Asian Journal of Research and Review in Agriculture

Volume 6, Issue 1, Page 533-541, 2024; Article no.AJRRA.1718

Response of Tomato (*Solanum lycopersicum* L.) to Irrigation and N-fertilizer Levels in Semi-arid Parts of Tigray, Ethiopia

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.globalpresshub.com/review-history/1718

Original Research Article

Received: 03/08/2024
Accepted: 06/10/2024
Published: 16/10/2024

ABSTRACT

Increasing crop productivity can be achieved through the proper use of water and fertilizer. In Tselemty district, Tigay, Ethiopia, a field experiment was conducted during the irrigation seasons of 2019 and 2020 to identify the optimal nitrogen rate and irrigation depth for maximizing tomato yield. The study involved factorial combinations of three irrigation depths (75% ETc, 100% ETc, and 125% ETc) and three nitrogen rates (75%, 100%, and 125% of the recommended amount). These treatments were laid out in a randomized complete block design (RCBD) with three replications. Data were collected on various growth and yield-related factors for tomatoes, including plant height, number of fruits per plant, fruit length, fruit diameter, marketable yield, and unmarketable yield. The collected data were analyzed using R software to determine statistical significance. The results showed that changing the rates of nitrogen fertilizer and the amounts of irrigation had little effect on the growth and yield of tomatoes. Likewise, the marketable yield remained largely unaffected by the

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Cite as: *Gebreigziabher, Ekubay Tesfay. 2024. "Response of Tomato (Solanum Lycopersicum L.) to Irrigation and N-Fertilizer Levels in Semi-Arid Parts of Tigray, Ethiopia". Asian Journal of Research and Review in Agriculture 6 (1):533-41. https://jagriculture.com/index.php/AJRRA/article/view/128.*

different treatments of nitrogen and irrigation. Therefore, it is advisable for tomato farmers in the region to use a combination of 100% of the evapotranspiration crop (ETc) and 100% of the recommended nitrogen fertilizer when resources allow. When water and fertilizer are limited, using 75% of ETc along with 75% of the recommended nitrogen fertilizer can improve water use efficiency while keeping yield levels stable in dryland irrigated agriculture.

Keywords: Irrigation; marketable yield; N-fertilizer; tomato; water use efficiency.

1. INTRODUCTION

Irrigation plays a vital role in boosting crop production and is fundamental to agriculture. Around 70% of global water resources are dedicated to farming, primarily through irrigation. In contemporary agriculture, expanding farmland without irrigation is nearly impossible, prompting researchers to concentrate on water management techniques to enhance crop yields per area and overall output [1]. Tomatoes, a crucial vegetable crop, are significant in irrigated farming [2]. They thrive mainly in warm and semi-arid regions, where limited water availability often restricts production. Therefore, improving water management practices is essential to optimize tomato production [3]. Tomato plants are particularly vulnerable to water stress, as research has shown in [4,5]. Studies examining different irrigation methods and schedules have revealed a significant reduction in both fresh and dry yields. Additional research has confirmed these findings [6-13].

Nitrogen deficiency and water scarcity are major challenges for crop production in arid and semi-arid regions [14]. Poor tomato yields are frequently attributed to water stress or insufficient soil nutrients [15 and 16]. Vegetables, in particular, need higher levels of soil nutrients than many other crops [17]. As a result, farmers often apply large quantities of nitrogen fertilizer to enhance both the quality and quantity of tomatoes and other vegetables [18-20]. However, applying too much fertilizer can lead to nitrate nitrogen leaching, especially where application rates exceed the needs of the crops and where soil erosion is common [21]. Without proper management, up to 70% of applied nitrogen in irrigated fields can be lost [22]. Recently, there has been an increasing emphasis on improving nitrogen management practices, as improper use of nitrogen fertilizers not only results in economic loss but also jeopardizes environmental sustainability [23,24]. Fertilizer-driven pollution is a widespread issue that requires innovative solutions for better control and mitigation. This highlights the critical role of fertilizer technology in optimizing nitrogen use [25]. Therefore, conducting trials with tagged fertilizers is an effective approach to obtain definitive insights into these matters [26].

