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Influence of Nitrogen Fertilizer Rates on Growth, Yield, and Grain Quality of Durum Wheat (*Triticum durum* Desf) Cultivars in Central Ethiopia

Firew GebreMariam Woldgiorgis[1,*], Kindie Tesfay Fantaye[2], Almaz Meseret Gezahegn[3], Tesfaye Balemi Tufa[4], Abdultif Ahmad Adam[1] and Negash Geleta Ayana[5]
*[1]Haramaya University College of Agriculture and Environmental Science School of Plant Sciences, Dire Dawa, Ethiopia; [2]International livestock research/International Maize and Wheat Improvement Centre (CIMMYT), Addis Ababa, Ethiopia; [3]Debre Zeit Agricultural Research Centre, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia; [4]Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia; [5]Kulumsa Agricultural Research Centre, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia; *__Corresponding author:__ Email: firewgmariam@gmail.com*

Abstract

Appropriate nitrogen rate recommendation is one of the realistic ways to save nitrogen fertilizer in Ethiopia. The field experiments were conducted in two years of 2022 and 2023 GC on heavy black soil to investigate the effect of nitrogen fertilizer rates on durum wheat growth, yield, and quality in the central part of Ethiopia. The treatments of the experiments have five nitrogen rates (0, 46, 92, 138, and 184 kg N ha^{-1}) and two durum wheat cultivars (Mangudo and Utuba). The experiments were conducted in randomized complete block design in the factorial arrangement with three replications. The results showed that increasing nitrogen rates up to 138 kg N ha–1 resulted in significant improvements in all studied parameters, with the exception of starch content. Mangudo and Utuba cultivars exhibited the highest yield and quality responses to nitrogen treatments, respectively. The yield and quality of the tested cultivars increased with increased nitrogen rates, with the maximum values recorded at 138 kg N/ha. However, the cost-benefit analysis revealed that 92 kg N/ha has the maximum marginal rate of return compared to other nitrogen treatments for both cultivars. Furthermore, for every birr invested in Mangudo production, farmers can recover their investment and earn an additional 10.1 birr compared to Utuba production. Therefore, we recommend applying 92 kg N/ha as the optimal nitrogen rate for durum wheat production in the study area and similar agro-climatic regions.

Keywords: Durum wheat; Nitrogen; Protein content; Starch content; Yield

Introduction

Durum (*Triticum turgidum* L.) and bread (*Triticum aestivum* L.) wheat species were cultivated Worldwide (Mathews *et al.*, 2006). Conversely; from the total wheat production area in the World, durum wheat production only accounted for 8% (Ceglar *et al.*, 2021). Of the total durum wheat cultivated areas in the world, 75% of the cultivated land is in Mediterranean countries (Mansouri *et al.*, 2018). Durum wheat is also grown in semi-arid zones such as North Africa, South Europe, and the Middle East (Hammami and Sissons, 2020).

In Ethiopia, both durum and bread wheat are cultivated under a rain-fed production system (Wuletaw Tadesse *et al.,* 2022) and durum wheat was predominantly cultivated in central, north-western, and north-eastern parts of the country (Meseret Asmamaw *et al.,* 2020). Durum wheat production accounts for only 5% to 10% of the total wheat cultivated land in Ethiopia (GAIN, 2018). As a result, from the total wheat cultivated areas of 1,605,654 hectares in Ethiopia, durum wheat approximately covered 0.6 million hectares (EPAR, 2016). On the other hand, the national average yield of durum wheat in Ethiopia was lower than 2.2 t ha^{-1} (Mekuria Temtme *et al.,* 2018). Durum wheat grain has dual purposes and is used for food security and as raw material for the small food processing industry in the country.

The durum wheat grain is a source of different types of nutrients (Alzuwaid *et al.,* 2021). The nutritional value of the grain and the grain production of durum wheat were affected by different factors such as the genotype, growing environment, management practices, and the interactions of all factors (Bożek *et al.,* 2022; Li, Z *et al.,* 2022; Mancinelli *et al.,* 2023). Durum wheat grain is a raw material mostly for pasta production but also bread, couscous, pizza, and other products (Ruisi *et al.,* 2021), and durum wheat grain produces high-quality pasta (Banach *et al.,* 2021). Thus, the international standard high-quality pasta should have vitreous appearance at the cross-section, golden -amber colour, distinctive taste and aroma both before and after cooking, and it should not be brittle or easy to break (Zuk-Gołaszewska *et al.,* 2016).

Despite its role in food security and as a raw material for Ethiopian food processing, durum wheat production and grain quality are hampered by various factors, including limited knowledge of nitrogen fertilization. Nitrogen, a crucial macronutrient for crops, significantly impacts protein content (De-Santis *et al.,* 2020; Wang *et al.,* 2022; Chakwizira *et al.,* 2023). Optimizing the rate, type, and timing of nitrogen application is essential for improving durum wheat yield and quality (Školníková *et al.,* 2022; Rafiq *et al.,* 2023). Rainfall patterns and soil distribution further influence nitrogen fertilizer effectiveness (Boulelouah *et al.,* 2022).

From the total amount of applied nitrogen fertilizer, only 33% of it is available in the soil whereas the rest of it misplaced by volatilization and leaching, which directly affects the nitrogen fertilizer use efficiency of the crops (Raun and Johnson, 1999). On the other hand, the nitrogen fertilizer use efficiency of the crops is also affected by the soil characteristics and growing condition of the crops (Li, Y *et al.,* 2022). Therfore, harmonizing nitrogen application at optimal timing can significantly enhance nitrogen use efficiency and reduce losses (Souissi *et al.,* 2018).

Effective N fertilizer management is critical for boosting durum wheat production and grain protein content (Mon *et al.,* 2016). In Ethiopia, poor soil fertility management, particularly on nitrogen, is the major constraint. This study aimed to update the recommend nitrogen fertilizer rates that enhance durum wheat production, productivity, and grain quality. We hypothesized that the application of nitrogen fertilizer rates could enhance the growth, yield components, yield, and grain quality of durum wheat at the Debre Zeit in central Ethiopia. The specific objectives were: i) identify the effect of nitrogen fertilizer rates on grain quality and yield of the selected durum wheat cultivars under rain-fed growing condition; (ii) to improved the existed recommend nitrogen rate for future production and grain quality of the improved durum wheat in central Ethiopia in rain-fed production system.

Materials and Methods

The study area

The experiments were conducted during the main cropping seasons of 2022 and 2023 at the Debre Zeit. The centre is locatedat 8°41'36" latitude and 39°03'17" longitude, and has an elevation of 1,880 meters above sea level (Ayele Badebo *et al.,* 2009). The experimental site receives an average annual rainfall of 851 mm, with maximum and minimum temperatures of 24.3°C and 8.9°C, respectively (Alemayehu Zemede *et al.,* 2019). The area's average relative humidity is 61.3% (Biggeri *et al.,* 2018).

