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Research Article

Agronomic and Quality Responses of Durum Wheat (*Triticum turgidum* L. var. Durum) Varieties to Varying Nitrogen Fertilizer Rates in Bishoftu, Ethiopia

Sisay Eshetu[*], Bizuwork Tafes

Department of Agronomy and Crop Physiology, Ethiopian Institute of Agricultural Research, Debre Zeit, Ethiopia

Abstract

In the 2021 cropping season, an experiment was conducted to enhance productivity and refine the grain quality of durum wheat varieties by identifying the optimal N-fertilizer rate in Ethiopia's central highlands. The treatments included five N fertilizer levels with recommended P_2O_5 (0, 46, 69, 92, and 115 kg ha^{-1}), alongside an absolute control group (no NP fertilizer application), and three durum wheat varieties (Utuba, Et cross -21, and Mangudo). Employing a design featuring randomized complete blocks in triplicate, the analysis of variance indicated that aboveground biomass yield, grain yield and straw yield were harvested significantly influenced by the main effect of nitrogen fertilizer level (P<0.01). The highest aboveground biomass (12975.0 kg/ha^{-1}) and straw yield (8312.2 kg/ha^{-1}) occurred at the highest nitrogen rate (115 kg ha^{-1}), while the maximum grain yield (4786.1 kg ha^{-1}) was observed at 69 kg N/ha. Additionally, factors like leaf area index, total tillers, productive tillers, thousand seeds weight, and lodging index were significantly impacted by the combined influence of nitrogen fertilizer application and different durum wheat varieties. The results demonstrated that applying 69 kg N ha^{-1} yielded the highest economic benefit of 180782.4 ETB ha^{-1} with an acceptable marginal rate of return of 3277.8%. Thus, it is concluded that applying 69 kg N ha^{-1} along with the three durum wheat varieties led to economically profitable yield production. However, to provide more conclusive recommendations, the experiment should be repeated across multiple locations and seasons, incorporating balanced nutrient management.

Keywords

Durum Wheat, Nitrogen, Fertilizers

1. Introduction

Ethiopia stands as a significant player in the Sub-Saharan Africa (SSA) region, boasting a substantial presence in durum wheat production. With a sprawling durum acreage of 0.6 million hectares, the country commands between 15-20% of wheat production and covers approximately 30% of the entire acreage dedicated to wheat cultivation. This translates to a substantial contribution, ranging from 18 to 20%, towards the national wheat output. The heartlands of wheat cultivation in Ethiopia reside in the elevated terrains of the central, southeastern, and northwest regions. A notable aspect of Ethiopia's wheat landscape lies in its regional distribution of production.

[*]Corresponding author: Siscoeshetu23@gmail.com (Sisay Eshetu)

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Oromia emerges as the frontrunner, contributing a staggering 57.4% to the main season wheat output, closely followed by Amhara with 27%. Southern Nations, Nationalities, and Peoples' (SNNP) and Tigray regions also make notable contributions, accounting for 8.7% and 6.2% of the national production, respectively [5].

Durum wheat, a staple in Ethiopian agriculture, finds its primary utility In pasta manufacturing. variants such as macaroni, spaghetti, and semolina [25]. Its versatility extends to various culinary applications. The recent surge in privatization policies and the burgeoning pasta processing industry in Ethiopia have fueled a heightened demand for durum wheat grains, primarily as raw material for processors [9]. However, this escalating demand often surpasses domestic production capacities, leading to substantial reliance on imports. In rural communities, the value of wheat biomass transcends grain production, with wheat straw serving as fodder for animals and a material for roof thatching. Consequently, alongside high grain yields and environmental resilience, farmers prioritize these traits when selecting landraces for cultivation. Despite its historical significance and pivotal role in Ethiopian agriculture, the average yield of durum wheat remains disappointingly low, hovering around 2.8 tons per hectare, far below its yield potential of 7.0 tons per hectare [5]. Nitrogen, as the primary nutrient essential for plant growth, emerges as a linchpin in enhancing crop productivity. Its application, when optimized, is pivotal in achieving bumper wheat yields, owing to its crucial role in protein synthesis, enzyme function, and various metabolic processes. [21]. The response of crops to nitrogen and phosphorus fertilizers has been well-documented, as demonstrated by [15].

However, a dearth of tailored information plagues farmers across Ethiopia, particularly in the study areas, where nuanced insights regarding the impact of Different levels of nitrogen fertilizer application on different varieties of durum wheat. are lacking. Prevailing recommendations, such as a blanket application of nitrogen at 50 kg Urea (46% N) and 100 kg NPS (19% N, 38% P_2O_5, and 7% S) per hectare, fail to address the nuanced requirements of different wheat varieties. Consequently, this study aims to fill this critical knowledge gap by evaluating the agronomic response and quality of durum wheat varieties to varying nitrogen fertilizer rates, thereby empowering farmers with targeted insights for enhanced wheat cultivation practices.

