Response of fruit quality of tomato grown under varying inorganic N and P fertilizer rates under furrow irrigated and rainfed production conditions

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Abstract

Experiments were conducted with the objectives to determine optimum combinations of N and P application rates on fruits quality of tomato under furrow irrigated and rain fed season. Four levels of N and P rates were factorially combined, laid on RCBD replicated three times. The experiment was conducted during cool-dry season using furrow irrigation, and the second similar experiment was conducted during the rainy season. Sample fruits were harvested at light-red ripe stage assessed for the parameters such as TSS, fruit pH, Titratable acidity (TA), juice volume, TSS/TA ratio, fruit weight, length and diameter and subjected to analysis of variance using SAS. The results indicated that application of N and P fertilizers under different production conditions affected most fruit quality characteristics. Higher average TSS and pH were recorded from furrow irrigated tomato cultivated during dry seasons; while lower TSS and pH was recorded from under rain fed growing. These studies showed that there is the possibility of achieving desired level of fruit quality such as TSS and pH under defined N and P application rates and production conditions which is important for use in tomato processing. Thus future research should confirm these findings.

Keywords: Tomato; Fruit quality; TSS, Fruit p; Titratable acidity; Juice volume

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1. Introduction

Tomato is cultivated for fresh use and for processing, thus varieties are categorized in to fresh, processing and multipurpose type. With regard to fresh use Jones (1999), described that consumers measure the quality of tomato fruit primarily by three factors, i) physical appearance (color, size, shape, defects, and decay), ii) firmness and iii) flavor. The nutritional characteristics of the tomato have gained interest because consumers are becoming more health conscious. Saltveit (2005), explained that fruit quality characteristics of fresh-market fruit are similar to those of processing tomatoes, but characteristics that are readily apparent to the consumer (color, size, shape, firmness and aroma) dominate the others. While appearance, texture and flavor are the important quality attributes of fresh-market tomatoes, the major quality components of processing tomatoes are soluble solids, pH, titratable acidity, viscosity and color (Saltveit, 2005). The major traits of processing tomatoes are determinate growth, dwarf habit, concentrated and uniform fruit set and ripening, tough skins, and high soluble solids content (George, 1999). Processing tomatoes are grown in open-field systems, where as fresh tomatoes are usually grown in greenhouse. The soluble solids include sugars, organic acids and other dry matter constituents, such as pectic fragments, that remain in solution. The production of tomato concentrates and paste requires removal of water, which is an energy intensive process; therefore, it is less expensive to produce concentrates from fruit with a high content of soluble solids and dry matter.

Saltveit, (2005) explained that soluble solids (SS) and titratable acids (TA) are important components of flavor. They exert their effect not only through the amount present (about 50% of the dry weight is SS and 12% TA), but also through their ratio. Fruit high in both acids and sugars have excellent flavor, while tart fruit have low sugar content and bland fruit have low acidity.

As described by Mozafar (1993), nutrition particularly nitrogen fertilization can have a significant effect on the vitamin content of tomato fruit. The range of pH for the tomato fruit is between 4.0 and 4.5; the lower the pH, the greater is the so-called "tartness," a factor, by which some consumers judge the quality of tomato fruit (Jones, 1999); the relationship between the pH and solids content (mainly sugars) of the tomato fruit is also a significant factor in its perceived flavor. Besides the genetics, field management affects tomato fruit quality (Ibid.). When canning, the pH of the canned tomato product will determine the safety of the final product. In order to improve the quality of tomato, there should have production packages which would eventually fulfill the grower's, consumers as well as processors needs. Studies on field management practices, particularly on the management of N and P would help increasing quality of tomato.

Over the years, a great deal of work has been done by traditional plant breeders however field management contributes to increase the soluble solids of tomato. A balanced supply of nutrients especially calcium, and the macronutrients P, K and to a lesser extent N are necessary for the production of high quality tomatoes (Jones, 2008). Additionally tomato fruit quality is significantly affected by stage of ripeness, harvest stages, number of times handled and storage temperature and time (Jones, 1999). Fruit quality is strongly affected by prevailing temperatures during fruit development and harvest (Saltveit, 2005 and Dorais et al., 2001). The available information on the stated subject under Ethiopian conditions is inadequate. Thus the objectives of the study was to determine optimum combinations of N and P application rates on quality of tomato fruits under furrow irrigated dry conditions and rain fed production seasons of tomato.

