Int.J.Curr.Res.Aca.Rev.2024; 12(5): 91-99

EXCELLENT PUBLISHERS

International Journal of Current Research and Academic Review

ISSN: 2347-3215 (Online) Volume 12 Number 5 (May-2024)

Journal homepage: http://www.ijcrar.com

doi: https://doi.org/10.20546/ijcrar.2024.1205.010

Effects of Optimal Irrigation Scheduling and Nitrogen Level on the Yield and Water Productivity of Maize (*Zea mays* L.) at Ambo Agricultural Research Center, West Shewa, Ethiopia

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Abstract

The growth and development of maize are limited by over or under-application of irrigation water and nutrients, resulting in lower yield and water productivity. Due to these, a field experiment was conducted at Ambo Agricultural Research Center Farm Site from 2021-2023 to evaluate the effects of nitrogen and allowable soil moisture depletion levels on the yield, yield components, water productivity, and economic return of furrow irrigated maize production. The experiment was a two-factor factorial experiment arranged in an randomize complete block design with split-plot arrangement. The two factors were the percentage of FAO-recommended allowable soil moisture depletion levels (80 %, 100 % and 120 %) and five nitrogen levels (0 Kg/ha, 69 Kg/ha, 92 Kg/ha, 115 Kg/ha, and 138 Kg/ha). The two-year data of fruit yield, yield components and water productivity were subjected to analysis of variance using SAS 9.4 software with significance level $p \leq 0.05$. least significant difference test was applied for statistically significant parameters to compare means among the treatments. The analysis results revealed that 120 % FAO recommended allowable soil moisture depletion and 92 Kg/ha nitrogen levels were the best results. In the case of economic analysis, 100 % FAO-recommended allowable soil moisture depletion and 138 Kg/ha nitrogen levels are economically feasible results. Therefore, we conclude from the above results that 100 % FAO recommended allowable soil moisture depletion level (55 %) and 138 Kg/ha nitrogen level are the best practice in the study area.

Article Info

Received: 12 March 2024
Accepted: 20 April 2024
Available Online: 20 May 2024

Keywords

Allowable soil moisture deletion level, nitrogen level, maize yield, water productivity, irrigated maize.

Introduction

In Ethiopia, the agricultural sector generates 40% of the country's GDP, 75% of jobs, and 80% of export earnings (Ferede and Kebede, 2015 and USAID, 2022). However, climate variability and management practices are affecting the sector negatively (Harrington, 1981 and Zerihun Abebe and Feyisa Hailu, 2017). Ethiopia's GDP growth was reduced by 10% as a result of climate shocks, in addition to other factors (World Bank, 2010 and World Bank, 2017).

Maize (*Zea mays* L.) serves as nourishment for both humans and animals and is essential as a raw material for numerous agro-based industries (Ahmad *et al.,* 2007). In Ethiopia, maize is grown on large-scale, irrigated fields by both smallholder farmers and investors during the Meher and Belg seasons (CSA, 2021). Production of maize during Belg season requires either supplementary or full irrigation, depending on the agro-climatic conditions of the areas in the country.

In Ethiopia, maize has the highest area coverage and total production (CSA, 2021). With a productivity of 3.4 tons ha year-1 in 2021, it covers a total cropping area of 3,419,008.09 ha year-1 and a total production of 11,737,527.7 tons year year-1 (CSA, 2021). But its productivity is far below the global average (5.6 tons ha-1). The most important management practices influencing maize production are nutrient and soil water availability to the crop.

Therefore, irrigation and nitrogen application are important management factors for producers. The growth and development of maize are limited by the over- or under-application of irrigation water and fertilizer, resulting in lower yields. Because it impacts root distribution, soil moisture distribution, nutrient uptake by roots, and water percolation beneath the root zone, the time interval between irrigation treatments is an essential component of irrigation management (El-Hendawy *et al.,* 2008; Mei-Xian *et al.,* 2013; Wang *et al.,* 2006 and Rudnick and Irmak, 2014).

