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Original Paper

Effect of Irrigation Depth and Nitrogen Fertilizer Rates on Pepper (*Capsicum annum L.*) Yield and Water Use Efficiency in Tselemty District, Tigray, Ethiopia

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***Abstract*— Optimizing agricultural crop production involves utilizing proper irrigation and fertilization techniques. A two-year experiment conducted in the Tselemty district during the off seasons of 2019 and 2020 aimed to assess the impact of varying irrigation levels and nitrogen fertilizer application rates on the growth, yield, and crop water productivity of pepper. The study included three irrigation levels (75%, 100%, and 125% of the required irrigation) and three nitrogen fertilizer application rates (75%, 100%, and 125% of the recommended amount). Analysis of the results using Gen-Stat software revealed that most pepper yield attributes were not significantly affected by the different irrigation and fertilizer levels. However, the marketable yield showed significant variation based on the combined application rates. The research indicates that, under ideal circumstances, the optimal approach for pepper growers is a combination of meeting 100% of the irrigation requirement and applying 100% of the recommended nitrogen fertilizer rate. Nevertheless, in scenarios where water resources are limited and fertilizer expenses are high, a reduced irrigation level of 75% of the requirement coupled with 75% of the recommended nitrogen fertilizer rate could be a viable alternative that does not lead to a substantial decrease in yield.**

Keywords*— Irrigation, Marketable yield, Nitrogen-fertilizer rates, Pepper, Water Use Efficiency

I. INTRODUCTION

Irrigation is essential for increasing crop production and is a key element in agriculture. Worldwide, 70% of water resources are used for agricultural purposes, with a strong emphasis on irrigation. In modern agriculture, it is nearly impossible to expand cultivated lands without irrigation, leading researchers to focus on water management strategies to improve crop yields per unit area and overall production levels [1]. Pepper, a significant vegetable crop, plays a major role in irrigated agriculture [2]. It is mainly grown in countries with warm and semi-arid climates, where water scarcity often hinders production. Thus, there is a critical need to improve water management strategies to maximize pepper cultivation [3].Pepper plants are highly sensitive to water deficit stress, as shown in studies conducted by researchers from [4 and 5]. Their research on various irrigation methods and schedules has demonstrated a notable decrease in both fresh and dry matter yields. Studies by [6-13] have further supported this discovery.

Nitrogen deficiency and water scarcity are significant constraints in arid and semi-arid regions for crop production [14]. The poor yield of peppers is often due to water stress or inadequate soil nutrients [15 and 16]. Vegetables, in particular, require high soil nutrient levels compared to other crops [17]. As a result, farmers commonly use large amounts of nitrogen fertilizer to improve the quality and quantity of peppers and other vegetables [18-20]. However, excessive fertilizer application can lead to nitrate nitrogen leaching, especially in areas where application rates exceed crop needs and soil erosion is widespread [21]. Up to 70% of applied nitrogen in irrigated fields can be lost if not properly managed [22]. In recent years, there has been a growing focus on enhancing nitrogen management practices because misusing nitrogen fertilizers not only causes economic losses but also threatens environmental sustainability [23 and 24]. Fertilizer-induced pollution is a prevalent problem that demands creative approaches for extended mitigation and control. It underscores the vital importance of fertilizer technology in enhancing nitrogen utilization [25]. Therefore, conducting trials using tagged fertilizers presents a direct and effective method for acquiring conclusive answers to these questions [26].

Pepper is the most extensively grown vegetable crop in Ethiopia, occupying the largest land area for cultivation. In 2017, approximately 152,752.94 hectares were used for cultivating hot pepper for dry pods (Berbere), with an additional 10,207.26 hectares allocated to green pepper (Karia) [27]. Small-scale and low-input growers in the country typically fertilize their crops by applying fertilizers through furrow irrigation during the growing season [28]. However, this method can lead to significant nitrogen losses. Even with the use of drip fertigation, challenges persist in terms of irrigation scheduling and the efficient use of water and fertilizers. Additionally, there is a lack of comprehensive data on the impact of irrigation and fertilization practices on nitrogen fertilizer use efficiency

(NFUE) in pepper cultivation in Ethiopia. Therefore, this study aimed to compare various irrigation and fertilization techniques for pepper crops to improve water and nitrogen utilization efficiency and increase pepper yields. The study also sought to assess how irrigation water and nitrogen fertilizer interact to affect crop yield.