2. Materials and methods

Two experiments were conducted at Melkassa, Central Rift Valley of Ethiopia with *Melkashola* multipurpose tomato. The first part deals with quality assessment of furrow irrigated tomato experiment under various N (0, 50, 100 and 150 kg N ha^{-1}) and P (0, 46, 92 and 138 kg P ha^{-1}) application rates. The experiment was conducted during cool-dry season from December to January using furrow irrigation, the second part deals with similar assessments of rainfed tomato experiment under similar four level of N and P application rates. For this rainfed experiment field transplanting was made on 1 July 2011 and no supplementary irrigation was made after rainfall cessation around mid of September. N and P levels were factorially combined and replicated three times. Sample tomato fruits were harvested at light-red and red-ripe stages, as processing tomatoes are harvested red-ripe (Saltveit, 2005) and immediately transported to a processing plant. For each experiment, tomato fruits from each treatments and replications were harvested at firm red-ripe stage and then various fruit quality assessment were made for each plot at harvesting stages. Fifteen sample fruits per plot were randomly taken and assessed for the required parameters.

The TSS (% Brix) was determined following the procedures described by Waskar et al., (1999). An aliquot of juice were extracted using a juice extractor (Type 6001x, USA). An Atago N, hand refractometer with a range of 0 to 32° Brix and resolutions of 0.2° Brix were used to determine TSS by placing 1 to 2 drops of clear juice on the prism. Between samples the prism of the refractor meter were washed with distilled water and dried with tissue paper before use. The referactometer were calibrated against distilled water (0 percent reading TSS) before every reading was started. The pH values of the tomato juice were measured with a pH meter, Model 3020 pH Meter, Jenway Company. The TA (%) of tomato juice was measured according to the methods described by Maul et al*.,* (2000). The titratable acidity expressed as percent citric acid, were obtained by titrating 10 ml of tomato juice to pH 8.2 with 0.1N NaOH. The TA was calculated from the following formula:

$$TA\,(\%) = \frac{Titre\ x\ 0.1N\ NaOH\ x\ 0.67}{1000}\ x\ 100\ \%$$

Tomato juices volume (ml) was extracted from 10 sample fruits using a juice extractor (Type 6001x, USA) from sample fruits with and clear juice was used for the analysis. Volumes were measured using graduated cylinder after removing seeds and pulps. Finally TSS/ TA ratio values were obtained by dividing TSS reading to the TA values.

Fruit sizes such as weight, length and diameter were assessed from ten randomly selected marketable sample tomato fruits per plot. Fruit weight was assessed from randomly selected marketable sample fruits per plot. Fruit lengths were measured at harvest from ten randomly selected sample fruits using Calipers. Similar to fruit length, fruit diameters were measured from ten randomly selected sample fruits using Calipers.

Data set were subjected to analysis of variance as CRB design in factorial experiment (Gomez and Gomez, 1984) using SAS analytical Software. Combined data analyses were not made because of different growing seasons in a year used for the experiment (Gomez and Gomez, 1984). When the F-value is significant, a multiple means comparisons were performed using DMRT at *P*-value of 0.05. Data were analyzed via regression analyses using linear/ quadratic and exponential terms and with the best fit were presented.

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 made at Deber Zeit Agricultural Research Centre soil laboratory. These are soil 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, 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.

Based on the results of soil laboratory analysis for furrow irrigated tomato, 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 analysis of physico-chemical properties of experimental soil used for rainfed tomato experiment 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. 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 moderate rating 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.

One meter ridges 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 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; however staking was made during additional rainfed experiment conducted during the rainy seasons on relatively fertile soil.