In Ethiopia, tomatoes account for the largest portion of commercial vegetable production [27]. The country's climate and soil conditions support the growth of a wide variety of fruits and vegetables, including tomatoes [28]. They can be cultivated at altitudes ranging from 700 to 2,200 meters above sea level, with annual rainfall varying between 700 and over 1,400 millimeters across different soils and climatic conditions [29]. However, the average yield of tomatoes in Ethiopia is notably low, at 8 tons per hectare, compared to the global average of 34 tons per hectare [30,31]. Additionally, tomato production in Ethiopia saw a decline from 6,298.63 hectares with a yield of 283,648.27 quintals in the 2016/17 season to 5,235.19 hectares and a yield of 277,745.38 quintals in the 2017/18 season [30].

2. METHODS AND MATERIALS

2.1 Description of the Experimental Site

The research was carried out at the Maitsebri Agricultural Research Farm, which is part of the Shire-Maitsebri Agricultural Research Center, during the off-seasons of 2019 and 2020. This farm is situated at a longitude of 38.15°E and a latitude of 13.59°N, at an elevation of 1307 meters above sea level. The site experiences average monthly maximum and minimum temperatures of 42.2°C and 13.2°C, respectively. It receives an average annual rainfall of 340.5 mm, with the rainy season generally occurring from June to September in a single peak pattern. The soil in this region is well-drained, varies in color from light to dark brown, has considerable depth, and features a loamy sand texture. It is also regularly cultivated.

2.2 Experimental Design

On December 18, 2019, and December 8, 2020, tomato seedlings that were thirty days old were transplanted into fields. The furrows were 60 cm apart, and each plant within a row was spaced

30 cm from the next. The study utilized a randomized complete block design (RCBD) with three replications. Each plot measured 3 m in width and 3.2 m in length. Fertilizer treatments included three levels at 75%, 100%, and 125% of the recommended nitrogen fertilizer rate (80 kg per hectare). The irrigation treatments were set at 75%, 100%, and 125% of the estimated crop water requirement (ETc) for tomatoes. Nitrogen fertilizers used were UREA and NPS. Recommended nitrogen fertilizer (80kg per hectare) was calculated from UREA and NPS.

2.3 Crop Water Requirement

This study utilized the "CROPWAT version 8.0" software to assess the water requirements for crops. The program incorporated data on climate, crops, and soil to calculate the necessary irrigation needs, employing the FAO Penman-Monteith method [31]. Long-term climate data were sourced from the Maitsebri meteorological station, located only 1 km from the experimental site.

2.4 Data Collection

2.4.1 Climatic data

Before starting the experiment, we collected secondary data from a local meteorological station. This dataset covered 20 years of weather information, including rainfall, minimum and maximum temperatures, relative humidity, wind speed, and hours of sunshine. We also gathered information on the effectiveness of furrow irrigation, the root depth of tomato plants, the various growth stages of the tomato crop along with their durations, and soil infiltration rates based on past records and FAO guidelines.

2.4.2 Soil data

At the experimental site, three soil profiles were randomly established to assess soil characteristics. The pipette method was employed to analyze soil texture at depths of 0 to 100 cm in each profile [32]. Bulk density was measured using the core method across all depths in the profiles [33]. Soil water content was obtained from disturbed samples collected from the same locations, utilizing the gravimetric method. Field capacity and permanent wilting points were identified at pressures of 0.3 and 15.0 bars, respectively, in accordance with established guidelines [34]. Additionally, the soil's basic infiltration rate was assessed in the field utilizing the double-ring infiltrometer method at two distinct locations within the experimental area, following the specified protocol [35] as indicated in Table 2.

