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Research Article

Effect of Irrigation Scheduling and Nitrogen Levels on Yield and Water Productivity of Wheat (*Triticum aestivum*) at Ambo, West Shoa, Ethiopia

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Abstract

Excessive fertilizer use and improper irrigation scheduling can accelerate soil degradation and increase the nitrogen leaching rate. This study, conducted at the Ambo Agricultural Research Center during the 2021/22 and 2022/23 irrigation seasons, aimed to identify optimal nitrogen fertilizer rates for wheat production under irrigation. The experiment followed a randomized complete block design with three replications, utilizing a split-plot arrangement. The main plot tested three soil moisture depletion levels: 80%, 100%, and 120%, while the sub-plot involved five nitrogen levels with 0, 46, 69, 92, and 115 kg N/ha. Results showed that nitrogen levels significantly influenced grain yield, above-ground biomass, and water productivity but not the irrigation regimes or their interaction with nitrogen levels. The 115 kg N/ha rate produced the highest grain yield, 5213 kg/ha, and water productivity of 1.24 kg/m^3; though these values were not significantly higher than those at 92 kg N/ha. Both 115 kg and 92 kg N/ha treatments significantly outperformed the 69 kg N/ha treatment and lower rates. Applying 120% allowable soil moisture depletion levels resulted in high net income and benefit-to-cost ratio values of 197,716.00 Ethiopian Birr (ETB) and 30.89%, respectively. At 120% allowable soil moisture depletion, the highest net income and benefit-cost ratio were observed (197,716 ETB and 30.89%, respectively). The 92 kg N/ha application resulted in the highest marginal rate of return (826.05%), well above the acceptable threshold of 100%, with a net income of 223,655 ETB. Based on grain yield, water productivity, and economic feasibility, we recommend applying 92 kg N/ha with 120% ASMDL for wheat production in this region.

Keywords

Economic Return, Irrigation Scheduling, Nitrogen Levels, Water Productivity, Wheat

1. Introduction

Agriculture is the primary economic activity in Africa, employing two-thirds of the workforce. In sub-Saharan Africa, including Ethiopia, farming predominantly centers on staple crop production for subsistence under rain-fed conditions. However, rain-fed agriculture is increasingly challenged by rainfall variability, land degradation, soil fertility depletion, and the impacts of climate change [1]. Expanding irrigation agriculture is, therefore, essential to ensuring food security and boosting the income of smallholder farmers.

According to [2-4] and other scholars, irrigation and fertilization majorly impact crop output and are essential for grain production and food security. About 20% of the world's arable

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land is used for irrigated agriculture, which is expected to produce 40% of all crops [5]. Water scarcity is a global problem that impacts agricultural productivity since agriculture uses a larger portion of the available water resources. Thus, allocating the limited water resource with appropriate irrigation scheduling in time and space is essential for increasing the marginal benefit provided per unit of irrigation water.

A consistent supply of nitrogen, in addition to water, is another crucial element that has enabled farmers to raise crop yields greatly [6]. Nitrogen fertilizer helps improve grain protein content, other quality indicators, and grain yield and increases plant nitrogen accumulation [7, 8]. Excessive nitrogen application has no discernible effect on grain yield; instead, the remaining nitrogen fertilizer in the soil is lost through nitrate leaching and nitrous oxide emissions [9]. Research indicates that combining appropriate fertilizer and irrigation water management can boost a crop's grain yield, water productivity, and nutrient usage efficiency. Crop yield is impacted by reduced water productivity and nutrient use efficiency, brought on by inadequate irrigation and overuse of chemical nitrogen fertilizer [10, 11].

Wheat is one of the most significant food crops worldwide and is necessary for both global food security and stability to sustain the food security of the world's fast-expanding population [12]. It constitutes 15% of total calories, second only to maize, and is a staple food for many Ethiopians [13]. Ethiopia produces 0.42 million tons of food on 1.7 million hectares of land, ranking it 31st globally [14]. Ethiopia is one of the top wheat producers in sub-Saharan Africa, only surpassed by South Africa for the overall area covered and the amount of wheat produced [15]. Wheat can be grown in Ethiopia by small-scale subsistence farmers and commercial farms, mainly under rain-fed conditions [16]. Ethiopia produces roughly 5.8 million tons yearly with a mean productivity of 3 tons per hectare [17], less than the crop's achievable yield of up to 5 t ha^{-1} [18].