Before planting, soil samples were collected from ten different spots across the experimental field, the composited, and analysed to determine soil physic-chemical properties at Debre Zeit Agricultural Research Centre using standard procedures. The values for these selected properties are shown in Table 1. The soil at the experimental site is a heavy black soil, characterized by high clay content (52%), moderate silt content (24%), and low sand content (18%). The soil has a pH of 6.61, with an organic matter content of 2.7%, very low total nitrogen levels (0.58%), and available P levels ranging from 2.4 to 23.6 ppm. Figures 1 and 2 show a map of the research centre and weather data during the study period, respectively.

Table 1. Soil physico-chemical characterization of the study sites.

Soil physico-chemical characterization	Values in the 0 to 20 cm soil profile
pH (1 : 2.5 H_2O)	6.27
Available P (ppm)	23.6
Total N (%)	1
Organic carbon (%)	0.10
Ex. Ca (cmol(+)·kg^{-1})	33.90
Ex. Mg (cmol(+)·kg^{-1})	8.59
CEC (cmol(+)·kg^{-1})	51.59

Source = Debre Zeit Agricultural Research Centre, Soil laboratory. Total N = total nitrogen, P = phosphorus, Ex = exchangeable, and CEC = Cation exchangeable capacity.

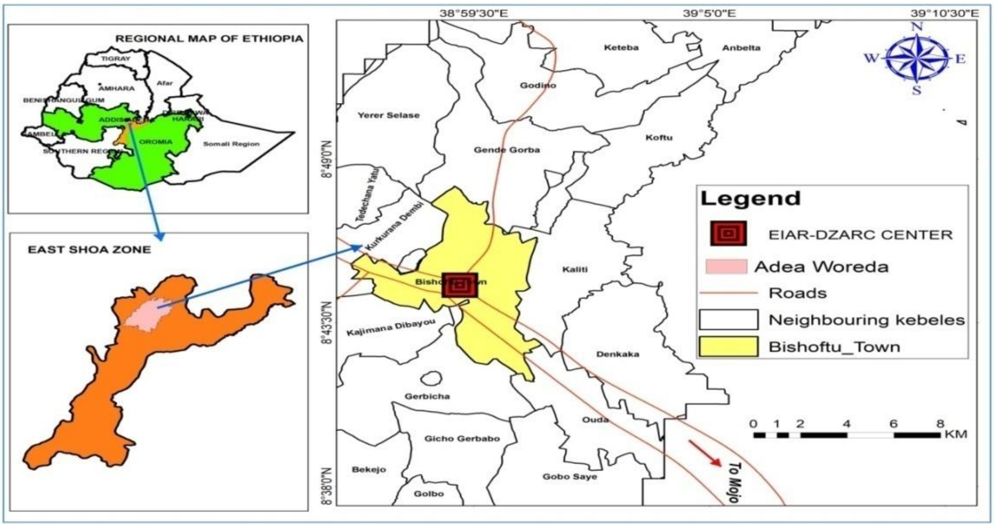

Figure 1. Map of the research site in East Shoa, Oromia, Ethiopia.

Treatments and experimental design

The experiment consisted of a factorial combination of two improved durum wheat cultivars, *Mangudo* and *Utuba*, and five nitrogen fertilizer rates (0, 46, 92, 138, and 184 kg N ha^{-1}). The selected cultivars were chosen based on previous research results that evaluated their performance under rain-fed and irrigated production systems in 2020 and 2021 G.C. These cultivars have demonstrated high production potential, with grain yields ranging from 3.5 to 6.5 ton per hectar^{1} in the release period (Table 2). The experiment was conducted using a Randomized Complete Block Design (RCBD) with three replicates. Each plot measured 3 m in length and 2 m in width (6 m²), with 0.5 m and 1 m between plots and blocks, respectively. Within each replication, there were ten rows with spacing of 20 cm between rows.

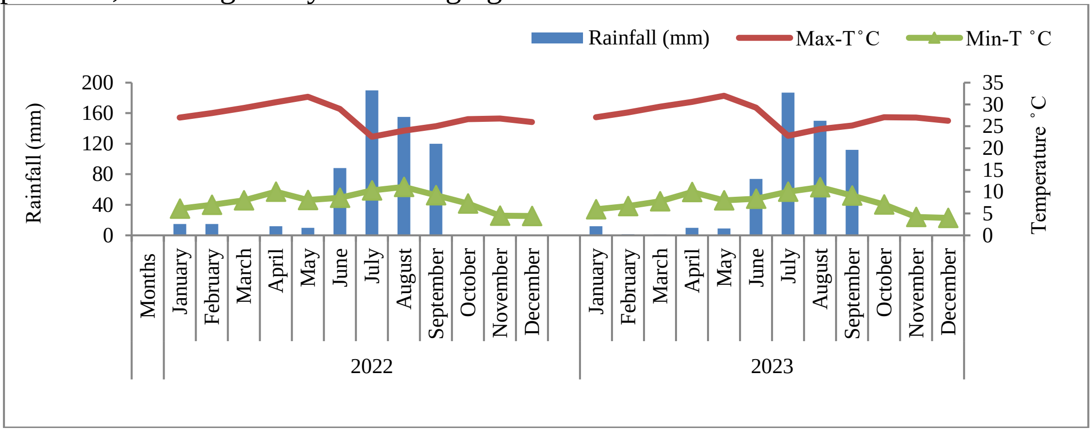

Figure 2.Rainfall and Temperature of the research site in the 2022 and 2023 cropping years.

Table 2. Description of the two improved durum wheat cultivars used in the experiment.

S/N	Cultivar	Year of release	Altitude (m above sea level)	Yield (kg ha^{-1})	Maintaining centres
1	*Mangudo*	2012	1800–2650	3500–6000	SARC
2	*Utuba*	2015	1800–2650	4000–6500	DZARC

DZARC = Debre Zeit Agricultural Research Centre and SARC = Sinana Agricultural Research Centre.

Experimental procedures and management

The seeds of the tested durum wheat cultivars were planted at a rate of 125 kg/ha using a hand drill to a depth of 10 cm, followed by soil covering. The recommended TSP (Triple super phosphate) fertilizer (100 kg/ha) was applied by banding the granules at planting. The nitrogen fertilizer rates (0, 46, 92, 138, and 184 kg N/ha) were applied in two splits. Urea was used as the nitrogen fertilizer source. The split application consisted of 2/3 of the total amount applied at the tiller initiation stage and 1/3 at the booting stage for all fertilizer rates. Urea was applied by lightly opening the soil and covering the fertilizer with soil to prevent loss. The experiments were planted on July 16, 2022, and July 15, 2023. Weeds were controlled by hand-weeding, while diseases and insects were managed using chemical applications. Harvesting was done manually. Grain quality evaluation of the tested cultivars conducted at the Kulumsa Agricultural Research Centre lab, following procedures outlined in the data collection section.