3. Results and discussions

All fruit quality characteristics were measured, calculated and estimated from both from both furrow irrigated and rain fed tomato experiments were presented under the following:

3.1. Furrow irrigated tomato grown under various N and P application rates

3.1.1. Main and interaction effects of N and P application rates on fruit quality of furrow irrigated tomato

Except TSS and pH data, all others were fitted to normal distribution. TSS and pH data were transformed using arc-sine transformation (decimal fraction). Analysis of variance had shown that application of N and P fertilizers were not interacted for all tomato fruit quality parameters assessed, however application of N had brought highly significant effect on Titratable Acidity (TA) and TSS/TA Ratio at $P < 0.01$. Similarly, application of N had shown significant effect on fruit length at $P < 0.05$ (Table 1). Saltveit, (2005) stated that there is a large variation among tomato genotypes for pH and titratable acidity; and he also generalized that a ripe tomato is acidic and its pH values range from 4.1 to 4.8, while storage and handling procedures should maintain the pH of red-ripe fruit at or below 4.7 to prevent growth of micro-organisms such as *Clostridium botulinum*.

Table 1. Analysis of variance table showing mean square values for quality parameter for tomato grown under different N and P application rates harvested at firm ripe stage under furrow irrigation

Source of variations	df	Mean square values							
		Total Soluble Solids (TSS) [a]	pH [a]	Juice volume	Titratable Acidity (TA)	Mean fruit weight	Mean fruit length	Mean fruit diameter	TSS/TA Ratio
Nitrogen (N)	3	0.368 NS	0.004 NS	57.380 NS	8.221**	87.35 NS	19.929*	1.595 NS	0.0423**
Phosphorous (P)	3	0.105 NS	0.027 NS	45.477 NS	0.878 NS	37.873 NS	2.109 NS	5.289 NS	0.0124 NS
N x P	9	0.192 NS	0.035 NS	59.523 NS	0.698 NS	36.698 NS	2.310 NS	3.221 NS	0.003 NS
Error	32	0.2081	0.0002	46.119	1.173	36.849	5.717	4.049	0.0049
Total	47								
R[2]		0.321	0.347	0.363	0.472	0.374	0.322	0.277	0.590
CV (%)		10.388	3.416	9.906	15.725	9.475	3.942	4.702	10.836
Root Mean MSE		0.456	0.156	6.791	1.083	6.070	2.391	2.012	0.070

*Note = NS indicates non significant at P < 0.05 and * significant at P < 0.05, and ** significant at P < 0.01 probability levels, respectively*

Application of both N and P nutrients did not bring any significant on any of the tomato fruit quality assessed at $P < 0.05$ probability level (Table 1). Although application of N did not bring significant difference on any of the quality parameters, mean values indicated that as application rate of N increase, the TSS and pH of the fruit value increased and peaked at N around 100 kg, beyond this value, the TSS tend to decrease. It is

the percent solids in the tomato fruit that determines its flavor; the higher the solids content, the higher the flavor (Jones, 2008).

Application of P did not bring any significant effect on all quality characteristics assessed, however mean separation have shown that N 100 kg N ha^{-1} and P 92 kg P ha^{-1} gave highest peak TSS recorded, thus from this experiment, maximum TSS and highest total marketable fruit yield were obtained from similar N at around 100 kg and P application rates around 92 kg ha^{-1} (Table 2). Using the LSD test for the mean separation at 5% significance level, significant N effects were separated and presented in this table.

Table 2. Mean values of fruit quality characteristics of tomato at various N and P application rates harvested at firm ripe stage under furrow irrigation*****

Nitrogen (kg ha^{-1})	Total Soluble Solids (TSS %) (%Brix) [a]	pH [a]	Juice volumes (ml)	Titratable acidity (TA)	TSS/TA ratio	Mean fruit weight (g)	Mean fruit length (mm)	Mean fruit diameter (mm)
0	(4.191) B	(4.575)	67.917	6.025 B	0.704 A	65.153 AB	61.647 AB	42.466
50	(4.333) AB	(4.575)	71.792	6.340 B	0.695 A	67.380 A	61.838 A	43.036
100	(4.608) A	(4.616)	67.417	7.550 A	0.618 B	61.810 B	59.807 BC	42.503
150	(4.433) AB	(4.591)	67.083	7.644 A	0.581 B	61.925 B	59.284 C	43.179
Mean	(4.391)	4.589	68.552	6.890	0.649	36.849	60.644	42.796
LSD (0.05)	0.037	NS	NS	0.901	0.0587	5.048	1.98	NS
Phosphorus (kg ha^{-1})								
0	(4.291)	(4.533)	70.542	7.212	0.604	65.832	60.999	43.387
46	(4.458)	(4.566)	65.875	6.915	0.650	61.639	60.866	42.206
92	(4.483)	(4.625)	68.958	6.882	0.670	64.745	60.660	42.237
138	(4.333)	(4.633)	68.833	6.550	0.674	64.703	60.051	43.355
Mean	(4.391)	4.589	68.552	6.890	0.649	36.849	60.644	42.796
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

