Determination of optimum rate and application time of nitrogen for yield and quality of malt barley (*Hordeum* vulgare L.) in Dabat district, Western Amhara, Ethiopia

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ABSTRACT

Malt barley is an important crop for Ethiopia's agro-industrial development and smallholder livelihoods. However, its productivity and grain quality remain low due to suboptimal agronomic practices. To address this limitation, a field experiment was conducted to investigate the effects of nitrogen (N) application rates and split-application strategies on agronomic traits, yield, and grain quality. The experiment was arranged in a randomized complete block design with three replications, and data were analyzed using R statistical software (version 4.3.2). The treatments comprised 12 combinations: four N rates (46, 92,138, and 184 kg N ha^{-1}) and three application schedules (½ at planting + ½ at tillering; ¼ at planting + ¼ at tillering + ½ at booting; and ⅓ at planting + ⅓ at tillering + ⅓ at booting). The results showed that both N rate and application timing significantly affected spike length, kernels per spike, thousand-kernel weight, grain yield, and protein content. The highest grain yield (2.65 t ha^{-1}), thousand-kernel weight (43.04 g), spike length (7.97 cm), kernels per spike (42), and protein content (13.6%) were achieved at 184 kg N ha^{-1}. However, partial budget analysis indicated that the treatment with 92 kg N ha^{-1} provided the highest net benefit (1324.84 USD ha^{-1}) and a marginal rate of return of 292.64%. Therefore, applying 92 kg N ha^{-1} split as 1/2 at planting, and ½ at tillering stage is the most effective and economically feasible practice for malt barley production in the study area and similar agro-ecological zones.

Keywords: Barley; Grain protein content; Grain yield; N rates; Time of N- application
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INTRODUCTION

Barley (*Hordeum Vulgare* L.) is the principal cereal used in malt production and represents an important source of income for smallholder farmers in Ethiopia's highland regions. These areas are characterized by environmental conditions that are less favorable for the cultivation of many other cereal crops (Demelash *et al*., 2025). Both malt and food barley varieties thrive under similar agro-ecological conditions, particularly at elevations between 1,800 and 3,400 meters above sea level (masl), with optimal growth occurring between 2,300 and 3,000 masl (Bogale *et al*., 2025). Globally, barley ranks as the fourth most important cereal crop (Bogale *et al*., 2025), while in Ethiopia it ranks fifth after teff, wheat, maize, and sorghum (CSA, 2022). Demand for malt barley in Ethiopia has increased significantly due to the rapid

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expansion and higher production levels of malt and beer factories (Tadesse *et al*., 2021). However, local malt barley supply has lagged behind this growing demand. As a result, Ethiopia faces a substantial supply–demand gap in malt barley, despite being a key center of the crop's genetic diversity (Bogale *et al*., 2025)

The national area under barley cultivation is 799,127 ha, with a total production of 20,718,071 tons and an average yield of 2.59 t ha^{-1}, accounting for 6.55% of the land covered by grain crops (CSA, 2022). This yield is significantly lower than that of major global producers, such as the Russian Federation, Australia, France, Germany, and Canada, with estimated productions of 16.25, 13.27, 11.3, 11.2, and 8.4 t ha^{-1}, respectively (USDA, 2024). In the Amhara Region, malt barley is cultivated on approximately 286,865 ha, with an average productivity of 2.25 t ha^{-1} (CSA, 2022). Despite being regarded as a promising area for malt barley cultivation, the West Gondar zone records a comparatively lower productivity of 1.98 t ha^{-1}, which is below the national average. This slight difference in productivity is attributed to the combined influence of agronomic practices and the varieties grown. The main factors that reduce barley yield and grain quality include poor soil fertility, inadequate agronomic practices (e.g., improper nitrogen rate and timing of application), water stress, frost, soil acidity, diseases and pests, and weed competition (Terefe *et al*., 2018).

In the barley-producing regions of North Gondar, farmers primarily cultivate malt barley using traditional agronomic practices due to limited research, particularly regarding nitrogen rates and split application methods. Several studies have investigated the effects of nitrogen fertilizer levels and split application on malt barley productivity in different areas of Ethiopia (Biruk and Demelash, 2016). However, data on nitrogen fertilizer management and split application are lacking for the Dabat district. Therefore, this study aimed to determine appropriate nitrogen rates and split application strategies necessary to achieve optimal yields and high-quality malt in the Dabat district.

MATERIALS AND METHODS

Description of the study area

A field experiment was conducted at the Dabat Station of the Gondar Agricultural Research Center during the 2023/2024 main growing season. The experimental site represents the highland areas of the major barley-growing region of West Gondar, specifically in the Dabat district. The research station is located at latitude of 12.963°N and a longitude of 37.700°E, at an elevation of 2,607 meters above sea level (masl). The long-term annual rainfall in the area ranges from 900 to 1,400 millimeters (mm), with the main rainy season extending from June to the end of September. The mean daily temperature varies between 18 and 32°C, with an average of 23°C. The soil at the site is characterized as clay loam and slightly acidic, with a pH of 5.5.

