# Effects of seeding and nitrogen fertilizer rates on malting barley yield and quality in highland tropical environment

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**The expansion of brewing industries in Ethiopia has been inducing a growing demand for the supply of malt with optimum kernel protein content. However, the supply has been constrained by the unavailability of sufficient volumes of acceptable quality of malting barley grain to meet the ever-increasing demand. In this regard, field experiments were conducted in the southeastern Ethiopian highlands to examine the combined effects of five seeding rates (100, 125, 150, 175 and 200 kg ha$^{-1}$) and four nitrogen (N) fertilizer levels (0, 18, 36 and 54 kg ha$^{-1}$) on the yield, yield components and protein concentration of malting barley. The experiment was laid out in a randomised complete block design with three replications. Increasing seeding rate from 100 to 125 and 150 kg ha$^{-1}$ improved the grain yields by 173 (6%) and 329 kg ha$^{-1}$ (10%), and economic profitability by US$6.58 and US$4.15 respectively, for each US$1.00 investment on seed. Similarly, application of 18, 36 and 54 kg N ha$^{-1}$ increased the grain yields by 309 (10%), 490 (17%) and 639 kg ha$^{-1}$ (22%), and economic benefits by US$8.14, US$4.44 and US$2.78 respectively, for each US$1.00 investment on N fertilizer, when compared to the control. These achievements were without detrimental effect to the kernel protein concentration of malting barley. The production of malting barley with improved yield, optimum kernel protein concentrations and enhanced economic benefit was attained through seeding at a rate of 125 – 150 kg ha$^{-1}$ along with 18 – 54 kg N ha$^{-1}$ on suitable soil types in the southeastern highlands of Ethiopia and other areas with similar agro-ecologies. Thus, to improve the likelihood of acceptance of malting barley by malting industries, growers are recommended to select low-protein containing varieties and decide application of N fertilization based on soil test results.**

Keywords: Malting barley, nitrogen fertilizer rate, protein concentration, seeding rate, yield

Barley (*Hordeum vulgare L.*) is an annual cereal crop, which grows in diverse environments ranging from the desert of the Middle East to the high elevation of Himalayas (Hayes et al. 2003). The soil and agroecological conditions of Ethiopia, where this study was conducted are very suitable for producing malting barley. Arsi and West Arsi, the specific study areas, are among the potential districts in the southeastern Ethiopian highlands identified for malting barley production (Atlas of Arsi Zone 2002). Apart from the benefits for food and feed, malting barley is a specialty crop for which a premium price is being paid by domestic malters and exporters (BMBRI 2010).

Ethiopia is the second largest barley producer in Africa after Morocco, accounting for about 25% of the total food and malting barley production (FAO 2014). In the 2021 cropping season, 0.93 million ha of land was allocated for food and malting barley production in Ethiopia; this was the fifth largest area under production after tef (*Eragrostis tef*), maize (*Zea mays*), wheat (*Triticum aestivum*) and sorghum (*Sorghum bicolor*) (CSA 2021).

In 2017, 0.095 and 0.063 million ha of land were allocated for barley production in Arsi and West Arsi districts, respectively; this was the third largest area after wheat and tef in Arsi, and wheat and maize in West Arsi (CSA 2017). Although there exist environmental, marketing and other opportunities for the production of malting barley in this region (Mohammed and Getachew 2003), provision of sufficient quantity and acceptable quality as set by the malting industry have been constrained due to many factors. This, in turn, resulted in lower revenues for malting barley growers since there is usually a much higher premium price for malting compared to food barley.

Successful growing of barley for malting purposes depends on many factors, and to be



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acceptable for malting, barley must meet these criteria, which are directly related to the processing efficiency and product quality in the malting and brewing industries (Vanova et al. 2006). Quality requirements for malting barley are reasonably strict and include relatively low protein content of 9 – 11.5% (Atherton 1984), pure seed of an acceptable variety and relatively large plump kernels (> 800 g $kg^{-1}$) of uniform size (BMBRI 2010; O'Donovan et al. 2011). Malting removes internal cell wall barriers, stimulates the production of enzymes for converting starch into extract in the brewery, and promotes flavour and colour development. This process is facilitated by uniform seed, which results in more uniform germination and relatively low protein content to increase extract levels and enhance beer stability (Mather et al. 1997). A plump kernel contains more starch and gives a higher percent of extract, which in turn produces a greater amount of beer from a given weight of malt (BMBRI 2010). Thus, agronomic practices that boost increased grain yield, seed uniformity, plumpness and acceptable protein levels will have important impacts on malting and brewing processes.