Table 1. Treatments and Their Combination

Irrigation	N_rate	Treatment Combinations
75% ETc	75%	75% of CWR with 75% of the blanket recommended N rate
75% ETc	100%	75% of CWR with 100% of the blanket recommended N rate
75% ETc	125%	75% of CWR with 125% of the blanket recommended N rate
100% ETc	75%	100% of CWR with 75% of the blanket recommended N rate
100% ETc	100%	100% of CWR with 100% of the blanket recommended N rate
100% ETc	125%	100% of CWR with 125% of the blanket recommended N rate
125% ETc	75%	125% of CWR with 75% of the blanket recommended N rate
125% ETc	100%	125% of CWR with 100% of the blanket recommended N rate
125% ETc	125%	125% of CWR with 125% of the blanket recommended N rate

Table 2. Soil Characteristics of the Experimental Site

Soil Characteristic parameters	Values
PH	6.9
OM (%)	2.05
N (%)	0.045
P(ppm)	4.2
Soil Texture	Sandy Loam
Bulk density (g/cm^3)	1.46
Field Capacity (weight basis %)	34.2
Permanent Wilting Point (weight basis %)	23.8
Total Available Water (mm/m)	152.3

2.5 Data Analysis

Prior to conducting the combined analysis, Bartlett's test was performed to assess the homogeneity of variances. Subsequently, the data underwent analysis of variance (ANOVA) using the general linear model (GLM) procedure in R software. Mean comparisons were conducted using Duncan's multiple range test (DMRT) at a 5% significance level.

3. RESULTS AND DISCUSSION

3.1 Data Homogeneity Test

Bartlett's test was conducted to assess the homogeneity of variances for the data collected over two years. As illustrated in Table 3, the data on tomato parameters such as 50% days to flowering (50%Fl), 50% days to fruit setting (50%FS), fruit length (FL), and fruit diameter (FD) showed homogeneity across the years. The p-values for each chi-square test exceeded the 5% significance level, indicating that these parameters can be combined for variance analysis. In contrast, the data regarding fruit number per plant (FNPP), marketable yield (MY), fruit yield per plant (FYPP), unmarketable yield (UMY), and water use efficiency (WUE) did not demonstrate homogeneity. The p-values for these parameters fell below the 5% significance threshold, meaning they cannot be combined for variance analysis across the years.

Table 3. Bartlett's Test for Homogeneity of Variance

Statistic	50% Fl[1]	50% FS[2]	FNPP[3]	FL[4]	FD[5]	MY[6]	FYPP[7]	UMY[8]	WUE[9]
Chi-square(x^2)	0.00	0.00	6.21	0.00	0.00	7.52	19.17	34.68	15.54
P-Value	1.00	1.00	0.013	1.00	1.00	0.006	<0.001	<0.001	<0.001

[1]Days to 50%flowering, [2] Days to 50%fruit setting, [3] Fruit Number per plant, [4] Fruit length, [5] Fruit diameter, [6] Marketable Yield, [7]Fruit Yield per plant, [8]Unmarketable Yield, [9]Water use efficiency

Table 4. Effect of nitrogen rates (N_rate) and Irrigation depth (CWR) on some vegetative and generative growth parameters of Tomato

Source of Variation	50% Fl [a]	50% FS[b]	F L[c](cm)	F D[d](cm)
N_rate(%)				
125	51.78[a]	61.89 [a]	6.721[a]	13.30[a]
100	50.33[a]	61.11 [a]	6.749[a]	11.26[a]
75	49.33[a]	61.56 [a]	5.658[b]	11.58[a]
P-Value	0.467	0.744	0.006	0.077
CWR (%)				
125	52.78[a]	62.44[a]	6.181[a]	12.29[a]
75	50.67[a]	61.00 [a]	6.457[a]	11.45[a]
100	48.00[a]	61.11[a]	6.491[a]	12.40[a]
P-Value	0.065	0.295	0.647	0.543
CWR (%) * N_rate(%)				
125*75	54.33[a]	63.00[a]	7.158[a]	11.12[bc]
125*100	52.67[a]	62.33[a]	6.565[ab]	9.97[c]
100*125	52.33[a]	61.33[a]	6.562[ab]	11.82[bc]
75*75	52.00[a]	60.67[a]	4.642[c]	9.79[c]
75*125	51.67[a]	62.33[a]	6.782[ab]	12.28[bc]
125*125	51.33[a]	62.00[a]	6.818[ab]	15.79[a]
100*100	50.00[a]	61.00[a]	6.768[ab]	14.02[ab]
75*100	48.33[ab]	60.00[a]	6.948[ab]	12.27[abc]
100*75	41.67[b]	61.00[a]	6.142[ab]	11.35[bc]
P-Value	0.038	0.794	0.014	0.011
Mean	50.48	61.52	6.38	12.05
C.V (%)	11.7	4.9	17.1	23.2