2. Materials and Methods

2.1. Site Description

The field experiment was conducted on research field of DebreZeit Agricultural Research Center, during 2021 cropping season under rain-fed conditions. The coordinates of its geographical position are approximately 80° 44′ N latitude and 380° 58′ E longitude. Situated at an altitude of roughly 1900 meters above sea level, the area predominantly features heavy soils (Vertisol), interspersed with occasional patches of lighter soils. [24]

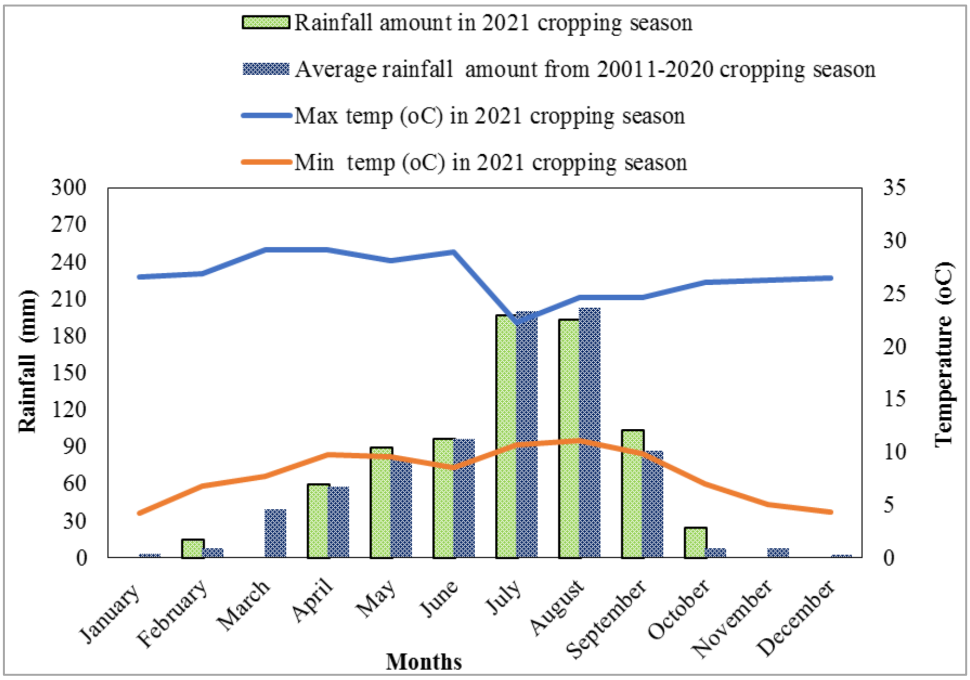

Figure 1. *Maximum and Minimum temperature and rain fall during 2021 and 2011-2020.*

2.2. Experimental Material Description

Three durum wheat varieties (*Utuba*, *ET cross -21*, and *Mangudo)* were used for this study. The varieties were selected based on year of release, yield, disease resistance, and farmer acceptance in the study area. The seed of the varieties was obtained from Debre Zeit Agricultural Research Center (DZARC).

2.3. Experimental Treatment and Design

The experimental setup comprises Five nitrogen fertilizer application rates rates (0, 46, 69, 92, and 115 kg N ha^{-1}), alongside the recommended P_2O_5 and a control group with no fertilizer (nil NP). Additionally, three durum wheat varieties (Utuba, Et cross -21, and Mangudo) were included. The experiment featuring randomized complete blocks with a factorial arrangement, replicated three times. In total, there were 54 unit plots (18×3), each measuring 3.2 m×3 m (9.6 m^2).

2.4. Soil Sample Collection and Analysis

About 9 soil sub-samples were collected from different spots at the depth of 0-20 cm using auger and thoroughly mixed to form a composite soil sample. The mixed composite soil sample was air-dried, then ground using a pestle and a mortar and allowed to pass through a 2 mm sieve. The samples were analyzed for selected Physico-chemical properties mainly organic carbon, total N, soil pH, available phosphorus (P) cation exchange capacity and soil texture were determined using standard laboratory procedures. Similar methods for soil characterization and their impact on wheat response to N and P fertilization have been documented by [12] OM was determined by Walkley and Black oxidation method.

Total nitrogen was analyzed by the Kjeldahl method (Dewis and Freitas, 1975). The pH of the soil was determined on a 1:2 (weight/volume) soils to water ratio using a pH meter [27]. Cation exchange capacity (CEC) was measured after saturating the soil with 1N ammonium acetate (NH_4OAc) and displacing it with 1N NaOAc [2]. Available phosphorus was determined by the Olsen method. Particle size distribution was done by the hydrometer method using particles less than 2 mm diameter.

2.5. Application of Fertilizer

The nitrogen fertilizer was administered through two split applications. (one third at sowing time, and two third at tillering) as recommended by [9]. Phosphorous at the rate of 100 kg ha^{-1} were applied at time of planting to all treatments, except the absolute control plot.

2.6. Management of Experimental Field

2.6.1. Preparation of Experimental Land

The experimental land underwent plowing on two occasions. Subsequently, The plots were readied for sowing using a row marker, ensuring 20 cm spacing between each row.

2.6.2. Sowing Seeds

Hand drilling was utilized for sowing at a rate of 150 kg per hectare, maintaining a row spacing of 20 cm.

2.6.3. Weed and Disease Control

Different types of weeds were removed from the experimental land. Additionally, to avoid damage and variability due to an outbreak of rust disease which often occur in the area, fungicide (Rex Duo) was applied at the rate of 0.5 L ha^{-1} immediately at the start of disease appearance.

2.7. Data Collection

2.7.1. Phenological and Growth Parameters

Days to 50% heading: The duration until 50% heading occurred: This metric was measured when approximately half of the plants within a plot began producing spikes.

Days to 90% physiological maturity: The duration until physiological maturity was documented when approximately 90% of the plants attained this stage.

Plant height (cm): At maturity ten plants were selected randomly and tagged the plants from the net plot area of each plot. Then plant height was measured from the ground to the tip with the help of a ruler with excluding of awns and the mean value was determined.

Leaf area index (LAI): It was calculated as the ratio of total leaf area per plant and the area occupied by the plant. It was measured by using a plant canopy analyzer (Model CI-110) starting from the crop reached at tillering stage with the interval of 30 days (at tillering, stem elongation, and grain fill period) until physiological maturity.

