cm) (with in row) were measured from 10 randomly selected plants per plot. Some of the yield and yield components at harvest such as fruit size, average fruit length and diameter at harvest were measured from sample fruits using digital calipers and total yield were assessed. Physiological disorders result from a combination of environmental, production and handling procedures were taken as unmarketable yield.

Sample plants at 90 days after transplant were cut at soil surfaces and were divided in to leaves, shoots and fruits for dry matter partitioning. These plant parts were put in oven at temperature of 105^0C for 24 hours, weight measurements were taken repeatedly by taking the samples from oven until the weight gets constant.

For irrigated field nine representative sample profile pits were dug out in a zigzag pattern for soil sampling in the field to the depths of 0-20 cm, 20-40 cm and 40-60 cm depth soil layers taken separately. Three samples were composited in to a sample based on their corresponding depths. The collected samples were air-dried on plastic trays in glasshouse crushed using pestle and mortar and passed through a 2 mm sieve.

The following general procedures and methods of routine soil test of soil physico-chemical properties for experimental field were made at Deber Zeit Agricultural Research Centre soil laboratory. These were soil pH (1:2.5) H_2O (1:2.5 soil: solution ratio), Texture (Bouycous Hydrometer Method), ECe (dS m^{-1}) (1:2.5) H_2O (Saturation Paste Extract Method), exchangeable cations (Neutral Ammonium Acetate methods), CEC, organic carbon (Walklay & Black, 1934); total nitrogen [Micro Kjeldshl Method, (1982)]; and available P (mg Kg^{-1} soil) were analysed using Olson *et al*., (1982) method.

The results of the particle size analysis for furrow irrigated experiment indicated the soil texture was classed as loam soil. The results of laboratory analysis for major soil chemical characteristics at different depths and composite samples were presented in Table 1.

Table 1. Results of laboratory analysis of field soil major chemical characteristics at different depths and composite samples of furrow irrigated tomato field

Soil depth	Soil samples			Mean
	Composite A	Composite B	Composite sample C	
pH (1:25)				
0-20 cm	7.66	7.8	7.63	7.69
20-40 cm	7.39	7.7	7.55	7.54
40-60 cm	7.41	7.68	7.58	7.55
ECe (dS m^{-1})				
0-20 cm	0.47	0.70	0.59	0.586
20-40 cm	0.46	0.57	0.61	0.546
40-60 cm	0.67	0.75	0.56	0.660
OC (%)				
0-20 cm	0.94	0.97	0.81	0.906
20-40 cm	1.03	0.76	1.04	0.943
40-60 cm	1.05	0.99	1.02	1.020
OM (%)				
0-20 cm	1.61	1.67	1.4	1.56
20-40 cm	1.78	1.32	1.8	1.63
40-60 cm	1.98	1.71	1.75	1.81
Total N (%)				
0-20 cm	0.05	0.07	0.05	0.0566
20-40 cm	0.07	0.06	0.07	0.0666
40-60 cm	0.08	0.08	0.08	0.0800
C: N Ratio				
0-20 cm	19.10	14.30	16.10	16.50
20-40 cm	13.80	18.80	14.90	15.83
40-60 cm	14.00	12.80	13.30	13.36
Available P (mg/kg**)**				
0-20 cm	5.68	6.30	3.81	5.26
20-40 cm	5.58	6.67	5.78	6.01
40-60 cm	5.35	6.00	6.17	5.84
Cu (ppm)				
0-20 cm	0.030	0.020	0.030	0.0266
20-40 cm	0.035	0.032	0.024	0.0303
40-60 cm	0.026	0.026	0.031	0.0276
CEC (meq/100gm)				
0-20 cm	20.64	14.88	18.16	17.89
20-40 cm	18.20	18.50	13.72	16.80
40-60 cm	14.86	15.42	15.08	15.12
Fe (ppm)				
0-20 cm	0.65	0.81	0.81	0.7566
20-40 cm	1.10	0.80	0.93	0.9433
40-60 cm	0.95	0.69	0.88	0.8400

Table 1. Continued…

Soil depth	Soil samples			Mean
	Composite A	Composite B	Composite sample C	
Mn (ppm)				
0-20 cm	3.57	4.97	4.35	4.29
20-40 cm	5.91	4.90	5.27	5.36
40-60 cm	5.1	3.89	5.06	4.68
Zn (ppm)				
0-20 cm	0.32	0.48	0.15	0.3166
20-40 cm	0.25	0.16	0.53	0.3133
40-60 cm	0.56	0.50	0.40	0.486
Exchangeable Cations cmol (+) kg^{-1}				
Na				
0-20 cm	0.36	0.45	0.63	0.480
20-40 cm	0.23	0.42	0.38	0.391
40-60 cm	0.31	0.39	0.42	0.373
K				
0-20 cm	4.81	3.14	2.56	3.503
20-40 cm	4.29	3.63	3.52	3.813
40-60 cm	3.34	3.22	2.67	3.076
Ca				
0-20 cm	24.35	19.03	21.56	21.646
20-40 cm	21.07	23.45	20.22	21.580
40-60 cm	21.11	21.24	17.60	19.983
Mg				
0-20 cm	3.44	2.67	2.98	3.030
20-40 cm	3.60	3.09	2.83	3.173
40-60 cm	2.85	3.25	2.79	2.963

The soil pH values ranges from 7.63 to 7.8 (moderately to strongly alkaline) in the surface soil 0-20 cm while it ranges from 7.39-7.7 (moderately to strongly alkaline) in the 20-40 cm, 7.41-7.68, for the lower 40-60 cm depths. In general, the soil pH for different layers ranges from 7.54 to 7.89, indicating that the soil is mildly alkaline, based on Hazelton and Murphy, (2007) interpretation guidelines, the pH of the soil measured in water is mildly alkaline; this pH somewhat higher than the pH suitable for tomato growth (Jones, 1999). At this pH value the availability of N, S, Zn, and Mo is not seriously affected (Hazelton and Murphy, 2007), but the availability of P, and some micronutrient like Mn, Fe, Cu, and B would be affected. Peet, (2005) generalized that for optimum growth of tomato, the soil pH should first be corrected to 6.0–6.5. This high pH values have an impact on tomato crop production and needs high consideration in the area.

