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Research Article

Influence of Nitrogen and Phosphorus Fertilizers Applications for Tomato (*Solanum lycopersicum* L.) Production Under Irrigation in the Fogera District, Northwest Ethiopia

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Abstract

Small-scale tomato production under irrigation is a common practice in the Fogera area of the Amhara Region in Northwest Ethiopia. However, there were no location-specific economic optimum N and P fertilizer recommendations for tomato production in the area. Therefore, a field study was conducted in 2020 and 2021 to investigate the response of tomato to N and P fertilizer applications and determine the economic return of N and P fertilizers applications. Four levels of N (0, 46, 92, and 138 kg N ha^{-1}) and three levels of P (0, 46, and 92 kg P_2O_5 ha^{-1}) were factorially combined and laid in a randomized complete block design with three replications. The results revealed that tomato yield and yield-related attributes were significantly ($p<0.01$) affected by the main effects of N. However, the main effect of P and its interaction with N did not considerably influence the yield and yield-related parameters. The highest marketable (39.3 t ha^{-1}) and total fruit yields (46.2 t ha^{-1}) of tomato were recorded from the application of 138 kg N ha^{-1}. The highest net economic return of Ethiopian birr 185,538.50 with a marginal rate return of 1326.1% was recorded from the application of 138 kg N ha^{-1}. Therefore, 138 kg ha^{-1} N can be recommended to increase the yield and economic return of tomato production in Fogera area. However, as the yield response to N followed a linear response curve, further study with higher rates of N than those considered in the present study is recommended.

Keywords

Fogera, Irrigation, Nitrogen, Optimum, Phosphorus, Small-Scale, Tomato, Yield Response

1. Introduction

Tomato is one of the most important vegetables in the world. It is an important source of essential minerals, vitamins, and antioxidants for human health [1]. Tomato is one of the most important and widely grown vegetable crops in Ethiopia. It is an important source of income for small-scale farmers and a source of employment for many people [2]. However, the national average productivity of tomato (9.4 tons ha^{-1}) is very low compared with the world average productivity of 38.3 tons ha^{-1} [3-6]. The lower productivity of tomato in the country is mainly due to diseases and pests as well as unbal-

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anced and sub-optimal fertilizer applications.

Nitrogen (N) is often a primary limiting factor for plant growth and yield in agriculture. Tomato is highly responsive to the application of N [7, 8]. The vegetative growth and fruit yield of tomato is highly influenced by N as it is a key component of enzymes, vitamins, chlorophyll, and other cell constituents, all of which are essential for crop growth and development. N application at early growth stages stimulates vegetative growth and fruit yield of tomato, and later application in the growing stages induces fruit development [9]. Phosphorus plays a central role in the growth and yield of tomato because it is a component of nucleic acids and phospholipids. It is also important in photosynthesis, root development, and absorption of nutrients [10]. However, P is absorbed in small quantities by the tomato plant [11].

In the Fogera area of Northwest Ethiopia, tomato production in the dry season under irrigation by smallholder farmers is most common and is the major source of fresh tomato for the surrounding towns. Accordingly, it has been a source of income for smallholder farmers and has created job opportunities for many actors involved in the value chain of tomato production and marketing. However, there were no location-specific optimum N and P fertilizers recommendations for tomato production in the study area and farmers were advised to use a blanket fertilizer recommendation. Therefore, this study was conducted to determine the location-specific and economic optimum N and P fertilizer rates to maximize the productivity of tomato under irrigation in the Fogera area.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in 2020 and 2021 irrigation cropping seasons at Fogera National Rice Research and Training Center (FNRRTC) research station in Fogera District, South Gondar Zone of the Amhara Region in Ethiopia. Fogera district is situated between latitude 11°49’55’’ N and longitude 37° 37′ 40’’ E with altitudinal ranges of 1774 and 2415 meters above sea level (masl). FNRRTC research station is located at 11° 54’ 22.84’’ N and 37° 41’ 9.97’’ E at an altitude of 1806.4 masl (Figure 1). Rainfall in the area is uni-modal, usually occurring from June to September, and its average annual total rainfall is 1363.7 mm. The mean minimum and maximum temperature of the study site is 12.7 ℃ and 27.4 ℃, respectively. The dominant soil type of the study area is classified as Pellic Vertisol.