Experimental materials, treatments and design

The recently released six-row malt barley variety *'Ras'* was used as the test crop. This variety was released in 2021 by the Gondar Agricultural Research Center and is now under production in the Dabat District. It performs well at elevations ranging from 1,500 to 2,800 meters above sea level (masl) with a maturity period of 120–132 days. The grain yield of *Ras* ranges from 3.3 to 4.4 t ha^{-1} under research field conditions (MOA, 2023). Urea (46% N) and triple superphosphate (TSP; 100 kg P_2O_5 ha^{-1}) were used as sources of nitrogen and phosphorus, respectively.

Treatments consisted of a combination of four nitrogen rates (46, 92, 138, and 184 kg N ha^{-1}) and three timings of nitrogen application: T1 = ½ dose at planting + ½ dose at tillering; T2 = ¼ dose at planting + ¼ dose at tillering + ½ dose at the booting stage; and T3 = ⅓ dose at sowing + ⅓ dose at the tillering stage + ⅓ dose at the booting stage, resulting in a total of 12 treatment combinations in a factorial arrangement. The 4 × 3 factorial treatments were laid out in a randomized complete block design (RCBD) with three replications. The gross plot size was 3 m in length and 2 m in width, comprising 10 rows (6 m^2), while the net plot size was 3 m × 1.6 m (4.8 m^2), consisting of eight central harvesting rows after excluding the outermost rows on both sides of each plot to minimize border effects. The spacing between blocks, plots, and rows was 1.5 m, 0.5 m, and 0.2 m, respectively.

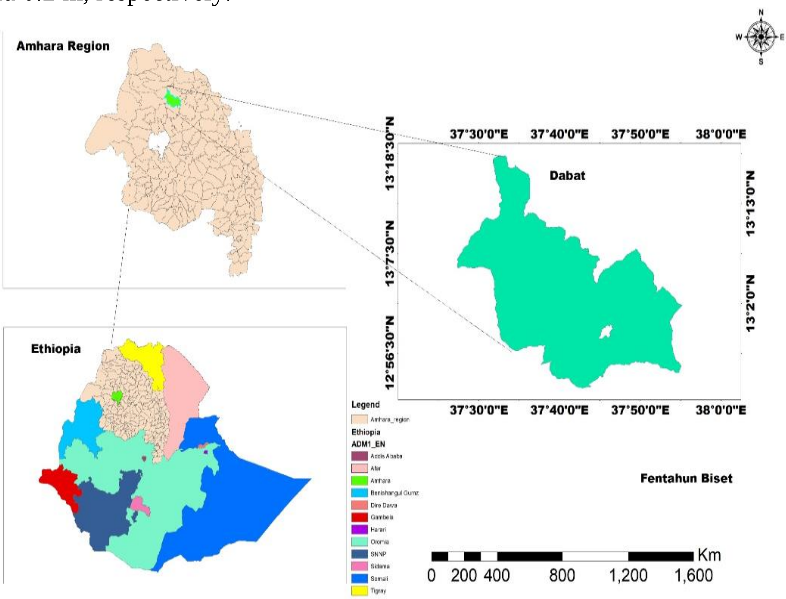

Figure1. Map of Dabat district (Source: Arc Map 10.8.https://www.esri.com)

Data collection and measurement

Days to 90% physiological maturity (DM)

DM was recorded as the number of days from sowing to the date when 90% of the peduncle turned yellow-straw in color.

Plant height (PH)

Plant height was measured in centimeters from ground level to the top of the spike (excluding the awns). Measurements were taken on ten randomly selected plants from the middle eight rows of each plot.

Spike length (SL)

Spike length was measured in centimeters from the base of the spike to its tip, excluding awns. Ten spikes were randomly selected from each plot's net plot area for measurement.

Kernels per spike (KPS)

KPS was determined before harvesting by counting the number of seeds on ten randomly selected plants from the middle eight rows of each plot.

Biomass yield (kg ha^{-1})

Plants in the net plot area were harvested at ground level using a sickle, tied into bundles, and sun-dried. Above-ground dry biomass yield was determined by weighing the bundles with a digital balance after drying to a constant weight.

Grain yield (kg ha^{-1})

Grain yield was measured from the net plot area. After sun-drying, plants were threshed, and seeds were separated from straw. Grain weight was recorded and adjusted to a standard moisture content of 12.5% before calculating yield per plot and converting to kg ha^{-1}.

Harvest index (HI)

HI was calculated on a plot basis as: $\mathrm{HI}(\%) = \frac{\text{economic yield}}{\text{above-ground dry biomass yield}} \times 100$

Thousand kernel weight (TKW) (g)

TKW was determined by weighing one thousand counted kernels using a sensitive electronic balance.

Quality and germination tests

Germination capacity

Germination capacity (germination percentage) refers to the proportion of viable seeds in a barley sample. It is used to assess seed viability. Water sensitivity describes the tendency of seeds to germinate after prolonged submersion.