Data collection and analysis

Data collection

Data collection for plant height (cm) and number of grains per spike was conducted by recording measurements from ten randomly selected plants from the middle rows of each plot and then dividing by 10. Days to heading and days to maturity were recorded as the numbers of days between the planting date and heading date, and maturity date, respectively, on a plot basis. Grain yield (t ha^{-1}) was obtained by harvesting the middle four rows of plants within a 0.9 m x 1.5 m area for each plot and weighing the total mass using a sensitive balance. The weight was then converted to tons per hectare. Biomass yield (t ha^{-1}) was calculated as the total mass of grain and straw harvested from 0.9 m2 for each plot, weighed after 24-hour sun drying, and then converted to tons per hectare. Protein content (%) was determined by analyzing the nitrogen content of the grain using micro-Kjeldehal method, while gluten index was calculated by divide the amount of gluten remaining on the sieve by the total gluten and multiplying by 100. Starch content was tested by diluting samples with water (300 µLsample + 700 µL H2O Mili-Q) and measuring using an ionic chromatography system (ICS-3000, Thermo Scientific Dionex, USA). The pellet was used to determine starch content.

Data analysis

The analyses of variance were conducted using statistical software, GenStat version 17, in a randomized complete block design with a factorial arrangement. Homogeneity tests were performed using the Bartlett test (Gomez and Gomez, 1984). After conducting the homogeneity test, the combined analysis over the year was carried out according to Gomez and Gomez (1984). Mean separations within individual parameters were performed using the least significant difference (LSD) method.

Partial budget analysis

A partial budget analysis conducted for each treatment, following the guidelines of CIMMYT (1988), to assess the economic superiority of alternative treatments over the control treatment. The cost of fertilizer and the mean price of wheat (grain and straw) were collected from the districts. The costs were as follows: grain yield per quintal was 4000 birr, straw per hundred kilograms was 1000 birr, and nitrogen fertilizer per quintal was 3500 birr. To account for the difference between experimental and farmer yields, the average yield was adjusted downward by 10%. The marginal rate of return (%)

Results and Discussion

Impact of nitrogen fertilizer rates on phenology and growth parameters of durum wheat

Population density per meter square

The combined analysis of variance over the years revealed that population density per mater square significantly affected by the main effect of cultivar and nitrogen rates at $p < 0.01$ and the interaction effect of cultivar with nitrogen rates at $p < 0.05$ (Table 3).

The combined data result indicated that the population density per meter square under the interaction effect of cultivar and nitrogen rates were ranged from 77 to 177 plants per meter square (Table 4). The highest and the smallest number of population density per meter square were recorded from the *Utuba* cultivar at 184 kg of N ha^{-1} and from *Mangudo* cultivar at 0 kg nitrogen fertilizer applied per hectare (Table 4). The combined data result over the years also showed that *Utuba* cultivar recorded the highest number of population density per meter square at any rates of nitrogen fertilizer compared to the *Mangudo* cultivar and it could be due to the tiller production capacity difference between the tested cultivars under the same nitrogen rates and cropping years. Conversely, *Utuba* and *Mangudo* cultivars statistically increased the number of population density per mater square when the nitrogen rates increased from 0 to 184 kg N ha^{-1}. Conversely, increased the nitrogen rate from 0 to 92 kg N ha^{-1} significantly increased the number of population density per meter square of tested cultivars but; increased the nitrogen rates from 92 to 184 kg N ha^{-1} did not significantly increase the number of population density per meter square of both cultivars (Table 4). Accordingly, from this research result 92 kg of N ha^{-1} was the optimum rate for better production of population density per mater square of the tested cultivars and it might be due to the response of the cultivars to the nitrogen fertilizer. This finding is also supported by different scholars who indicated that increase the application of nitrogen fertilizer rates increased the number of population density of wheat (Fernandez *et al.,* 2020; Alemayehu Assefa *et al.,* 2023).

Table 3. Mean squares values for phenology and growth parameters of durum wheat cultivars combined over 2022 and 2023 cropping years.

Source of variation	Degrees of freedom	Population density per meter square	Days to heading	Days to maturity	Plant height (cm)
Replication (R)	2	473	0.7	19.1	1.4
Years (Y)	1	714^{ns}	0.5^{ns}	2.8^{ns}	5.5^{ns}
Cultivars (C)	1	4183**	44.2*	10.4^{ns}	232.1^{ns}
Nitrogen rate (N)	4	16211**	38.6**	272.7**	510.2**
Y*C	1	0.2*	0.1*	0.02^{ns}	0.1^{ns}
Y*N	4	1.2*	0.05*	0.23*	0.1*
C*N	4	340*	0.5*	2.9*	36.6*
Y*C*N	4	0.3*	0.02*	0.26*	0.1*
Error	38	283.3	6.4	14.8	90.0
Grand mean		129.85	57.81	111.18	84.50
CV (%)		12.96	4.40	3.46	11.23

ns, *and **, non-significant, and significant at $P < 0.05$ and 0.01, respectively. Y*C= Years and Cultivar interaction, Y*N= Years and Nitrogen interaction, C*N= Cultivar and Nitrogen interaction, Y*C*N= Years, Cultivar, and Nitrogen interaction, CV (%) = Percentage of coefficient of variation.

Days to heading

The combined analysis was exhibited that the main effect of cultivar and nitrogen rates on the number of days to heading had significant at $p < 0.05$ and $p < 0.01$, respectively. However, the interaction effect of cultivar with nitrogen rates, on days to heading was significant at $p < 0.05$ (Table 3).

The combined analysis of variance over the years indicated that the interaction effect of cultivar and nitrogen rates increased the number of days to heading from 55 to 61 days (Table 4). The highest and smallest numbers of days to heading were recorded at 184 kg N ha^{-1} and 0 kg N ha^{-1} by the *Mangudo* and *Utuba* cultivars, respectively (Table 4).The number of days to heading was delayed when the nitrogen rate was increased from 0 to 184 kg N ha^{-1} for both tested cultivars. Conversely, the *Mangudo* cultivar headed relatively late ($p < 0.05$) compared to *Utuba* cultivar that were evaluated under the same nitrogen rates. As a result, the number of days to heading recorded by the *Mangudo* cultivar was higher compared that of the *Utuba* cultivar at any rate of nitrogen fertilizer. Thus, result of the study showed that the tested cultivars have different days to heading that were tested under the same nitrogen rates and it could be due to the genetic variability of the tested cultivars for nitrogen use efficiency. In this regard, the previous result also showed that nitrogen rates were significantly affected the number of days to the heading of wheat cultivars under the same production system (Gebrel *et al.,* 2020; Almaz Meseret *et al.,* 2022).