Studies on irrigation scheduling based on ASMDL concluded that applying 80% ASMDL reduced grain yields by 12.8% and 8.5% compared to the 100 % ASMDL and 120 % ASMDL treatments, respectively. On both surface and drip irrigation, applying 100 % ASMDL resulted in the highest grain yield of a wheat crop [19]. The integrated application of 92 kg N/ha with 100% supplementary irrigation resulted in an optimum grain yield and economic return for the crop in the Tigray area [20].

Proper irrigation and fertilizer application are crucial for enhancing land and water productivity. However, excessive use of these resources can negatively impact overall productivity. In Ethiopia, subsistence farmers primarily grow wheat under rain-fed conditions, and ideal nitrogen fertilizer rates have been established for many regions, including the study area. However, the optimal fertilizer rate for irrigated wheat was previously unknown, with rain-fed recommendations often applied to irrigated farming. This study aimed to determine the optimal nitrogen fertilizer rate to improve wheat grain yield and water productivity under different irrigation regimes.

2. Material and Method

2.1. Description of the Study Area

The experiment was conducted at West Shoa Zone, Ambo Woreda, in the Ambo Agricultural Research Center Farm site for two consecutive years during the 2021 and 2022 irrigation seasons. The geographical location is 37.5135 °E and 08. 5816 °N with an altitude of 2144 m.a.s.l. The area is about 115 km from Addis Ababa (Figure 1). The annual precipitation of 1029 mm and the mean temperatures of the area range from 26.4 to 10.3 °C described in (Table 1). The soil texture for the experimental area is clay soil (Table 3).

2.2. Treatments and Experimental Design

The experiment used a split-plot arrangement within a randomized complete block design with three replications. Soil moisture deletion levels served as the main plot factor and Nitrogen as the sub-plot factor. The main plot included three allowable soil moisture depletion levels (80%, 100%, and 120% of ASMDL). The sub-plot consisted of five nitrogen levels (0, 46, 69, 92, and 115 kg/ha) applied as urea within each irrigation treatment.

Table 1. *Treatment Combination.*

Treatment	Main plot	Sub-plot
T1	80 % FAO Recommended allowable soil moisture depletion level (80% ASMDL)	N1 (0 kg/ha Nitrogen)
T2		N2 (46 kg/ha Nitrogen)
T3		N3 (69 kg/ha Nitrogen)
T4		N4 (92 kg/ha Nitrogen)
T5		N5 (115 kg/ha Nitrogen)

Treatment	Main plot	Sub-plot
T6		N1 (0 kg/ha Nitrogen)
T7		N2 (46 kg/ha Nitrogen)
T8	FAO Recommended allowable soil moisture depletion level (100% ASMDL)	N3 (69 kg/ha Nitrogen)
T9		N4 (92 kg/ha Nitrogen)
T10		N5 (115 kg/ha Nitrogen)
T11		N1 (0 kg/ha Nitrogen)
T12		N2 (46 kg/ha Nitrogen)
T13	120 % FAO Recommended allowable soil moisture depletion level (80% ASMDL)	N3 (69 kg/ha Nitrogen)
T14		N4 (92 kg/ha Nitrogen)
T15		N5 (115 kg/ha Nitrogen)