Germination energy

Germination energy was determined as the percentage of grains expected to germinate fully under normal malting/test conditions within the specified test time. It also reflects the vigor of the sample (i.e., the fraction that germinates early/rapidly).

Sieve test (grain plumpness)

The sieve test assessed grain plumpness by determining the proportion of barley kernels retained on sieves of different mesh sizes: >2.8 mm, >2.5 mm, >2.2 mm, and <2.2 mm. Kernels remaining above each sieve size were recorded as fractions/percentages.

Grain protein concentration (%)

Protein concentration (a key quality trait for malting barley) was determined using the Kjeldahl method. A 100-seed sample of malt barley was weighed and transferred into a completely dry Kjeldahl flask for digestion and subsequent protein estimation.

Statistical data analysis

Analysis of variance (ANOVA) was performed for all collected data using R statistical software (version 4.3.2). Treatment means were compared using the least significant difference (LSD) test at the 5% probability level. In addition, a partial budget analysis was conducted to evaluate the economic feasibility of the treatments following the methodology described by CIMMYT (1988).

RESULTS AND DISCUSSION

Soil physiochemical properties before sowing

Based on the analysis of the physical and chemical properties of the soil in the Dabat district, pre-planting soil sample was analyzed for texture, pH, total nitrogen, available phosphorus, organic carbon, and cation exchange capacity (CEC). The results indicated that the soil in the experimental area consisted of 32.7% sand, 34.7% silt, and 32.7% clay (Table 1). According to Ashley *et al*. (2014), barley grows best in well-drained, fertile loam or clay loam soils. Clay loam soils are particularly important in agriculture due to their balanced composition of sand, silt, and clay, which supports favorable water retention and nutrient availability.

Table 1. The major physical and chemical properties of pre-sowing soil of the experimental area at Dabat district in 2023/2024

Soil characteristics	Rating	Rating range
Soil Ph	6.67	Slightly acidic
Organic carbon (%)	1.97	Low
Total Nitrogen (%)	0.13	Low
Organic matter (%)	1.48	Low
Available P (ppm)	5.61	Low
Texture		
Sand (%)	32.7	
Clay (%)	32.7	
Silt (%)	34.7	

Phenological data

The analysis of variance revealed that days to 90% physiological maturity were highly significantly affected ($p < 0.01$) by the main effect of nitrogen rates and significantly affected ($p < 0.05$) by the interaction between nitrogen rates and time of application. In contrast, the main effect of time of nitrogen application alone was not significant (Table 2).

Table 2. Interaction effect of rates and time of N application on days to 90% physiological maturity of malt barley at Dabat district during 2023/2024

	Time of N- application		
Nitrogen rate (kg ha^{-1})	T1	T2	T3
46	122.0^{abc}	123.0^{a}	120.0^{bcd}
92	119.7^{cd}	119.3^{d}	120.3^{bcd}
138	123.6^{a}	122.3^{ab}	121.6^{abcd}
184	124.0^{a}	120.0^{bcd}	122.3^{ab}
Mean	121.5		
LSD ($p < 0.05$)	2.4		
CV (%)	1.2		

LSD: Least significant difference; CV: Coefficient of Variation (%); T1: Time of N application 1/2 at planting and 1/2 at tillering stage; T2:1/4 at planting, 1/4 at tillering and 1/2 at booting stage of the crop; T3:1/3 at planting, 1/3 at tillering and 1/3 at booting stage of the crop. Means with a column followed by the same letter (s) are not significantly different at 5% level of significance.

The longest duration to 90% physiological maturity (124 days) was observed in plots that received the highest nitrogen rate of 184 kg N ha^{-1}, applied in two splits (half at planting and half at the tillering stage). Conversely, the shortest time to physiological maturity (119.3 days) was recorded in plots treated with 92 kg N ha^{-1} applied in three splits ¼ at planting, ¼ at tillering, and ½ at the booting stage.

These findings are consistent with those of Ketema Niguse and Mulatu Kassaye (2018), who reported that days to 90% physiological maturity in barley were significantly influenced by nitrogen fertilizer rates. Moreover, the results align with the well-established principle that excessive nitrogen supply delays physiological maturity by promoting vigorous vegetative growth (Yohannes Erkeno and Nigussie Dechassa, 2019).

Growth parameters

Spike length

The analysis of variance indicated that the main effect of nitrogen rate had a highly significant effect ($p < 0.01$) on spike length, while the time of nitrogen application also showed a significant effect ($p < 0.05$). However, the interaction between nitrogen rate and time of application was not significant. The maximum spike length (7.9 cm) was recorded at the highest nitrogen rate of 184 kg N ha^{-1}, whereas the minimum value (6.0 cm) was observed at the lowest nitrogen rate of 46 kg N ha^{-1} (Table 3).