Table 4. The phenology and growth parameter performance of durum wheat cultivars under different nitrogen fertilizer rates combined over the 2022 and 2023 cropping years.

Cultivar	Nitrogen rate (kg N ha^{-1})	Population density per meter square	Days to heading	Days to maturity
Mangudo	0	77^{f}	55.8^{ef}	103.5^{d}
Mangudo	46	98^{de}	$57.7^{b–e}$	108.8^{bc}
Mangudo	92	141^{c}	$58.8^{a–d}$	112.7^{ab}
Mangudo	138	145^{c}	60^{ab}	113.5^{a}
Mangudo	184	146^{c}	60.9^{a}	115^{a}
Utuba	0	82^{ef}	54.8^{f}	104.5^{cd}
Utuba	46	106.6^{d}	$56.5^{d–f}$	108.5^{bc}
Utuba	92	156.5^{bc}	$57^{c–f}$	112.9^{ab}
Utuba	138	169.5^{ab}	$58^{a–e}$	115^{a}
Utuba	184	176.5^{a}	$59^{a–c}$	117^{a}
Grand mean		129.8	57.86	111.15
LSD 5%		19.67	2.97	4.5
CV (%)		12.96	4.4	3.46
LS		*	*	*

Mean followed by the same letter are non-significant. LSD (%) = Listed significant different at 5% level, and CV (%) = Percentage of coefficient of variation, LS=level of significant.

Days to Physiological Maturity

The pooled data analysis of variance over the years showed that the main effect of nitrogen rates at $p < 0.01$ and the interaction effect of cultivar and nitrogen rates at $p < 0.05$ level were significant influence on the number of days to physiological maturity of durum wheat (Table 3).

Under the tested nitrogen rates, the number of days to reach physiological maturity of the tested cultivars ranged from 104 to 117 days. The *Utuba* cultivar matured late at 184 kg N ha^{-1}while *Mangudo* cultivar matured earlier at 0 kg N ha^{-1}. From this research result *Utuba* cultivar taken higher days to physiological maturity compared to the *Mangudo* cultivar at any rate of nitrogen fertilizer and it might be due to the genetic instability for nitrogen use efficiency between the tested cultivars under the same production years. Conversely, the rate of 92 kg N ha^{-1} was the optimum nitrogen rate to the physiological maturity for both cultivars at the same production year. In this regard, various scholars also reported that if the rate of nitrogen increased, the number of days to physiological maturity of wheat cultivars prolonged (Dereje Dobocha, 2022; Gawdiya *et al.*, 2023).

Plant height (cm)

The outcome of the combined data analysis of variance over the years showed that the main effect of nitrogen rates and its interaction with cultivar had a significant effect on plant height of durum wheat cultivars at $p < 0.01$ and $p < 0.05$ at level of significance, respectively (Table 3).

The result of the study showed that under the tested nitrogen rates and cultivars, the plant height of durum ranged between 74.5 cm to 94.5 cm (Figure 3). The highest plant height was recorded from *Utuba* cultivar at the nitrogen rate 184 kg ha^{-1} while *Manguda* cultivar recorded the lowest plant height at zero nitrogen rates per hectare (Figure 3). Conversely, the *Utuba* cultivar increased its height at any rate of nitrogen per hectare but the *Mangudo* cultivar increased its height from 0 to 138 kg N ha^{-1}(Figure 3). This result indicated that the tested cultivars have different potentials to plant height production under the same nitrogen rate and it might due to the genetic variability that responded to nitrogen use. Therefore, *Utuba* cultivar genetically has a large plant height and proven high straw yield and will be used for livestock production in Ethiopia compared to the *Mangudo* cultivar. In this regard, Khan *et al.* (2022) indicated that the considerable variations in plant height between wheat cultivars are due to different nitrogen rates. Likewise, Alemayehu Assefa *et al.* (2023) also stated that the difference in plant height is due to the nitrogen rates that were applied during the growing season of wheat.

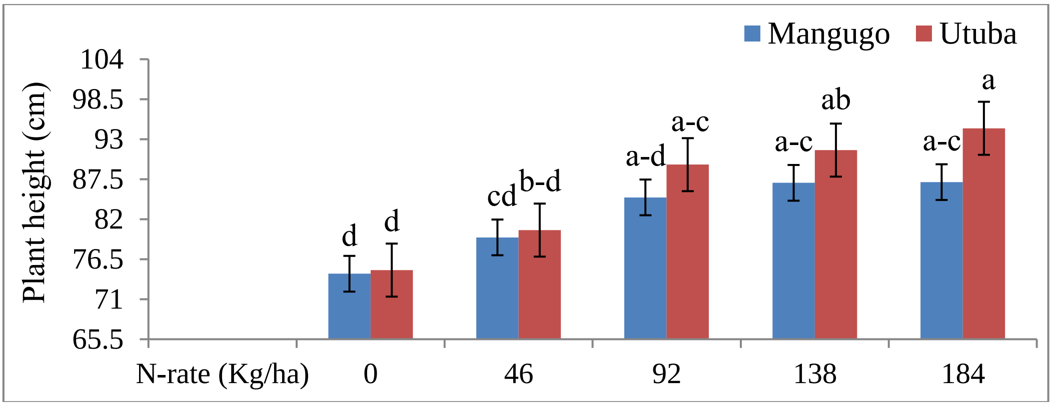

Figure 3. The performances of plant height under different nitrogen rates combined over 2022 and 2023 cropping years at Debre Zeit.

Mean followed by the same letter are non-significant. Grand mean =84.4, Percentage of coefficient of variation =11.23, Listed significant different at 5% level =11.09, and Level of significant =*.

Effect of nitrogen rate on yield and yield component parameters of durum wheat

Number of productive tillers per plant

The pooled data analysis of variance over the years revealed that the number of productive tillers per plant was significantly affected by the main effect of cultivar, nitrogen rates and their interaction effect at $p < 0.01$(Table 5).