For these reasons, even for the same total amount of irrigation, water use efficiency and crop yield can vary depending on the irrigation interval. Water applied too much or too little at each irrigation can affect grain yield and water use efficiency. On the other hand, overwatering during irrigation depletes soil nutrients and reduces oxygen levels in the root zone (Bakht *et al.,* 2006). In a similar manner, the over application of inorganic fertilizers raises surface and groundwater pollution as well as greenhouse gas emissions (Valipour & Montazar, 2012 and CSA, 2021). Therefore, determining the right irrigation and fertilizer levels is essential for sustainable maize production.

Several studies have been conducted in different parts of Ethiopia on the response of maize to irrigation levels and/or fertilizer rates. All of the previous studies considered irrigation amount and/or fertilizer levels (how much to irrigate and how much fertilizer to apply). However, when to irrigate is an important parameter in irrigated maize production. Therefore, a field experiment was conducted at Ambo Agricultura Research Center Farm Fields, West Shewa, to determine the effects of optimal irrigation scheduling and nitrogen fertilizer rates on yield, yield components, water productivity, and the economic benefit of maize.

Objectives

To evaluate the effect of allowable soil moisture depletion levels on the yield and water Productivity of irrigated maize production.
To evaluate the effect of nitrogen levels on the yield and water productivity of irrigated maize production.
To evaluate the best combination of allowable soil moisture depletion level and nitrogen level on the yield and water productivity of irrigated maize production.

Materials and Methods

Description of the study area

The experiment was conducted at the Ambo Agricultural Research Center Farm Site, Ambo Woreda, West Shewa Zone. The geographical location of the site is 37^0 52' E longitude, $8^0$57' N latitude, and 2180 m.a.s.l. altitude. The area lies in the semi-arid belt, 115km from Adis Abeba, and experienced bimodal rainfall with a mean annual precipitation of 1003.7 mm. The mean maximum and minimum temperatures of the area range from 26.4 oC to 10.3 oC, respectively. The soil texture of the study area is clay.

Experimental design and field layout

The experiment was a two-factor factorial experiment arranged in an RCBD split plot arrangement. The two factors were allowable soil moisture depletion levels and nitrogen levels. Allowable soil moisture depletion has three levels (80 %, 100 %, and 120 % of FAO recommended allowable soil moisture depletion levels), and nitrogen has five levels (0 kg/ha, 69 kg/ha, 92 kg/ha, 115 kg/ha, and 138 kg/ha nitrogen levels). A total of fifteen treatments with three replications were allocated on 45 plots of size 4.5 m × 3 m (13.5 m^2) each, with a spacing of 2 m between plots and blocks. This experiment was done under dry conditions.

Management of the experiment

The field was uniformly irrigated for land preparation before sowing. The land was plowed using a disc-mounted tractor two times and harrowed on the third stage. Seeds of the “Jibat” maize variety were sown at 75 cm inter-row and 25 cm intra-row spacing. The gross area of the experiment field is 607.5 m2. Two seeds of maize were sown per hill and covered with soil. The full dose of TSP fertilizer was applied at the sowing. As the nitrogen source, urea was used to apply the 5 levels of nitrogen treatments (0 kg/ha N, 69 kg/ha N, 92 kg/ha N, 115 kg/ha N, and 138 kg/ha N). Urea (N treatment) was applied in a split time (10% at planting, 45% at the knee stage, and 45% at the tasseling stage). For 15 days after sowing, the plots were irrigated at the FAO-recommended soil moisture depletion level (55%), depending on their crop water requirements throughout the experiment period. Application of irrigation treatments was started 15 days after the sowing date. Thinning to a single plant per hill was done manually after the seedlings produced three to four leaves. All other management practices (e.g., weeding and pest management) were kept as recommended in all the treatments throughout the experiment period.