2.7.2. Parameters Related to Yield and Its Components

At maturity, total tillers, comprising both effective and non-effective ones, were tallied from ten randomly chosen pre-tagged plants within each net plot area. Productive tillers (effective ones) were specifically recorded from the same set of ten pre-tagged plants in each net plot area. Additionally, ten spikes were randomly selected from the main tillers within each plot, excluding awns, and their lengths were measured from base to tip to determine the mean. Similarly, another set of ten spikes from each plot were randomly chosen to count the number of kernels per spike, and the mean was noted. Following this, all above-ground Plant components such as leaves, stems, and seeds were harvested from the designated plot area. and sun-dried until reaching a constant weight. Subsequently, the above-ground biomass (AGB) was measured using an electronic balance. Following the harvest, all plants from each plot's net plot area were collected, threshed, cleaned, and weighed. The grain yield was then adjusted to a moisture content of 12.5% on a wet basis. Grain yield was measured using an electronic balance, while moisture content was determined using moisture testers, and yield adjustment was calculated using a formula described by [2].

$$\text{Grain yield (kg ha}^{-1}\text{) at 12.5} = \text{Grain yield obtained kg ha}^{-1} \times \frac{(100-MC\%)}{(100-12.5)} \quad (1)$$

Where, MC= grain moisture content.

Straw yield: Straw yield per net plot was obtained out by subtracting total grain yield weight from the total biomass yield for respective treatments. Later the straw yields ha^{-1} were computed and expressed in kg ha^{-1}.

Lodging index: Lodging severity was evaluated prior to harvest using a visual assessment scale ranging from 1 to 5, where: 1 (0-15°) signifies no lodging, 2 (15-30°) indicates 25% lodging, 3 (30-45°) indicates 50% lodging, 4 (45-60°) indicates 75% lodging, and 5 (60-90°) indicates complete lodging. Each plot was categorized based on the angle of deviation of the main stem from the vertical line at its base. The lodging percentage for each plot was calculated by multiplying the scale value by its corresponding percentage, with the average of these values representing the overall lodging percentage. Data on lodging percentage underwent arcsine transformation as outlined for data presented in percentages.

Harvest index (HI) (%): Harvest index (HI), representing the ratio of grain to total biological yield, serves as an indicator of a crop's efficiency in allocating photosynthetic products to grains. Harvest index was determined as the ratio of grain yield to the total aboveground biomass. HI was calculated according to the following formula:

$$\text{HI (\%)} = \frac{\textit{Grain yield}}{\textit{Biological yield}} \times 100 \quad (2)$$

Thousand kernels weight (TKW) (g): It was determined based on the weight of 1000 kernels sampled from the grain yields of each plot.

2.7.3. Quality Parameters

Grain protein and moisture contents

The grain sample was collected and subjected to analysis of protein content and moisture content. The protein and moisture measurement was conducted employing Near Infrared reflectance spectrometry (NIRS), Model EU Perten Instrument- IM8800.[14]

Hectoliter weight

It was determined for dockage-free grain samples using a Seed burro Hectoliter mass device and an electronic balance.

2.8. Statistical Analysis

Statistical analysis was conducted using software and included a two –way analysis of variance. When significant treatment effects occurred, means separation were compared using LSD (0.05). The correlation between grain yields, growth parameters, physiological parameters, and yield components were determined using Pearson's correlation, according to [16].

3. Results and Discussion

3.1. Soil Physio-Chemical Properties

Available phosphorus in the soil was determined using the Olsen method [18], which is a standard procedure for assessing plant-available phosphorus. The results indicated a very high level of available phosphorus (22.24 mg/kg). The results of the soil physio-chemical properties analysis of the experimental site are presented in Table 1.

Soil nutrient management practices were based on established principles of plant nutrition, as outlined by [20].

Table 1. *Selected physicochemical properties of the experimental soils before sowing at Bishoftu in 2021 cropping season.*

Soil Physical Properties	**Value**	**Textural class**	**Methodology**
Clay (%)	45.6		
Silt (%)	10.8	Clay	Rowell (1994)
Sand (%)	43.6		
Soil Chemical Properties	Value	Rate	Source
pH (1: 2.5 H_2O)	6.61	Neutral	Tekalign (1991)
CEC [Cmol(+)kg^{-1} soil]	15.28	Medium	Landon (1991)
Organic matter (%)	1.60	Low	Tekalign (1991)
TN (%)	0.12	Low	Tekalign (1991)
Available phosphorus	22.24	Very High	Olsen (1954)

3.2. Phenological and Growth Parameters

3.2.1. Time Taken to Reach 50% Heading

The main effect of N fertilizer level and durum wheat varieties exhibited high significance ($P < 0.01$). However, no interaction effect was observed between the two factors.

The control N plot showed a delayed onset of heading at 65.5 days, a value statistically comparable to the control NP treatment. Conversely, the earliest onset of heading, at 62.2 days, was observed with the application of 92 kg N ha^{-1}, a result statistically similar to rates of 69 and 115 kg N ha^{-1}.

Regarding durum wheat varieties, Et cross-21 demonstrated delayed heading at 65 days compared to Mangudo (63.0 days) and Utuba (62.8 days) varieties. This variation may be attributed to genetic differences among the durum wheat varieties. Additionally, previous studies have also noted varietal disparities in heading days [19].

3.2.2. Days to 90% Physiological Maturity

The study revealed a significant main effect of N-fertilizer rate ($P < 0.05$) on days to 90% physiological maturity. However, neither the main effect of variety nor the interaction effect of N-fertilizer rates by variety demonstrated a significant influence on days to 90% physiological maturity.