The level of exchangeable Ca^{2+} ranges from 19.03 to 24.35 cmol (+)/kg (very high), 20.45 to 23.45 cmol (+)/kg (very high) and 17.6 to 21.24 cmol (+)/kg (high to very high) were recorded respectively for the top 0 to 20cm, subsurface 20 to 40 cm and the last 40 to 60 cm depth soil layers. The exchangeable Mg^{2+} cation ranges 2.68 to 3.44 cmol (+)/kg (high) for the surface 0-20 cm depth, while 2.83 to 3.6 cmol (+)/kg (high) were recorded from 20-40 cm soil depth and finally 2.75 to 3.25 cmol (+)/kg (high) were recorded from the lowest 40-60 cm depth. The exchangeable K^+ cation ranges from 2.56 to 4.81 cmol (+)/kg (very high) for the surface soil 0-20 cm depth, while 3.52 to 4.29 cmol (+)/kg (very high) for 20-40 cm soil depth and finally 2.67 to 3.44 cmol (+)/kg (very high) were recorded from 40-60 cm soil depth.

Due to some antagonism among cations in the uptake process, appropriate Ca/Mg, ratios are important for uptake of Ca, Mg, and K by crop plants (Fageria, 2009). When the cations are not in balance, plant stress would occur. In some instances, Mg deficiency can induce Ca deficiency (Jones, 2008). Thus, the quantitative ratios between Ca: Mg and soil macronutrients were computed; the analysis indicated that the Ca: Mg cationic balance of the top 0-20 cm soil depth ranges from 7.078 to 7.234, indicating that the soil has low Mg concentration (Hazelton and Murphy, 2007)]. While the ratio of 5.85 to 7.58 was recorded from subsurface 20-40 cm soil depth, still showing low soil Mg concentration. Finally the ratio of Ca: Mg cationic range from 6.30 to 7.40 (low Mg concentration rating) were recorded from subsurface 40-60 cm soil depth.

The analysis of furrow irrigated experimental plots showed that the samples from the surface top soil of 0-20 cm depth has OM content of 1.56% (low), while low OM content values of 1.32 to 1.8% (low) were recorded from the subsurface 20-40 cm soil depth, indicating that there is absence of both crop residues and animal manures in the area.

The analysis of furrow irrigated soil samples indicated that the total nitrogen content of the top 0-20 cm soil depth ranges from 0.05-0.07 % (very low), 0.06-0.07% (very low) in the subsurface 20-40 cm soil depth and 0.08% (very low). The results indicated that the total N in the experimental plot soil is very low to low (Hazelton and Murphy, 2007). The low to very low OC and TN status of experimental plot indicates the poor fertility status of the soils and of organic and inorganic fertilizers for higher tomato yield. In addition, the soil analysis indicates that, the total N content of the field increases with depth in the same manner as organic carbon. The available P values range from 3.81-6.30 (very low to low) for the top surface 0-20 cm depth of the soil, while it ranges from 5.57-6.67 ppm [very low to low rating] for the 20-40 cm depth. Available P ranging from 5.35-6.17 ppm (very low to low) was obtained in lower 40-60 cm soil depth. This could be related to high P-precipitation in the soil due to high pH and high Ca content. These results indicate that applications of high amount of P fertilizers are required for higher crop yield.

Similarly the results of physico-chemical properties of experimental soil used for rainfed tomato experiment is shown in Table 2. The results of the particle size analysis indicated all sample sites and depths have relatively equal proportional of sand, silt and clay content and the soil texture is said to be clay loam.

Table 2. Results of laboratory analysis of field soil physical properties and major chemical characteristics at different depths and composite samples for rainfed tomato at different depths and sampling sites

	Composite soil samples			
	Composite sample A	Composite sample B	Composite sample C	Mean
pH (1:25)				
0-20 cm	7.44	7.46	7.71	7.54
20-40 cm	7.58	7.74	7.71	7.68
40-60 cm	7.84	7.83	7.82	7.83
OC (%)				
0-20 cm	1.77	1.85	1.81	1.81
20-40 cm	1.69	1.56	1.48	1.58
40-60 cm	1.37	1.51	1.30	1.40
OM (%)				
0-20 cm	3.06	3.20	3.12	3.13
20-40 cm	2.92	2.68	2.55	2.71
40-60 cm	2.35	2.61	2.23	2.40
Total N (%)				
0-20 cm	0.17	0.19	0.15	0.170
20-40 cm	0.15	0.11	0.06	0.106
40-60 cm	0.05	0.16	0.14	0.116
C: N Ratio				
0-20 cm	5.42	9.59	12.09	9.03
20-40 cm	11.09	13.17	24.84	16.36
40-60 cm	27.48	9.66	9.25	15.46
Available P				
0-20 cm	32.54	31.76	37.00	33.77
20-40 cm	37.16	33.80	36.20	35.73
40-60 cm	37.36	36.84	37.64	37.28
Cu (ppm)				
0-20 cm	0.30	0.24	0.27	0.27
20-40 cm	0.30	0.22	0.24	0.25
40-60 cm	0.13	0.23	0.24	0.20
Fe (ppm)				
0-20 cm	0.88	0.82	0.58	0.76
20-40 cm	0.12	0.10	0.14	0.12
40-60 cm	0.14	0.18	0.15	0.15
Mn (ppm)				
0-20 cm	30.85	31.06	28.00	29.97
20-40 cm	18.49	14.89	17.93	17.10
40-60 cm	16.86	7.283	11.59	11.91

Table 2. Continued…

	Composite soil samples			
	Composite **A**	Composite **B**	Composite **C**	Mean
Zn (ppm)				
0-20 cm	0.850	0.774	1.236	0.953
20-40 cm	0.830	0.800	0.885	0.838
40-60 cm	0.632	0.411	0.628	0.557
Exchangeable Cations [cmol (+) kg^{-1}]				
Na				
0-20 cm	0.324	0.216	0.327	0.289
20-40 cm	0.390	0.534	0.636	0.520
40-60 cm	0.512	0.582	0.692	0.595
K				
0-20 cm	4.06	3.50	3.38	3.64
20-40 cm	3.41	2.80	2.67	2.96
40-60 cm	2.75	2.78	2.65	2.72
Ca				
0-20 cm	42.10	37.60	37.50	39.06
20-40 cm	39.10	38.90	38.40	38.80
40-60 cm	43.90	45.20	40.40	43.16
Mg				
0-20 cm	6.60	5.10	5.30	5.66
20-40 cm	5.50	4.90	5.00	5.13
40-60 cm	4.40	5.00	5.20	4.86