The combined data analysis over the years indicated that *Utuba* cultivar recorded the highest number of productive tillers per plant at 184 kg N ha^{-1}, while the cultivars *Mangudo* and *Utuba* recorded the smallest number of productive tillers per plant at 0 kg N ha^{-1} (Figure 4). However, increased the nitrogen rate from 0 to 92 kg N ha^{-1} and 0 to 184 kg N ha^{-1} it was enhancing the number of productive tillers of the *Mangudo* and *Utuba* cultivars, respectively (Figure 4). As a result, the *Utuba* cultivar increased the number of productive tillers at any rate of nitrogen fertilizer compared to the *Mangudo* cultivar it could be due to the genetic variability that responded to nitrogen fertilizer. In this regard, the previous research result indicated the genetic characteristics of the cultivars and the nitrogen rates affected the productive tillers of the wheat crop (Alemayehu Biri *et al.*, 2023).

Table 5. Mean squares values of yield-components and yield of the durum wheat cultivars combined over 2022 and 2023 cropping years.

Source of variation	Degrees of freedom	Productive tillers plant^{-1}	Number of grain spike^{-1}	Grain yield (t ha^{-1})	Biomass yield (t ha^{-1})
Replication (R)	2	1.40	16.2	0.03	0.7
Years (Y)	1	0.6^{ns}	1008.6*	14.1*	131.6*
Cultivar (C)	1	38.4**	15.0^{ns}	0.04^{ns}	0.1^{ns}
Nitrogen rates(N)	4	55.3**	1744.1**	33.5**	144.8**
Y*C	1	0.0*	0.6*	0.4*	0.7*
Y*N	4	0.1*	0.1*	0.1**	1.8*
C*N	4	8.9**	8.5*	0.2*	0.4*
Y*C*N	4	0.04*	0.1*	0.05*	0.2*
Error	38	0.2	9.2	0.2	0.9
Grand mean		3.70	26.1	3.10	6.77
CV (%)		13.30	11.59	12.74	13.05

ns, *and **, non-significant, and significant at $P < 0.05$ and 0.01, respectively. Y*C= Years and Cultivar interaction, Y*N= Years and Nitrogen interaction, C*N= Cultivar and Nitrogen interaction, Y*C*N= Years, Cultivar, and Nitrogen rate interaction, CV (%) = Percentage of coefficient of variation.

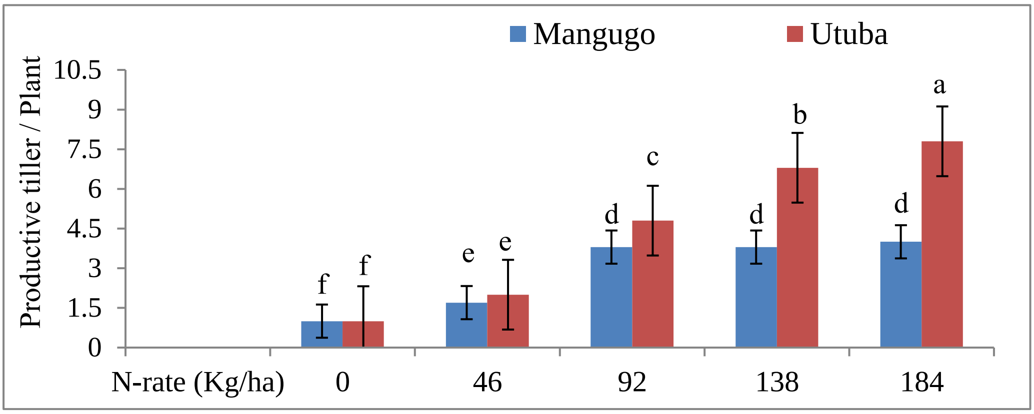

Figure 4. The performances of productive tiller per plant under different nitrogen rates combined over 2022 and 2023 cropping years at Debre Zeit.

*Mean followed by the same letter are non-significant. Grand mean =3.7, Percentage of coefficient of variation =13.3, Listed significant different at 5% level =0.6l, and Level of significant =**.*

Number of grains per spike

Combined data analysis of variance over the years showed that the number of grains per spike was significantly affected by the main effect of nitrogen fertilizer rates and the interaction effect of cultivar with nitrogen rates at $p < 0.01$ and $p < 0.05$, respectively (Table 5).

The combined analysis result indicated the numbers of grains per spike of the tested cultivar under the tested nitrogen rates ranged from 8 to 38 kernels per spike. The highest and the smallest number of grains per spike were recorded from *Utuba* at 184 kg N ha^{-1} and *Mangudo* cultivar at 0 kg of N ha^{-1}, respectively (Table 6). But, increasing the nitrogen rate from 0 to 92 kg N ha^{-1} and 0 to 138 kg N ha^{-1} it was lead to increased grains per spike of the *Mandugo* and *Utuba* cultivars, respectively. Conversely, the number of grains per spike recorded from the *Utuba* cultivar at any rate of nitrogen fertilizer was higher compared the *Mangudo* cultivar and it could be due to their genetic variability between the cultivars for nitrogen use efficiency under the same nitrogen rate. Regarding this the preceding research reports also showed that the number of grains per spike was affected by the application of nitrogen rates, cultivars, and their interactions (Kubar *et al.*, 2021; Shoukat *et al.*, 2023).

Biomass yield

The outcome of the combined data analysis over the years showed that the main effect of nitrogen rates was significantly affected the biomass yield of durum wheat at $p < 0.01$. In the same way, all the interaction effects of the tested factors affected the biomass yield of durum wheat at $p < 0.05$. Quite the reverse, the main effect of the cultivars was not having significant effect on the biomass yield of durum wheat at $p < 0.05$ (Table 5).

The combined data analysis result indicated the as the amount of nitrogen rates increased from 0 to 184 kg N ha^{-1} statistically increased the biomass yield of the tested cultivars (Table 6). Yet, increment of nitrogen fertilizer rates from 0 to 92 kg ha^{-1} significantly increased the biomass yield of both tested cultivars of durum wheat while increasing the nitrogen rate from 92 to 184 kg ha^{-1} the biomass yield of the cultivars did not significantly different (Table 6). The smallest biomass yield per hectare was recorded by the *Utuba* cultivar at 0 kg N ha^{-1} although the highest biomass yield was obtained by the *Utuba* cultivar at 184 kg N ha^{-1} (Table 6). In line with the current research result previous reports also confirmed that nitrogen fertilizer rates affect the biomass yield of wheat cultivars (Khan *et al.,* 2022; Zerihun Tufa *et al.,* 2022).

Table 6. Combined mean performances for grains per spike and biomass yield (t ha^{-1}) of durum wheat cultivars over 2022 and 2023 cropping years at Debre Zeit.