Application of 115 kg ha^{-1} of N accelerated the days to physiological maturity, with maturity dates progressively advancing with increasing N rate. The shortest duration to reach 90% physiological maturity (107.3 days) was observed at a rate of 69 kg N ha^{-1}, statistically comparable to rates of 92 kg N ha^{-1} (108.2 days) and 115 kg N ha^{-1} (107.6 days). Conversely, delayed maturity was recorded at the control NP (111.3 days) and control N plots (111.2 days).

This acceleration in maturity could be attributed to the increased nitrogen fertilizer levels, coupled with optimal soil moisture conditions, enhancing nitrogen use efficiency and promoting growth and development. This finding aligns with previous research [4], suggesting that adequate nitrogen levels and soil moisture content facilitate rapid growth and heading in wheat. However, contrary findings from [13] and [23] indicate that higher N fertilizer application rates may lead to significant delays in heading for wheat and barley production compared to lower levels.

Table 2. *Effects of N fertilizer level and durum wheat varieties on days to 50% heading, days to 90% physiological maturity, and plant height in 2021 cropping season at Bishoftu.*

Treatments	**Days to 50% heading**	**Days to 90% Physiological Maturity**	**Plant height (cm)**
Variety			
Utuba	62.8^{b}	108.3	80.9
Et cross-21	65.0^{a}	109.2	82.8
Mangudo	63.0^{b}	109.3	81.8
LSD (5%)	0.8	NS	NS
Nitrogen level ($kgha^{-1}$)			
Without NP	65.1^{ab}	111.3^{a}	74.2^{c}
Without N	65.5^{a}	111.2^{a}	71.4^{c}
46	64.0^{b}	108.2^{b}	82.2^{b}
69	62.5^{c}	107.3^{b}	86.6^{a}
92	62.2^{c}	108.2^{b}	88.1^{a}
115	62.4^{c}	107.6^{b}	88.6^{a}
LSD (5%)	1.2	2.0	3.5
CV (%)	1.9	2.0	4.5

Means with the same letter in columns are not significantly different at a significance level of 5%; LSD= Least Significant differences at 5%; CV (%) = Coefficient of variation.

3.2.3. Plant Height

The result showed that only the main effect of N fertilizer rates highly significantly (P< 0.01) influenced plant height.

The results suggest a clear relationship between nitrogen (N) application rates and plant height in wheat. The tallest plant height was observed at the highest N application rate (115 kg ha^{-1}), with statistically similar heights recorded at slightly lower rates (92 kg ha^{-1} and 69 kg ha^{-1}). These heights were significantly greater in comparison to the control plot where no nitrogen was applied.

The increase in plant height with N application indicates that nitrogen plays a vital role in enhancing vegetative growth in wheat. Nitrogen facilitates the synthesis of various essential macromolecules such as proteins, enzymes, pigments, and hormones. Additionally, it promotes vital processes like photosynthesis, cell division, and cell elongation, which collectively contribute to increased internode length and ultimately taller plants.

This finding is consistent with previous studies cited (references [26, 9], which also reported a positive correlation between nitrogen application and plant height in wheat. For example, [26] and [9] demonstrated that increasing nitrogen fertilizer rates led to increased plant height in durum wheat.

Overall, the results indicate that proper nitrogen fertilization significantly influences wheat plant height, with higher application rates generally resulting in taller plants due to improved vegetative growth and internode elongation.

3.2.4. Leaf Area Index

The results of the study demonstrate a significant impact of nitrogen (N) fertilizer levels and durum wheat varieties on leaf area index (LAI) at various stages after sowing. Both factors individually influenced LAI at 30, 60, and 90 days after sowing (DAS), with their interaction also proving to be significant at these time points. [9]

At 30 DAS, the highest LAI (3.8) was observed with 115 kg N ha^{-1} application combined with the Et cross -21 variety, while the lowest LAI (2.3) was recorded with the Utuba variety grown on control NP, though statistically similar to several other treatments. However, the results were inconsistent at this stage.

By 60 DAS, the highest LAI (4.5) was seen with 115 kg N ha^{-1} application and the Et cross -21 variety, though not significantly different from several other treatments. Conversely, the lowest LAI (3.8) was recorded with the Mangudo variety on the unfertilized plot, statistically similar to control N with Et cross -21. Unlike the 30 DAS stage, a positive response to N fertilizer rates was observed, albeit inconsistently.

At 90 DAS, the highest LAI (3.8) was again with 115 kg N ha^{-1} combined with the Et cross -21 variety, statistically similar to several other treatments, while the lowest LAI (2.3) was obtained with 92 kg N ha^{-1} with Mangudo, and 92 kg N ha^{-1} with Et cross -21.

Overall, the application of N fertilizers positively influenced LAI, particularly at the mid-growth stage (60 DAS), enhancing tissue formation and plant growth. This effect may be attributed to increased leaf size and number per tiller. The findings align with previous studies indicating the positive impact of N fertilization on leaf area, dry matter production, and grain yield in wheat and barley. [22]

Table 3. *Interaction effects of N fertilizer and varieties on LAI at 30, 60, and 90 DAS.*

Variety	Nitrogen Level kg ha^{-1}	LAI at 30 DAS	LAI at 60 DAS	LAI at 90 DAS
Utuba	Without NP	2.3^{c}	4.3^{bcd}	3.0^{c}
	Without N	2.3^{c}	4.3^{cd}	3.0^{c}
	46	3.2^{b}	4.2^{d}	3.2^{bc}
	69	3.0^{b}	4.5^{a}	3.0^{c}
	92	3.0^{b}	4.5^{a}	3.8^{a}
	115	3.0^{b}	4.3^{bcd}	3.0^{c}
Et cross -21	Without NP	2.5^{c}	3.9^{f}	3.0^{c}
	Without N	3.0^{b}	3.8^{g}	3.1^{c}
	46	2.3^{c}	4.3^{cd}	3.2^{bc}
	69	3.0^{b}	4.4^{abc}	3.5^{ab}
	92	3.0^{b}	4.3^{bcd}	2.3^{d}
	115	3.8^{a}	4.5^{a}	3.8^{a}
Mangudo	Without NP	2.5^{c}	3.8^{f}	3.0^{c}
	Without N	3.0^{b}	4.2^{d}	3.0^{c}