Growing malting barley of acceptable quality is associated with challenges that are not unique to Ethiopia. In Canada (O'Donovan et al. 2011) and France (Le Bail and Meynard 2003), for example, growers also have had difficulty of achieving the quality requirements for malting barley. Previously published literature revealed that malting barley yield and quality are influenced by a multitude of factors including agronomic practices such as seeding and nitrogen (N) rates; genetics (cultivar choice); environmental factors such as soil type, soil temperature and water content; and other management practices (McKenzie et al. 2005; Potterton and McCabe 2017; Therrien et al. 1994; Wade and Froment 2003). Seeding and N fertilizer rates are among the most influential agronomic factors affecting yield and quality of malting barley (McKenzie et al. 2005). Both low and high rates of seeding and N fertilizer result in reduced yield and unacceptable protein concentration. Malting barley with high protein content results in lower extracts for the breweries and slows down water uptake during steeping, which potentially affect final malt quality. A low protein level, on the other hand, results in lack of enzymes necessary to modify the barley kernel and to break down the starch during brewing (BMBRI 2010). Hence, the use of optimum seeding and N rates are vital for achieving the required quality parameters for malting and brewing purposes.

There have been very few studies from Ethiopia on the influences of agronomic practices such as seeding and N rates on the yield and quality of malting barley. This study was therefore conducted with the overall objectives of determining the agronomic and economic optimum seeding and N fertilizer rates that help to boost yield without compromising the protein quality of malting barley.

## Materials and methods

### Description of the study sites

This study was conducted in the southeastern highlands of Ethiopia, in the Chole and Kofele districts of Arsi and West Arsi zones, respectively. Chole and Kofele districts are among the zoned areas for both food and malting barley production. The study was conducted at seven different sites over a three-year period. Throughout those three growing seasons, the experiments were located on different sites each year. The previous crops on these sites were small cereals.

The study sites at Kofele were all located close to 7°04' N and 38°47' E and at an altitude around 2685 m above sea level (a.s.l). The study sites at Chole were located between 8°07' – 8°13' N and 39°54' – 39°56' E and at altitude ranging between 2715 – 3130 m a.s.l. The agroecology of Kofele and Chole is categorised as warm temperate per humid

(MoA 2000). The dominant soil type of both Kofele and Chole districts is pellic vertisol (IUSS working group WRB 2014).

Since there were no established stations in both Chole and Kofele districts, weather data were unavailable. For that reason, the New LocClim: Local Climate Estimator database developed by FAO (FAO 2005), was used to estimate the weather patterns for both locations. The estimated mean annual rainfall totals of Chole and Kofele districts were 1014 and 1170 mm, respectively. Both Chole and Kofele districts have an extended rainy season, which starts in March and continues to October. The highest rainfall concentrations were in June, July and August. The mean minimum and maximum annual temperatures of Chole district were 6.3° and 26.7°C respectively. The corresponding values for Kofele district were 8.5° and 19.6°C respectively.

Before sowing, 27 composite soil samples were collected at a depth of 0 – 15 cm from each of the experimental sites for the purpose of soil characterisation. All samples were air-dried, ground to pass through a 2 mm sieve and analysed at the soil and plant nutrition laboratory of Kulumsa Agricultural Research Center (KARC). The soil samples were analysed for pH, available phosphorous (P), organic carbon (OC) and total nitrogen (N). The pH of soil was determined from a 1:1 (soil:water) ratio as described in McKeague (1978). The methods employed for the analyses of available P, OC and total N contents were Mehlich-3 (Mehlich 1984), Walkley and Black (Walkley 1947) and Kjeldahl (Bremner and Mulvaney 1982), respectively. The results of soil analyses showed that the mean values of pH, available P, total OC and total N for Kofele were 5.43, 13.33 mg kg$^{-1}$, 4.18% and 0.33%, respectively. While the pH, available P and total N for Chole were 4.9, 21.2 mg kg$^{-1}$ and 0.25%, respectively. Data on OC content for Chole district was unavailable.