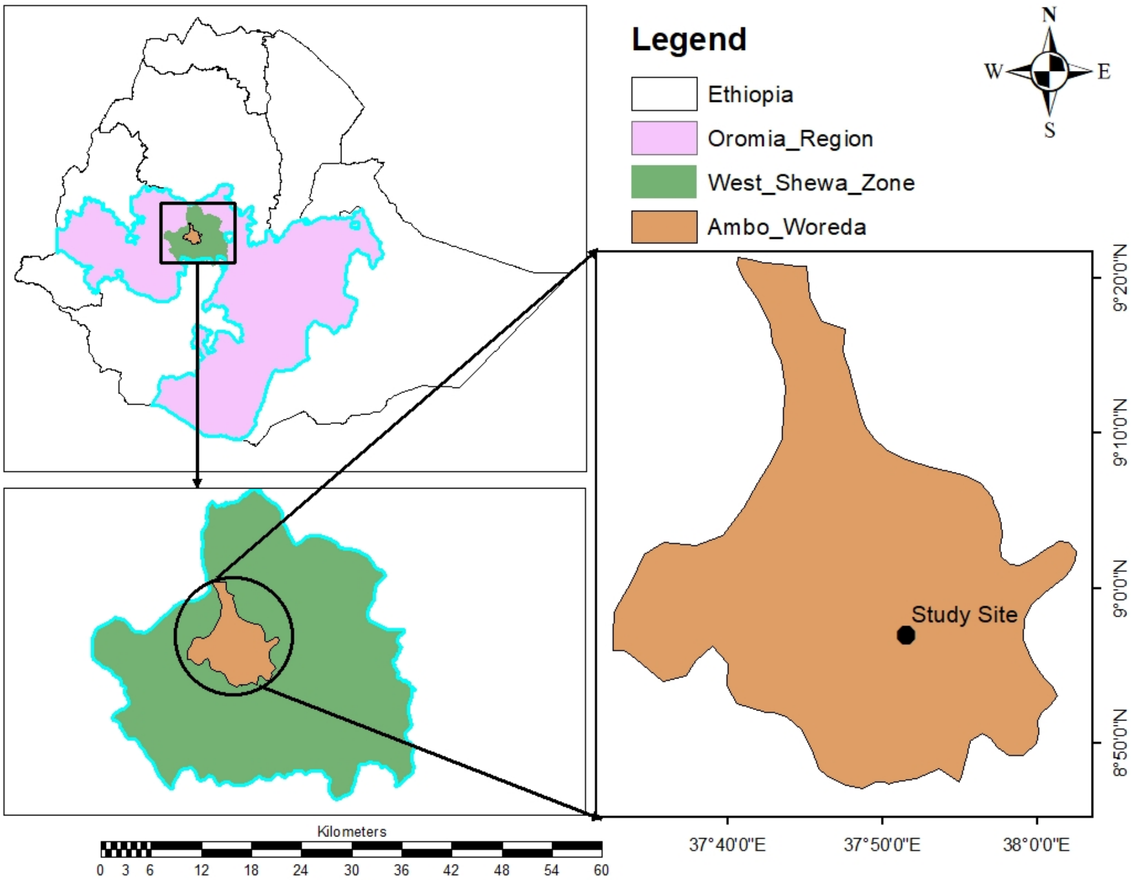

Figure 1*. Location of Study Area.*

2.3. Experimental Field Layout and Management

For the experiment, 45 plots were prepared, each measuring 2.5 m x 2.8 m (7 m^2). A 2 m space between plots and blocks was maintained to prevent lateral water movement. The Wane wheat variety was sown in the first week of November at a 150 kg/ha seeding rate over two consecutive irrigation seasons (2021/22 and 2022/23). At sowing, 100 kg/ha of triple superphosphate (TSP) was uniformly applied to all plots. Nitrogen fertilizer (urea) was used in split doses according to the treatment design, while all other management practices were uniformly applied across the plots as required.

2.4. Determination of Crop Water Requirement and Irrigation Scheduling

The crop water requirement of wheat was determined by the CropWat 8.0 model, which incorporates climate, soil, and crop data. Long-term daily climate data for the study area, including maximum and minimum temperatures, relative humidity, wind speed, sunshine hours, and rainfall, were collected from the Ambo Agricultural Research Center meteorological station to calculate reference evapotranspiration. The study area's long-term daily climate data (maximum and minimum temperature, relative humidity, wind speed, sunshine hours, and rainfall) were collected from the Ambo Agricultural Research Center metrological station to determine reference evapotranspiration (table 2). Crop data, such as crop coefficient (kc), length of growing stage, effective root depth, and critical depletion factors, were sourced from FAO Irrigation and Drainage Paper No. 56 [21] (table 3). Irrigation scheduling for each treatment was done based on the wheat's allowable soil moisture depletion levels. The amount of water applied to the experimental plots was measured by a 3-inch Par shall flume.