The analysis of rainfed soil samples showed that the pH values of surface soil 0-20 cm depth ranges from 7.44 to 7.71 [rated as mild alkaline, Hazelton and Murphy, (2007)], while it ranges from 7.58 to 7.74 (mild alkaline) in the subsurface 20-40 cm soil depth. The pH value ranges from 7.82 to 7.84 (mild alkaline) for the subsurface 40-60 cm depth. This indicates that care should be taken making the availability of some plant nutrients for tomato.

The OC content of the experimental plot was found to be moderate in the range of 1.00 to 1.80 organic carbons (%) where highest 1.81% from surface soil (0-20 cm depth) and lowest 1.4 % from the bottom soil (40-60 cm depth) were recorded. This moderate OC rating indicates that the soil has average structural condition with average structural stability (Hazelton and Murphy, 2007).

The OM content of this experimental field has highest 3.13% OM in the surface soil (0-20 cm depth) where as lowest 2. 40% OM found in the bottom 40-60 cm soil depth. Hazelton and Murphy, (2007) indicated that all the values of OM range within 1.70–3.00% level of organic matter is rated as moderate rating indicating the field has an average structural condition with average structural stability. This indicates that the experimental site for rainfed tomato experiment is naturally much fertile than the plots used for furrow irrigated tomato experiment. The total N recorded from experimental field ranges from 0.10 to 0.17 (% by weight) where Hazelton and Murphy, (2007) put the value within 0.05–0.15 % range as low rating. The available P of surface soil 0-20 cm depth ranges from 31.76 to 37.00 mg kg^{-1} [very high, Hazelton and Murphy, (2007)] and the available P for the sub soil 20-40 cm depth ranges from 33.80 to 37.16 mg kg^{-1}(very high rating), while the last depth 40-60 cm available P ranges from 36.84 to 37.64 mg kg^{-1}(very high). These very high available P across 0.6 m soil depth in the field indicates that application of additional P might not be important for tomato production. This high P concentration has probably been built up to great concentrations and Hochmuth *et al*., (2009) described that crop response to added P fertilizers on high P residual soil content is unlikely in Florida.

The experimental soil has extremely very high levels of exchangeable Ca^{2++} cation, range from 38 to 43 cmol (+)/kg where Hazelton and Murphy, (2007) rated >20 cmol (+)/kg as very high. The exchangeable Ca^{2++} cations is lower in the top surface soil [about 39.00 cmol (+)/kg] and highest in the bottom 40-60 cm soil depth which is about 43.16 cmol (+)/kg. The exchangeable Mg^{2++} of sample soil ranges from 3 to 8 cmol (+)/kg where it is rated as high exchangeable Mg^{2++} cations.

This experimental plot has highest surface 3.64 cmol (+)/kg levels of exchangeable K^+ cation where >2 cmol (+)/kg is rated as very high exchangeable K^+ cations (Hazelton and Murphy, 2007). Although the exchangeable K^+ cation of experimental plot is decreasing depth wise, highest in the surface soil and lowest in deepest soil (40-60 cm), it is still within the range very high rating class.

The Ca: Mg cationic balance ratio ranges from 6.30 to 7.30 for the top surface soil 0-20 cm depth [low Mg rating, Hazelton and Murphy, (2007)], while ratio ranges from 7.10 to 7.93 (low Mg rating) for sub surface soil 20-40 cm depth. Finally 7.76 to 9.97 Ca: Mg ratios (low Mg rating) were found for the subsurface 40 to 60 cm soil depth. These low concentrations range of Mg indicates that the presence of high Ca in the experimental plot that may disrupt Mg uptake.

The growth and yield components data were subjected to analysis of variance as CRBD design in factorial experiment using SAS analytical Software. Combined data analyses were not made because of different growing seasons in a year used for the experiment (Gomez & Gomez, 1984). When the F-value was significant, a multiple means comparisons were performed using DMRT at a *P*-value of 0.05. Data were analyzed via regression analyses with the best fit were presented. Simple correlation coefficients were estimated within and among different growth characteristics, yields, yield attributes and tested at r^2 probability level. Associations between response variables were examined thoroughly to see direct and indirect relationships.

Results and Discussion

Furrow Irrigated Experiment

Effect of Inorganic N and P fertilizers on Tomato Growth and Yield Components

Fertilizer N application affected biomass yield of stems and leaves, total and marketable fruit yields. Neither P application nor the interaction between fertilizer N and P influenced these variables (Table 3). Application of N fertilizers had significant effect on plant height, shoot fresh weight, total number of fruits per plot, total dry mass above the ground at $P < 0.01$ level of significance (Table 4). Similarly, application of N fertilizers had significant effect on canopy diameter, fruit fresh weight, unmarketable yield and Canopy Cover (CC) at $0.05 < P \leq 0.01$ level of significance. However, application of N did not bring significant change on stem diameter, canopy width and lateral branch length.

Application of P fertilizers brought significant difference on total number of fruits per plot and no significance for canopy diameter at $P \leq 0.05$ significant levels, and on shoot dry weight at $0.10 \leq P \leq 0.05$ level of significance. However, neither the main nor the interaction effect of N and P had significant influence on the stem diameter, canopy width and lateral branch length. Zhang *et al*., (2010), reported similar findings where neither P application nor the interaction between fertilizer P and N influenced biomass yield of stems and leaves as well as total and marketable fruit yields of tomato. The results of mean separation indicated that as N rate increased plant height, shoot fresh weight, shoot dry weight, and total dry mass above the ground per plot were increased (Table 3).