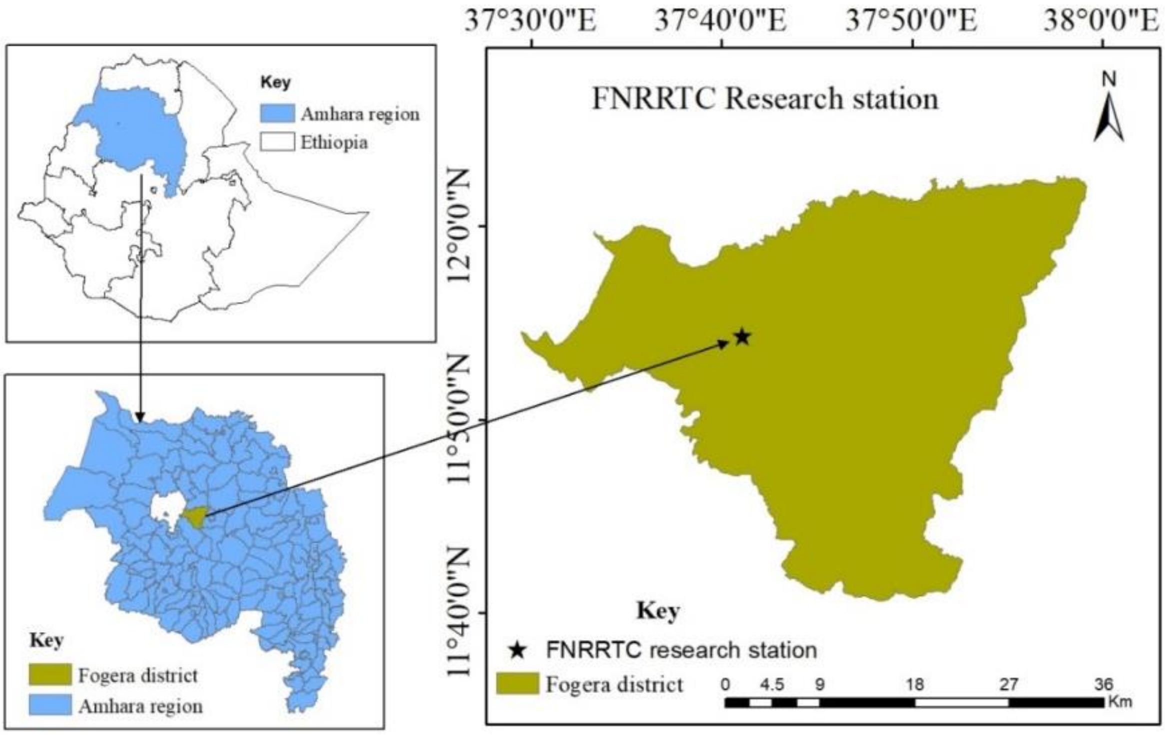

Figure 1. *Location map of the study site (FNRRTC) in the Fogera district of the Amhara Region in Ethiopia.*

2.2. Treatments and Experimental Procedures

Four levels N (0, 46, 92 and 138 kg N ha^{-1}) and three levels of P (0, 46 and 92 kg P_2O_5 ha^{-1}) were factorially combined and laid in a randomized complete block design with three replications. The local tomato variety, Roma VF, with the local name, *Senbersa*, was used for the study. Tomato seedlings were raised on fine nursery seed beds in the FNRRTC research station. Thirty (30) day old seedlings were transplanted to the experimental plots with furrow spacing of 100 cm. Tomato seedlings were transplanted along the side of the ridge with a plant spacing of 30 cm. Phosphorus (Triple Super Phosphate) was applied all at basal during transplanting, while N (Urea) was applied in split, half at transplanting and the remaining half was side-dressed 45 days after transplanting. The gross and harvestable (net) plot size of the experimental plots were 5 m * 3 m and 3 m * 3 m, respectively.

2.3. Data Collection and Analysis

Agronomic data such as stand count, plant height, number of fruits per plant, fruit length, fruit diameter, marketable yield and unmarketable yield were collected from the harvestable area. All the agronomic data collected were subjected to two-way analysis of variance using SAS Statistical Software package version 9.3 [12]. Means separation was done using the Least Significant Difference (LSD) test method at 5% level of significance.

Soil sampling and analysis

Composite soil samples (5 Sub-samples) were collected randomly at a depth of 0-20 cm from the experimental field before transplanting. The soil samples were air dried and ground to pass 2 mm sieve for laboratory analysis. The soil samples were analyzed for pH, organic matter (OM), total nitrogen (TN), available P and Cation Exchange Capacity (CEC) using the standard soil testing procedure.