$$ETc = ETo * Kc$$

Table 2. *Climate and Eto data for the study area.*

Month	**Rain** Mm	**Min Temp** ℃	**Max Temp** ℃	**Humidity** %	**Wind** km/day	**Sun** hours	**Rad** MJ/m^2/day	**Eto** 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 physio-chemical characteristics of the study area.*

Depth Cm	**FC** vol. %	**PWP** vol. %	**TAW** mm/m	**Sand** %	**Silt** %	**Clay** %	**Texture** -	**PH** -	**OM** %	**Available** P (ppm)
0-30	39.05	18.53	205.2	16	18	66	Clay	7.83	3.66	5.9
30-60	38.53	17.13	214.0	16	18	66	Clay	8.13	2.06	4.3
60-90	34.73	17.07	177.3	18	14	68	Clay	8.01	2.09	3.6
Average	37.44	17.58	198.6	16.7	16.7	66.7	Clay	8.0	2.6	4.6

Table 4. *Wheat Crop data.*

Parameters	Growth stage				
	Initial	Development	Mid	Late	Total
Growth stage (days)	15	25	50	30	120
Crop coefficient (Kc)	0.4	0.8	1.15	0.5	
Depletion fraction (ρ)	0.55	0.55	0.55	0.55	

2.5. Data Collection

2.5.1. Grain Yield, Above-Ground Dry Biomass, and Harvest Index

Once the wheat reached full maturity, wheat grain yield (GY) and dry biomass data were collected from the eight central rows of each plot. The harvest index (HI) was calculated as the ratio of grain yield to aboveground biomass.

2.5.2. Yield Attribute Parameters

Measurements of plant height, spike length, and seed count per spike were gathered from five specifically selected plants in the central rows.

2.5.3. Water Productivity

Water productivity was computed by the ratio of total grain yield (kg/ha) to the total crop water applied throughout the growing season (m^3/ha), following the method outlined by [22], with the following equation.

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

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

Y is bulb yield (kg/ha),

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

2.5.4. Economic Analysis

A partial budgeting approach was used for the economic analysis, incorporating the net profit from agricultural production and the marginal return value based on the current market price for costs and returns. As outlined by [23], the adjusted grain yield was calculated by reducing the average grain yield by 10%. The economic analysis considered fertilizer and labor costs associated with irrigation at different allowable soil moisture depletion levels, influencing irrigation intervals. It was assumed that all other fixed costs remained constant across treatments. The costs used for the analysis were 200 ETB/day for labor, 3800 ETB/100 kg for fertilizer, and 50 ETB/kg for wheat, with all expenses expressed in Ethiopian Birr per hectare (ETB/ha).

$$TR = Y * P$$

Y is the adjusted wheat grain yield (kg), and P is the average market price (ETB/kg). Net income (NI) was calculated by subtracting the total costs (TC) from the total return (TR) for a given treatment:

$$NI = TR - TC$$

$$TC = FC + LC$$

Where: TC is the total cost incurred, FC is the Fertilizer cost in ETB, and LC is the Labour cost in ETB.

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

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

Where: ΔNI is the difference between the net income in ETB, and ΔTC is the additional expense unit in ETB between the two treatments.

2.6. Data Analysis

Grain yield, yield component, and water productivity data were subjected to analysis Variance (ANOVA) using SAS Software 9.4. The least significant difference (LSD) test was applied at a 5 % significance level to compare means among the treatments.

3. Results and Discussion

3.1. Effects of Soil Moisture Depletion and Nitrogen Levels on Wheat

The Analysis of variance on Nitrogen levels showed a significant effect on grain yield, above-ground dry biomass water productivity, and other yield-contributing parameters of wheat at ($P < 0.05$). However, soil moisture depletion levels and the interaction between nitrogen levels and soil moisture depletion did not significantly affect these factors, as presented in Figure 2, Tables 5 and 6 below.

