Effects of Nitrogen and Phosphorus Fertilization Rates on Tomato Yield and Partial Factor productivity Under Irrigation Condition in Southern, Ethiopia

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Abstract: Tomato is one of the most important vegetable crops grown under irrigation in Southern, Ethiopia. Nitrogen and phosphorus are the most essential nutrients/ important inputs/, to increase the yields of vegetables including tomatoes typically depending on the fertility status of the particular soil types. An experiment was carried out to find suitable levels of nitrogen and phosphorus fertilizers under balanced fertilizer and to assess the economic feasibility of N and P fertilizer at Meskan, Gurage districts of Ethiopia. This experiment was designed in a Randomized Complete Block Design with the factorial arrangement in three replicates. Treatments were four nitrogen level (0, 46, 92, and 138 kg ha^{-1}) and four phosphorous level (0, 20, 40, and 60 kg ha^{-1}). The results of this study revealed that there are highly significant ($P < 0.01$) interaction effects of nitrogen and phosphorus fertilizer application during all growing seasons on total and marketable fruit yields of tomatoes. The maximum marketable fruit yield; 55.1, 60.1, and 52.8 t ha^{-1} were obtained during the 2019,2020, and 2021 growing seasons respectively by application of 138 kg ha^{-1} of N and 40 kg ha^{-1}. Similarly, the maximum total fruit yield (59.5, 62.9, and 56.8 t ha^{-1}) was obtained during the 2019,2020, and 2021 growing seasons respectively by application of 138 kg ha^{-1} of N and 40 kg ha^{-1}. However, the lowest marketable and total fruit yields were obtained from the control or unfertilized plot. A linear increase in yield was noted with soil application of N and P for· all years. The more unmarketable yield was recorded at the unfertilized or controlled treatments. Therefore, application 138 kg ha^{-1} of N combined with 40 kg ha^{-1} P fertilizers pointed out that the fertilizer level seems to allow a good balance of production and productivity and is economically advisable for farmers in the study area for better tomato production and similar soil types and agro-ecologies.

Keywords: Fruit yield, Nitrogen, Phosphorous, Production, Food, Tomato

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1. Introduction

Fertilizers, which are essential and the most important material input in modern agricultural production have played important role in improving the yield and quality of crops (Chen *et al*.,2018 and Li *et al.,* 2019). However, over-fertilization not only inhibits the improvement of crop yield and quality, but it also results in serious issues, such as habituation and acidification of the soil, aggravation of crop pests, leaching loss of soil nutrients, and threats to groundwater safety. These matters exert a serious impact on agricultural sustainability and the ecological environment (Dubos et al., 2016). To date, numerous studies have explored the effects of fertilizer application rate on crop growth, yield, and quality (Mahajan and Singh 2006). For example, Qu et al. (2019) found that the yield increased with a rising fertilizer application rate up to a point, after which yield decreased in cucumbers grown in substrate bags in spring. Zhang *et al,* (2018) noticed that, compared to the conventional fertilizer application method, a controlled-release fertilizer management method significantly increased yield, with more accumulated total dry weight in bitter gourd.

Tomato (*Lycopersicon esculentum. mill*) is one of the most widely grown Solanaceae vegetable crops in the world. It is also one of the most important and widely grown vegetables in Ethiopia. The national average tomato fruit yield under farmers' conditions in Ethiopia is very low. Several improved varieties and other agronomic packages have been recommended to farmers to overcome the low productivity and quality of tomatoes in the country. And yet, the average national yield remains very low and is reported to be about 7 tons/ha (CSA,2009), which is less than 50% of the world average of 27 tons/ha. The production and productivity of the crop in Ethiopia are influenced by different factors among declining soil fertility, insufficient and inefficient use of fertilizers, inappropriate agronomic practices, and inadequate pest and disease management are major.