Columns assigned with the same script letters have no significance difference at 5% significance level. [a] Days to 50%Flowering, [b] Days to 50% fruit setting, [c] Fruit length (cm), [d] Fruit diameter (cm), CWR= Crop water requirement, N_rate= Nitrogen fertilizer rate, C.V= Coefficient of variation

Table 5. Effect of nitrogen rates (N_rate) and Irrigation depth (CWR) on yield and yield parameters of tomato

Source of Variation	2019				2020			
	MY [1] (kg/ha)	FNPP [2]	UMY [3] (kg/ha)	FYPP [4](kg)	MY [1] (kg/ha)	FNPP [2]	UMY [3] (kg/ha)	FYPP [4](kg)
N_rate(%)								
125	64767.4[a]	45.89[a]	3715.4[a]	0.3278[a]	28912.4[a]	26.56[a]	659.1[a]	0.9022[a]
100	70506.7[a]	39.47[a]	3378.6[a]	0.3711[a]	27558.8[a]	24.21[a]	655.1[a]	1.1156[a]
75	58984.9[a]	33.89[a]	3204.5[a]	0.2300[a]	27856.7[a]	21.74[a]	665.5[a]	0.8322[a]
P-Value	0.069	0.099	0.599	0.305	0.812	0.162	0.997	0.432
CWR (%)								
125	61583.6[a]	39.67[a]	3845.7[a]	0.3011[a]	28659.5[a]	25.11[a]	684.3[a]	0.9411[a]
75	66958.4[a]	37.22[a]	3468.3[a]	0.2856[a]	27641.4[a]	23.95[a]	549.2[a]	0.8144[a]
100	65715.2[a]	42.36[a]	2984.4[a]	0.3422[a]	28027.6[a]	23.45[a]	546.3[a]	1.0944[a]
P-Value	0.485	0.620	0.261	0.813	0.896	0.776	0.640	0.467
CWR*N_rate								
125*75	54087.4[a]	29.33[a]	3213.7[a]	0.2267[a]	28240.5[a]	23.28[a]	809.0[a]	0.9533[a]
125*100	69153.8[a]	40.83[a]	4576.2[a]	0.3567[a]	27517.2[a]	24.45[a]	909.7[a]	0.9367[a]
100*125	67608.1[a]	44.42[a]	2965.4[a]	0.2733[a]	28681.7[a]	25.50[a]	513.9[a]	0.8667[a]
75*75	60549.9[a]	30.50[a]	2962.6[a]	0.1967[a]	26417.4[a]	19.61[a]	454.9[a]	0.7100[a]
75*125	65184.7[a]	48.83[a]	4434.4[a]	0.3900[a]	27837.6[a]	26.56[a]	529.5[a]	0.9067[a]
125*125	61510.6[a]	48.83[a]	3746.5[a]	0.3200[a]	30219.5[a]	27.61[a]	934.0[a]	0.9333[a]
100*100	67222.4[a]	40.83[a]	2551.5[a]	0.4867[a]	26488.3[a]	22.50[a]	392.4[a]	1.5833[a]
75*100	75142.5[a]	36.75[a]	3007.8[a]	0.2700[a]	28670.3[a]	25.67[a]	663.2[a]	0.8267[a]
100*75	62316.3[a]	41.83[a]	3436.2[a]	0.2667[a]	28913.6[a]	22.34[a]	732.6[a]	0.8333[a]
P-Value	0.845	0.739	0.242	0.686	0.908	0.874	0.549	0.520
Mean	64752.8	39.8	3432.5	0.310	28109.3	24.17	660.5	0.950
C.V (%)	15.0	27.6	31.2	16.7	16.5	20.9	10.6	11.2

Columns assigned with the same script letters have no significance difference at 5% significance level. [1] Marketable Yield, [2] fruit number per plant, [3] unmarketable yield, [4] Fruit yield per plant, CWR= Crop water requirement, N_rate= Nitrogen fertilizer rate, C.V= Coefficient of variation