Table 3. The main effect of N- application on spike length at different rates and times in Dabat district during 2023/2024

Nitrogen rates (kg N ha^{-1})	**Spike length (cm)**	**Time of N application**	**Spike length (cm)**
46	6^{d}	T1	7.4^{a}
92	6.5^{c}	T2	6.68^{b}
138	7.38^{b}	T3	6.8^{b}
184	7.97^{a}	Mean	6.9
LSD ($p < 0.01$)	0.5	LSD ($p < 0.05$)	0.43
		CV (%)	7.3

LSD: Least significant difference; CV: Coefficient of Variation (%); T1: Time of N application 1/2 at planting and 1/2 at tillering stage; T2:1/4 at planting, 1/4 at tillering and 1/2 at booting stage of the crop; T3:1/3 at planting, 1/3 at tillering and 1/3 at booting stage of the crop. Means with a column followed by the same letter (s) are not significantly different at 5% level of significance.

The increase in spike length at higher nitrogen rates, particularly at 184 kg N ha^{-1} applied in two well-timed split applications may be attributed to improved synchronization between plant nitrogen demand and soil nitrogen availability, resulting in enhanced nitrogen uptake by the roots. As the nitrogen rate increased from 46 to 184 kg N ha^{-1}, spike length increased by 32.83%. This finding is consistent with the results of Mohammadi and Samadiyan (2014), who reported a significant increase in barley spike length with increasing nitrogen rates.

With respect to the timing of nitrogen application, the highest mean spike length (7.4 cm) was obtained when nitrogen was applied in two splits (½ at planting and ½ at the tillering stage), while the lowest mean value (6.68 cm) was recorded under three split applications (¼ at planting, ¼ at tillering, and ½ at the booting stage). However, this treatment did not differ significantly from the three-way split application of nitrogen (⅓ at planting, ⅓ at tillering, and ⅓ at the booting stage). Similar findings were reported by Begashaw *et al*. (2022), who demonstrated that applying nitrogen at appropriate rates and times enhances nitrogen partitioning toward spike development and grain formation.

Plant height

Analysis of variance indicated that plant height was significantly affected by nitrogen fertilizer rate and timing ($p < 0.01$), and their interaction effect was also significant ($p < 0.05$). The tallest plants (89.7 cm) were recorded in plots treated with 138 kg N ha^{-1} applied in two splits (½ at planting and ½ at the tillering stage), whereas the shortest plant height (76.6 cm) was observed at the lowest nitrogen rate (46 kg N ha^{-1}) applied in three splits (¼ at planting, ¼ at tillering, and ½ at the booting stage) (Table 4).

Table 4. Interaction effect of nitrogen rate and timing of application on plant height at Dabat District during the 2023/24 cropping season.

	Time of N application		
N-rate (kg ha^{-1})	**T1**	**T2**	**T3**
46	82.6^{de}	76.6^{f}	81.4^{e}
92	87.3^{abc}	80.9^{e}	85.6^{abcd}
138	89.7^{a}	84.5^{cde}	85.4^{bcd}
184	87.7^{abc}	89.4^{ab}	86.2^{abcd}
Mean	84.6		
LSD ($p < 0.05$)	4.02		
CV (%)	2.8		

LSD: Least significant difference; CV: Coefficient of Variation (%); T1: Time of N application, 1/2 at planting and 1/2 at tillering stage; T2:1/4 at planting, 1/4 at tillering and 1/2 at booting stage of the crop; T3= 1/3 at planting, 1/3 at tillering and 1/3 at booting stage of the crop. Means with a column followed by the same letter (s) are not significantly different at 5% level of significance.

Similar results were reported by Fasil Shimels and Demelash Kefale (2021), who observed increased plant height in malt barley with increasing nitrogen rates. Likewise, Ramu (2008) reported significant increases in plant height under split nitrogen application, with the highest plant height obtained from two split applications compared with three splits in barley and wheat crops. However, these findings contrast with those of Singh *et al*. (2016), who reported that the tallest plants were obtained when nitrogen was applied in three splits.

The increase in plant height in response to higher nitrogen fertilizer rates may be attributed to enhanced nitrogen availability, which promotes cell division and leaf area development. This, in turn, increases photosynthetic capacity and assimilate production, leading to greater dry matter accumulation (Nesgea Shiferaw *et al*., 2012).

Yield and yield components

Kernel number per spike

The number of kernels per spike in malt barley was highly significantly affected ($p < 0.01$) by the main effects of nitrogen rate and the timing of nitrogen application. However, their interaction effect was not significant. The maximum number of kernels per spike (42.0) was recorded at the highest nitrogen rate (184 kg N ha^{-1}), whereas the minimum value (37.5) was obtained at the lowest nitrogen rate (46 kg N ha^{-1}) (Table 5). These results are in agreement with the findings of Dubey et al. (2018), who reported that kernel number per spike in barley increased with increasing nitrogen application rates. The present study is also supported by Biruk Gezahegn and Demelash Kefale (2016), who reported that nitrogen fertilizer rate, had a significant effect on kernel number per spike. Overall, kernel number per spike showed a positive response to increasing nitrogen rates, with a highly significant difference observed between low and high nitrogen levels.