3.2. Effects of Soil Moisture Depletion and Nitrogen Levels on Grain Yield of Wheat

The Analysis of variance revealed that Nitrogen levels had significant effects on grain yield, as illustrated in Figure 2. In contrast, the application of different soil moisture depletion levels, as well as its interaction with nitrogen, did not impact grain yield. The wheat grain yield increased significantly as Nitrogen levels rose from 0 kg/ha to 115 kg/ha, as described in Figure 3. However, the rate of increase began to decline when nitrogen application exceeded 98 kg/ha. Several studies have similarly found that increasing nitrogen levels positively influences wheat grain yield [24-26]. The maximum grain yield of 5213.3 kg/ha was achieved with 115 kg N/ha, statistically comparable to the 5138.9 kg/ha yield from 92 kg N/ha. Both were significantly superior to grain yield obtained from treatment with nitrogen levels of 69 kg N/ha and below. This aligns with the findings of [25], who observed a non-significant yield reduction when applying 120 kg N/ha compared to 100 kg N/ha. Also, it is agreed with [20, 26] research findings, stating that applying 92 kg N/ha gives a higher wheat grain yield.

3.3. Effects of Soil Moisture Depletion and Nitrogen Levels on Above-Ground Biomass of Wheat

The graph illustrates wheat's grain yield (GY) and dry biomass (DBM) under varying nitrogen rates and optimal irrigation conditions. DBM consistently increased with increasing nitrogen application rate. While GY and DBM were lowest at 0 kg/ha, they exhibited significant growth with nitrogen levels up to 115 kg/ha, peaking at this rate. The nitrogen rates significantly influenced above-ground dry biomass, with noticeable increases from 0 N kg/ha (N-1) to 115 N kg/ha (N-5). However, varying soil moisture depletion levels and their interaction with Nitrogen fertilizer had no significant effect on above-ground biomass. The highest above-ground dry biomass value of 9061.3 kg/ha was achieved with 115 kg/ha of nitrogen, significantly surpassing the values obtained with 46 kg/ha and 0 kg/ha. Conversely, increasing nitrogen from 69 kg/ha to 115 kg/ha did not yield a significant increase in above-ground biomass, as described in Figures 2 and 3. The maximum above-dry biomass value of 9061.3 kg/ha was obtained from the experimental treatment having 115 N kg/ha, which is statistically higher than the treatment receiving 46 N kg/ha and 0 N kg/ha and a minimum value of 6298.9 with a nitrogen level of 0 kg/ha. These findings align with previous research by [20].