= Average of three replications. Means within each column with different letters are significantly different using LSD at P = 0.05 levels of significance respectively, [a]: Transformed data, means in brackets are original data

3.1.2. Correlations among and within fruit quality characteristics of furrow irrigated tomato under N and P application rates

Some variables have strong and positive associations such as fruit weight vs. fruit length (r^2= 0.72**), fruit weight with fruit diameter (r^2= 0.43**), juice volume with fruit diameter (r^2 = 0.49**), juice volume with fruit weight (r^2= 0.93**) showed highly positive significant correlations. Whereas, TSS with TA (r^2=-0.81**) and TSS/TA with fruit length (r^2=-0.55**), TA with juice volume (r^2 = -0.43**), TA with fruit weight (r^2 = -0.54**) are highly negatively correlated (Table 3).

Table 3. Estimation of Pearson correlation coefficient (r^2) of within and between fruit quality characteristics of tomato at various N and P application rates on harvested fruit at firm ripe stage grown under furrow irrigation conditions

	Average fruit length (FL)	Average fruit diameter (FD)	Average fruit weight (FW)	Juice volumes (JV)	Total Soluble Solids (% Brix) [a]	Titratable Acidity (TA)	TSS/TA ratio
FD	0.28*						
FW	0.72**	0.43**					
JV	0.67	0.49**	0.93**				
TSS [a]	-0.55**	-0.42**	-0.56**	-0.55**			
TA	-0.70**	-0.06	-0.54**	-0.43**	0.70**		
TSS/TA	0.54**	-0.21	0.34*	0.19	-0.18	-0.81**	
pH [a]	-0.04	0.12	0.01	0.04	-0.07	-0.10	0.12

*Note: ** indicates significant at P < 0.01, and * significant at P < 0.05. The decimal numbers without any asterisk are non-significant at P < 0.05 levels respectively. FL: Average fruit length, FD: Average fruit diameter, FW: Average fruit weight, JV: Juice volumes, TSS: Total Soluble Solids (% Brix), TA: Titratable Acidity, [a]: Original data were transformed.*

Associations among N and P fertilizers applications with fruit quality traits of furrow irrigated tomato were explored. Fruit quality characteristics such as TA had showed strong and positive associations with N application where r^2 = 0.55**; whereas TSS/TA ratio with N application (r^2= -0.56**) and average fruit length with N application showed negative and significant correlation (Table 4).

However examination of associations indicated that application N fertilizer had no direct relationship with the fruit quality characteristics assessed such as average fruit diameter, average fruit weigh, juice volumes (JV) and fruit pH. Average fruit length and TSS/TA ratio had showed strong and negative associations with N fertilizer applications where r^2 is significant. All fruit quality characteristics examined with application of P fertilizers showed very weak or no direct associations with the P applications.