Water application method and scheduling

The total available water in the soil and allowable soil moisture depletion level were calculated for irrigation applications based on treatment levels (80 % ASMDL, 100 % ASMDL, and 120 ASMDL). Water was applied to plots using a Parshall flume with a throat width of 3 inches. CROPWAT 8.0 was used to determine the reference evapotranspiration (ETo: mm day-1) using the fifty years of climate data (mean annual minimum and maximum temperatures (◦C), wind speed (km day-1)), sunshine hours, and relative humidity (%) collected) from the Ambo Agricultural Research Center agrometeorological station. The crop evapotranspiration (ETc) was calculated as a product of ETo and crop coefficient (Kc) using equation 1. Crop coefficients of maize in sub-humid areas were adopted from FAO 56.

$$ETc = ETo*K$$

Where: Kc in fraction

ET_c in mm/day and

ETo in mm/day

The time required to deliver the desired depth of water into each plot was calculated using the equation.

$$t = \frac{dg \times A}{6 \times Q}$$

Where: d_g is the gross depth of water applied (cm)

t is application time (min)
A is Area of the experimental plot (m^2) and

Q is discharge of Parshall flume (l/s)

The irrigation depth was converted to the volume of water by multiplying it by the area of the plot (Valipour and Montazar, 2012).

$$V = A * dg$$

Where: V is the Volume of water in (m^3)

A is the Area of a plot (m^2)

Data Collection

Maize grain yield and yield component

Maize grain yield and dry biomass were collected from the whole plants of the four central rows to avoid the border effect. Plant height was collected from five plants selected from the four central rows.

Water productivity

Water productivity was calculated by a ratio of total grain yield (kg/ha) to the total crop water applied through the growing season in (m^3 /ha) according to Zwart and Bastiaanssen (2004) using the following equation.

$$WP = \frac{Y}{ETc}$$

Where: WP is water productivity (kg/m^3)

Y is grain yield (kg/ha)

ETc is the seasonal crop water applied (m^3/ha).

Economic analysis

The economic analysis of the experimental treatments was done using partial budget by using the costs of Urea fertilizer for the nitrogen treatments and manpower costs for irrigation water application in case of allowable soil moisture depletion treatments using the following formula.

$$TR = Y * P$$

Where: Y is the adjusted bulb yield (kg)

P is the average market price (ETBirr/kg)

$$NI = TR - TC$$

Where: Net income (NI) was calculated by subtracting the total costs

TC is total cost

TR is total return

$$TC = MC + LC$$

Where: TC is the total cost incurred

MC is the Mulching material cost in ETBirr and

LC is the Laboure cost in ETBirr

Finally, the percent marginal rate of return (MRR) was calculated by the following formula:

$$\text{MRR} = \frac{\Delta \text{NI}}{\Delta \text{TC}} * 100\%$$

Where: MRR is marginal rate of return

ΔNI is the difference between the total income and variable costs in ETBirr and

ΔTVC is the additional unit of expense in ETBirr, between the two treatments.

Data Analysis

Maize grain yield, yield component, and water productivity data were subjected to analysis of variance (ANOVA) using SAS Software. The list significant difference (LSD) test was applied at 5 % significancy level to compare means among the treatments.

Results and Discussion

Effects of allowable soil moisture levels on grain yield, dry biomass, plant height, thousand grain weight and water productivity of maize

The two-year combined analysis results of grain yield, dry biomass, plant height, thousand-grain weight, and water productivity of maize due to the effects of allowable soil moisture depletion levels are shown in Table 5.1. The mean values of grain yield, dry biomass, plant height, thousand-grain weight, and water productivity of maize showed that allowable soil moisture depletion levels and nitrogen levels had no significant interaction effects.

The main effect results revealed that there is no statistically significant difference between grain yields due to the effects of allowable soil moisture depletion levels.

The dry biomass result showed that there is no significant difference between 100% FAO-recommended allowable soil moisture depletion level and 120 % FAO-recommended allowable soil moisture depletion level, and the highest dry biomass results were obtained from both treatments.

The lowest dry biomass result was obtained at 80 % of the FAO-recommended allowable soil moisture depletion level. The results showed that plant height and thousand-grain weight were not affected by the levels of allowable soil moisture depletion.