Variety	Nitrogen Level kg ha^{-1}	LAI at 30 DAS	LAI at 60 DAS	LAI at 90 DAS
	46	2.3^{c}	4.4^{ab}	3.2^{bc}
	69	3.0^{b}	4.4^{ab}	3.0^{c}
	92	2.3^{c}	4.5^{a}	2.3^{d}
	115	3.0^{b}	4.0^{e}	3.5^{ab}
LSD (5%)		0.1	0.08	0.20
CV (%)		6.1	2.0	6.7

LAI= Leaf area Index, DAS = days after sowing

3.3. Yield and Yield Components Parameters

3.3.1. Number of Total and Productive Tillers

The analysis of variance indicated highly significant main effects of N fertilizer rates and their interaction on the number of total tillers ($P < 0.01$), while the main effects of variety were not significant. The highest total tiller count (8.6) was observed at 115 kg N ha^{-1} with the Mangudo variety, statistically comparable to the same N rate with Utuba variety, and Et cross-21 varieties, as well as 92 kg N ha^{-1} with Mangudo (Table 4). Conversely, the lowest total tiller count (4.0) was recorded in plots treated with control N and the Mangudo variety. Notably, the increase in total tillers with higher N fertilizer levels was consistent for Mangudo but not for Utuba and ET cross-21 varieties. This disparity in tiller count may be attributed to nitrogen's role in promoting carbohydrate utilization and stimulating rapid growth by increasing total tillers. These findings align with previous research [10], which emphasized the positive impact of optimal N fertilizer application on tillering and survival percentage in wheat crops.

Similarly, the number of productive tillers was significantly influenced by N fertilizer rates and their interaction ($P < 0.01$), while the main effects of durum wheat variety were not significant. The highest count of productive tillers (8.6) was again associated with 115 kg N ha^{-1} and the Mangudo variety, while the lowest count (4.0) was observed in control N plots with Mangudo. This suggests that N plays a crucial role in stimulating vegetative growth and tillering capacity in durum wheat varieties. These results corroborate previous studies [3], which demonstrated an increase in effective tillers with nitrogen fertilization. Additionally, research by [9] and [1] also supports the significant impact of nitrogen fertilization on the effective number of tillers in durum wheat.

Table 4. *The interaction effects of N fertilizer level and durum wheat varieties on the number of total tillers and productive tillers per plant at Bishoftu in 2021 cropping season.*

Variety	Nitrogen Level kg ha^{-1}	Number of total tillers per plant	Number of productive Tillers per plant
Utuba	Without NP	6.0^{cdef}	5.6^{bcdef}
	Without N	4.6^{fgh}	4.3^{fg}
	46	4.3^{gh}	4.3^{fg}
	69	5.6^{defg}	5.3^{cdefg}
	92	6.3^{bcde}	6.3^{bcd}
	115	7.6^{ab}	7.0^{b}
Et cross -21	Without NP	5.6^{defg}	5.3^{cdefg}
	Without N	6.3^{bcde}	6.0^{bcde}
	46	5.3^{defgh}	5.0^{defg}
	69	5.0^{efgh}	5.0^{defg}
	92	6.3^{bcde}	6.3^{bcd}
	115	7.3^{abc}	6.6^{bc}

Variety	Nitrogen Level kg ha^{-1}	Number of total tillers per plant	Number of productive Tillers per plant
Mangudo	Without NP	4.0^{h}	4.0^{g}
	Without N	4.6^{fgh}	4.6^{efg}
	46	5.6^{defg}	5.6^{bcdef}
	69	6.6^{bcd}	6.6^{bc}
	92	7.3^{abc}	7.0^{b}
	115	8.6^{a}	8.6^{a}
LSD (5%)		1.3	1.4
CV (%)		13.6	14.9

3.3.2. Spike Length and Number of Kernels per Spike

The length of spikes was significantly influenced by both the N rate and variety, with a highly significant effect ($P < 0.001$) observed for N rate and a significant effect ($P < 0.05$) observed for variety. However, there was no significant interaction between these two factors. The longest spike length of 6.0cm was observed at an N rate of 115 kg ha^{-1}, while the shortest mean spike length of 4.6cm was recorded under the control N treatment, which was statistically similar to the control NP treatment (Table 5). This increase in spike length may be ascribed to spike elongation resulting from cell division and expansion due to N addition. These findings are consistent with those of [6], who found that durum wheat spike length increased with N fertilizer application, with the longest spike length of 7.93 cm recorded at 75 kg N ha^{-1} and the shortest of 4.26 cm under control conditions. Additionally, the Et cross-21 variety exhibited the longest spike length (5.4 cm) compared to Utuba (5.1cm) and Mangudo (5.3 cm) varieties, suggesting a genetic influence on spike length.

The number of kernels per spike was significantly influenced by the nitrogen rate ($P< 0.001$), with no significant effects observed for either the main effect of durum wheat varieties or their interaction. There was a noticeable rise in the number of kernels per spike as the nitrogen application rate increased. The highest average number of kernels per spike (60.0) was observed at an N rate of 115 kg ha^{-1}, which was comparable to the rate of 92 kg N ha^{-1}, while the lowest mean number of kernels per spike (40.6) was recorded under the control NP treatment. These findings are consistent with [25], who noted a significant increase in the number of kernels per spike with increasing N rates up to an optimal level. Similarly, Ahmed et al. (2008) reported a similar increase in kernels per spike with N application in wheat.