Table 3. Mean values of response of selected growth characteristics and yield components of tomato in response to N and P fertilizers grown under furrow irrigated conditions measured at 80 DAT

	Vegetative growths (mean of four plants)*						
Nitrogen (kg ha^{-1})	Plant height (cm)	Canopy diameter (cm)	Canopy width (cm)	Stem diameter (mm)	Lateral branch length (cm)	Total dry mass above the ground per plot (g)	Shoot fresh weight [a] (g/plant)
0	47.975 C	38.867 B	31.133	13.2908	25.658	90.00 C	193.380 C
50	55.604 B	46.875 A	38.425	13.8313	24.696	119.46 B	356.670 BC
100	59.083 AB	46.050 A	37.842	14.2008	25.921	131.42 AB	365.33 A B
150	62.454 A	47.125 A	39.483	14.3908	25.271	154.50 A	413.04 A
Phosphorus (kg ha^{-1})							
0	54.100	41.696	35.767	13.574	25.050	116.46	294.67
46	55.763	42.675	35.738	13.805	25.546	120.00	301.67
92	56.392	49.950	38.888	13.955	24.671	126.88	376.63
138	58.863	44.596	36.492	14.378	26.279	132.04	355.46
Grand Mean	56.279	44.729	36.720	13.928	25.386	123.843	332.1075

*= Average of three replications. Means within each column with different letters are significantly different using DMRT at $P < 0.05$ levels, [a] = Transformed data

Table 3. Continued…

	Vegetative growths*						
N (kg ha^{-1})	Fruit fresh weight [a] (g/plot)	Total number of fruits per plot [a]	Shoot dry weight [a] (g/plot)	Marketable fruit yield (t/ha)	Unmarketable yield (t/ha)	Total yield (t/ha)	Canopy Cover (CC)
0	960.0 B	31.167 B	28.292 C	22.902 B	27.605 C	50.507 C	0.4124B
50	1612.0 A	51.208 A	46.958 BC	22.513 B	39.165 B	61.678 B	0.6087A
100	1597.8 A	57.333A	50.20 AB	26.846 A	51.655 A	78.501 A	0.587 A
150	1569.8 A	67.333 A	63.583 A	20.757 C	45.796 A	66.553 B	0.6374A
Phosphorus (kg ha^{-1})							
0	1223.3	334038 B	40.708	20.322 C	36.376 C	56.697 C	0.5060
46	1487.2	340686 A	42.708	21.786 BC	43.231 AB	65.017 B	0.5308
92	1518.5	341499 A	48.583	26.086 A	46.088 A	72.175 A	0.6590
138	1510.8	339443 A	57.042	24.823 AB	38.526 BC	63.350 B	0.5505
Grand Mean	1434.92	2526.454	47.26025	23.254	41.055	643.09	0.561575

*= Average of three replications. Means within each column with different letters are significantly different with DMRT at $P < 0.05$ level, [a] = Transformed data

The analysis of variance indicated that the main effect of N had significant influence on canopy diameter. It had highly significant effect on plant height and total above ground dry biomass yield. The main effect of nitrogen had, however, no significant effect on canopy width, stem diameter and length of lateral branches. Application of nitrogen as well as the interaction effects of the two fertilizers did not influence all growth parameters. The analysis of variance revealed that there is no interaction between N rate and P rate treatments for variables such as plant height, canopy diameter, canopy width, stem diameter, lateral branch length, total aboveground dry mass, shoot and fruit fresh weight, and shoot dry weight. The lack of significance for the interaction indicated that under the experimental conditions N and P rates acted independently; therefore, both factors were analyzed separately.

This experiment indicated the existence of synergetic effect of N and P on total fruit yield in which the effect of each factor depended on the levels of the other factor. Since the interaction is significant for total fresh fruit yield, both N and P functional relationship were sketched together to describe the interaction effect of the two fertilizers (Figure 1).

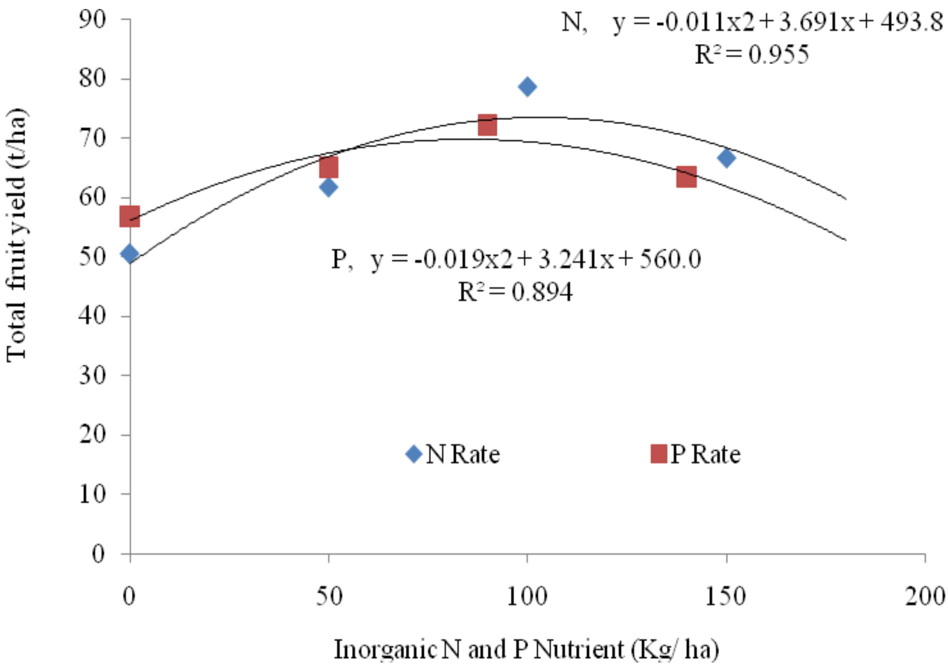

Figure 1. Estimated total fruit yield of tomato as a function of N and P fertilizers application rates under furrow-irrigated condition

Visual examinations of this figure together with the large R^2 values of regression, indicates that the quadratic response fitted the data reasonably well, the fitted equation was plotted along with the raw data. The fitted curve regression showed the maximum total fresh fruit yield of about 74 tons ha^{-1} obtained at the rate of about 105 kg N ha^{-1}. Similarly, maximum total fresh fruit yield of 70 tons ha^{-1} was attained at about 85 kg P ha^{-1}. These rates of the two fertilizers should provide a good estimate of the levels of both N and P that maximizes mean tomato fruit total yield. The adequacy of the regression model for nitrogen, R^2 = 0.95 and, R^2 = 0.89 for P shows the proportion of variability that is explained by the model. The two-way table of means for total fruit yield is indicated in Table 4.