The analysis results showed that the 100 % FAO recommended allowable soil moisture depletion level was significantly different from the 80 % and 120% FAO recommended allowable soil moisture depletion levels, with the highest water productivity results of 1.2 kg/m3, and there is no significant difference between the 80 % and 120 % FAO recommended allowable soil moisture depletion levels.

The study conducted by Ashebir Haile Tefera (2021) on the Optimization of Irrigation Scheduling and Fertilizer Rate of Maize (*Zea mays* L.) to Improve Yield and Water Use Efficiency under Irrigated Agriculture revealed that the highest grain yield and water productivity of 4.8 t ha-1 and 2.05 kg/m3 were obtained from irrigation with a 14-day irrigation interval.

The finding of Muktar *et al.,* (2016) on Optimal Irrigation Scheduling for Maize (*Zea mays* L.) at Teppi, Southwest Ethiopia, confirmed that the maximum grain yield was obtained when the soil moisture depletion level reached 120 % (SMD4) of the FAO-recommended level (55%). Elzubeir and Mohamed (2011) also recommended that 10 10-day irrigation intervals give the highest values of plant height, cob length, 100-seed weight, grain yield, stover yield, and field water use efficiency of maize. Shinoto *et al.,* (2018) Conclude that lengthening the irrigation interval to 14 days saved water without a significant decline in the growth and yield of maize.

Table.1 Treatment Combination

Treatment	Main plot of FAO Recommended Allowable Soil Moisture Depletion Level (%)	Subplot Nitrogen Level (Kg/ha)
T1	80	0
T2		69
T3		92
T4		115
T5		138
T6	100	0
T7		69
T8		92
T9		115
T10		138
T11	120%	0
T12		69
T13		92
T14		115
T15		138

Table.2 Climate and Eto data of the study area

Month	Rain	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	Eto
	Mm	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	14	11.6	27.5	50	59	8.2	19.7	3.66
February	15.1	12.8	28.9	49	61	9.5	22.8	4.32
March	53.7	13.4	28.9	50	70	7.9	21.5	4.39
April	56.9	13.7	28.1	57	66	7.4	20.9	4.28
May	99.4	12.8	27.2	61	56	6.8	19.5	3.94
June	157.1	12.6	24.9	71	40	6	17.9	3.46
July	228.1	12.7	22.8	79	31	4.1	15.3	2.93
August	204	12.8	22.3	80	25	3.9	15.3	2.89
September	111.2	11.8	24	75	23	4.5	16.2	3.04
October	37	11.3	26	59	43	7.8	20.5	3.73
November	18.3	11	26.3	54	52	8.2	19.8	3.6
December	8.9	11.2	26.5	51	64	8.6	19.7	3.6
Average	1003.7	12.3	26.1	61	49	6.9	19.1	3.65

Table.3 Soil water characteristics of the study area

Soil Type (USA Soil Texture Classification)	Soil Water Characteristics		
	FC (m3/m3)	PWP (m3/m3)	FC – PWP (m3/m3)
Clay	0.36	0.22	0.16

Table.4 Maize crop data

Crop	**Maize**				
Variety	Jibat				
Growth period (day)	Initial	development	Mid-season	Late-season	Total
	30	50	60	40	180
Kc values	0.30		1.05	0.08	
Root depth (m)	0.3			1.00	
Max. Plant Height (m)	2.27				

Table.5 Main effects of allowable soil moisture level on grain yield, dry biomass, plant height, thousand grain weight and water productivity of maize.

% Of Allowable soil Moisture Depletion Level	Plant Height (cm)	Dry Biomass (Kg/ha)	Thousand gain Weight (g)	Grain Yield (Kg/ha)	Water Productivity (kg/m^{3})
80	218.187	23490.2^{b}	416.64	6947.5	1.13133^{b}
100	217.713	25611.7^{a}	444.35	7306.9	1.20200^{a}
120	217.733	24959.8^{a}	429.74	6953.0	1.11933^{b}
LSD (0.05)	NS	1056.1	NS	NS	0.0674
CV (%)	4.38	7.18	11.73	9.17	9.84

Table.6 Main effects of allowable soil moisture level on grain yield, dry biomass, plant height, thousand grain weight and water productivity of maize.