Chemical fertilizers have been the prime means of enhancing soil fertility in small farm agriculture (Thangavel, and Mohammed, 2014). Nitrogen and phosphorus are often referred to as the primary macronutrients because of the large quantities they are taken up by plants from the soil relative to other essential nutrients (Marschner, 1995). Tomato plants produce stunted growth, small leaves, and poor fruit yield if the plants are not properly nourished by NP fertilizers at different growth stages (vegetative, flowering, and fruiting). Application of N promotes vegetative growth and fruit yield of tomato, and later application in the growing stages favors 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, the 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). Mehla *et al.*, (2000) were also reported that fruit yield in tomatoes is highly influenced by the NP fertilizers rates applied. Likewise, Sharma *et al.*, (1999) also reported average fruit weight of tomatoes has been influenced by the amount of NP fertilizers rates applied. Thus, the tomato plants should receive the optimum amount of NP fertilizers to produce higher fruit yields. So far, in Ethiopia, the recommended fertilizer rate for Tomato is, 200 kg/ha DAP and 100 kg/ha for UREA (EARO, 2004). The common fertilizer application rates according to literature are 60-120 kg N, and 60-140 kg P_2O_5 and 60-120 kg K_2O per hectare (http://www.avrdc.org, 2007).

However, this would also be too general to use for specific regions. Since the spacing requirement of a tomato depends on soil type and its inherent fertility (Lemma *et al.*, 1992) and the type of cultivars (Mehla *et al.*, 2000), the use of blanket recommendation would be inappropriate and it would be indispensable to identify appropriate recommendation for specific soil types and cultivars grown in the region. Sustainable agriculture production requires balanced and judicious, efficient, eco-friendly, and environmentally sound management practices. To achieve the national goal of agricultural sustainability and food security, vertical diversification of agriculture in terms of more crops output from the unit quantity of land through judicious use of fertilizer inputs especially nitrogen has special significance in modern agriculture (Fageria and Barbosa, 2001 and Kumar *et al.*, 2016). However, little information is available on the response of the tomato rates of the fertilizers in terms of fruit yield, which is important to optimize fertilizer application for enhanced productivity and quality of the crop. Keeping in view these aspects, the present study was initiated to the response of tomatoes to different rates of nitrogen and phosphorus fertilizers under balanced fertilizer and to assess the economic feasibility of N and P fertilizer rate in southern, Ethiopia.

2. Materials and Method

A field experiment was conducted on farmers' fields in Mesqan Woreda, Gurage Zone of the South Nations Nationalities and Peoples Region (SNNPR) under irrigation conditions during 2019-2021. The site is located southwest of Addis Ababa at 8^{O}06′ 422" latitude and 38 ^{O} 24′ 909" longitude and with an altitude of 1960 *m.a.s.l*. The average annual rainfall of the area over a decade was 1206.8 mm with a range of 504.7 mm to 1783.3 mm with an average annual temperature of 18.6ºC. The experiment consisted of four levels of Nitrogen (0, 46, 92, and 138) and Phosphorous (0, 20, 40, and 60) with 16 treatments combination was laid out in RCBD Design with the factorial arrangement in three replications. The source of Nitrogen and phosphorus was Urea and TSP respectively. The full dose of P and half dose of N fertilizer was applied at transplanting time and the remaining half dose of N was side-dressed two weeks after transplanting. Other agronomic practices were carried out uniformly for all treatments as a recommendation. Before the establishment of the experiment and after uprooting geo-referenced composite soil samples (0 to 20cm) was collected for the analysis of texture, soil pH, total N, available P, CEC, micronutrient (B, Zn, Fe, Cu, Mn) based on their recommended and standard laboratory procedure.

1. Data collection

All Agronomic data on yield and yield components were measured and taken from 10 randomly selected plants per plot. The total number of marketable and unmarketable (cracked, damaged, and infected) fruits per plant was obtained by counting the number of fruits of the respective categories from the successive harvests of pre-selected plants of each plot (dropped fruits were not considered at all).