Table 5. *Effects of N fertilizer and varieties on the spike length and number of kernels per spike.*

Treatments	Spike length in (cm)	Number of kernels per spike
Variety		
Utuba	5.1^{b}	46.8
Et cross-21	5.4^{a}	50.3
Mangudo	5.3^{ab}	52.1
LSD (5%)	0.18	NS
Nitrogen Level (kg ha^{-1})		
Without NP	4.8^{c}	40.6^{d}
Without N	4.6^{c}	48.1^{bc}
46	5.2^{b}	49.1^{bc}
69	5.5^{b}	51.8^{b}
92	5.4^{b}	53.8^{ab}

Treatments	Spike length in (cm)	Number of kernels per spike
115	6.0[a]	60.0[a]
LSD (5%)	0.26	6.8
CV (%)	5.2	14.3

Means with the same letter in columns are not significantly different at 5% level of significance; LSD= least significant differences at 5%; CV (%) = Coefficient of variation

3.3.3. Aboveground Biomass Yield

The analysis revealed a highly significant effect of N rates on aboveground dry biomass yield (P<0.001), while the main effect of varieties and their interaction were found to be not significant.

The highest aboveground dry biomass yield (12975.0 kg ha^{-1}) was observed with the application of 115 kg ha^{-1} of N fertilizer, statistically equivalent to yields obtained with 92 kg ha^{-1} and 69 kg ha^{-1} of N fertilizers, which recorded yields of 12644.0 kg ha^{-1} and 12637.0 kg ha^{-1}, respectively. Conversely, the lowest yield (6794.0 kg ha^{-1}) was observed in the control N plot, with no significant difference from the control NP plot. This outcome could be attributed to the optimal supply of nitrogen, enhancing photosynthetic activity, promoting vigorous vegetative growth, and resulting in deep green leaves, ultimately improving carbohydrate utilization. Previous research [7] supports this finding, indicating that optimal nitrogen application significantly enhances durum wheat biomass yield.

3.3.4. Grain Yield

Regarding grain yield, the ANOVA revealed a highly significant effect of N rates (P<0.001), while the main effect of variety and their interaction were not significant.

The maximum grain yield (4786.1 kg ha^{-1}) was attained with the application of 69 kg N ha^{-1}, statistically comparable to yields obtained with 92 kg ha^{-1} and 115 kg ha^{-1} of N fertilizers. Conversely, the lowest grain yield (2216.8 kg ha^{-1}) was observed in the control plot. The results suggest that increasing N rates beyond 69 kg ha^{-1} did not significantly increase grain yield, indicating that excessive N fertilizer application does not enhance yield beyond optimal levels. This aligns with previous findings [9], which indicated that increasing nitrogen fertilization rate only marginally increased wheat grain yield. applying 46 kg N ha^{-1} increased grain yield by 115.3% compared to the control and by 38.5% compared to 23 kg N ha^{-1}, further supporting the optimal nitrogen application for maximizing wheat yield.

3.3.5. Straw Yield

The N fertilizer rate significantly influenced straw yield (P<0.001), while the main effects of varieties and their interaction were found to be non-significant.

The analysis revealed that the highest straw yield (8312.2 kg ha^{-1}) was achieved with the application of 115 kg N ha^{-1}, whereas the lowest yield (4577.2 kg ha^{-1}) was observed in the control N plot. However, the yield obtained with 115 kg N ha^{-1} was statistically similar to yields obtained with N rates of 92, 69, and 46 kg N ha^{-1}. These findings suggest that N fertilizer primarily promoted vegetative growth over reproductive growth, as indicated by a decreased harvest index at the highest N rate [5]. This aligns with previous research [4] and [9], which demonstrated an increase in wheat straw yield with higher N rates.

Table 6. *Effect on N fertilizer and varieties on aboveground biomass, grain yield, straw yield, and harvest index.*

Treatments	Aboveground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
Variety				
Utuba	10159.0	3649.2	6509.4	35.8
Et cross-21	9902.0	3752.3	6149.4	38.5
Mangudo	10961.0	3770.6	7190.2	34.5
LSD (5%)	ns	ns	ns	ns
Nitrogen Level (kg ha^{-1})				
Without NP	8287.0[c]	2766.9[c]	5520.1[c]	33.5

Treatments	Aboveground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
Without N	6794.0^{c}	2216.8^{d}	4577.2^{c}	34.4
46	10226.0^{b}	3386.6^{b}	6839.3^{ab}	33.8
69	12637.0^{a}	4786.1^{a}	7850.0^{ab}	37.9
92	12644.0^{a}	4625.5^{a}	8018.5^{ab}	39.1
115	12975.0^{a}	4662.3^{a}	8312.2^{a}	36.3
LSD (5%)	1759.2	542.3	1606.3	NS
CV (%)	17.7	15.2	25.3	18.0

3.3.6. Harvest Index

The main effects of nitrogen fertilizer and varieties, as well as their interaction, did not significantly impact the harvest index. However, there were numerical differences observed among nitrogen rates, suggesting a trend of decreasing harvest index with increasing nitrogen rates beyond 92 kg ha^{-1}. This reduction in harvest index at higher nitrogen rates may be attributed to the greater production of vegetative biomass compared to grain yield, indicating a proportionally higher vegetative biomass yield than grain yield at higher nitrogen rates [2].