Regarding the timing of nitrogen application, the highest kernel number per spike (42.4) was obtained when nitrogen was applied in two splits (½ at planting and ½ at the tillering stage), whereas the lowest value (38.3) was a recorded under three equal split application (⅓ at planting, ⅓ at tillering, and ⅓ at the booting stage). However, this treatment did not differ significantly from the split application of ¼ at planting, ¼ at tillering, and ½ at the booting stage.

Grain yield

Grain yield was significantly influenced by nitrogen rate and the timing of split applications ($p < 0.05$), while their interaction did not have significant difference. The highest yield (26.5 qt ha^{-1}) was recorded with 184 kg N ha^{-1}, followed by 138 kg N ha^{-1}, whereas the lowest yield (21.9 qt ha^{-1}) occurred at 46 kg N ha^{-1}. Application of 184 kg N ha^{-1} produced significantly higher yields than the lower rates of 46 and 92 kg N ha^{-1}, indicating a positive response of grain yield to increasing N levels from 46 to 184 kg ha^{-1} (Table 5). This aligns with Dubey et al. (2018), who reported a similar increase in barley yield with N application, showing an increasing trend from 0 to 60 kg ha^{-1}. For N split application timing, the highest yield (26.1 qt ha^{-1}) was obtained when N was applied half at planting and half at tillering, while the lowest yield (21.9 qt ha^{-1}) occurred when N was equally split across planting, tillering, and booting (⅓ at each stage). However, No significant differences were observed with the ¼–¼–½ split at planting, tillering, and booting stage. These results indicate that malt barley benefits more from N applied at planting and tillering than at booting, as higher N availability during these stages promotes tiller development and enhances grain yield.

Table 5. The main effect of nitrogen rates and time of N application kernel per Spike and Grain yield at Dabat district during 2023/2024

Nitrogen rates (kg N ha^{-1})	**KPS**	**GY (ton ha^{-1})**	**Time of N application**	**KPS**	**GY (ton ha^{-1})**
46	37.5^{b}	2.19^{c}	T1	42.4^{a}	2.61^{a}
92	39.8^{ab}	2.26^{bc}	T2	39.7^{b}	2.25^{b}
138	41.2^{a}	2.46^{a}	T3	38.3^{b}	2.19^{b}
184	42.0^{a}	2.65^{a}	Mean	40.1	2.35
LSD (*0.05*)	2.40	0.27	LSD ($p < 0.01$)	2.1	0.22
			CV (%)	6.2	11.68

KPS: Kernel per spike; SD Least significant difference; CV: Coefficient of Variation (%); T1: Time of N application 1/2 at planting and 1/2 at tillering stage; T2: 1/4 at planting, 1/4 at tillering and 1/2 at booting stage of the crop; T3: 1/3 at planting, 1/3 at tillering and 1/3 at booting stage of the crop. Means with a column followed by the same letter (s) are not significantly different at 5% level of significance.

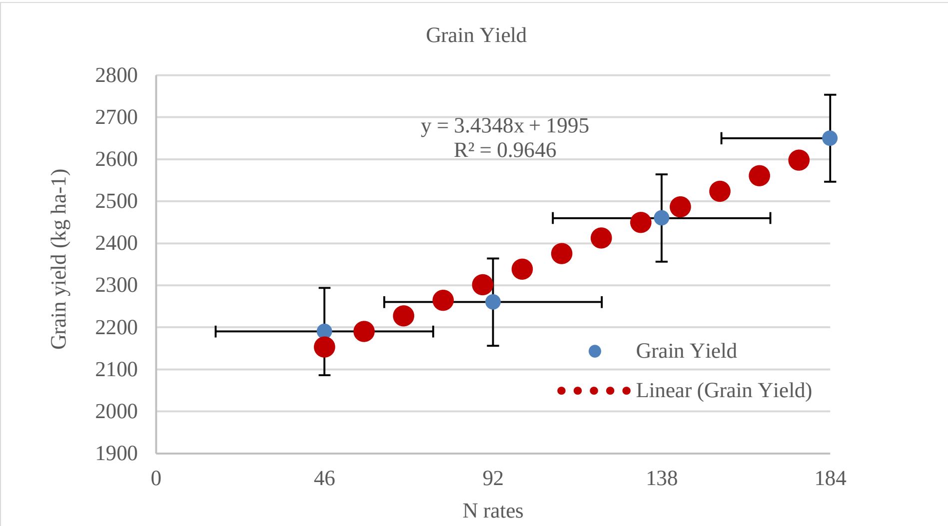

Figure 1. Regression graph grain yield response of nitrogen rate on malt barley

Above ground dry biomass

The analysis of variance indicated that aboveground biomass was significantly affected ($p < 0.01$) by nitrogen rate, split application timing, and their interaction. The highest biomass (7,986.1 kg ha^{-1}) was recorded with 138 kg N ha^{-1} applied in two splits (half at planting and half at the tillering stage), whereas the lowest biomass (4,166.7 kg ha^{-1}) occurred with 46 kg N ha^{-1} applied in three equal splits (⅓ at planting, ⅓ at tillering, and ⅓ at booting) (Table 6).