2. Economic analysis

Besides, an economic analysis was carried out for every treatment using partial budget analysis involving marginal rate of return was calculated for the marketable yield to obtain the economically optimum rate of applied NP fertilizer. The prices of Urea, TSP, and tomato fruit were valued based on the prices of the local market during the time of planting and harvesting which were considered to be 19.50, 22.20, and 14.50 ETB kg^{-1}, respectively. Gross field benefit (GFB), total variable cost (TVC), and net benefit (NB) were some of the concepts used in the partial budget analysis. The dominance analysis was also carried out to select potentially profitable treatments and a percentage marginal rate of return (% MRR) was calculated for the non-dominated treatments (CIMMYT, 1988).

3. Data analysis

All collected data were subjected to a two-way analysis of variance to test for the least significant differences (LSD) at the 5% level. All analyses were performed using Statistics Analysis System (SAS version 9.4) software package (SAS, 2014)

3. Result and Discussion

1. Physicochemical Properties of Soil

The experimental site was analysis results indicated that soil particle size distribution of the experimental sites was in proportions of 22% of sand, 30% of silt, and 48% of clay with the textural class of clay loam (Table 1). When the proportion of clay is > 45% on the surface area, more active both chemically and biologically, high water holding capacity (WHC), relatively high nutrient holding capacity, the slow movement of water and air, hardier for the workability of implements and slow release of water to plants with poor drainage are its important features (Chandrasekaran *et al.*, 2010). Similarly, a high clay proportion of the soil may be important as it describes the stability in soil aggregates and less liability of the surface soil layers to wind and water erosion. Therefore, this characteristic of the soil of the study area indicates its potential to increase crop productivity provided that other limitations are minimized.

The soil pH (H_2O) analysis shows the pH value of 7.10 which is neutral (Table 1). Tekalign (1991) reported that when the soil pH ranges from 6.7-7.3 rates as neutral. Soil pH has a vital role in determining several chemical reactions and in influencing plant growth by affecting the activity of soil microorganisms and altering the solubility and availability of most of the essential plant nutrients and particularly the micronutrients such as Fe, Zn, B, Cu, and Mn (Sumner, 2000). The analysis result shows that the available P content was 18 mg kg^{-1} (Table 1) which is rated as medium according to (Cottenie (1980). The total nitrogen content was 0.32% which is ranged at a high level according to Tekalign's (1991) classification. Similarly, organic carbon content was 4.25% which is ranged at a high level according to Tekalign's (1991) classification. The cation exchange capacity (CEC) of the soils was 60 cmol (+) kg^{-1} which is very high (Table 1). Hazelton and Murphy (2007) classified that the CEC values moderate 12-25, and very high >40 cmol (+) kg^{-1}.

2. Effect of Nitrogen and Phosphorous fertilizer on tomato fruit yield

The main effect of nitrogen and phosphorous fertilizer did not show significantly influenced marketable, unmarketable, and total fruit number and yield of tomato. However, there was a highly significant (<0.01) interaction effect between nitrogen and phosphorous fertilizer were noted on the marketable, unmarketable, and total fruit yield of tomatoes (Table 2-5). According to the analysis, the maximum marketable and total fruit yield of tomatoes were obtained from the combined application. The maximum marketable fruit yield; 55.1, 60.1, and 52.8 t ha^{-1} were obtained during the 2019,2020, and 2021 growing seasons respectively by application of 138 kg ha^{-1} of N and 40 kg ha^{-1}. Similarly, the maximum total fruit yield (59.5, 62.9, and 56.8 t ha^{-1}) were obtained during the 2019,2020, and 2021 growing seasons respectively by application of 138 kg ha^{-1} of N and 40 kg ha^{-1}. However, the lowest marketable and total fruit yields were obtained from the control or unfertilized plot. The trend of pooled data remained the same as in the individual years (Table 5). A linear increase in yield was noted with soil application of N and P for· all years. The more unmarketable yield was recorded at the unfertilized or controlled treatments.