3.3.7. Lodging Index

Table 7. *The interaction effects of N fertilizer level with durum wheat varieties on lodging index in %.*

Nitrogen Rate (kg ha^{-1})	Durum wheat varieties		
	Utuba	***Et cross -21***	***Mangudo***
Without NP	6^{h}	16^{e}	7^{h}
Without N	12^{f}	10^{g}	9^{g}
46	19^{d}	29^{b}	15^{e}
69	14^{e}	30^{b}	15^{e}
92	15^{e}	30^{b}	14^{e}
115	23^{c}	50^{a}	15^{e}
LSD (5%)	1.8		
CV (%)	10.7		

The ANOVA analysis revealed significant impacts of both the N fertilizer rate, durum wheat varieties, and their interaction on the lodging index ($P < 0.01$). The highest lodging index (50%) occurred in plants treated with 115 kg ha^{-1} of N fertilizer combined with the Et cross-21 variety, while the lowest indexes (7% and 6%) were observed in control plots with the Utuba and Mangudo varieties respectively (refer to Table 7). The escalation of lodging with increased nitrogen application could be attributed to nitrogen's tendency to promote excessive vegetative growth, leading to weaker stems [17]. Previous studies have noted how heavy nitrogen use reduces stem strength, stem diameter, and stem wall width. The taller stature resulting from higher nitrogen rates may also predispose plants to lodging. who observed increased lodging with maximum nitrogen application. Furthermore, there were variations in lodging susceptibility among durum wheat varieties, with Et cross-21 showing higher susceptibility to increasing N rates compared to Utuba and Mangudo, possibly due to inherent genetic traits.

3.3.8. Thousand Seeds Weight

The ANOVA outcomes indicated a significant influence of nitrogen rates ($P < 0.001$), durum wheat varieties ($P < 0.005$), and their interaction ($P < 0.001$) on the thousand seed weight. The highest thousand seed weight (46.8g) was observed in plots treated with control NP and the Et cross-21 variety, statistically comparable to plots treated with 69 kg N ha^{-1} combined with the Mangudo variety (46.1g) and control NP with the Utuba variety (45.8g). Conversely, the lowest seed weight (41.3g) was recorded with the application of 46 kg N ha^{-1} in conjunction with the Mangudo variety. Notably, there was a declining trend in thousand seed weight with higher N rates; beyond 69 kg ha^{-1}, the application of N fertilizer tended to reduce the thousand seed weight. This decline might be attributed to excessive nitrogen fertilization stimulating vegetative growth at the expense of grain weight due to reduced carbohydrate translocation to reproductive organs. This finding aligns with previous studies reporting a decrease in thousand seed weight with increasing nitrogen levels. For instance, [9] observed a 3.7% reduction in thousand seed weight of bread wheat when nitrogen rates were raised from 92 kg ha^{-1} to 138 kg ha^{-1}. Similarly, [11] reported decreases in wheat thousand seed weight with increasing nitrogen levels.

Table 8. Interaction effects of nitrogen level and varieties on thousand seed weight in gm.

Nitrogen Rate (kg ha^{-1})	Durum wheat varieties		
	Utuba	*Et cross-21*	*Mangudo*
Without NP	45.8^{ab}	46.8^{a}	44.2^{def}
tWithout N	41.867^{gh}	44.4^{cdef}	45.4^{bcd}
46	43.1f^{g}	45.7^{abc}	41.3^{h}
69	44.2d^{ef}	44.8^{bcde}	46.1^{ab}
92	43.6^{ef}	44.9^{bcde}	44.9^{bcde}
115	45.0^{bcd}	44.8^{bcde}	44.9^{bcde}
LSD (5%)	1.39		
CV (%)	1.88		

3.3.9. Agronomic Use Efficiency Parameters

The results showed that a significant difference was observed in agronomic use efficiency between the main effect of N rates (Table 9).

The higher agronomic efficiencies (37.23 kg/kg) were recorded at 69 kg N ha^{-1}. While the lowest agronomic efficiencies were obtained at the highest (115 kg N ha^{-1}). This implied that at a high N rate the applied N could be excess and the efficiency becomes diminished. Therefore, the agronomic efficiencies are linearly related to the N rate. Similarly, [5, 9] also reported that the agronomic and physiological efficiency of wheat decreases with increasing N rates. According to [8], agronomic efficiency has been a common value of between 10 and 30.

If the obtained results are above these common values, it could be concluded that the farm was under a well-managed system and the reverse is true, if the results obtained are below the common values. The present result values for agronomic use efficiency was within the ranges for the fertilizer rates tested which indicated the farm was under a well-managed system.

Table 9. Agronomic use efficiency as affected by nitrogen fertilizer rate.

Nitrogen Rate (kg ha^{-1})	AUE (kg/kg)
Without NP	-
Without N	-
46	25.43
69	37.23
92	26.18
115	21.26

AUE= Agronomic use efficiency

4. Quality Parameters of Durum Wheat

4.1. Grain Protein Content

The ANOVA analysis demonstrated a highly significant difference (P < 0.001) in grain protein content due to the main effects of nitrogen rates and durum wheat varieties, although their interaction did not show significance.

The highest protein content (13.43%) was noted in wheat grain harvested from plots treated with 115 kg N ha^{-1}, while the lowest (12.84%) was recorded in grain from plots treated with control NP, though statistically similar to rates of control N, 46, 69, and 92 kg N ha^{-1} (refer to Table 10). The variation in protein content concerning nitrogen fertilization may be attributed to increased nitrogen levels enhancing dry matter and amino acid concentrations, consequently raising protein content. This outcome resonates with [27], who observed maximum grain protein content (11.52%) for durum wheat at the highest N rate (92 kg ha^{-1}). Similarly, [17] reported that the highest grain protein (13.09%) accumulated at the highest N rate (120 kg N ha^{-1}) in bread wheat.