Cultivar	Nitrogen rate (kg N ha^{-1})	Grains per spike	Biomass yield (t ha^{-1})
Mangudo	0	8^{e}	1.9^{d}
Mangudo	46	17^{d}	4.7^{c}
Mangudo	92	32.6^{bc}	8.6^{b}
Mangudo	138	34^{bc}	9.2^{ab}
Mangudo	184	36^{ab}	9.7^{a}
Utuba	0	9.8^{e}	1.6^{d}
Utuba	46	18.3^{d}	4.5^{c}
Utuba	92	31^{c}	8.3^{b}
Utuba	138	36^{ab}	9.3^{ab}
Utuba	184	38^{a}	10.2^{a}
Grand mean		26.1	6.77
LSD 5%		3.53	1.03
CV (%)		11.59	13.05
LS		*	**

Mean followed by the same letter are non-significant. LSD (%) = Listed significant different at 5% level, and CV (%) = Percentage of coefficient of variation, LS=level of significant.

Grain yield

The pooled data analysis over the years revealed that the main effect of nitrogen rates had a significant effect on the grain yield at $p < 0.01$ whereas, interaction effects of cultivar and nitrogen rates had a significant effect on the grain yield of durum wheat at $p < 0.05$ (Table 5).

The combined data result showed that the grain yield production under the tested nitrogen rates ranged from 0.65 to 4.8 t ha^{-1}. The highest and the smallest grain yield per hectare were obtained by *Utuba* cultivar at 184 kg N ha^{-1} and 0 kg ha^{-1} of nitrogen rates, respectively. The nitrogen rates were increased from 0 to 184 kg N ha^{-1} the grain yield of both tested cultivars was statistically increased. Conversely, in the *Mangudo* cultivar, the nitrogen rates increased from 0 to 92 kg N ha^{-1} significantly enhanced the gain yield while from 92 to 184 kg N ha^{-1} did not significantly increase the grain yield of this cultivar (Figure 5).

In the *Utuba* Cultivar, increased the nitrogen rates from 0 to 138 kg N ha^{-1} increased the grain yield increased from 138 to 184 kg N ha^{-1} statistically increased but did not significantly increase the grain yield of the *Utuba* cultivar (Figure 5). But, the partial budget analysis indicated that the highest percent of marginal rate of return registered by 92 kg N ha^{-1} in both tested cultivars. For instance, the marginal rate of returns 3371.5% and 2360.0% were registered from the nitrogen treatment of 92 kg N ha^{-1} in the *Mangudo* and *Utuba* cultivars, respectively. This implies that for each Birr that invested in the cultivation of *Mangudo* and *Utuba* cultivars, the farmer can receive to recover the one Birr invested plus an additional return of 33.7 and 23.6 birr for *Mangudo* and *Utuba* production, respectively (Table 10). Thus, the application of 92 kilogram of nitrogen fertilizer rate per hectare it gave 180,700 and 170,500 birr net benefit from *Mangudo* and *Utuba* cultivars, respectively (Table 10). Accordingly, the result of the partial budget analysis indicated that the *Mangudo* cultivar was the highest profitable cultivar to the area farmers compared to *Utuba* cultivar under the application of 92 kg N ha^{-1}. Therefore, the profitability difference between the tested cultivars was grain and straw production viabilities due to their genital inconsistency of the cultivars that responded to nitrogen rates under the same rate of nitrogen application. Therefore, the response of cultivars to the nitrogen fertilizer rates affected the grain and straw yield of durum wheat. In this regard, the previous research result also indicated that an increase in nitrogen rates significantly increased the grain yield of wheat cultivars (Boulelouah *et al.*, 2022; Ghimire *et al.*, 2021).

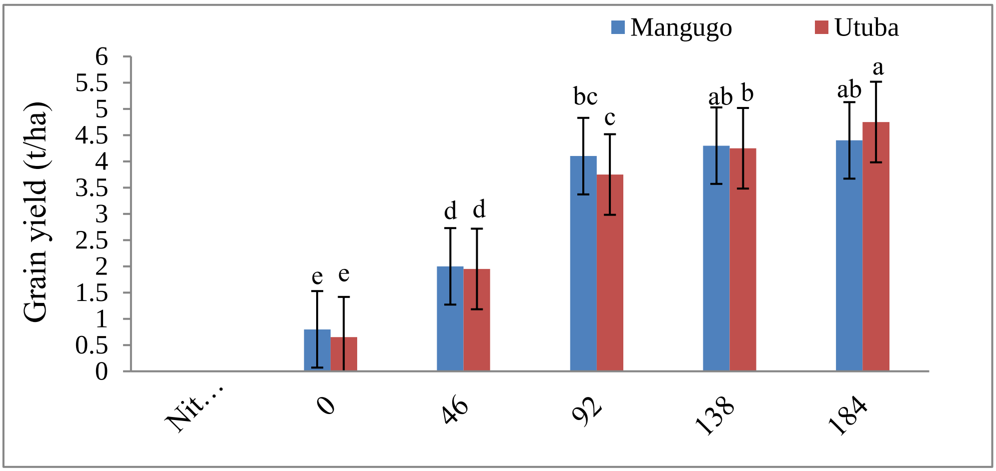

Figure 5.*The performances of grain yield (t ha^{-1}) under different nitrogen rates combined over 2022 and 2023 cropping years at Debre Zeit.*

*Mean followed by the same letter are non-significant. Grand mean =3.1, Percentage of coefficient of variation = 12.74, Listed significant different at 5% level = 0.46, and level of significant = **.*

Grain quality performance of the durum wheat cultivars under different nitrogen rates

Thousand kernel weight

The pooled data analysis of variance over the years revealed that the main effect of cultivar and nitrogen fertilizer rates and their interaction effect had a significant effect on the thousand kernel weight of durum wheat at $p < 0.01$ and $p < 0.05$, respectively (Table 7).

The combined data analysis over the years showed that the value of the thousand kernel weight was increased when the nitrogen rates were increased for both tested cultivars. So, the largest value of thousand kernel weight was recorded by the *Mangudo* cultivar at the rate of 184 kg N ha^{-1} but the smallest thousand kernel weight was obtained by the *Utuba* cultivar at the rate of 0 kg N ha^{-1} (Table 8). Yet, increasing the rate of nitrogen fertilizer from 0 to 46 kg N ha^{-1} significantly improved the thousand kernel weight of *Mangudo* and *Utuba* cultivars but increasing the nitrogen rates from 46 to 184 kg N ha^{-1} did not significantly increase the thousand kernel weight of *Mangudo* and *Utuba* cultivars. Instead, the mean average value of the thousand kernel weights that were registered by *Mangudo* was increased by 9.48 g compared to the *Utuba* cultivar. In line with the preceding research results of Alemayehu Assefa *et al.,* (2023) indicated that the thousand kernel weight was mostly affected by the response of cultivars to nitrogen rate.

Table 7. Mean squares values for grain quality of the durum wheat cultivars combined over 2022 and 2023 cropping years.