The result of the present investigation agrees with earlier findings of (Tesfaye, 2008) who reported that the addition of a range of N fertilizer at 110 kg ha^{-1}, to tomato fields, improved tomato fruit yield. Similar to the current findings, Balemi (2008) also reported the highest fruit yield obtained from the highest rate and lowest from the lowest rate of NP. The nutrient requirement of the tomato is an important factor if large quantities of high-quality fruits are to be produced effectively and efficiently (Anderson *et al*., 1999). Higher yields at high levels of N and P are due to better fertilizer responsiveness of the tomato crop (Mishra *et al*., 2004). Similarly, the report of (FAO, 1979) where generalized that fertilizer requirements for high producing tomato varieties range from 100 to 150 kg N ha^{-1} and P requirements range from 65 to 110 kg ha^{-1}.

3. Economic Analysis

The cost-benefit analysis revealed that the highest net benefit of 801,710.00 Eth-Birr with MRR% of 132.8 was obtained by application of 138 kg ha^{-1} of N and 40 kg ha^{-1} P (Table 6). The lowest net benefit, 216050.00 Eth-Birr was obtained from the control or unfertilized plot. Moreover, the dominance analysis in Table 6 showed that 2,3, 4,6 12, 10, and 16 treatments were dominated. Dominated treatments were of the comparison for marginal analysis. Calculation of

net benefit accounts for costs that vary but also it is important to compare the extra or marginal costs with the extra or marginal net benefits. Therefore, applications of 138 kg ha^{-1} N and 40 kg ha^{-1} of P is economically advisable for farmers in the study area for better tomato production; beneficial as compared to the other treatments in the study area because the highest net benefit and the marginal rate of return were above the minimum level (100%). Thus, 1328% MRR indicates that by investing 1 Birr a farmer can get 13.28 Eth-birr.

Table 1. Some physic-chemical properties of the experiment field soil

Properties	Level
Sand	22
Silt	30
Clay	48
Textural Class	Clay loam
pH H_2O (1:2.5)	7.10
Available P (mg kg^{-1})	18.0
% Total Nitrogen	0.32
Organic Carbon %	4.25
CEC (cmol $(^+)$ kg^{-1})	60.0
Ca (cmol $(^+)$ kg^{-1})	38.3
Mg (cmol $(^+)$ kg^{-1})	7.28
K (cmol $(^+)$ kg^{-1})	1.13
Na (cmol $(^+)$ kg^{-1})	2.03
Fe (mg kg^{-1})	0.62
Mn (mg kg^{-1})	3.75
Cu (mg kg^{-1})	1.44
Zn (mg kg^{-1})	0.75

Table 2: Interaction effects NP fertilizers on tomato yield during 2019 cropping season

Nitrogen (Kg ha^{-1})	**Marketable fruit yield (t ha^{-1})**				**Unmarketable fruit yield (t ha^{-1})**				**Total fruit yield (t ha^{-1})**			
	Phosphorous (Kg ha^{-1})				**Phosphorous (Kg ha^{-1})**				**Phosphorous (Kg ha^{-1})**			
	0	20	40	60	0	20	40	60	0	20	40	60
0	13.1^{h}	19.9^{g}	22.1^{fg}	25.9^{ef}	10.5^{a}	6.4^{bcd}	5.5^{cd}	4.8^{d}	23.6^{gh}	26.3^{gh}	27.7^{gh}	30.7^{fgh}
46	27.0^{def}	40.4^{ab}	41.4^{ab}	43.1^{ab}	5.8^{bcd}	5.8^{bcd}	7.5^{bc}	7.7^{bc}	32.8^{fg}	46.2^{bcd}	48.9^{bcd}	50.8^{bc}
92	30.2^{de}	37.7^{c}	39.3^{ab}	44.2^{b}	6.7^{bcd}	6.8^{bcd}	7.9^{abc}	7.5^{bc}	36.9^{ef}	44.5^{bcde}	47.2^{bcd}	51.8^{ab}
138	32.0^{d}	40.5^{ab}	55.1^{a}	38.6^{c}	10.3^{a}	8.2^{ab}	4.4^{d}	4.6^{d}	42.3^{de}	48.7^{bcd}	59.5^{a}	43.2^{cde}
CV%	9.7				22.8				11.5			
Lsd≤0.05 %	5.5^{**}				2.6^{*}				7.9^{**}			