Regarding varieties, the highest protein content (13.12% and 13.02%) was obtained from the Mangudo and Utuba varieties, respectively, while the lowest (12.8%) was recorded from the Et cross-21 variety. (Table 11) Likewise [21] found significant differences in grain protein content among different wheat genotypes. [24] described wheat grain protein content as influenced by various factors such as variety, location, crop year, temperature, rainfall, and soil fertility.

4.2. Hectoliter Weight

The primary impact of nitrogen fertilizer levels and durum wheat varieties, along with their interaction, did not show a significant influence on hectoliter weight. This could be attributed to the limited impact of nitrogen fertilizer rates on the hectoliter weight of durum wheat.

Table 10. Effect of N fertilizer and varieties on protein content and Hectoliter weight.

Treatments	Protein content (%)	Hectoliter weight (kg hl^{-1})
Varieties		
Utuba	13.02^{a}	79.58
Et cross-21	12.8^{b}	79.35
Mangudo	13.12^{a}	79.50
LSD (5%)	0.17	NS
Nitrogen Level (kg ha^{-1})		
Control NP	12.84^{b}	78.95
Control N	12.95^{b}	79.33

Treatments	Protein content (%)	Hectoliter weight (kg hl^{-1})
46	12.75^{b}	79.37
69	12.97^{b}	79.73
92	12.97^{b}	79.60
115	13.43^{a}	79.88
LSD (5%)	0.24	NS
CV (%)	1.9	0.84

5. Association of Selected Yield Components Traits

The correlation analysis reveals the extent of association between variables, indicating how one variable changes in response to changes in another. Using Pearson's correlation method, the relationship between durum wheat the components contributing to yield and the grain yield were investigated. The results demonstrate significant and positive correlations between plant height (r=0.895**), total tillers (r=0.46**), productive tillers (r=0.48**), spike length (r=0.78**), kernels per spike (r=0.50**), thousand seed weight (r=0.26**), and harvest index (r=0.38**) with grain yield. This suggests that enhancing any of these traits could lead to increased grain yield. Furthermore, yield exhibited highly significant and positive correlations with the number of productive tillers per plant, spike length, number of spikelets, and number of grains per spike. Previous studies have also identified positive and significant correlations between biological yield, harvest index, and grain yield [6].

6. Partial Budget Analysis

The partial budget analysis revealed that the plot treated with 69 kg N ha^{-1} resulted in the maximum net benefit of 180,782.4 ETB, with a marginal rate of return (MRR) of 3277.8%. In contrast, the control plot yielded the lowest net benefit of 90,074.49 ETB. The MRR between any pair of un-dominated treatments represented the return per unit of investment as a percentage. The results of un-dominated treatments indicated that for every birr invested in treatments, an additional 32.70 Birr could be recovered by using 69 kg N ha^{-1}. The recommendation was based on changes from one treatment to another, considering a marginal rate of return greater than the minimum rate of return of 100%. Therefore, the economically profitable application rates, indicated by both the net benefit and the higher MRR, suggest that 69 kg N ha^{-1} can be recommended for farmers in the study area.

Table 11. *Partial budget analysis of durum wheat as influenced by N fertilizer rates at Bishoftu in 2021 main cropping season.*

Nitrogen Rate (Kgha^{-1})	AGY (Kg/ha^{-1})	ASY (Kg/ha^{-1})	BGY (ETB/ha^{-1})	BSY (ETB/ha^{-1})	TGB (ETB/ha^{-1})	TVC (ETB)	NB (ETB)	MRR
Without NP	2490.21	4968.09	79686.72	35190.64	114877.4	0	114877.4	0
Without N	1995.12	4119.48	63843.84	29179.65	93023.49	2949	90074.49	D
46	3047.94	6155.37	97534.08	43600.54	141134.6	5717	135417.6	359.28
69	4307.49	7065.01	137839.68	50043.75	187883.4	7101	180782.4	3277.80
92	4162.95	7216.65	133214.4	51117.94	184332.3	8485	175847.3	D
115	4196.07	7480.98	134274.24	52990.28	1872264.5	9869	177395.5	D

D=Dominated treatments, ETB=Ethiopian birr. MRR= Marginal rate of return.

7. Conclusions

The study highlights the lack of information on the optimal nitrogen fertilizer rate for durum wheat production, particularly for newly released varieties, as a significant challenge contributing to low productivity in the area. Various nitrogen fertilizer rates were tested, revealing differences in plant characteristics and yield metrics. The highest grain yield, net benefit, and acceptable marginal rate of return were achieved with an application rate of 69 kg N ha^{-1}. This rate also resulted in the highest agronomic use efficiency. Consequently, the use of 69 kg N ha^{-1} is recommended for newly released durum wheat varieties in the study area, including Utuba, Et cross-21, and Mangudo. However, the findings are based on a single-year experiment at one location, thus necessitating further research across different soil types, environments, cropping sequences, and locations to provide comprehensive and reliable recommendations for longer-term and diverse cropping systems.

Abbreviations

AUE	Agronomic Use Efficiency
ATA	Agricultural Transformation Agency
CIMMYT	International Centre for Wheat and Maize Improvement
DZARC	Debre Zeit Agriculture Research Centre
EPAR	European Public Assessment Report
MoA	Ministry of Agriculture
NIRS	Near Infrared Reflectance Spectrometry
PAR	Photosynthetically Active Radiation
RGR	Relative Growth Rate
RUE	Radiation Use Efficiency
SSA	Sub Saharan Africa

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Data Availability

The raw data represents the author's attributes; hence it's not permissible to distribute the raw data.

Conflicts of Interest

The authors declare no conflicts of interest.

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