II. Materials And Methods

A. Description of the Study Area

The study was conducted at the Maitsebri Agricultural Research Farm, part of the Shire-Maitsebri Agricultural Research Center, during the off-seasons of 2019 and 2020. Geographically, the farm is located at 38.15°E longitude and 13.59° N latitude, with an elevation of 1307m above sea level. The average monthly maximum and minimum temperatures recorded at the site are 42.2°C and 13.2°C, respectively. The area receives an average annual precipitation of 340.5 mm, with the rainy season typically falling between June and September in a mono-modal pattern. The soil in this area is well-drained, ranging in color from light to dark brown, deep in depth, with a loamy sand texture, and is continuously cultivated.

In northern Botswana, winter is milder, and the maximum temperature is around 24/26 °C and the minimum temperature is around 8/10 °C. The hottest period in the north occurs from September to November while in the summer, the temperature slightly decreases because of the prevalence of more humid air masses of tropical origin. In the northernmost area, which is the rainiest of the country, rainfall exceeds 600 mm per year, though the rains are concentrated, as usual, in the summer. In this area, the sun regularly shines in the long dry season, while in the rainy period, the sunshine hours decrease as compared to in the rest of the country.

B. Experimental Design and Treatment Set up

Pepper seedlings that were thirty days old were planted in furrow irrigation fields on January 10, 2019, and January 2, 2020. The furrows were spaced 64cm apart, with a distance of 30cm between each plant in a row. The experiment employed a randomized complete block design (RCBD) with three replications. Each plot measured 3m in width and 3.2m in length. The fertilizer treatment included three different levels: 75%, 100%, and 125% of the recommended nitrogen fertilizer rate (80 kg ha-1). The irrigation treatments comprised 75%, 100%, and 125% of the estimated crop water requirement (ETc) for pepper. Nitrogen fertilizer rates were sourced from DAP and NPS fertilizers. DAP was applied during transplanting, while NPS fertilizer was split into two applications, with one-third applied at transplanting and the remaining two-thirds applied one month later.

C. Crop Requirements

Three commonly used methods exist for calculating crop water requirements and irrigation schedules. The first method involves assessing soil moisture content. The second method examines specific plant attributes that indicate water deficiency. The third and most popular method utilizes atmospheric conditions to develop a model. In this study, the computer program "CROPWAT version 8.0" was employed to calculate reference evapotranspiration, crop water needs, and irrigation schedules using meteorological data. Climatic, crop, and soil data were inputted into the program to determine irrigation requirements, with the FAO Penman-Monteith method [29] used for calculations. Reference evapotranspiration (ETo) and crop water requirement (ETc) were estimated based on long-term climatic data from the Maitsebri meteorological station situated 1km from the experimental site.

D. Data Collection

Climatic data

Prior to commencing the experiment, we gathered secondary data from a nearby meteorological station. This data included climatic information spanning 20 years, covering rainfall (R.F.), minimum and maximum temperatures, relative humidity (RH), wind speed (WS), and sunshine hours (SH). Additionally, we collected data on irrigation efficiency for furrow irrigation, root depth of pepper crop, pepper crop growing stages and their respective durations, as well as soil infiltration rate data from previous records and FAO guidelines.

Soil data

Ground sample (0.3 g) was weighed into a Kjeldahl Three soil profiles were established randomly at the experimental site to evaluate soil properties. The soil texture was analyzed using the pipette method according to [30] at depths ranging from 0 to 100 cm in each of the three profiles. Bulk density measurements were carried out using the core method as described by [31] at all depths within the profiles. Soil water content was determined for disturbed samples taken from the same locations using the gravimetric method. Field capacity and permanent wilting points were identified at 0.3 and 15.0 bars, respectively, following the guidelines of [32]. Furthermore, the soil's basic infiltration rate was evaluated in the field using the double-ring infiltrometer method at two different locations within the experimental area, following the protocol detailed in Table 1 [33].

TABLE 1. PROXIMATE COMPOSITION OF *GUIBOURTIA COLEOSPERMA* SEEDS COLLECTED FROM SHAKAWE AND KASANE

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

E. Data Analysis

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

III. Results And Discussion

A. Data Homogenity Test

Ensure data homogeneity before merging data from different years or locations for variance analysis. In this study, Bartlett's test was used to evaluate variances homogeneity for pepper parameters collected over two years. The results in Table 2 show that parameters like 50% days to flowering, 50% days to fruit setting, pod length, pod diameter, marketable yield, and water use efficiency have consistent data across years, with p-values for each chi-square test exceeding the 5% significance level. This indicates that these parameters' data can be combined for further analysis. However, pod number per plant, fruit yield per plant, and unmarketable yield data are inconsistent over the years, as their p-values fall below the 5% significance level. Therefore, merging data for these parameters for variance analysis is not recommended.