Table 4. Interaction effect of N and P fertilizer application rates on tomato total fruit yield (t ha^{-1}) under furrow irrigated condition at Melkassa

N	P (kg ha^{-1})				
(kg ha^{-1})	0	46	92	138	Mean
0	37.5116 i	53.583 h	57.803 g	53.130 h	50.507 C
50	54.974 h	61.022 f	71.913 e	58.803 g	61.678 B
100	81.178 bc	63.148 f	82.924 a	86.7528 a	**78.501 A**
150	53.126 h	82.313 b	76.058 d	54.713 h	66.553 B
Mean	56.697 C	65.017 B	**72.175 A**	63.350 B	***64.309***

Means followed by the same letter are not significantly different at 5% level of significance.

The significant interaction between N and P indicates that N effects varied with the rate of P applied and vice versa. Hence, more appropriate mean comparisons are between nitrogen means under same P rate or between P rate means under same N means.

The combination of N100 and P92; and N100 and P138 produced the highest fruit yield, 82.924 and 86.752 t ha^{-1}. Pair-wisee comparisons of all treatment combinations were made. Thus, application of 100 kg N ha^{-1} produced the highest mean total fruit yield of 78.501 t ha^{-1} (Table 3). It is clearly seen that there is a wide range of N fertilizer yields from zero to 50.950 t ha^{-1} to 78.501 t ha^{-1} with N100; while P fertilizer rates yielded mean of 56.697 t ha^{-1} for zero P and 72.175 t ha^{-1} total fruit yield for P92 (Table 3).

Jones, (2008) stated that the general N fertilizer recommendations for tomato in several countries ranges from 70 kg N ha $^{-1}$(Senegal) to 159 kg N ha $^{-1}$ (Pakistan). This finding is in line with the report of (FAO, 1979) where they generalized that fertilizer requirement for high producing tomato varieties range from 100 to 150 kg N ha^{-1} and P requirement range from 65 to 110 kg ha^{-1}. The result of present investigation agrees with earlier findings of (Tesfaye, 2008) who reported that addition of a range of N fertilizer at 110 kg ha^{-1}, to tomato field improved tomato fruit yield on vertisol of West Showa.

These findings proved that what farmers in the CRV are currently applying on the average 289 kg of Urea, with total N average estimated to 185 kg ha^{-1} (both from Urea and from DAP) is very high dose. These N applications are extremely in excess of tomato requirement, nearly threefold. Farmers still apply Urea for tomato higher than the blanket recommendation 200 kg ha^{-1} given by Zonal Agricultural Offices. The survey result conducted by Edossa *et al*., (2013a, unpublished) also indicated that tomato growers are currently applying on the average 283 kg DAP ha^{-1}, estimated to 59.43 kg P ha^{-1}. Those growers are applying around 283 kg DAP ha^{-1}, however the quantity of P fertilizer applications are in acceptable range for tomato except that household vegetable growers use at second and third split application of DAP where plants may not use pre-plant fertilizers when applied as second and third splits.

Correlations Among and Within Growth and Yield Components of Tomato under Furrow Irrigated Growing Condition

Among growth characteristics, those variables with positive and significant relationships are: total fruit yield vs. canopy diameter, total fruit yield vs. fresh fruit weight, total fruit yield vs. total number of fruits (Table 5). This relationship indicates that manipulating one of the correlated factors for improving yield may also lead to the improvement in the other parameter.

The analysis indicated that total fruit yield versus plant height, total fruit yield Vs canopy diameter, total fruit yield Vs canopy depth (diameter with in a row), total fruit yield Vs stem diameter, total fruit yield Vs total dry weight, total fruit yield Vs shoot fresh weight, total fruit yield Vs shoot dry weight showed very weak positive associations. However, some variables showed strong and negative correlation with each other and still some variables had very weak negative associations. Those variables with either negative or positive significant correlation coefficient (r^2) among them indicted direct relationship, while those with no significant have indirect relationship.

Table 5. Estimation of Pearson correlation coefficient (r^2) among and between yield and agronomic parameters of tomato as influenced by nitrogen and phosphorus application rates under furrow irrigated condition

	PH	CD	CW	SD	LBL	TDW	SFW	FFW	TNF	SDW	MY	UMY
PH	1											
CD	0.40**	1										
CW	0.44**	0.71**	1									
SD	0.52**	0.26	0.40**	1								
LBL	0.12	0.10	0.02	0.20	1							
TDW	0.61**	0.65**	0.68**	0.44**	0.23	1						
SFW	0.79**	0.31*	0.48**	0.57**	0.21	0.70**	1					
FFW	0.53**	0.58**	0.55**	0.53**	0.38**	0.55**	0.43**	1				
TNF	0.51**	0.31*	0.41**	0.21	0.01	0.51**	0.42**	0.36*	1			
SDW	0.79**	0.31*	0.48**	0.57**	0.21	0.70**	1.0**	0.43**	0.42**	1		
MY	0.15	0.16	0.18	0.31*	-0.09	0.05	0.04	0.16	0.23	0.04	1	
UMY	0.37**	0.44**	0.50**	0.33*	0.14	0.46**	0.37**	0.43**	0.53**	0.37**	0.42**	1
Total fruit yield	0.25	0.27*	0.25	0.17	0.02	0.21	0.20	0.42**	0.62**	0.207	0.22	0.22