2.4. Economic Analysis

Partial budget analysis was done following the procedure of CIMMYT by taking variable costs such as fertilizer and tomato fruit yield costs [13]. Based on the data obtained from the Fogera district trade and industry bureau, the farm gate price of tomato was 5.36 birr kg^{-1} and cost of urea fertilizer was 14.38 birr kg^{-1}. The mean marketable fruit yield used for the partial budget analysis was adjusted to 90% of the measured yield. The most profitable treatment was selected based on the highest net economic return with marginal rate of return of above 100%.

3. Results and Discussion

3.1. Initial Soil Fertility Status of the Study Site

The soil analysis results of the surface soil samples collected before planting from the study site indicated the surface soil was slightly acidic (pH-H_2O 6.2) in soil reaction, with low organic matter (2.4%), low total N (0.12%) and low available P (8.8 mg kg^{-1}) contents and very high Cation Exchange Capacity (46.1 $Cmol_c$ kg^{-1}) based on the ratings mentioned in the Table below (Table 1).

Table 1. *Some selected soil chemical properties of surface soil (0-20 cm) of the study site before planting.*

Parameter	Values	Ratings	References
pH (H_2O)	6.2	Slightly acidic	[14]
Organic matter (%)	2.40	Low	[15]
Total nitrogen (%)	0.12	Low	[15]
P_{Olsen} (mg kg^{-1})	8.8	Low	[15]
Cation Exchange Capacity ($Cmol_c$ kg^{-1})	46.1	Very high	[16]

3.2. Effect of N and P on the Fruit Yield and Yield-related Attributes of Tomato

First Year (2020)

The first year results showed that the marketable yield and total yield of tomato were significantly ($p<0.01$) affected by the main effects of N and P. However, fruit length and fruit diameter were not significantly ($p>0.05$) affected by both the main and interaction effects of N and P (Table 2). The highest marketable fruit yield (55.4 t ha^{-1}) and total fruit yield (65.6 t ha^{-1}) were obtained from the 138 kg N ha^{-1} followed, with significant ($p<0.05$) difference, by the 92 kg N ha^{-1}. The highest marketable fruit yield (46.8 t ha^{-1}) and total fruit yield (52.7 t ha^{-1}) were recorded from the 92 kg P_2O_5 ha^{-1} statistically at par with the 46 kg P_2O_5 ha^{-1}. The lowest marketable and total fruit yields were recorded from the Zero fertilizer treatment.

Table 2. Mean values of the yield and yield-related attributes of tomato as affected by the main effects of N and P fertilizers in the 2020 irrigation cropping season in the Fogera District.

N level* (kg ha^{-1})	Fruit length (mm)	Fruit diameter (mm)	Marketable yield (kg ha^{-1})	Unmarketable yield (kg ha^{-1})	Total yield (kg ha^{-1})
0	57.7	37.0	34424d	4217c	37927d
46	59.4	37.5	41041c	6793b	49759c
92	61.0	37.8	47237b	8078ab	57760b
138	60.7	37.9	55413a	9262a	65694a
Mean	59.7	37.5	44636.9	7087.3	52405
CV (%)	4.9	5.0	8.9	32.4	7.5
LSD (5%)	NS	NS	4937.7	2248	4749.4
P level* (kg P_2O_5 ha^{-1})					
0	59.6	36.8	41304b	6808.3	48264b
46	59.4	37.9	45658a	8016.7	56111a
92	60.2	38.0	46821a	6437.0	52753a
LSD (5%)	NS	NS	4273.2	NS	4123.6
N level * P level	NS	NS	NS	NS	NS

*Means within a column followed by the same letter are not significantly different at p=0.05. NS= Non-significant at p=0.05.

Second Year (2021)

The second experimental year results revealed that the fruit diameter, marketable, and total fruit yields were significantly ($p<0.01$) affected by the main effect of N (Table 3). The highest fruit diameter (3.6 cm) was recorded from the 138 kg N ha^{-1}. The highest marketable fruit yield (27.3 t ha^{-1}) and total fruit yield (33.3 t ha^{-1}) were obtained from the 138 kg N ha^{-1} statistically at par with the 92 kg N ha^{-1}. However, the main effect of P and its interaction with N did not significantly ($p>0.05$) influence the yield and yield-related attributes of tomato.

Table 3. Mean values of the yield and yield-related parameters of tomato as affected by the main effects of N and P fertilizers in the 2021 irrigation cropping season.