Nitrogen Level	Plant Height (cm)	Dry Biomass (Kg/ha)	Thousand gain Weight (g)	Grai Yield (Kg/ha)	Water Productivity (kg/m^{3})
0	203.189^{c}	17997.5^{e}	422.55	6048.1^{c}	0.98722^{c}
69	217.622^{b}	22034.2^{d}	425.49	6775.3^{b}	1.10167^{b}
92	219.778^{ba}	25300.7^{c}	421.27	7258.2^{ba}	1.18444^{ba}
115	222.300^{ba}	27589.1^{b}	450.26	7473.8^{a}	1.21833^{a}
138	226.500^{a}	30514.5^{a}	431.66	7790.3^{a}	1.26278^{a}
LSD (0.05)	7.6078	856.24	NS	583.58	0.0948
CV (%)	5.21	5.17	16.76	12.32	12.30

Table.7 Economic analysis of Allowable soil Moisture Depletion Level

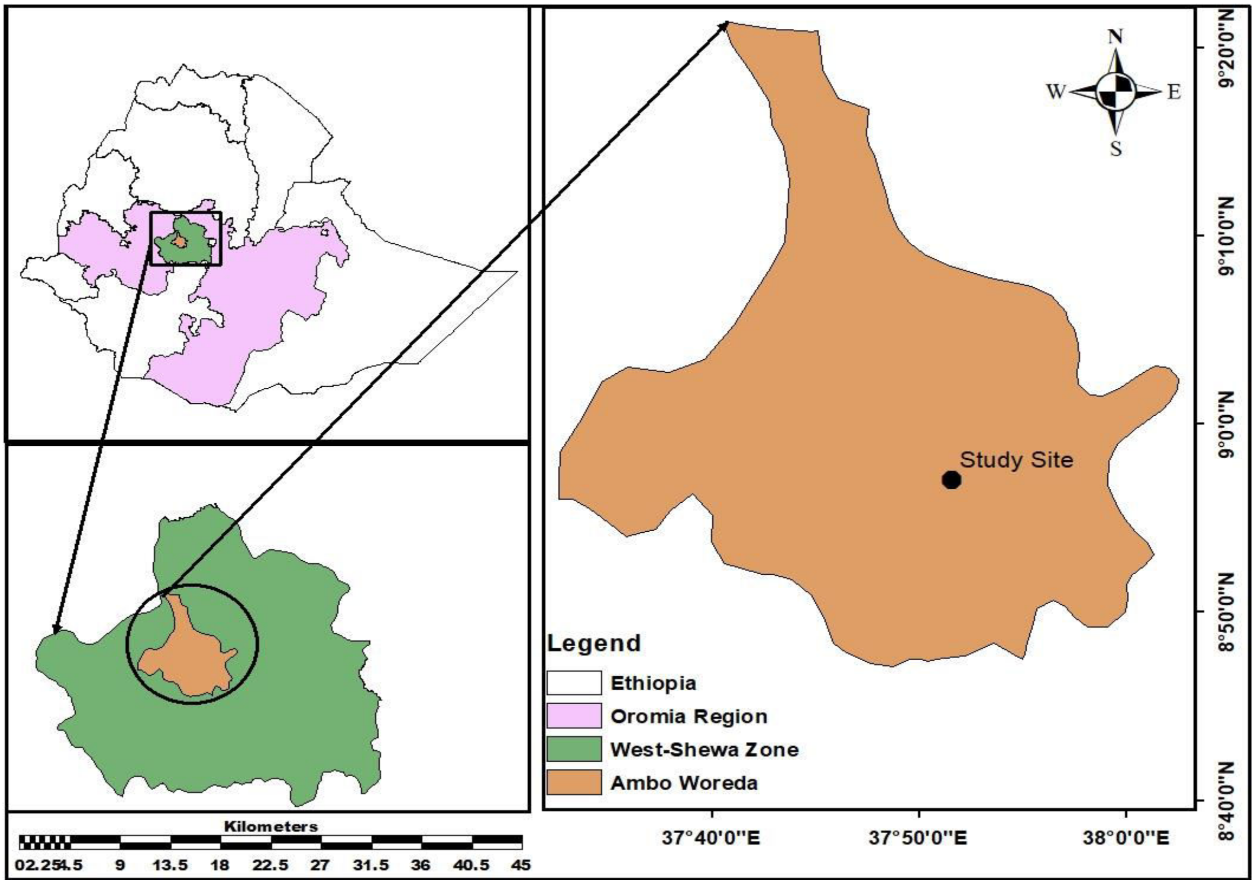
Treatment	Total yield (kg/ha)	Adjusted yield (kg/ha)	Total Income (Birr/ha)	TVC (Birr/ha)	Net Income (Birr/ha)	MRR (%)
120% ASMDL	6953	6257.7	250308	2600	247708	-
100% ASMDL	7306.9	6576.21	263048	3200	259848	2023
80% ASMDL	69475	625275	250110	4000	2461100	D