Note: ** indicates significant at $P < 0.01$, and * indicates significant at $P < 0.05$. The decimal numbers without any asterisk are non-significant at $P > 0.05$ levels, PH: Plant height, CD: Canopy diameter, CW: Canopy width, SD: Stem diameter, LBL: Lateral branch length, TDW: Total dry weight above the ground, SFW: Shoot fresh weight, FFW: Fruit fresh weight, TNF: Total number of fruit, SDW: Shoot dry weight, LDW: Leaf dry weight, SDW: Shoot dry weight, MY: Marketable yield, UMY: Unmarketable yield, TFY: Total Fruit Yield, Qy: Quantum Yield, Ft: Leaf Fluorescence, ChloCon: Leaf chlorophyll content, TLN: Total leaf N, L P: Leaf P, L K: Leaf K, L Ca: Leaf Ca, L Cu: leaf Cu, L Fe: Leaf Fe, [a]= Raw data were transformed

Rainfed Tomato Experiment

Effect of Inorganic N and P fertilizers on Tomato Growth and Yield Components

Various field response of tomato to application of N and P fertilizers the rainfed production conditions were shown in Table 6. There were extreme vegetative growths with high fruit bearing capacity under this rainfed production conditions, showing very different growth performance under dry and rainy season cropping, same variety with same fertilizer rates. There is a soil fertility and field management variations between the two experiments. Rainfed tomato field management practices were completely different from dry season’s field management; rainy season pest problems are completely different from dry season’s pest problems requiring different types of chemical applications.

Analyses of mean variance for each parameter were made to see interactions and main effects of application of N and P on tomato growth, yield and yield components during the rainy season. The results of analysis for all parameters under considerations are presented in Table 6. The ANOVA indicated that under rainfed with relatively fertile soil experimental conditions there is no existence of joint factor N and P interaction effects on total, marketable, unmarketable fruit yield and all vegetative and physiological parameters assessed.

Table 6. Mean values of response of selected growth response of tomato to N and P fertilizers grown under rainfed conditions measured at 80 DAT

	Mean values of growth characteristics*					
Nitrogen (kg ha^{-1})	Plant height (cm)	Canopy diameter (cm)	Canopy width (cm)	Stem diameter (mm)	Shoot fresh weight (g/ plot)	Shoot dry weight (g/ plot
0	97.133	40.525	46.708 AB	18.2167	914.63 C	84.04 B
50	97.242	40.300	46.033 AB	18.7938	1028.96 BC	96.58 AB
100	103.508	43.258	49.821 AB	19.4929	1172.92 AB	105.71 A
150	103.287	41.767	51.525 A	20.4167	1276.67 A	112.58 A
Phosphorous (kg ha^{-1})						
0	100.404	43.063	50.004	18.463	1129.71 AB	112.42
46	96.804	38.546	45.438	19.125	961.38 C	85.67
92	99.617	41.396	49.225	19.409	1069.13 BC	94.83
138	104.346	42.846	49.421	19.922	1232.96 A	106.00
Grand Mean						

*= Average of three replications. Means within each column with different letters are significantly different using DMRT at a $P < 0.05$ levels, [a] = Raw data were transformed

Table 6. Continued ……

	Mean values of growth characteristics						
Nitrogen (kg ha^{-1})	Total dry weight above the ground (g/ plot)	CC	Lateral branch number [a]	Leaf fresh weight [a] (g/ plot)	Total yield (t ha^{-1})	Unmarketable weight (t ha^{-1})	Marketable fruit weight (t ha^{-1})
0	307.58	0.284 B	6.458	208.54	75.541 B	22.325	53.216 AB
50	368.13	0.288 B	6.041	216.04	83.697 A	22.815	60.882 A
100	365.17	0.324AB	6.250	264.42	70.166 B	20.909	49.256 B
150	367.42	0.352 A	7.000	260.67	69.618 B	20.370	49.281 B
Phosphorous (kg ha^{-1})							
0	407.38	0.30983	6.7917	303.54 A	80.087 AB	22.196	57.891 AB
46	309.13	0.29022	6.0833	195.67 B	81.356 A	23.334	60.489 A
92	325.96	0.31798	6.6667	194.42 B	68.870 B	23.334	45.536 C
138	365.83	0.33132	6.2083	256.04AB	68.709 B	19.990	48.719 BC
Grand Mean							

*= Average of three replications. Means within each column with different letters are significantly different using DMRT at a $P < 0.05$ levels. [a] = Raw data were transformed.

Application of N under rainfed with relatively fertile soil brought significant effect on shoot fresh weight of tomato at $P < 0.01$ probability levels. Similarly application of N showed significant effect on total fruit yield, shoot dry weight and CC at $0.05 < P \leq 0.01$ level of significance (Table 6).

Yield data from rainfed experiment indicated a clear negative response with rates of N above 50 kg N ha^{-1} and P above 46 kg ha^{-1}. Unlike furrow irrigated dry season experiment, the combination of 50 kg ha^{-1} of N and 46 kg ha^{-1} of P produced the highest total fruit yield of 101.642 t ha^{-1}; with the grand mean 74.966 t ha^{-1} total fruit yield; similarly pair-wise comparisons of all treatment combinations were made.

Thus, application of 50 kg N ha^{-1} rate gave the highest mean total fruit yield 101.6427 t ha^{-1} (Table 7) with a 106.83% (at P0), 108.52% (at P46), 91.86% (at P92) and 92.77% (at P138) increment relative to the grand mean and the smallest value of the interaction means, respectively.

Table 7. Interaction effect of N and P fertilizers on total fruit yield (t ha^{-1}) of tomato grown under rain-fed conditions at Melkassa during the 2010 main growing season

N	P (kg ha^{-1}) [a]				
(kg ha^{-1})	0	46	92	138	Mean
0	83.507	79.6373	68.1931	70.82494	75.541 AB
50	74.997	101.6427	78.8150	79.3333	83.697 A
100	79.3019	72.5892	66.1735	62.5977	70.166 B
150	82.5414	71.5543	62.2976	62.082	69.618 B
Mean	80.0878AB	81.355 A	68.869 B	68.709 B	***74.754***

[a]: Average of three replications. Means followed with same letters are not significantly different using DMRT at a $P \leq 0.05$ level.