Source of variation	Degrees of freedom	Thousand kernel weight (g)	Hectolitre weight(kg/hl)	Protein content (%)	Starch content (%)	Gluten index
Year (Y)	1	252.2**	29.4*	8.06**	7.6^{ns}	4.8^{ns}
Cultivar (C)	1	1372.8**	5.4^{ns}	76.2**	0.9^{ns}	843.7^{ns}
Nitrogen(N)	4	323.6**	173.1**	3.4**	9.1*	57.5**
Y*C	1	2.8*	5.4*	0.5*	6.3*	43.0**
Y*N	4	0.57*	4.8*	0.2*	1.4*	0.6*
C*N	4	17.07*	4.1*	0.03*	0.1*	4.0*
Y*C*N	4	0.57*	5.0*	0.08*	0.4*	2.1*
Error	38	7.40	6.4	0.3	2.0	8.9
Grand mean		39.0	44.8	12.8	69.64	78.13
CV (%)		6.98	5.65	4.44	2.02	3.82

ns, *and **, non-significant, and significant at $P < 0.05$ and 0.01, respectively. Y*C= Years and Cultivar interaction, Y*N= Years and Nitrogen interaction, C*N= Cultivar and Nitrogen interaction, Y*C*N= Years Cultivar, and Nitrogen interaction, CV (%) = Percentage of coefficient of variation.

Table 8. Mean performances for kernel weight and hectolitre weight of durum wheat cultivars at Debre Zeit research centre combined over 2022 and 2023 cropping years.

Cultivar	Nitrogen rate (kg N ha^{-1})	Thousand kernel weight (g)	Hectolitre weight (kg/hl)
Mangudo	0	37.5^{d}	40.2^{fg}
Mangudo	46	41.5^{c}	42.5^{e}
Mangudo	92	45^{ab}	45.5^{d}
Mangudo	138	46.5^{a}	48^{bc}
Mangudo	184	48^{a}	51^{a}
Utuba	0	26.2^{f}	39^{g}
Utuba	46	30.9^{e}	42.3^{ef}
Utuba	92	33.4^{e}	45^{d}
Utuba	138	38.7^{cd}	46.05^{cd}
Utuba	184	41.9^{bc}	49.1^{ab}
Grand mean		39.0	44.87
LSD 5%		3.18	2.31
CV (%)		6.98	4.41
LS		*	*

Mean followed by the same letter are non-significant. LSD (%) = Listed significant different at 5% level, and CV (%) = Percentage of coefficient of variation, LS=level of significant.

Hectolitre weight

The combined data analysis over the years showed that the main effect of nitrogen rates had a significant effect on the hectolitre weight of durum wheat at $p < 0.01$. Conversely, the interaction effect of cultivar and nitrogen rate affected the hectolitre weight at $p < 0.05$ (Table 7).

The highest hectolitre weight was recorded by the *Mangudo* cultivar at 184 kg N ha^{-1} while the smallest was obtained by the *Utuba* cultivar at 0 kg N ha^{-1} (Table 8). The average value of the hectolitre weight registered by the *Mangudo* cultivar was enlarged by 2.6% compared to the mean average value of the *Utuba* cultivar. On the other hand, increasing the rate of nitrogen fertilizer from 0 to 184 improved the hectolitre weight of durum wheat however; the hectolitre weight value that was recorded at 184 kg N ha^{-1}significantly different from 0 to 138 kg N ha^{-1} values (Table 8). Thus, this research result indicated that the value of the hectolitre weight of the tested cultivars was affected by any rate of nitrogen fertilizer but the maximum value of hectolitre weight registered at 184 kg N ha^{-1}. However, the highest value of hectolitre weight recorded by the *Mangudo* compared to *Utuba* at the same nitrogen rates; this result was due to the effect of genetic inconsistency. Regarding this, the proceeding report also indicated that the different application of nitrogen fertilizer rate affected the hectolitre weight and other yield component parameters of wheat cultivars (Khan *et al.*, 2022).

Starch content (%)

The pooled data analysis revealed that the main effects of nitrogen rates and its interaction effect with cultivar significantly affected the starch content at $p < 0.05$ (Table 7).

The smallest starch content was recorded by the *Utuba* cultivar at 0 kg N ha^{-1} and it was statistically non-significant from all tested nitrogen rates except the 138 and 184 kg N ha^{-1}(Table 8). However, the highest starch content of the tested cultivars was registered at 184 kg N ha^{-1} although not significantly different from the starch content that was registered at 138 kg N ha^{-1}(Table 8). Thus, from this research result as the amount of nitrogen rates increased from 0 to 46 kg N ha^{-1} the amount of starch content in the grain increased but increasing the nitrogen rate from 46 to 184 kg N ha^{-1} had no significant effect on starch content of durum wheat cultivars. The earlier research result indicated that the starch content of the wheat cultivars was significantly increased at the critical levels of nitrogen rate but if the nitrogen rate increased above the critical levels did not affect grain starch content (Xiong *et al.,* 2014; Lv *et al.,* 2021).

Gluten index (%)

The two years of combined data analysis of variance revealed that the gluten index was significantly affected by the main effect of the nitrogen rates at $p < 0.01$ and its interaction effect with cultivar at $p < 0.05$ (Table 7).

The combined data indicated that the highest gluten index was recorded by *Utuba* cultivar at the nitrogen rate of 184 kg ha^{-1} but the smallest grain protein content was registered by *Mangudo* cultivar at the nitrogen rate of 0 kg ha^{-1}. This result indicates that the *Utuba* cultivar increased the gluten index under the same production season compared to the *Mangudo*. On the other hand, if the nitrogen rate was increased from 0 to 184 kg N ha^{-1} the gluten index of the *Utuba* cultivar increased compared to the *Mangudo* cultivar and it might be due to the genetic difference between the *Utuba* and *Mangudo* gluten index production. Previous findings stated that genotype, growing season, and nitrogen level affect the gluten index of durum wheat (Vida *et al.,* 2014).

Table 9. Mean performances for starch content and gluten index of durum wheat cultivars at Debre Zeit research centre combined over years.

Cultivar	Nitrogen rate (kg N ha^{-1})	Starch content (%)	Gluten index (%)
Mangudo	0	69^{bc}	72^{f}
Mangudo	46	69.65^{a-c}	73.4^{ef}
Mangudo	92	69.9^{a-c}	74.9^{ef}
Mangudo	138	70.1^{ab}	75.8^{de}
Mangudo	184	70.4^{a}	75.9^{de}
Utuba	0	68.8^{c}	78.5^{cd}
Utuba	46	69.05^{bc}	79.9^{bc}
Utuba	92	69.4^{a-c}	82^{ab}
Utuba	138	69.7^{a-c}	84^{a}
Utuba	184	69.95^{ab}	85^{a}
Grand mean		69.59	78.13
LSD 5%		1.19	3.48
CV (%)		1.46	3.82
LS		*	*

Mean followed by the same letter are non-significant. LSD (%) = Listed significant different at 5% level, and CV (%) = Percentage of coefficient of variation, LS=level of significant.