Table 3: Interaction effects NP fertilizers on tomato yield during 2020 cropping season

Nitrogen (Kg ha^{-1})	Marketable fruit yield (t ha^{-1})				Unmarketable fruit yield (t ha^{-1})				Total fruit yield (t ha^{-1})			
	Phosphorous (Kg ha^{-1})				Phosphorous (Kg ha^{-1})				Phosphorous (Kg ha^{-1})			
	0	20	40	60	0	20	40	60	0	20	40	60
0	18.1^{h}	24.9^{gh}	27.1^{fgh}	30.9^{efg}	10.0^{a}	4.9^{cde}	4.0^{de}	5.6^{cd}	27.1^{i}	29.8^{hi}	31.1^{ghi}	34.5^{fghi}
46	32.0^{defg}	42.1^{bcd}	43.7^{bc}	47.1^{b}	5.9^{cd}	4.2^{cde}	6.0^{cd}	6.1^{cd}	36.9^{efgh}	43.0^{cdef}	49.7^{bcd}	53.3^{ab}
92	35.2^{cdefg}	44.4^{bc}	46.9^{b}	40.6^{bcde}	5.2^{cde}	5.2^{cde}	6.4^{bcd}	6.0^{cd}	40.4^{defg}	49.6^{bcd}	53.4^{ab}	46.6^{bcde}
138	36.0^{cdef}	43.8^{bc}	60.1^{a}	41.6^{bcd}	8.8^{ab}	6.7^{bc}	2.8^{e}	3.0^{e}	44.8^{bcde}	50.5^{bc}	62.9^{a}	44.6^{bcde}
CV%	16.5				26.1				13.5			

Table 4: Interaction effects NP fertilizers on tomato yield during 2020 cropping season

Nitrogen (Kg ha^{-1})	Marketable fruit yield (t ha^{-1})				Unmarketable fruit yield (t ha^{-1})				Total fruit yield (t ha^{-1})			
	Phosphorous (Kg ha^{-1})				Phosphorous (Kg ha^{-1})				Phosphorous (Kg ha^{-1})			
	0	20	40	60	0	20	40	60	0	20	40	60
0	13.4^{h}	23.3^{fg}	20.5^{gh}	23.6^{fg}	11.2^{a}	6.0^{bcd}	5.2^{cd}	6.7^{bc}	24.6^{g}	29.3^{fg}	26.0^{g}	30.3^{efg}
46	24.7^{efg}	32.1^{bcdef}	36.4^{bcd}	38.2^{bc}	7.1^{bc}	5.4^{cd}	7.1^{bc}	7.3^{bc}	31.8^{efg}	38.8^{bcdef}	43.5^{bcd}	45.4^{bc}
92	27.9^{defg}	37.1^{bcd}	39.6^{b}	33.3^{bcde}	6.3^{bcd}	6.4^{bcd}	7.6^{bc}	7.2^{bc}	34.2^{defg}	43.5^{bcd}	47.2^{ab}	40.4^{bcde}
138	28.7^{cdefg}	36.5^{bcd}	52.8^{a}	34.3^{bcde}	7.9^{b}	7.8^{b}	4.0^{d}	4.2^{d}	36.6^{cdef}	44.3^{bcd}	56.8^{a}	38.5^{bcdef}
CV%	18.5				21.7				16.6			
Lsd≤0.05%	9.7**				2.4**				10.6*			
Lsd≤0.05 %	10.6*				2.5*				9.8*			