ASMDL = Allowable Soil Moisture Depletion Level

Table.8 Economic analysis results of Nitrogen Level

Treatment	Total yield (kg/ha)	Adjusted yield (kg/ha)	Total Income (Birr/ha)	TVC (Birr/ha)	Net Income (Birr/ha)	MRR (%)
0 % Nitrogen	6048.1	5443.29	217731.6	-	217731.6	
69 % Nitrogen	6775.3	6097.77	243910.8	5700	238210.8	359
92 % Nitrogen	7258.2	6532.38	261295.2	7600	253695.2	815
115 %Nitrogen	7473.8	6726.42	269056.8	9500	259556.8	309
138 % nitrogen	7790.3	7011.27	280450.8	11400	269050.8	500

Figure.1 Location of Study Area



Effects of Nitrogen levels on grain yield, dry biomass, plant height, thousand grain weight and water productivity of maize

The two-year combined analysis results of grain yield, dry biomass, plant height, thousand-grain weight, and water productivity of maize due to the effects of nitrogen fertilizer levels are shown in Table 5.2.

The results showed that the use of different nitrogen levels significantly affected grain yield, dry biomass, plant height, and water productivity of maize but not thousand-grain weight ($P<0.05$). Applying 92 kg/ha, 115 kg/ha, and 138 kg/ha nitrogen levels produced the highest non-significantly different grain yield values of 7,258.2 kg/ha, 7,473.8 kg/ha, and 7,790.3 kg/ha, respectively, and the lowest grain yield value of 6,048.1 kg/ha was obtained from 0 kg/ha nitrogen.

The nitrogen levels of 92 kg/ha, 115 kg/ha, and 138 kg/ha produced the highest non-significantly different water productivity values of 1.14 kg/m^3, 1.22 kg/m^3, and

1.26 kg/m^3, respectively, while 0 kg/ha nitrogen produced the lowest water productivity values of 0.99 kg/m^3. The highest dry biomass value of 30,514.5 kg/ha was observed from 138% nitrogen, whereas the lowest value of 17,997.5 kg/ha was obtained from 0% nitrogen. Plant height with the highest non-significantly different values of 219.778 cm, 222.3 cm, and 226.5 cm was obtained from nitrogen levels of 92 kg/ha, 115 kg/ha, and 138 kg/ha, respectively; the lowest plant height values, 203.189 cm, were obtained from nitrogen levels of 0 kg/ha.

The above results were validated by Zerihun Abebe and Feyisa Hailu (2017), who found that the highest grain yield was obtained at 92 N kg ha−1. It is also further supported by the Rudnick and Irmak (2014) study, which found that the most economical nitrogen rate for maize production was 92 kg ha−1. Abbas *et al.,* (2005) reported that the application of the 200 kg ha-1 urea rate resulted in the maximum grain yield (> 7.0 t ha-1). Bakht *et al.,* (2007), it was recorded that the plot treated with 200 kg Urea ha-1 recorded maximum cob length (15.67 cm), thousand-grain weight (289.67 g), and grain yield (3934.80 kg ha-1). Bakht *et al.,* (2006) reported that the maximum number of leaves per plant, number of cobs per plant, number of grains per cob, taller plants, grain, and biological yield were recorded in the application of 200 kg of urea ha-1.