Percent increment over the grand mean as to P application, the P2, 46 kg P ha^{-1} rate gave the highest mean fruit yield 82.45 t ha^{-1} with a 100.76% (at N0), 114.64% (at N50), 93.59% (at N100) and 93.99% (at N150) increment relative to the grand mean. It is clearly seen that there is a wide range of N fertilizer yielded from 70.166 t ha^{-1} with N 100 kg of N, to 83.697 t ha^{-1} with N50; while P fertilizer rates yielded lowest mean yield of 68.869 t ha^{-1} for P92 and highest P, 81.355 t ha^{-1} total fruit yield for P46 (Table 7). However, the rain had gone while field tomato was flowering and producing yield.

Strange *et al*., (2000), suggested that in California, soils with bicarbonates-extractable P greater than 13 ppm are unlikely to respond to P application under warm conditions, but below 12 ppm yield response to applied P would be expected. This investigation indicates that tomato crop responses to small amounts of P added as starter fertilizer on soils with high P and calcium concentrations; similar situations were reported by (Hochmuth *et al*., 1994; Hochmuth *et al*., 1996) where vegetable crop responded to small amounts of P as starter fertilizer on soils with high P and calcium concentrations such as some shallow Histosols in southern Florida.

The peak total fruit yield was obtained from regression line equation at N around 50 kg ha^{-1} application (Figure 4). Application of P fertilizer under similar conditions brought highly significant effect on marketable fruit weight at $P < 0.01$ level of significance. Similarly the effects were observed for, shoot fresh weight and total fruit yield at $0.05 \leq P \leq 0.01$ level of significance. Application of P did not affect plant height, canopy diameter, canopy width, lateral branch number, leaf fresh weight. Similarly, peak total fruit yield was obtained from another regression line equation at application of P 10 kg ha^{-1} application rate. There is less P response from this experiment as compared to the previous one, since there is higher soil P content nearly 34 ppm in the test soil, while 5.64 ppm of P concentration in the first furrow irrigated experiment.

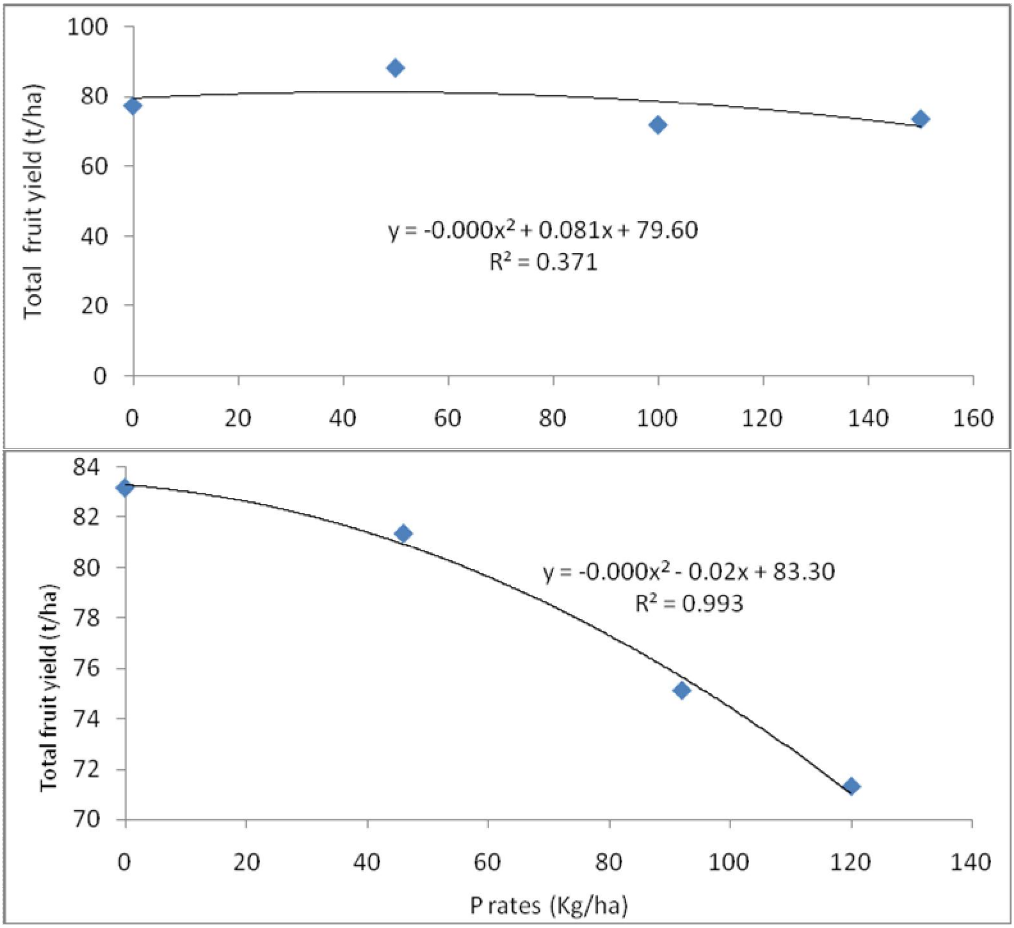

Figure 4. Estimated total fruit yield of tomato as a function of N and P fertilizers application rates under rainfed conditions at Melkassa

Generally highest mean marketable fruit yield 60.489 t ha^{-1} was recorded from application of P46; while highest mean marketable fruit yield 60.882 t ha^{-1} was recorded from N50 (Table 7). Mean separations were made for all parameters assessed under this experiment in order to visualize the trends of development towards increasing or decreasing rates of both N and P applications.

Summary and Conclusions

This study indicated that application of combined N rate 100 kg ha^{-1}, and P rate at 46 kg ha^{-1} under furrow irrigated conditions gave the highest tomato total fruit yield. However from regression lines fitted, peak yield of 73.45 t ha^{-1} total fruit yield was estimated from application of N rate 105 kg ha^{-1}, while 70.003 t ha^{-1} total fruit yield was estimated from application of 85 kg of application of P ha^{-1}.