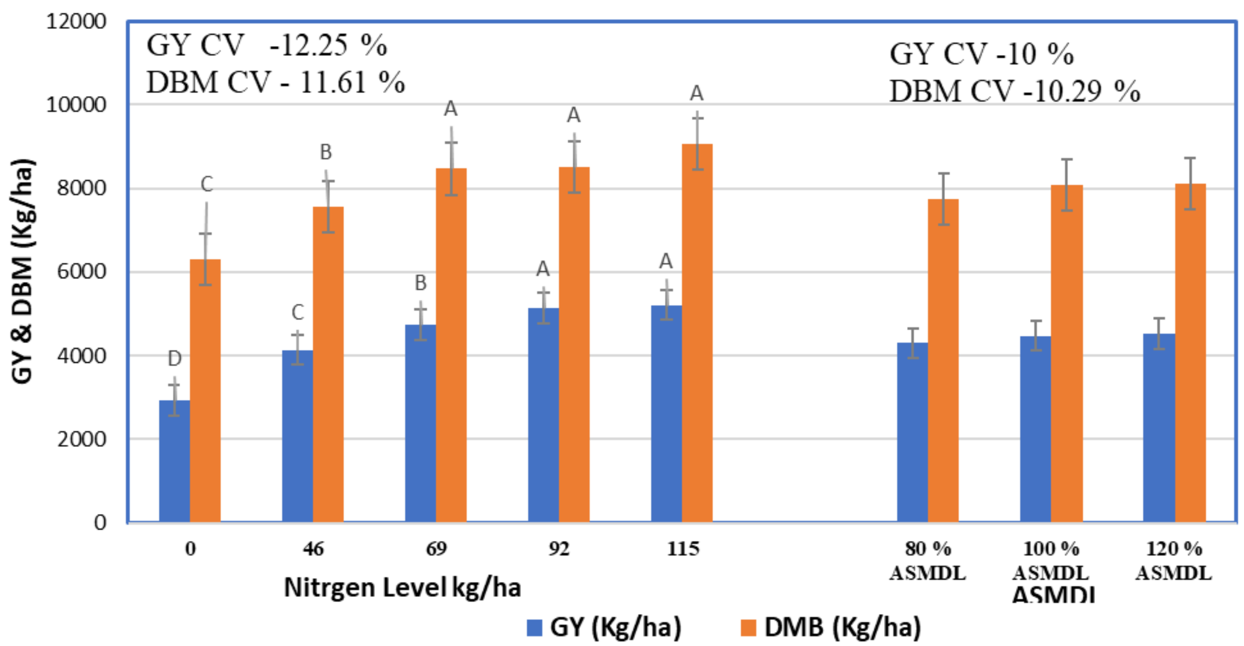

Figure 2. *Nitrogen and soil moisture depletion levels affect grain yield and dry biomass.*

Note: GY-Grain yield, DBM-Above ground dry biomass, CV- coefficient of variation, and ASMDL- Allowable Soil Moisture Depletion Levels

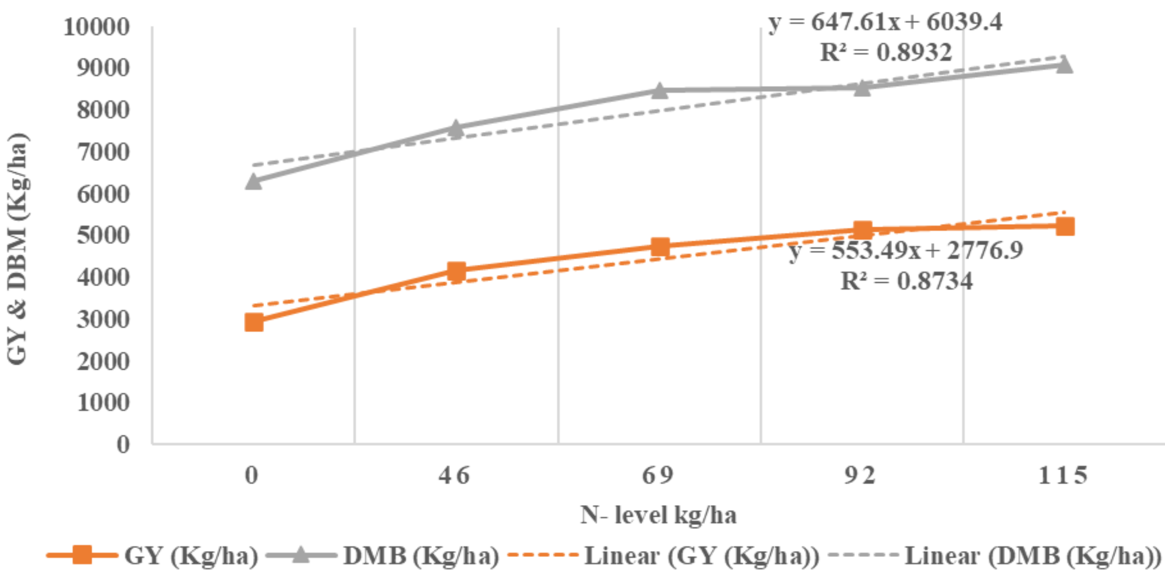

Figure 3. The response curve of wheat grain yield and above-ground dry biomass to Nitrogen levels.

3.4. Effects of Soil Moisture Depletion Levels and Nitrogen Rate on Yield Attribute Parameters of Wheat

Different nitrogen levels significantly impacted all yield-attributing parameters, except for 1000 seeds' weight ($p < 0.05$) (table 4). Variations in soil moisture depletion and its interaction with nitrogen levels did not influence these factors. Plant height, spike length, and harvest index increased with nitrogen application from 0 to 115 N kg/ha (Table 4). The maximum plant height and spike length values of 82.5 cm and 6.04 cm were achieved by applying 115 N kg/ha, significantly exceeding treatment receiving 69 N kg/ha and below, but not significantly superior to treatment receiving 92 N kg/ha. However, 92 N kg/ha resulted in a maximum harvest index (60.5%), followed closely by 115 N kg/ha, with no significant difference. In contrast, these treatments were significantly superior to 69 N kg/ha and below. HI affects the assimilation transfer from the straw to the grain; therefore, the application of 92 N kg/ha was more efficient than 115 N kg/ha. These findings are supported by research [27], which demonstrated that varying fertilizer rates affect wheat yield-attributing factors and increase with rising nitrogen levels.