Table 4. Estimation of correlation coefficients (r^2) among soil total N and total P status with fruit quality traits of tomato grown under field furrow irrigated conditions
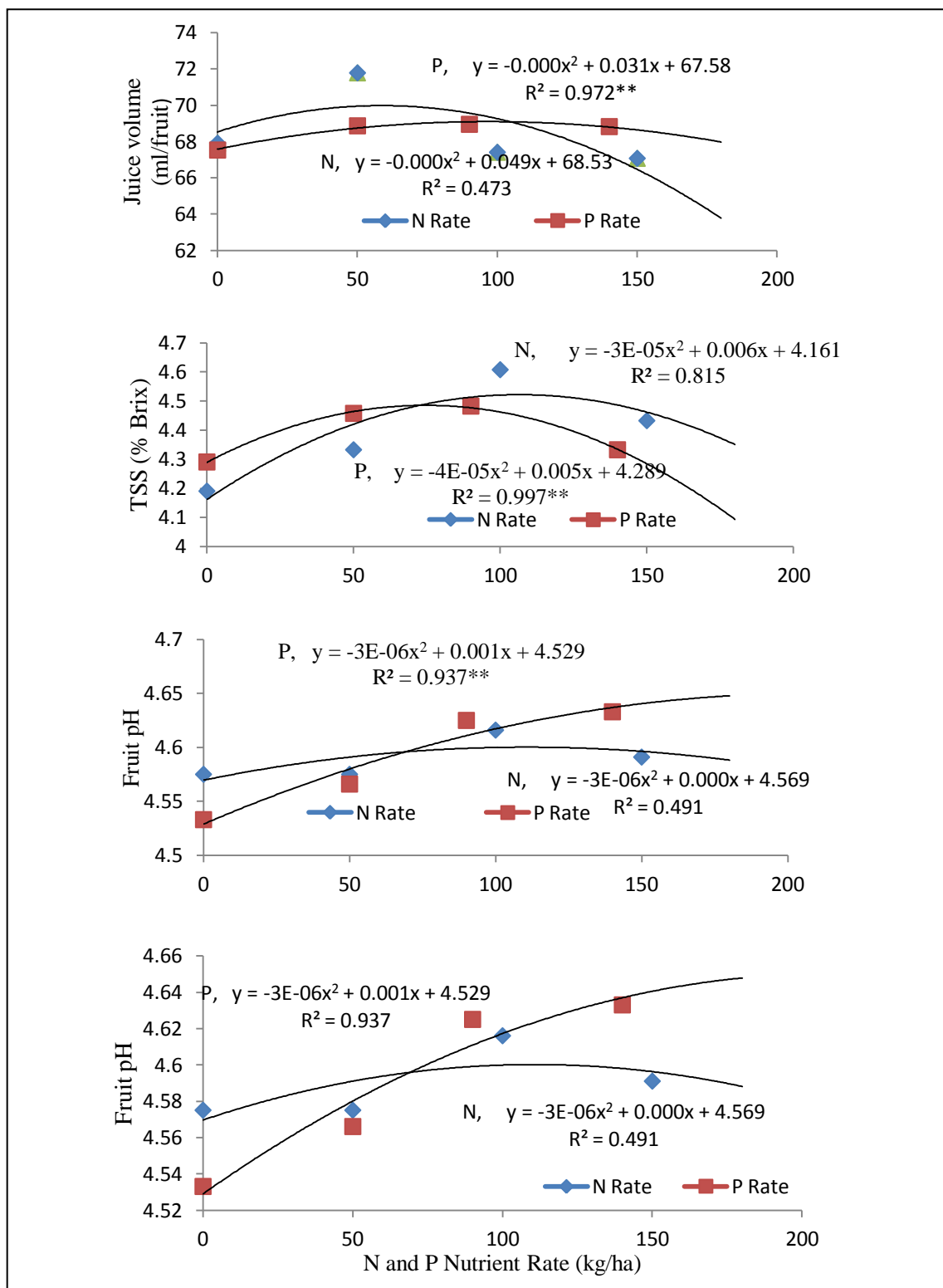
N and P application	Quality criteria							
	Average fruit length (FL)	Average fruit diameter (FD)	Average fruit weight (FW)	Juice volumes (JV)	Total Soluble Solids (%Brix)	Titratable Acidity (TA)	pH	TSS/TA ratio
N	-0.43**	0.09	-0.27	-0.11	0.24	0.55**	0.07	
Applied P	0.009	-0.003	-0.03	-0.03	0-04	-0.18	0.20	0.29

*Note: * indicates significant at P < 0.05, and ** indicates significant at P < 0.01 probability levels, respectively. The decimal numbers without any asterisk are non-significant at P < 0.05 levels*

3.1.3. Regression analyses of fruit quality characteristics furrow irrigated tomato under N and P application rates

Although analysis of variance indicated that most fruit quality characteristics were not affected by application of N and P nutrients, regression of fruit quality characteristics of furrow irrigated tomato to N and P fertilizer application rates are shown in Figure 1. that It is clearly seen under this investigation that most characteristics such as juice volume, TSS, and fruit pH tends to increase as both N and P rate increase tending to higher somewhere in between and turn down indicating there a need of application of N and P nutrients for quality improvement. All regression lines of juice volume, TSS, fruit pH and TA in relation to Both N and P nutrient applications are shown with their R^2 (Figure 1).