Table 5: Pooled mean interaction effects NP fertilizers on tomato yield during 2019-2021 cropping season

Nitrogen (Kg ha^{-1})	Marketable fruit yield (t ha^{-1})				Unmarketable fruit yield (t ha^{-1})				Total fruit yield (t ha^{-1})			
	Phosphorous (Kg ha^{-1})				Phosphorous (Kg ha^{-1})				Phosphorous (Kg ha^{-1})			
	0	20	40	60	0	20	40	60	0	20	40	60
0	14.9^{e}	22.7^{ef}	23.2^{def}	26.8^{de}	10.6^{a}	5.8^{ef}	4.9^{efg}	5.7^{ef}	25.1^{i}	28.5^{hi}	28.2^{hi}	31.8^{gh}
46	27.9^{de}	38.2^{b}	40.5^{b}	42.8^{b}	6.3^{cde}	5.1^{ef}	6.9^{cde}	7.0^{cde}	33.8^{fg}	42.6^{cd}	47.4^{bc}	49.8^{b}
92	31.1^{cd}	39.7^{b}	41.9^{b}	39.4^{b}	6.1^{cde}	6.1^{cde}	7.3^{cd}	6.9^{cde}	37.2^{ef}	45.9^{bcd}	49.3^{b}	46.3^{bcd}
138	32.2^{c}	40.2^{b}	56.0^{a}	38.1^{b}	9.0^{b}	7.6^{c}	3.7^{fg}	3.9^{fg}	41.2^{de}	47.8^{bc}	59.7^{a}	42.1^{cd}
CV	15.4				23.1				13.7			
Lsd≤0.05%	4.9*				1.4*				5.3*			

Table 6. Partial budget analysis of different levels of NP fertilizer for tomato production in district

Treatments (kg ha^{-1})	MFY (tone ha^{-1})	GB (ETB ha^{-1})	TVC (ETB ha^{-1})	NBC (ETB ha^{-1})	MRR%	D
1	14.9	216050.00	0.00	216050.00		
5	27.9	404550.00	1950.00	402600.00	95.7	
2	22.7	329150.00	2220.00	326930.00		d
9	31.1	450950.00	3900.00	447050.00	71.5	
8	42.8	620600.00	4170.00	616430.00	627.3	
3	23.2	336400.00	4440.00	331960.00		d
13	32.2	466900.00	5850.00	461050.00	91.6	
11	41.9	607550.00	6120.00	601430.00	519.9	
6	38.2	553900.00	6390.00	547510.00		d
4	26.8	388600.00	6660.00	381940.00		d
14	40.2	582900.00	8070.00	574830.00	136.8	
12	39.4	571300.00	8340.00	562960.00		d
7	40.5	587250.00	8610.00	578640.00	58.1	
15	56.0	812000.00	10290.00	801710.00	132.8	
10	39.7	575650.00	10560.00	565090.00		d
16	38.1	552450.00	12510.00	539940.00		d

Where: ETB = Ethiopian Birr (currency); TCV = Total cost that vary; NBC = Net benefit cost; MRR = MFY=marketable fruit yield, GB=Growth benefit, Marginal rate of return; d=Dominance

4. Conclusion And Recommendation

Soil nutrient is one of the most important factors to attain optimum yield in all crop production systems. Nitrogen and Phosphorous plays important role in vegetative and fruit development in crops. Tomato is the third most important vegetable crop in the world and its production is challenged by many factors from which optimum amount of nitrogen and phosphorous nutrient is the primary problem, particularly in Ethiopia. This study revealed that N and P rates at 138 and 40 kg ha^{-1} respectively, were provides 56.0 t ha^{-1} marketable fruit yield and are economically advisable for farmers in the study area for better tomato production.

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Conflicts of Interest

The authors declare no conflict of interest.

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