N level* (kg ha^{-1})	Plant height (cm)	Fruit length (cm)	Fruit diameter (cm)	No. of fruits per plant	Marketable yield (kg ha^{-1})	Total yield (kg ha^{-1})
0	58.5	5.33	3.46b	25.1	19469c	24028b
46	63.5	5.35	3.52b	27.0	22737b	28629ab
92	63.9	5.22	3.50b	26.7	25667a	32344a
138	65.2	5.30	3.66a	28.9	27314a	33292a
Mean	62.8	5.30	3.5	26.8	23696.2	29573.1
CV (%)	11.7	4.2	3.8	11.2	12.1	20.1
LSD (5%)	NS	NS	NS	NS	2862.7	5818
P level (kg P_2O_5 ha^{-1})						
0	62.6	5.29	3.51	27.1	24383	29983
46	63.9	5.31	3.50	24.9	24111	29481
92	61.9	5.30	3.59	28.2	22652	29255

N level* (kg ha^{-1})	Plant height (cm)	Fruit length (cm)	Fruit diameter (cm)	No. of fruits per plant	Marketable yield (kg ha^{-1})	Total yield (kg ha^{-1})
LSD (5%)	NS	NS	NS	NS	NS	NS
N level * P level	NS	NS	NS	NS	NS	NS

*Means within a column followed by the same letter are not significantly different at p=0.05. NS= Non-significant at p=0.05.

Pooled analysis over the two experimental years

The pooled analysis over the two experimental years revealed that the main effect of N significantly ($p<0.05$) affected the marketable and total fruit yields of tomato (Table 4). However, the fruit diameter and fruit length were not significantly ($p>0.05$) affected by N. The highest marketable and total fruit yields of 39.3 t ha^{-1} and 46.2 t ha^{-1}, respectively, were obtained from the application of 138 kg N ha^{-1} followed by the 92 kg N ha^{-1}. However, the main effect of P and its interaction with N did not significantly ($p>0.05$) influence the yield and yield-related attributes.

Table 4. *Mean values of the fruit length, fruit diameter, marketable fruit yield and total fruit yield of tomato pooled over the two experimental years as affected by the main effects of N and P fertilizers.*

N level* (kg ha^{-1})	Fruit length (cm)	Fruit diameter (cm)	Marketable Yield (kg ha^{-1})	Total yield (kg ha^{-1})
0	5.55	3.58	25451d	30109c
46	5.65	3.63	30058c	37081b
92	5.66	3.64	35104b	43464a
138	5.68	3.73	39356a	46253a
Mean	5.63	3.64	32421.5	39147.8
CV (%)	5.1	4.4	10.5	14.8
LSD (5%)	NS	NS	2534.0	4216.8
N*Year	NS	NS	***	***
P level (kg P_2O_5 ha^{-1})				
0	5.62	3.59	31508	37295
46	5.62	3.65	33346	40133
92	5.66	3.7	32319	39936
LSD (5%)	NS	NS	NS	NS
P*Year	NS	NS	**	NS
N level * P level	NS	NS	NS	NS

*Means within a column followed by the same letter are not significantly different at p=0.05. *** and ** = Significant at p=0.001 and 0.01, respectively. NS= Non-significant at p=0.05.

In line with the present results, it was reported that the yields of tomato were highly responsive to the application of N fertilizer and growers tend to use excess N fertilizer rather than risk under-fertilization and reduced yields [8, 17]. Significantly higher tomato fruit yield was reported from the application of higher rates of N (110 kg N ha^{-1}) [18]. In contrast to the results of the present study, it was indicated that the application of P (120 kg P_2O_5 ha^{-1}) had significant effect on the fruit yield of tomato [18]. Application of 138 kg N + 40 kg P ha^{-1} was found superior in the marketable fruit yield of tomato [19]. Application of 105 kg N + 85 kg P ha^{-1} in less fertile soil under irrigation and 40 kg N + 10 kg P ha^{-1} in relatively fertile soil under rain-fed condition was recommended for maximum fruit yield of tomato in Melkassa area [20].

3.3. Yield Response

The mean marketable and total fruit yield response of tomato to the application of N fertilizer from 0 to 138 kg N ha^{-1} was linear (Figure 2). This indicated there was a potential to increase the yield of tomato by increasing the level of N beyond 138 kg N ha^{-1}. Similar to the result in the present study, it was indicated that the total fruit yield of tomato was increased linearly as N rate was increased from 0 to 200 kg N ha^{-1} [21].