Table 6. Effect of Irrigation amounts (CWR) and nitrogen fertilizer rate on water use efficiency of Tomato

Source of Variation	Water Use Efficiency(WUE)	
	2019	2020
CWR (%)		
125	10.35[c]	5.142[c]
75	18.91[a]	8.264[a]
100	13.83[b]	6.286[b]
P-Value	<.001	<.001
N_rate(%)		
125	14.33[a]	6.724[a]
100	15.66[a]	6.483[a]
75	13.10[a]	6.484[a]
P-Value	0.071	0.852
CWR*N_rate		
125*75	9.09[a]	5.067[a]
125*100	11.62[a]	4.937[a]
100*125	14.23[a]	6.430[a]
75*75	17.10[a]	7.900[a]
75*125	18.41[a]	8.320[a]
125*125	10.34[a]	5.423[a]
100*100	14.15[a]	5.940[a]
75*100	21.22[a]	8.573[a]
100*75	13.12[a]	6.487[a]
P-Value	0.754	0.876
Mean	14.36	6.56
C.V (%)	15.1	15.8

3.2 Growth Parameters

Most agronomic parameters, including the days to flowering (50%Fl), days to fruit setting (50%FS), and fruit diameter (FD) of tomatoes, were not significantly influenced by varying irrigation levels or nitrogen fertilizer rates ($p>0.05$), as shown in Table 4. However, fruit length (FL) was impacted by different nitrogen fertilizer rates but remained unaffected by different irrigation amounts. The longest fruit length measured 6.749 cm at the recommended nitrogen rate of 80 kg/ha, while the shortest, at 5.658 cm, was recorded at 60 kg/ha, which is 75% of the recommended nitrogen rate. Additionally, the parameters of 50% days to flowering, fruit length, and fruit diameter showed slightly affected by the interaction of nitrogen fertilizer rates and irrigation levels, although 50% days to fruit setting did not exhibit this trend, as indicated in Table 4. The interaction of irrigation and nitrogen fertilizer at the recommended rates (100% ETc and 100% N) did not show significant differences compared to other treatments, except for the 75% ETc and 75% recommended N treatments regarding fruit length and diameter.

3.3 Yield Parameters

Table 5 shows that there is no significant main or interaction effect of nitrogen rates and irrigation amounts on marketable yield (MY), average fruit number per plant (FNPP), unmarketable yield (UMY), and fruit yield per plant (FYPP) for both years [36,37].

3.4 Water Use Efficiency (WUE)

Table 6 demonstrates that varying irrigation amounts had a significant impact on the water use efficiency of tomatoes in both experimental years ($p<0.001$). The highest water use efficiency was observed at 18.91 kg/m3 in 2019 and 8.264 kg/m3 in 2020 when irrigation was set at 75% of the full crop water requirement. Conversely, the lowest efficiencies were noted at 10.35 kg/m3 in 2019 and 5.142 kg/m3 in 2020 for plots receiving 125% of the full crop water requirement. Additionally, the effects of nitrogen and interactions related to it did not show any significant influence on the water use efficiency of tomatoes in this study, as indicated in Table 6.

4. CONCLUSIONS

The two-year statistical analysis showed no notable interaction between nitrogen fertilizer and irrigation levels regarding the growth and water efficiency of tomato plants. Different amounts of nitrogen fertilizer did not affect the yield, yield parameters, or water usage efficiency of tomatoes in the specific ecological and soil conditions studied. Farmers in this area can save money by using lower levels of nitrogen fertilizer and irrigation, specifically 75% of the recommended amount. However, in regions with ample water and fertilizer supplies, it's advisable to use the full recommended levels, which equate to 100% nitrogen and 100% crop evapotranspiration, for the best results.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENTS

The author thanks the team at the Shire-Maitsebri Agricultural Research Center, particularly the Natural Resource Research Core Process, for their essential help with the study. I also express sincere appreciation to the Tigray Agricultural Research Institute (TARI) for their financial support, which was vital for completing the research successfully.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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