Table 6. Interaction effect of N-rate and time of N split application on biomass at Dabat district during 2023/2024

	Time of N-split application		
N-rates (kg ha^{-1})	**T1**	**T2**	**T3**
46	5729.2^{de}	5381.9^{e}	4166.7^{f}
92	6167.4^{cde}	5208.3^{ef}	5841.7^{cde}
138	7986.1^{a}	5902.8^{cde}	5555.5^{de}
184	7638.9^{ab}	6597.2^{bcd}	6944.5^{abc}
Mean	6093.3		
LSD($p < 0.01$)	1183.2		
CV (%)	11.5		

LSD: Least significant difference; CV: Coefficient of variation; Bb: biomass; T1: Times of N-split application; 1/2 at planting and 1/2 at tillering stage; T2:1/4 at planting, 1/4 at tillering and 1/2 at booting stage of the crop; T3: 1/3 at planting, 1/3 at tillering and 1/3 at booting stage of the crop. Means with a column followed by the same letter (s) are not significantly different at 5% level of significance.

The increase in biomass with higher nitrogen rates is likely due to enhanced nutrient availability during planting and tillering, which stimulates physiological growth and promotes greater biomass accumulation. These results are consistent with Tilahun *et al.* (2017), who reported that double split nitrogen application at planting and mid-tillering produced higher biomass than triple split applications in durum wheat.

Harvesting index (%)

The analysis of variance showed that harvest index was not significantly affected by nitrogen rate and the timing of split nitrogen application (p > 0.05); however, their interaction was highly significant ($p < 0.01$). The highest harvest index (44.7%) was observed at 184 kg N ha^{-1} applied in two splits (½ at planting and ½ at tillering), likely due to a greater proportional increase in grain yield compared to total biomass. In contrast, the lowest harvest index (31.8%) occurred with 46 kg N ha^{-1} applied in three equal splits (⅓ at planting, ⅓ at tillering, and ⅓ at booting), possibly due to a higher proportion of biomass allocated to vegetative parts rather than grain (Table 7). These results show a trend similar to that reported by Demelash *et al*. (2025), who observed changes in harvest index with increasing nitrogen rates.

Quality standard parameter

Thousand kernel weights

The analysis of variance showed that the thousand kernel weight was highly significantly different ($p < 0.01$) on the main effects of N rates and time of N application, but the interaction effects of the two factors were not significantly different. Among the N levels, the maximum thousand kernel weight (43 g) was recorded when the N was applied at the rate of 184 kg N ha^{-1}, while the minimum thousand kernel weight (34.3 g) was obtained from the plot receiving the lowest N rate at 46 kg N ha^{-1} (Table 8).

Table 7. Interaction effect of N-rate and time of N split application of harvesting index on malt barley at Dabat during 2023/2024

	Time of N- split application		
N-rate (kg ha^{-1})	**T1**	**T2**	**T3**
46	40.37^{bcd}	37.91^{def}	31.79^{g}
92	42.53^{a}	39.13^{cde}	34.38^{fg}
138	43.64^{g}	42.05^{abc}	37.32^{df}
184	44.74^{abc}	36.24^{ef}	40.30^{bcd}
Mean	39.20		
LSD ($p < 0.01$)	3.68		
CV (%)	5.60		

LSD: Least significant difference; CV: Coefficient of variation; HI: harvesting index; T1: Times of N-split application; 1/2 at planting and 1/2 at tillering stage; T2:1/4 at planting, 1/4 at tillering and 1/2 at booting stage of the crop; T3: 1/3 at planting, 1/3 at tillering and 1/3 at booting stage of the crop. Means with a column followed by the same letter (s) are not significantly different at 5% level of significance

Table 8. The main effect of nitrogen rates and time of N application on thousand kernel weight of malt barley at Dabat district during 2023/2024.

Nitrogen rate (kg N ha^{-1})	**TKW**	**Time of N application**	**TKW**
46	34.3^{d}	T1	40.5^{a}
92	36.6^{c}	T2	38.5^{b}
138	40.7^{b}	T3	37^{c}
184	43.04^{a}	Mean	38.6
LSD ($p < 0.01$)	1.7	LSD ($p < 0.01$)	1.5
		CV (%)	4.5

LSD: Least significant difference; CV: Coefficient of Variation (%); T1: Time of N application 1/2 at planting and 1/2 at tillering stage; T2:1/4 at planting, 1/4 at tillering and 1/2 at booting stage; T3: 1/3 at planting, 1/3 at tillering and 1/3 at booting stage; TSW: Thousand seed weight. Means with a column followed by the same letter (s) are not significantly different at 5% level of significance.