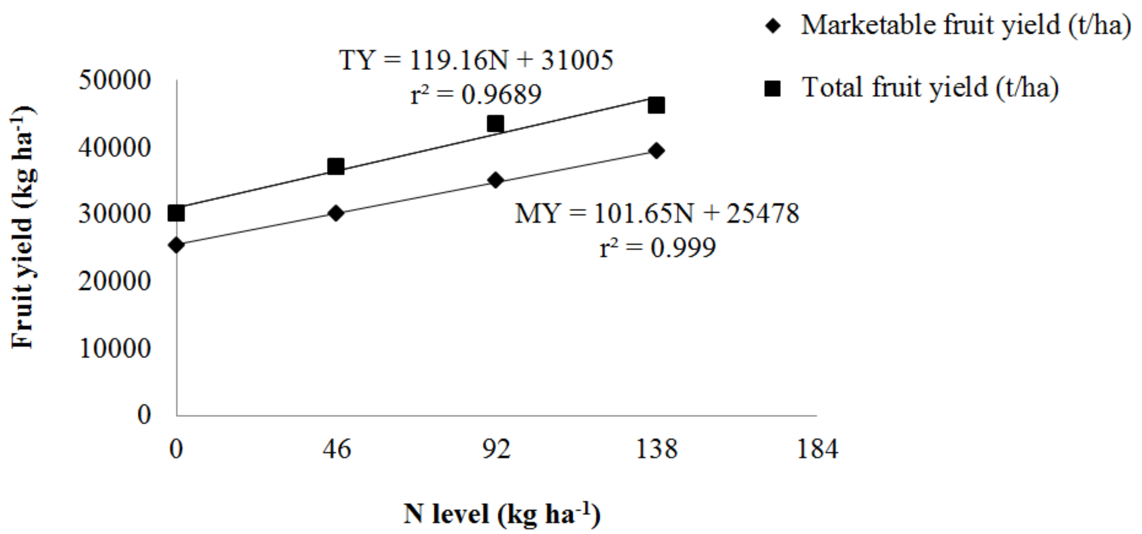

Figure 2. Yield response of the mean values of marketable (MY) and total (TY) fruit yields of tomato pooled over the two experimental years to N fertilizer.

3.4. Partial Budget Analysis

The partial budget analysis results indicated that the net economic return increased as the level of N fertilizer increased to the highest rate considered in the study (Table 5). The highest net economic return of Ethiopian Birr (Birr) 185538.50 with a marginal rate return (MRR) of 1326.1% was obtained from the application of 138 kg N ha^{-1}. The sensitivity analysis, by considering an inflation of productions costs by 15% and deflation of tomato fruit yield costs by 15%, also indicated that the highest net economic return was obtained from the application of 138 kg N ha^{-1} followed by the application of 92 kg N ha^{-1}.

Table 5. Partial budget analysis results of the variable costs of fertilizer and tomato fruit yield.

N (Urea) (kg ha^{-1})	Marketable fruit yield (kg ha^{-1})	Adjusted marketable fruit Yield (kg ha^{-1})	Gross return (Birr)	Cost of fertilizer (Urea) -Birr	Net return (Birr)	MRR (%)
0	25451	22905.9	122775.6	0	122775.6	-
46	30058	27052.2	144999.8	1438.3	143561.5	1445.2
92	35104	31593.6	169341.7	2876.6	166465.1	1592.4
138	39356	35420.4	189853.3	4314.8	185538.5	1326.1
Sensitivity Analysis						
0	25451	22905.9	104359.3	0	104359.3	-
46	30058	27052.2	123249.8	1653.7	121596.1	1042.3
92	35104	31593.6	143940.4	3307.5	140633.0	1151.1
138	39356	35420.4	161375.3	4961.2	156414.1	954.3

4. Conclusion and Recommendations

The study results revealed that application of N significantly affected the yield and yield-related attributes of tomato. The fruit yield of tomato was increasing linearly along with the N fertilizer, and the highest marketable and total fruit yield was recorded from the application of 138 kg N ha^{-1}. However, the main effect of P and its interaction with N did not significantly influence the yield and yield-related attributes of tomato. The partial budget analysis results revealed that the highest net economic return of Ethiopian birr 185,538.50 with a marginal rate return of 1326.1% was recorded from the application of 138 kg N ha^{-1}. Therefore, application of 138 kg N ha^{-1} can be recommended for the high yield of tomato and maximum economic return in the Fogera plain and similar agro-ecologies. As the yield response followed a linear response curve, further studies with higher rates of N than those considered in the present study are recommended. With regard to P, as the study was conducted on one testing site, multi-location studies should be conducted to make sure that the tomato yield response to P was not significant in the study area.

Abbreviations

CIMMYT	International Maize and Wheat Improvement Center
LSD	Least Significant Difference
MRR	Marginal Rate of Return
SAS	Statistical Analysis System

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Conflicts of Interest

The authors declare no conflicts of interest.

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