Table 5. Effect Nitrogen and Soil Moisture Depletion Level on Yield Contributing Factors of Wheat.

Treatments	Plant Height (cm)	Spike Length (cm)	Harvest Index (%)	Thousand seed weight (gm)
Main- plot factor (ASMD Levels %)				
80	78.88	5.649	55.2	41.08
100	76.307	5.76	54.8	40.84
120	77.887	5.588	55.75	40.23
LSD (0.05)	NS	NS	NS	NS
CV (%)	6.13	9.82	7.84	3.18
Sub-plot factor (Nitrogen levels kg/ha)				
0 N (kg/ha)	71.067^{d}	5.529^{b}	47.22^{c}	40.17
46 N (kg/ha)	76.622^{cb}	5.546^{b}	54.91^{b}	40.48
69 N (kg/ha)	77.933^{cb}	5.613^{b}	56.03^{b}	40.78
92 N (kg/ha)	80.022^{ba}	5.899^{ba}	60.5^{a}	40.77

Treatments	Plant Height (cm)	Spike Length (cm)	Harvest Index (%)	Thousand seed weight (gm)
115 N (kg/ha)	82.511[a]	6.041[a]	57.61[ba]	41.38
LSD (0.05)	2.59	0.23	3.4	NS
CV (%)	4.98	6.04	9.13	3.62

3.5. Effects of Soil Moisture Depletion Levels and Nitrogen Rate on Water Productivity of Wheat

Nitrogen levels significantly influenced wheat water productivity, while varying soil moisture depletion levels and their interaction with fertilizer had no significant effect. Water productivity increased with an increasing nitrogen application rate. The highest water productivity of 1.24 kg/m ^{3}was achieved with 115 kg/ha of nitrogen, followed closely by 1.22 kg/m ^{3}with 92 kg/ha. Water productivity significantly decreased with nitrogen levels below 69 kg/ha compared to 115 kg/ha and 92 kg/ha.

Table 6. *Effect Nitrogen Levels and Soil Moisture Depletion Level on Water Productivity of Wheat.*

Main-plot factor (ASMDL %)	Water Productivity (Kg/m^3)	Sub-plot factor Nitrogen levels kg/ha	Water Productivity (Kg/m^3)
80	1.02	0	0.698[d]
100	1.07	46	0.982[c]
120 L	1.07	69	1.125[b]
LSD (0.05)	NS	92	1.218[a]
	10.29	115	1.236[a]
CV (%)		LSD (0.05)	0.09
		CV (%)	12.16

3.6. Economic Analysis

The partial budgeting analysis was conducted to assess the economic variability of different nitrogen and allowable soil moisture depletion levels. It was done by arranging the total variable cost in increasing order as described by the procedure of [23]. According to the International Maize and Wheat Improvement Center (CIMMYT), the minimum acceptable marginal rate of return (MRR) should be between 50% and 100% and above [23]. For this experiment, the minimum acceptable MRR value considered for the recommendation was 100%. The results, presented in (table 7), show that applying 92 kg/ha of nitrogen provides a MRR of 826.05%, exceeding the CIMMYT-recommended minimum of 100%. This treatment also yields the highest net income of 249,345.00 ETB, making it economically more advantageous than other nitrogen levels. Meanwhile, the application of 115 N kg/ha gave a MRR value of 75.26%, which is lower than the minimum acceptable value for MRR.

Economic analysis for allowable depletion levels considered labor costs for irrigation. In the study area, the labor cost was 200 ETB per person, and the farm gate price of wheat during the experimental period was 50 ETB per kg. The results indicate that 80% of ASMDL requires the most irrigation, leading to higher costs and lower net profit and benefit-to-cost ratio. Conversely, 120% of ASMDL offers the highest benefit-to-cost ratio of 30.89 and a net income of 197,716.00 ETB/ha with a minimum variable cost of 6400.00 ETB (table 8).