Generally, thousand-kernel weights increased almost linearly with increasing nitrogen rates. An increase in seed weight at higher N rates might be primarily due to an increase in the chlorophyll content of the leaves, which means higher photosynthetic rates and, ultimately, plenty of photosynthesis available during grain development. This result coincides with Megersa *et al*. (2022) who reported an increase in thousand-kernel weight, in bread wheat when the N rate increased. Haile *et al*. (2012) also reported that the thousand-kernel weight of bread wheat was significantly affected by different nitrogen levels. The highest thousand kernel weight (40.5 g) was recorded at the N time of application (½ at planting + ½ at the tillering stage of the crop), whereas the lowest thousand kernel weight (37 g) was obtained at the three times of N splitting of application (1/3 at planting, 1/3 at tillering, and 1/3 at the booting stage of the crop). According to Ethiopian quality standards, the acceptable grain size (thousand-kernel weights) for barley is in the range of 25-35 g (Ethiopia Quality Standard Authority, 2006).

Grain protein content

Analysis of variance showed significant effects of nitrogen rate and nitrogen application timing on grain protein content ($p < 0.05$), while their interaction was not significant. The highest grain protein content (13.6 %) was obtained at the highest nitrogen rate (184 kg N ha^{-1}), and the lowest protein content (10.9 %) was observed at the lowest rate (46 kg N ha^{-1}) (Table 9). Grain protein content increased with increasing nitrogen rates from 46 to 184 kg N ha^{-1}. These results agree with Halvorson *et al.* (2004), who reported that grain yield and protein content in cereals generally increase with higher nitrogen levels. According to the standards of the Gondar Malt Factory, acceptable protein content ranges from 9.5% to 12.5%. Among nitrogen application timings, the highest protein content (12.2 %) was recorded when nitrogen was split ½ at planting and ½ at tillering, whereas the lowest protein content (10.1 %) occurred with a split of ¼ at planting, ¼ at tillering, and ½ at booting. This observation contrasts with findings that early nitrogen application at planting and tillering reduces protein content compared with later application timings (Taalab *et al.*, 2015).

Table 9. The main effect of rate and time of N application on grain protein content, germination energy, and germination capacity and sieve size at Dabat district during 2023/2024

Nitrogen rates (kg N ha^{-1})	**GPC**	**GE%**	**GC**	**SS (2.8, 2.5, 2.2) mm**
46	10.9^{c}	98.8	99.7	92.66^{b}
92	12.1^{b}	97.9	99.3	93.96^{ab}
138	12.4^{b}	99	99.6	95.7^{a}
184	13.6^{a}	98.7	99.8	96.3^{a}
LSD ($p < 0.05$)	0.85	NS	NS	2.6
Time of N application				
T1	12.2^{a}	98.6	99.6	94.4
T2	11.2^{b}	98.8	99.5	94.7
T3	10.1^{c}	98.4	99.7	94.8
Mean	12.25	98.6	99.6	94.7
LSD ($p < 0.05$)	0.74	NS	NS	NS
CV (%)	7.03	1.3	0.55	2.8

LSD: Least significant difference; CV: Coefficient of Variation (%); NS: Non-significant; T1: time of N application, 1/2 at planting and 1/2 at tillering stage; T2: 1/4 at planting, 1/4 at tillering and 1/2 at booting stage; T3: 1/3 at planting, 1/3 at tillering and 1/3 at booting stage; TSW: Thousand seed weight; GE : Germination Energy; GC: Germination capacity ; GPC: Grain protein content; SS: Sieve Size. *Means with a column followed by the same letter (s) are not significantly different at 5% level of significance.*

Sieve test (St)

The sieve test was conducted to determine the proportions of barley retained on >2.8 mm, >2.5 mm, and >2.2 mm sieves. Analysis of variance showed that sieve size was significantly affected ($p < 0.05$) by the main effect of nitrogen rates, while the timing of nitrogen application and its interaction with rate were not statistically significant. The highest sieve retention percentages (96.3% and 95.7%) were observed at the highest nitrogen rates of 184 kg N ha^{-1} and 138 kg N ha^{-1}, respectively, whereas the lowest sieve retention (92.6%) occurred at the lowest nitrogen rate of 46 kg N ha^{-1}

(Table 9). These results are consistent with Shimelis and Mulatu (2021), who reported a linear relationship between nitrogen fertilizer rate and sieve test percentage. According to the Ethiopian Malt Factory standards and the European Brewery Convention (EBC), the acceptable sieve retention percentage is over 90% for two-row barley and over 80% for six-row barley.

Germination energy and Germination capacity

The main effect of nitrogen rates, time of N application, and their interaction effects didn't show significant differences ($p>0.05$) on germination energy. According to EBC (1998) the germination energy of malt barley should be above 95%. The current result indicated that the germination energy and germination capacity were in the acceptable range in all nitrogen rates and times of application (Table 9).