B. Mineral Contents

Analyzing data from two consecutive years showed that key agronomic factors such as the time for 50% of peppers to flower (50% FL), the time for 50% of peppers to set fruit (50% FS), and the diameter (PD) and length (PL) of the pods remained stable despite different irrigation and nitrogen fertilizer levels. Furthermore, no notable interaction effect was detected among these treatments, as indicated in Table 3, where all p-values were above 0.05.

C. Marketable and Unmarketable Yield

Table 4 indicates that there is no significant effect on the number of pods per plant, fruit yield per plant, and unmarketable yield of pepper when considering nitrogen fertilizer and irrigation amount for both experimental years. Moreover, Table 3 shows that varying levels of nitrogen fertilizer and irrigation do not impact the marketable yield of pepper. However, the interaction between nitrogen fertilizer levels and irrigation amounts does influence the marketable yield, as depicted in Table 3. The highest marketable yield of 9835.6 kg/ha was attained when the recommended nitrogen fertilizer and irrigation amounts were applied together. In contrast, the lowest marketable yield of 6778.4 kg/ha was observed when only 75% of the recommended nitrogen fertilizer and irrigation amount were used.

D. Water Use Efficiency (WUE)

Analyzing data from two consecutive years showed that key In Table 3, it is shown that pepper's water use efficiency was notably influenced by different irrigation levels, showing a p-value below 0.001. The greatest water use efficiency (1.946 kg/m3) was attained with 75% of the total crop water requirement, whereas the lowest water use efficiency (1.333 kg/m3) was observed with 125% of the full irrigation requirement. Notably, the water use efficiency of pepper remained unaffected by varying nitrogen fertilizer rates or the joint impacts of irrigation and nitrogen in this research (Table 3).

TABLE 2. BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCE

Statistic	**50% Fl[1]**	**50% FS[2]**	**NPPP[3]**	**P L[4] (cm)**	**PD[5] (cm)**	**MY[6] (kg/ha)**	**FYPP[7]**	**UMY[8] (Kg/ha)**	**WUE[9] (kg/m^3)**
Chi-square(x^2)	0.15	0.15	102.07	0.00	0.00	2.51	22.39	15.63	0.50
P-Value	0.695	0.695	<0.001	1.00	1.00	0.113	< 0.001	< 0.001	0.480
Is Homogenous?	yes	yes	no	yes	yes	yes	no	no	yes

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

TABLE 3. EFFECT OF NITROGEN AND IRRIGATION DEPTH ON SOME PARAMETERS OF PEPPER

Source of Variation	**50%Fl[a] (days)**	**50%FS[b] (days)**	**P L[c] (cm)**	**P D[d] (cm)**	**MY[e] (kg/ha)**	**WUE[f] (kg/m^3)**
CWR (%)						
125	73.78[a]	78.78[a]	6.57[a]	6.38[a]	8598.4[a]	**1.333[b]**
75	73.78[a]	78.78[a]	6.67[a]	6.57[a]	7665.3[a]	**1.946[a]**
100	74.89[a]	79.89[a]	6.97[a]	6.77[a]	8013.5[a]	1.526[b]
P-Value	0.536	0.536	0.492	0.589	0.190	**<.001**
N_rate(%)						
125	74.56[a]	79.56[a]	6.46[a]	6.66[a]	8216.6[a]	1.619[a]
100	74.94[a]	79.94[a]	6.58[a]	6.40[a]	8489.7[a]	1.668[a]