Table 7. *Economic analysis results on wheat using Partial budgeting for Nitrogen levels.*

Treatments	TY (kg/ha)	AY (kg/ha)	TR (ETB/ha)	TC (ETB/ha)	NI (ETB/ha)	∆ NI (-)	∆ TC (-)	MRR (%)
0 N (kg/ha)	2944	2649.6	132,480	0	132,480			
46 N (kg/ha)	4142	3727.8	186,390	3,800	182,590	50,110	3,800	1318.68

Treatments	TY (kg/ha)	AY (kg/ha)	TR (ETB/ha)	TC (ETB/ha)	NI (ETB/ha)	∆ NI (-)	∆ TC (-)	MRR (%)
69 N (kg/ha)	4748	4273.2	213,660	5,700	207,960	25,370	1,900	1335.26
92 N (kg/ha)	5139	4625.1	231,255	7,600	223,655	15,695	1,900	826.05
115 N (kg/ha)	5213	4691.7	234,585	9,500	225,085	1,430	1,900	75.26

(Note: N- Nitrogen TY- Total yield, AY-Adjusted yield, TR-Total revenue, TC- Total cost, NI- Net Income, ∆ NI -change in net income, ∆TC - change in total cost, B/C benefit to cost ratio and MRR- Marginal Rate of Return ETB- Ethiopian Birr)

Table 8. Economic analysis results on wheat using partial budgeting for ASMDL.

Treatments	TY (kg/ha)	AY (kg/ha)	TR (ETB/ha)	TC (ETB/ha)	NI (ETB/ha)	BC Ratio
80 % ASMDL	4297.6	3867.84	193392	8800	184592	20.98
100 % ASMDL	4478.6	4030.74	201537	7600	193937	25.52
120 %ASMDL	4535.9	4082.31	204116	6400	197716	30.89

(Note: ASMDL- Allowable Soil Moisture Depletion Levels TY- Total yield, AY-Adjusted yield, TR-Total revenue, TC- Total cost, NI- Net Income, and BC- Benefit to cost ratio)

4. Conclusion

The highest grain yield (5213 kg/ha) and water productivity (1.24 kg/m³) were achieved with 115 kg/ha of nitrogen, with a non-significant difference compared to 92 kg/ha. These values and other yield-attribution parameters were significantly superior to those obtained with lower nitrogen levels (69 kg/ha or less).

An economic analysis revealed that 120% of ASMDL provided the highest net income (197,716.00 ETB) and benefit-to-cost ratio (30.89%). Additionally, 92 kg/ha of nitrogen had a higher MRR (826.05%), exceeding the CIMMYT-recommended minimum, and a net income of 223,655.00 ETB.

These findings on optimal nitrogen fertilizer rates for irrigated wheat in Ethiopia could significantly boost wheat production, contribute to food security, and improve farmers' livelihoods. Based on the experimental results, 120% ASMDL with 92 kg/ha of nitrogen is recommended for the study area.

Abbreviations

ASMDL	Allowable Soil Moisture Depletion Level
CIMMYT	International Maize and Wheat Improvement Center
CV	Coefficient of Variation
ETB	Ethiopian Birr
ETc	Crop Evapotranspiration
Eto	Reference Evapotranspiration
FAO	Food and Agriculture Organization
Kc	Crop Coefficient
LC	Laboure Cost
LSD	Least Significant Difference
MRR	Marginal Rate of Return
N	Nitrogen
NI	Net Income
TC	Total Cost
TR	Total Return
WP	Water Productivity
Y	Grain Yield

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Author Contributions

Selamawit Bekele: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing

Oli Frrisa: Conceptualization, Data curation, Formal Analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review and editing

Kalkidan Degefa: Data curation, Validation, Visualization, Writing – original draft, Writing – review and editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Fields

Selamawit Bekele: Water Resource Management, Irrigation Engineering, Natural Resource Management, Agriculture Engineering and Mechanization, Soil Fertility

Oli Frrisa: Water Resource Management, Irrigation Engineering, Natural Resource Management, Agriculture, Soil Fertility

Kalkidan Degefa: Water Resource Management, Irrigation Engineering, Natural Resource Management, Agriculture, Water and Sanitation