Thus, it is clearly seen from this experiment that the contour line TSS curve (Figure 2) showed that predetermined N and P application rates on *Melkashola* tomato fruit could be targeted to achieve the desired level quality aspects such as TSS under furrow irrigated conditions of main tomato harvest. This is aspect of N and P management is important for cultivation of processing tomato for industry where currently hybrid varieties of with similar TSS requirement are purchased with expensive price per kilo of seed. Highest TSS, 4.98 were achieved at peak contour line curve N rate range between approximately 3.00 and 3.15 scale (estimated 100 kg-115 kg N ha $^{-1}$) while P rate approximately range between 1.75 and 2.60 scale (estimated 60 kg-85 kg P ha^{-1}) in this experiment (Figure 2). Thus maximum TSS requirement for the tomato processing industry in the country could be obtained from application rates of these N and P rates. The levels of N and P levels produced highest TSS peak coincides the treatment that gave highest fruit yield per ha.

Figure 1. Regression functions of fruit quality characteristics of field furrow irrigated tomato grown under different N and P applications rates
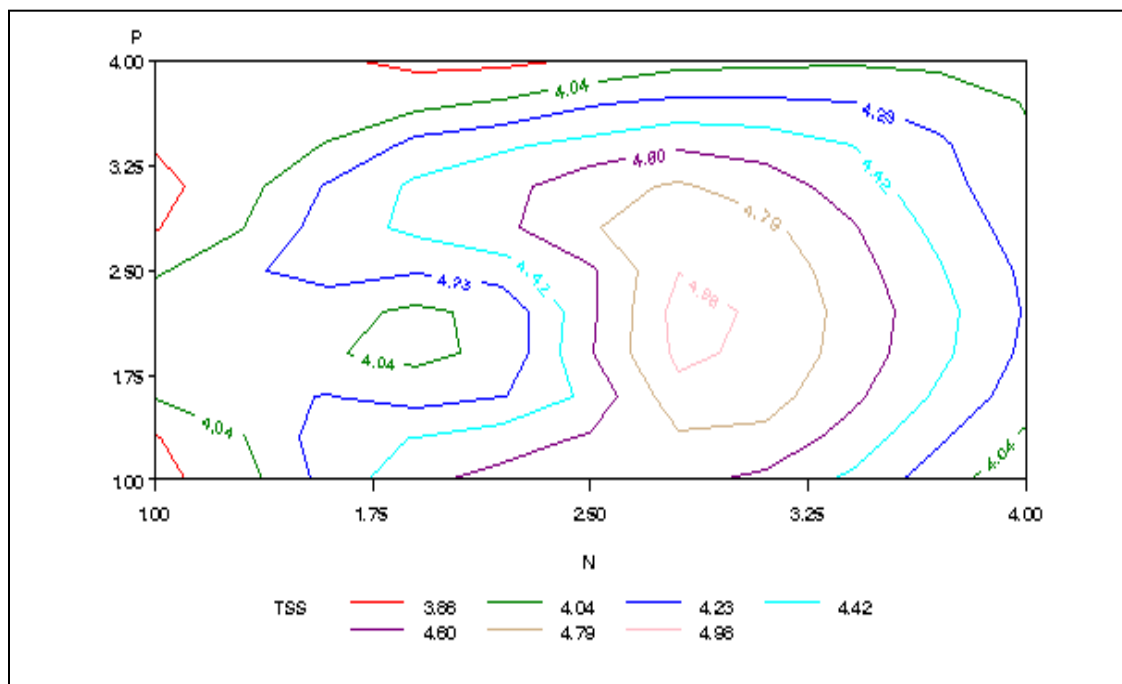
Figure 2. Contour curve showing response of fruit TSS characteristics in a radius of tomato to N and P application rates grown under furrow irrigated condition

3.2. Quality of rain fed tomato grown under different N and P application rates

Unlike furrow irrigation during dry season where high fruit quality obtained, there is low TSS for same application of N and P rate during rainy season as compared to same application rate during dry season of furrow irrigated same tomato variety.