75	72.94[a]	77.94[a]	7.18[a]	6.65[a]	7571.4[a]	1.518[a]
P-Value	0.192	0.192	0.100	0.721	0.191	0.484
CWR*N_rate						
125*75	73.50[a]	78.50[a]	7.60[a]	6.69[a]	8099.6[ab]	1.310[a]
125*100	73.83[a]	78.83[a]	5.93[a]	5.90[a]	8132.3[ab]	1.237[a]
100*125	74.67[a]	79.67[a]	6.34[a]	6.07[a]	7189.8[b]	1.297[a]
75*75	72.00[a]	77.00[a]	6.46[a]	6.01[a]	6778.4[b]	1.832[a]
75*125	75.00[a]	80.00[a]	6.83[a]	7.38[a]	8306.7[ab]	2.107[a]
125*125	74.00[a]	79.00[a]	6.20[a]	6.54[a]	9564.3[a]	1.453[a]
100*100	76.67[a]	81.67[a]	7.10[a]	6.97[a]	9835.6[a]	1.868[a]
75*100	74.33[a]	79.33[a]	6.72[a]	6.31[a]	7500.7 [b]	1.900[a]
100*75	73.33[a]	78.33[a]	7.48[a]	7.26[a]	7425.4[b]	1.412[a]
P-Value	0.728	0.728	0.114	0.070	0.011	0.086
Mean	74.15	79.15	6.74	6.57	8092.45	1.602
C.V (%)	4.6	4.3	15.5	17.10	18.7	23.6

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 Pod length, [d] Pod diameter, [e] Marketable Yield, [f] Water use efficiency CWR= Crop water requirement, N_rate= Nitrogen fertilizer rate, C.V= Coefficient of variation

TABLE 4. EFFECT OF NITROGEN AND IRRIGATION DEPTH ON SOME PARAMETERS OF PEPPER

Source of Variation	**2019**			**2020**		
	NPPP[a]	**FYPP[b](kg)**	**UMY[c] (kg/ha)**	**NPPP[a]**	**FYPP[b](kg)**	**UMY[c] (kg/ha)**
CWR (%)						
125	156.1[a]	0.2944[a]	618.5[a]	16.30[a]	0.1367[a]	333.3[a]
100	155.6[a]	0.3122[a]	535.3[a]	16.07[a]	0.1278[a]	186.3[a]
75	189.0[a]	0.3256[a]	416.4[a]	14.70[a]	0.1056[a]	148.1[a]
P-Value	0.278	0.823	0.363	0.468	0.649	0.725
N_rate(%)						
125	173.1[a]	0.327[a]	537.8[a]	15.57[a]	0.1289[a]	231.5[a] a
100	178.2[a]	0.304[a]	601.2[a]	16.28[a]	0.1289[a]	237.3[a]
75	149.3[a]	0.301[a]	431.6[a]	15.22[a]	0.1122[a] a	199.1[a]
P-Value	0.426	0.857	0.480	0.739	0.295	0.814
CWR*N_rate						
125*75	125.3[a]	0.3267[a]	534.7[a]	15.45[a]	0.1333[a]	354.2[a]
125*100	176.3[a]	0.2567[a]	673.6[a]	18.83[a]	0.1433[a]	246.5[a]
100*125	136.3[a]	0.2600[a]	461.8[a]	16.28[a]	0.1233[a]	107.6[a]

75*75	172.3[a]	0.2633[a]	395.8[a]	14.95[a]	0.0967[a]	111.1[a]
75*125	216.3[a]	0.4200[a]	503.5[a]	15.83[a]	0.1300[a]	187.5[a]
125*125	166.7[a]	0.3000[a]	645.8[a]	14.61[a]	0.1333[a]	399.3[a]
100*100	180.0[a]	0.3633[a]	781.2[a]	16.67[a]	0.1533[a]	319.4[a]
75*100	178.3[a]	0.2933[a]	347.2[a]	13.33[a]	0.0900[a]	145.8[a]
100*75	150.3[a]	0.3133[a]	361.1[a]	15.28[a]	0.1067[a]	131.9[a]
P-Value	0.612	0.285	0.632	0.383	0.171	0.218
Mean	166.9	0.311	523.45	15.69	0.1233	223.56
C.V	24.2	28.3	31.2	15.8	20.4	15

Columns assigned with the same script letters have no significance difference at 5% significance level. [a] Number of pods per plant, b Fruit Yield per plant, [c] Unmarketable Yield, CWR= Crop water requirement, N_rate= Nitrogen fertilizer rate, C. V= Coefficient of variation

IV. Conclusions

The results of the two-year statistical analysis indicated that there was no significant interaction between nitrogen fertilizer and irrigation levels on the growth and water use efficiency of pepper plants. Varying rates of nitrogen fertilizers had no impact on the yield, yield parameters, or water use efficiency of pepper in the specific agro-ecological and soil conditions of the study area. Farmers in this region can economically benefit from using reduced levels of nitrogen fertilizer and irrigation (75% of the recommended amount). However, in areas with abundant water and fertilizer resources, it is recommended to apply the full recommended amounts (100% nitrogen rate and 100% ETc) for optimal outcomes

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