From the rainfed tomato experiment, the treatment N 50 kg and P 46 kg ha^{-1} gave the highest total fruit yield, however peak total fruit yield was estimated from regression lines were from application of N treatment at 40 kg N ha^{-1} and application of P treatment at 10 kg ha^{-1}. There is a weak regression lines for yield response to both N and P, and there is no yield increment responses observed from N beyond 40 kg ha^{-1} and P beyond 10 kg ha^{-1} and but yield reductions were observed beyond these levels under this specific soil type and growing conditions, indicating that much application is not. Thus in orders to propose provisional recommendations of N and P requirement from low fertile soil and from good fertile soil were averaged. Thus N, 78 kg and P 48 kg ha^{-1} could be suggested for further study on representative farmer's field around Melkassa area for *Melkashola* variety was tested at this population.

However, there would be wide range of N 105 kg ha^{-1} under low soil fertility and 40 kg $^{-1}$ under relatively good fertile soils' and wide range of P fertilizer as low as 10 kg P ha^{-1} on fertile soil and as high as 85 kg P ha^{-1} would be proposed for use around Melkassa and similar soil types in the CRV area; indicating site, season, variety and management specific recommendation would be required for both N and P fertilizers since tomato is grown in the open field throughout the year. This would assist that fertilizer inputs should be adjusted to the varying demand across the household farms in order to optimize net returns and avoid losses to the environment. In addition, detailed studies of tomato crop and canopy characteristics using furrow (marginal soil) and wet season (fertile soil) at Melkassa revealed that the growths of the crop to various environments are extremely elastic. Tomato growth responds to under luxuries growth conditions of inputs and field management practices indicates the possibility of getting much higher yields under better growth conditions although the rain fall period was short. This result confirmed that there is seasonal variation in canopy growth and development in tomato, so that all field management practices should be adjusted to the specific growing season.

References

Brady, N. C., and R .R. Weill. 2008. Elements of the Nature and Properties of Soils: 14th ed. Prentice-Hall, Inc., Upper Saddle River, New Jersey, USA

Csizinszky, A. A. 2005. Production of Tomato in Open Field. Pp 257-256. (*In*): Ep Heuvelink (*Eds*). Tomatoes: Crop Production Science in Horticulture Series. CAB International. Wallingford, Oxfordshire OX10 8DE, UK

Edossa Etissa, Nigussie Dechassa, Tena Alamirew, Yibekal Alemayehu and Lemma Desalegne. 2013a. Small Scale Vegetable Growers N and P Fertilizers Use and Soil Fertility Management Practices in the Central Rift Valley of Ethiopia (Unpublished)

Edossa Etissa, Nigussie Dechassa, Tena Alamirew, Yibekal Alemayehu and Lemma Desalegne. 2013b. Irrigation Water Management Practices in Small Scale Household Vegetable Crops Production System in the Central Rift Valley of Ethiopia (Unpublished)

Fageria N. K.. 2009. The Use of Nutrients in Crop Plants. CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL

Getachew Legese and Mohammed Hassena. 2012. Assessment of Vegetables Value chain in Central Rift Valley, Ethiopia. Oxfam America, Horn of Africa Regional Office (HARO), Addis Ababa, Ethiopia, July 2012 (Unpublished).

Gomez, K.A. and A. A. Gomez. 1984. Statistical Procedures for Agricultural Research (2nd ed.) Jhon Wiley and Sons Inc.; New York.

Hazelton, P. and B. Murphy. 2007. Interpreting Soil Test Results, CSIRO Publishing, 150 Oxford Street (P O Box 1139) Collingwood VIC 3066, Australia.

Hochmuth G., Ron Rice and Eric Simonne. 2009. Phosphorus Management for Vegetable Production in Florida, Publication # HS105, University of Florida IFAS (Institute of Food and Agricultural Sciences) Extension

Hochmuth, G., Ed Hanlon, George Snyder, Russell Nagata, and Tom Schueneman. 1996. Fertilization of sweet corn, celery, romaine, escarole, endive, and radish on organic soils in Florida. Florida Extension Serv. Bull. 313. http://edis.ifas.ufl.edu/CV008.

Hokam E. M., S. E. El-Hendawy and U. Schmidhalter. 2011. Drip Irrigation Frequency: The Effects and Their Interaction with Nitrogen Fertilization on Maize Growth and Nitrogen Use Efficiency under Arid Conditions. *J. Agronomy & Crop Science* 197: 186–201Jones J. B. Jr., 2008. Tomato Plant Culture: In the Field, Greenhouse and Home Garden, 2nd Editions, CRC Press.

Jones J. B. Jr. 2003. Agronomic Handbook; Management of Crops, Soils, and Their Fertility, CRC PRESS.

Jones J. B, Jr. 1999. Tomato Plant Culture: In the Field, Greenhouse, and Home Garden, CRC Press LLC, Washington, D.C.

Lemma Desalegn. 2002. Major Vegetable Crop Varieties and Their Production Practices, 2002. Vegetable IPM Project (EARO/ICIPE) EARO, Addis Ababa, Ethiopia.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus, pp. 403-429. (*In*) A.L. Page (*Eds*). *Methods of Soil Analysis*, Part 2. 2nd (*Ed.*) Amer. Soc. Agron., Madison, Wisconsin.

Peet, M. M. and G. Welles. 2005. Greenhouse Tomato Production. pp 257-304. (*In*) Ep. Heuvelink (*Eds*). Tomatoes. CABI International. Wallingford, UK

Strange M. L., W. L. Schrader, and T. K. Hartz. 2000. Fresh-market tomato production in California. University of California, Division of Agriculture and Natural Resources, Publication Number 8017

Taha Mume. 2007. Determinants of Adoption of Improved Onion Production Package in Dugdaa Boorraa District, East Showa, Ethiopia, M Sc. Thesis, Haramaya University pp. 113.

Tesfaye Balemi. 2008. Response of tomato cultivars differing in growth habit to nitrogen and phosphorus fertilizers and spacing on vertisol in Ethiopia, *Acta agriculturae Slovenica*, 91 (1), 103-119, DOI: 10.2478/v10014-008-0011-8.

Walkley, A. and A. Black. 1934. An Examination of the Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method, *Soil Sci.*, 37: 29–38.

Zhang T. Q., C. S. Tan, K. Liu, C. F. Drury, A. P. Papadopoulos and J. Warner. 2010. Yield and Economic Assessments of Fertilizer Nitrogen and Phosphorus for Fresh Tomato with Drip Fertigation, *Agron J,* 102: 774-780.