Economic analysis

Economic analysis of allowable soil moisture depletion Level

The economic analysis was made following the procedure of the CIMMYT economic analysis of 2^4 factorial agronomic experiments, economics training note (Harrington, 1981). As required by the procedure, the average yield of the 3 treatments was adjusted downward by 10% (Table 5.3.1), as yields from the experimental plots are supposed to be higher than farmers' fields.

The total costs and net benefits were calculated for different combinations. To obtain the gross benefit, the adjusted yield was multiplied by the field price of maize (40 birr·kg−1), and the manpower cost (200 ETB/day) for irrigation water application was used to calculate the variable cost. The variable cost was subtracted from the gross benefit to obtain the net benefit. The highest net benefit of Birr 259,848.4 ha−1 was recorded at 100% of the allowable soil moisture depletion level. The marginal rate of return (MRR) was also higher (2023.4) for 100% of the allowable soil moisture depletion level (Table 5.3.1).

Economic analysis of Nitrogen Level

The CIMMYT procedure was followed in the economic analysis (Harrington, 1981). Since yields from the experimental plots are expected to be higher than those from farmers' fields, the procedure required that the average yield of the three treatments be adjusted downward by 10% (Table 5.3.2). For various combinations, the net benefits and total costs were computed. The adjusted yield was multiplied by the field price of maize (40 ETB/kg) to determine the gross benefit, and the cost for fertilizer purchase (3800 ETB/day) and fertilize application cost (200 ETB/day) were used as variables. To calculate the net benefit, the variable cost was deducted from the gross benefit. At the 138 kg/ha nitrogen level, the largest net benefit of 269,050.8 ETB ha−1 was observed (Table 5.3.2).

Conclusion

The growth and development of maize are limited by over- or under-application of irrigation water and nutrients, resulting in lower yields. Due to these, a field experiment was conducted at the Ambo Agricultural Research Center Farm Site from 2021 to 2023 to evaluate the effects of nitrogen and allowable soil moisture depletion levels on the yield, yield components, water productivity, and economic return of furrow-irrigated maize production. Results from the experiment indicated that there is not a significant difference in maize grain yield between the 80 %, 100 %, and 120 % FAO recommended allowable soil moisture depletion levels, with yields of 6947.5 kg/ha, 7306.9 kg/ha, and 6953 kg/ha, respectively. But the highest water productivity (1.2 kg/m^3) was obtained at a 100 % allowable soil moisture depletion level. In the case of nitrogen levels, the highest grain yields of 7258.2 kg/ha, 7473.8 kg/ha, and 7790.3 kg/ha and the highest water productivity results of 1.18 kg/m3, 1.22 kg/ha, and 1.26 kg/ha resulted from 92 %, 115 %, and 138 % nitrogen levels, respectively. Economic analysis results revealed that a 100% allowable soil moisture depletion level and a 138 kg/ha nitrogen level resulted in the highest net income of 259,848 ETB/ha and 269,050.8 ETB/ha, respectively. We therefore draw the conclusion that the optimal practices for furrow irrigated maize production in the study area are the 138 kg/ha nitrogen level (300 kg/ha urea) and the 100 % FAO recommended allowable soil moisture depletion level (55 % allowable soil moisture depletion level) based on the results of the economic analysis.

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How to cite this article:

Oli Frrisa, Selamawit Bekele and Kalkidan Degefu. 2024. Effects of Optimal Irrigation Scheduling and Nitrogen Level on the Yield and Water Productivity of Maize (*Zea mays* L.) at Ambo Agricultural Research Center, West Shewa, Ethiopia. *Int.J.Curr.Res.Aca.Rev.* 12(5), 91-99. doi: https://doi.org/10.20546/ijcrar.2024.1205.010