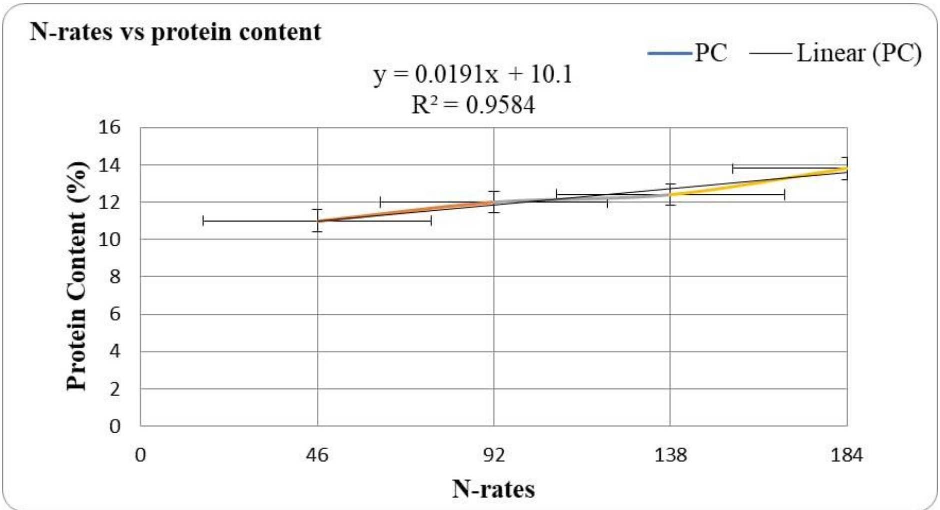

Figure 3. Regression graph protein content response of Nitrogen rate on malt barley

Partial budget analysis

The partial budget analysis revealed that the highest marginal rate of return (MRR) values were 4,258.37% and 3,862.37% at 46 kg N ha^{-1}, corresponding to split application timings of 1/3 at planting, 1/3 at tillering, and 1/3 at booting, and ½ at tillering and ½ at booting, respectively (Table 10). On the other hand, the application of 92 kg N ha^{-1}, split 1/2 at planting, and ½ at tillering, resulted in the MRR of 292.64%, indicating a highly efficient return on investment relative to input costs. According to CIMMYT (1988), among treatments with MRR greater than 100%, the one with the highest net benefit should be recommended. Based on this criterion, the application of 92 kg N ha^{-1}, split ½ at planting, and 1/2 at tillering, achieved the highest net benefit (1,324.84 USD ha^{-1}) while maintaining MRR above 100%, indicating its economic feasibility for recommended in the Dabat District.

Table 10. Partial budget analyses on yield and quality response of malt barley for nitrogen rates and time of N applications

N Rate	Sp	AGY ($t\ ha^{-1}$)	ASY ($t\ ha^{-1}$)	GB (USD/ha^{-1})	TVC (USD)	NB (USD)	DA	MRR (%)
46	T1	2.12	3.49	1122.04	33.12	1088.93		
46	T2	2.35	3.20	1198.93	35.06	1163.86		3862.37
46	T3	2.29	4.90	1283.92	37.01	1246.91		4258.97
92	T1	2.64	4.24	1388.47	63.64	1324.84		292.64
92	T2	1.95	3.20	1029.43	65.58	963.84	D	
92	T3	1.83	2.85	959.61	67.53	892.08	D	
138	T1	2.17	2.73	1093.75	94.16	999.59	D	
138	T2	2.15	3.79	1154.12	96.10	1058.02	D	
138	T3	1.4	2.35	743.38	98.05	645.33	D	
184	T1	1.93	3.68	1053.87	126.62	927.25	D	
184	T2	2.19	2.81	1106.03	127.27	978.76	D	
184	T3	2.36	3.99	1256.45	128.57	1127.88	D	

Where, AGY: Adjusted grain yield; ASY: Adjusted straw yield; TVC: Total variable cost; NB: net benefit; ETB: Ethiopian birr; DA: dominance analysis; N: nitrogen rate; Price of urea: 0.305 USD per kg; price of sale straws 0.065 USD per kg; labor cost for application nitrogen 0.65 USD per days; Malt barely sale of current price 0.42 USD per kg; Time of N application of nitrogen:T1 :Time of N application at ½ at planting +1/2 at tillering stage; T2:1/4th at planting +1/4th tillering and ½ at booting stage; T3:1/3 at planting +1/3 at tillering and 1/3 at booting stage ,Sp: split application; GB: Growth Benefit

CONCLUSION

The results revealed that both nitrogen rate and the timing of split application significantly influenced grain yield, spike length, number of grains per spike, thousand-grain weight, grain protein content, germination energy, and germination capacity. Grain yield increased with increasing nitrogen rate, reaching a maximum of 26.5 qt ha^{-1} at 184 kg N ha^{-1}, followed closely by 26.1 qt ha^{-1} obtained from the split application of half at planting and half at the tillering stage. In contrast, the lowest grain yield (21.9 qt ha^{-1}) was recorded at 46 kg N ha^{-1} with a split application of one-third at planting, one-third at tillering, and one-third at the booting stage. Although the highest grain yield was achieved at the maximum nitrogen rate, economic analysis revealed a different outcome. The partial budget analysis indicated that the application of 92 kg N ha^{-1}, split as ½ at planting, ½ at tillering, stage, generated the highest net benefit (1,324.84 USD ha^{-1}) and an acceptable marginal rate of return (292.64%). Therefore, 92 kg N $ha^{-1}$with ½ at planting, and ½ at tillering stage to be better in terms of both agronomic performance and economic feasibility for malt barley production in the study area and similar agro ecology.

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