Protein content (%)

The analysis of the combined data over the years showed that the protein content significantly affected by the main effect of cultivar and nitrogen rates at $p < 0.01$ and their interaction at $p < 0.05$ (Table 7).

This research result showed that if the nitrogen rates were increased from 0 to 184 kg N ha^{-1} also the protein content of the tested cultivars increased (Figure 6). However, the highest percentage of protein content was recorded by the *Utuba* cultivar at 184 kg N ha^{-1}, and the lowest protein content was also registered by the *Mangudo* cultivar at 0 kg N ha^{-1}(Figure 6). The difference in protein content between the highest and the smallest giving nitrogen rates and cultivars were 31.8% (Figure 6). Therefore, if the nitrogen rate increased the grain protein content of durum wheat cultivars also increased but the *Utuba* cultivar has higher protein content compared to the *Mangudo* cultivar due to the differential response of cultivars to the nitrogen fertilizer rate. Previous research result also indicated that the grain protein content of wheat cultivars affected by the nitrogen rates (Call *et al*., 2020; Lollato *et al.*, 2021).

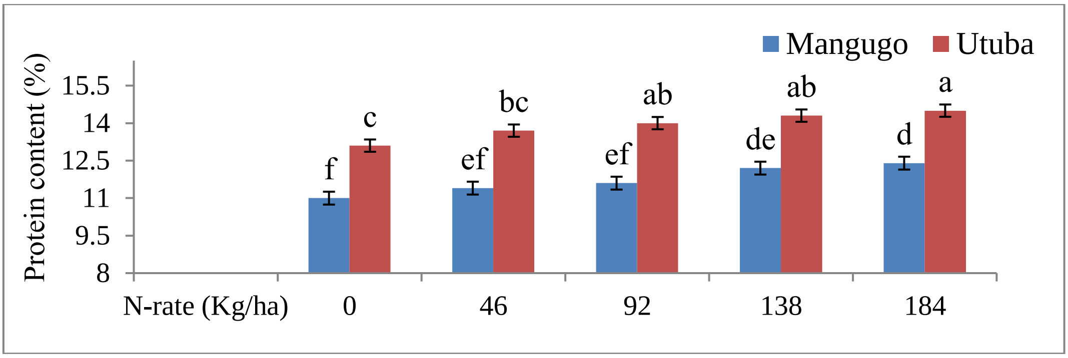

Figure 6.*The performances of grain protein content under different nitrogen rates combined over 2022 and 2023 cropping years at Debre Zeit.*

*Mean followed by the same letter are non-significant. Grand mean = 12.8, Percentage of coefficient of variation = 4.44, Listed significant different at 5% level =0.66, and Level of significant = *.*

Partial budget analysis

Based on the partial budget analysis of the combined data result over the cropping years, the application of nitrogen fertilizer rate of92 kg ha^{-1} it gave 180,700 birr and 170,500 birr net benefit from *Mangudo* and *Utuba* cultivars, respectively (Table 10). The marginal rate of returns (3371.5% and 2360.0%) were gained from the nitrogen treatment of 92 kg N ha^{-1}, this implies that for each Birr that invested in the new technology, the producer can receive to recover the one Birr invested plus an additional return of 33.7 and 23.6 Ethiopian birr due to *Mangudo* and *Utuba* cultivar production, respectively (Table 10). However, the partial budget analysis indicated that the cultivar *Mangudo* has higher net benefit under the nitrogen treatment of 92 kg N ha^{-1} compared to cultivar *Utuba*. Therefore, *Mangudo* cultivar produced higher net benefit which can be recommended for farmers in the study area and areas with similar agro-ecology.

Table 10. Partial budget analysis for nitrogen treatments research at Debre Zeit

Cultivars	Nitrogen rates	Unadjusted yield (t ha^{-1})		Adjusted yield (t ha^{-1})		Gross- benefit (birr)	N-cost (birr)	Net- benefit (birr)	MRR (%)
		Grain	Straw	Grain	Straw				
	0	0.8	1.16	0.72	1.04	39,200	0	39,200	-
Mangudo	46	2	2.69	1.8	2.42	66,200	3500	62,700	671.4
	92	4.1	4.45	3.69	4.01	187,700	7000	180,700	3371.5
	138	4.3	4.92	3.87	4.43	199,100	10,500	188,600	225.7
	184	4.4	5.25	3.96	4.73	205,700	14,000	191,700	88.6
	0	0.65	0.89	0.59	0.80	31,600	0	31,600	-
Utuba	46	1.9	2.55	1.71	2.30	91,400	3500	87,900	1608.5
	92	3.8	4.52	3.42	4.07	177,500	7000	170,500	2360.0
	138	4.3	4.91	3.87	4.42	199,000	10,500	188,500	514.3
	184	4.8	5.37	4.32	4.83	221,100	14,000	207,100	531.4

NB: N= Nitrogen, MRR (%) = Marginal rate of return,

Conclusion and Recommendation

Durum wheat is one of the dominant crops in Ethiopian agriculture in the central region. Optimization of nitrogen fertilizer rate for durum wheat production in a specific soil and growing conditions is quite important. The current study indicated that increased the nitrogen rates from 0 to 184 kg N ha^{-1}it led to enhanced all the tested parameters except the starch content of the tested durum wheat cultivars. However, the highest and the smallest values of the tested parameters were recorded at 184 kg N ha^{-1} and 0 kg N ha^{-1}, respectively. The partial budget result indicated that the application of 92 kg N ha^{-1} was registered the highest marginal rate of return in both tested cultivars. However, the marginal rate return which was recorded by *Mangudo* cultivar was higher compared to *Utuba* cultivar. As a result, Cultivation of *Mangudo* cultivar at the application of 92 kg N ha^{-1} has the higher profitability compared to other nitrogen treatments in both cultivars. Therefore, the application of 92 kg N ha^{-1} was one of the recommended nitrogen fertilizer rates and the cultivar *Mangudo* has high grain and straw production for the study area. Finally, I concluded that cultivation of *Mangudo* cultivar at 92 kg N ha^{-1} is advantageous for the study area and the areas which have similar Agro-climatic conditions.

Data Availability

The availability of data was some of it used to support the findings of this study are included in the article. Additional data are available from the corresponding author upon request.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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