3.2.1. Main and interaction effects of N and P application rates on fruit quality characteristics of rainfed tomato

Analyses of variance were made for all fruit quality parameters assessed (Table 5). Similar to furrow irrigated tomato, no interactions were observed between inorganic N and P fertilizer application for all quality parameters assessed under rainfed experimental conditions. Application of N fertilizer did not bring any difference on all quality parameters assessed under rainfed conditions at $P < 0.05$ probability level (Table 5). Similarly, application of P did not bring any significant difference for all fruit quality parameters assessed on tomato at same $P < 0.05$ probability level. Mean separations were made for all fruit quality traits to show the trends weather application of N and P is improving across the rates used. Generally low TSS were found from same N and P application rates with same variety *Melkashola* tomato under rainfed conditions showing that TSS depends on among others the season, lower TSS were found probably due to cool season harvest.

Table 5. Analysis of variance table showing mean square values for quality variables for tomato under different N and P application rates under rain fed condition harvested at firm ripe stage

Source of variations	df	Mean of square values					
		TSS (%)	Fruit pH	Juice volumes	Fruit weight	Fruit length	Fruit diameter
Nitrogen (N)	3	0.296 NS	0.001 NS	8.222 NS	5.985 NS	9.1165 NS	46.601 NS
Phosphorous	3	0.005 NS	0.008 NS	43.000 NS	11.295 NS	0.5817 NS	7.059 NS
N x P	9	0.237 NS	0.010 NS	39.555 NS	38.860 NS	9.007 NS	4.834 NS
Error	32	0.163	0.0045	66.398	42.77	12.256	19.243
Total	47						
R^2		0.674	0.299	0.226	0.227	0.267	0.299
CV (%)		1.58	2.243	12.238	11.749	6.062	10.164
Root MSE		0.067	0.095	8.148	6.525	3.500	4.401

*Note = NS indicates non significant at P < 0.05; * and significant at P < 0.05 and ** significant at P < 0.01 probability levels, respectively*

These results are substantiated by the findings of low temperatures at ripening greatly affect tomato fruit quality. Many literatures have been documented that tomato fruit quality is strongly affected by temperature (Dorais et al., 2001). Temperature directly influences metabolism and indirectly, cellular structure and other components that determine fruit quality such as colour, texture, size and organo-leptic properties (Saltveit, 2005). An air temperature of 23°C improved the taste of tomatoes, increased fruit dry matter and reduced the proportion of softer and mealy fruit as compared with fruit grown at 17°C (Janse and Schols, 1992). Growth at 17°C produced softer and less juicy and aromatic fruits. Such fruit have a less resistant cuticle, despite a higher content of reducing sugars and a lower content of titratable acids (Janse and Schols, 1992). Jones, (2008) summarized that the role of factors external to the plant, such as climate, rooting media (soil, soilless, hydroponic), and cultural practices, have on fruit flavor may be equally significant.

Additionally Tan, (1990) stated that optimizing both yield and quality of tomato is accomplished by matching water application to peak crop water use rate, where the peak water use periods occur during fruit set and fruit development; irregular and inadequate water supply during these periods can result in poor fruit set. However, since this experiment was conducted under rainfed, where daily rainfall record and daily ETo estimation indicated that 67.5% of growth period was dry days while the wet days were as small as 32.5% of the growth period, thus these fluctuations might additionally contributed to low tomato fruit TSS. Jones, (2008) generalized that Brix determinations were made on organic versus non-organically grown fruit,

greenhouse versus field grown fruit; such results suggest that there is not a consistent association between a Brix value and growing procedure.

Application of N and P did not interact, bring effect separately on the pH response of tomato although there is no significant difference, the grand mean of pH was found to be 4.589 (Table 6). Jones, (2008) stated that the range of pH in tomato fruit lies between 4.0 and 4.5; the lower the pH, the greater the so-called tartness, a factor by which some consumers judge the quality of the tomato fruit; the average pH range for most tomato fruit lies between 4.3 and 4.4.

Mean separations were made for all fruit quality characteristics to show the trends weather application of N and P is improving across the rates used (Table 6).

3.2.2. Correlations among and within fruit quality characteristics of rainfed tomato under N and P application rates

In the rain fed tomato experiment, it was found that the fruit weight was positively associated with juice volumes at $r^2 = 0.89$, while most of the quality characteristics assessed in this experiment showed non-significant associations among them indicating there is no direct relationships among them (Table 7).

4. Summary and conclusions

It could be generalized that quality assessments from different tomato experiments application of N and P nutrients growing under different production conditions affected most fruit quality characteristics. TSS and pH are the most important quality parameters used for processing tomato. Higher TSS and pH were recorded from furrow and drip irrigated tomato cultivated during dry seasons. Similar higher average TSS was recorded from container grown tomato under starter N, P and media mixtures growing conditions during rainy season. Compared to field rain fed conditions, container grown tomato faced frequent stress from dry spells. However lower average TSS and pH was recorded from tomato planted under relatively luxurious rain fed growing conditions most likely due to prevailing low temperature during ripening and at harvest. These studies showed that there is the possibility of achieving desired level of tomato fruit quality such as TSS and pH under different N and P application rates and production conditions which is important for use in tomato processing plants in the country such as Upper Awash Agro-industry Enterprise (UAAIE) and *MelgeWendo* Food Processing Plant. Additionally some agronomic and irrigation field management practices would contribute to produce vegetable quality improvements.

Tomato processing industries such as Upper Awash Agro- Industry Enterprise instead of buying expensive hybrid tomato variety with high TSS that can be affected during following field management could have local tomato variety like *Melkashola* with high and exact TSS content would be obtained through controlling N and P nutrients rates, irrigation and other production conditions. Further these TSS could be more improved through withholding irrigation water before harvest. This investigation has shown that rain fed tomato *Melkashola* variety have low TSS, which is not suitable for the processing industry while have high TSS that suits for the processing during cool dry season.

Table 6. Mean values of fruit quality traits of tomato at various N and P application rates on harvested at firm ripe stage under field rain fed production*

Nitrogen (kg ha-1)	Total Soluble Solids (TSS %)	Fruit pH	Juice volumes (ml)	Mean fruit weight (g)	Mean fruit length (mm)	Mean fruit diameter (mm)
0	3.75	4.24	65.91	55.25	57.73	42.70
50	3.99	4.26	66.08	55.13	58.96	45.84
100	3.95	4.24	67.75	56.59	57.06	42.97
150	4.12	4.25	66.58	55.15	57.18	41.10
Mean	3.957	4.251	66.58	55.53	57.73	43.156
LSD (0.05)	NS	NS	NS	NS	NS	NS
Phosphorus (kg ha-1)						
0	3.97	4.27	69.16	56.95	57.71	42.41
46	3.97	4.22	65.16	55.10	58.05	42.58
92	3.94	4.23	66.83	54.79	57.62	43.85
138	3.93	4.27	65.16	55.28	57.55	43.78
Mean	3.952	4.247	66.577	55.53	57.732	43.15
LSD (0.05)	NS	NS	NS	NS	NS	NS

*= Average of three replications. Means within each column with different letters are significantly different using LSD at P = 0.05 levels of significance

Thus future research should confirm these results high TSS during dry irrigated season (both furrow and drip irrigation system) at wider areas, across all available varieties and production conditions and looking for additional options to improve TSS during rainy season should investigated. Thus with the fruit quality parameters assessed from all experiments under different production conditions, the hypothesis that fruit quality of tomato could be improved through manipulation of N, P nutrient and FYM including irrigation water management practices was proved. Additionally this study proved that *Melkashola* tomato variety; fulfill the requirement of both fresh and processing types having the major traits of processing tomatoes that are determinate dwarf growth habit, uniform fruit set and ripening, and a high soluble solids content during dry season required for processing. Whereas this variety grown very tall that requires staking, has semi-determinate (continuous harvest) growth habit during rainfed growing season.

Table 7. Estimation of Pearson correlations coefficients (r^2) among and within fruit quality traits of tomato as influenced by N and P application rates under rain fed conditions

	TSS	Fruit pH	Fruit length	Fruit diameter	Juice volumes
Fruit pH	0.18				
Fruit length	-0.24	-0.20			
Fruit diameter	-0.13	0.005	0.19		
Juice volumes	0.029	0.07	-0.19	0.01	
Fruit weight	-0.01	-0.03	-0.033	0.06	0.89**

*Note: * indicates significant at P < 0.05, and ** indicates significant at P < 0.01 probability levels, respectively. The decimal numbers without any asterisk are non-significant at P < 0.05 levels*

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