## Experimental design and procedure

The experiment consisted of a factorial combination of four levels of N fertilizer (0, 18, 36 and 54 kg N ha$^{-1}$) and five levels of seeding rates (100, 125, 150, 175 and 200 kg ha$^{-1}$). The treatments were arranged in randomised complete block design with three replications. Before sowing, the seedbeds were ploughed four times using a traditional plough, locally called *maresha*, drawn by ox. All experimental plots at each location and site were sown with two-row malting barley (cv *Holker*). Seeds were drilled by hand at 0.20m spacing between rows during the first 2 weeks in July at all sites and in all years. The experiments had plot sizes of 3m by 4m. The spacing between plots and replications were 0.5m and 1m, respectively. Triple super phosphate (20 kg P ha$^{-1}$) was uniformly applied to all plots at sowing. Nitrogen fertilizer from urea was applied in splits; half at sowing and the remaining half at the tillering stage. Weeding was carried out by hand based on the research recommendations. For protection of malting barley against shoot fly and scald, pesticides, namely phenotrotion (1L ha$^{-1}$) and tilt (0.5L ha$^{-1}$), respectively were applied.

## Data collection

The measured and computed parameters for yield, yield attributes and quality of malting barley were stand count, number of tillers per plant, plant height, number of spikes per square meter, grain and above-ground total biomass yields, kernel weights, hectoliter weight and kernel protein concentration. Malting barley stand density was determined 3 weeks after germination by counting the total number of plants grown in 0.5 m row length from ten randomly selected rows in each plot. The number of tillers per plant from each plot was recorded by counting tillers in ten plant samples. The plant height (from the soil surface to the tip of spike excluding awns) was measured at physiological maturity and taken from ten randomly chosen plants in each plot. The number of spikes per square meter was determined from a 0.5m row length sample randomly selected from the middle ten rows of each plot just prior to harvesting.

Harvesting for yield determination was done manually from the net plot area of 2m by 2m. The harvested samples were air-dried to constant moisture content, threshed manually, cleaned and the grain weight recorded. The weighed samples were adjusted to a standard moisture content of 12.5% and converted into kg $ha^{-1}$ for the purpose of statistical analysis. Harvest index was calculated as percentage ratio of grain and biological yields. Grain samples were randomly collected from each plot and their respective kernel and hectoliter weights were determined using seed counter and hectoliter weighing devices in the physiology laboratory. Kernel N concentration was determined using Kjeldahl method in the plant nutrition laboratory of KARC.

## Economic analysis

The economic feasibility of seeding and nitrogen (N) fertilizer rates for malting barley production was evaluated based on the procedure set by CIMMYT (1988). The gross field benefits (GFB) and variable costs (VC) were computed relying on the average farm gate market prices over the two locations during the 2022 cropping season. The partial budget analyses were conducted independently for the seeding rate and N levels, because the two treatments did not interact with each other. The VC considered for seeding and N levels were the prices of seeds and urea fertilizer, respectively. All other costs such as those related to land preparation, phosphorous fertilizer, pesticides, harvesting, threshing and associated labour costs were considered as constant. The GFB were calculated based on the current market prices of grains and straws of malting barley. The grain and straw yields of malting barley were adjusted downwards by 10% to represent the actual production that the farmers commonly harvest. The seeding and N treatments were recorded in accordance to their increasing order of VC. The minimum acceptable marginal rate of return considered to declare economic feasibility for the use of seeds and N fertilizers was greater than or equal to 100%. Sensitivity analysis was also performed based on the assumption that the costs of inputs that do not vary stay constant, but all VC increase by 30% over the next 3 years with the base year taken as 2022.

## Data analysis

Analysis of variance was carried out for each of the measured (computed) parameters following the method described by Gomez and Gomez (1984). All yield, yield components and kernel protein content data were subjected to analysis of variance using the general linear model (PROC GLM) procedure of SAS version 9.0 (SAS Institute 2002). The significant differences among treatment means were compared using Duncan multiple range test at $P \leq 0.05$.

# Results and discussion

The analysis of variance indicated no significant interaction effects between seeding rate and N fertilizer levels for all of the measured variables. However, environment and year were large sources of variation for all of the variables measured (Table 1). Statistical analysis also revealed that the effects of treatments were generally consistent among the seven sites in Chole and Kofele districts. Thus, only the main and location effects are presented and discussed.

Table 1: The effects of seeding rate and nitrogen fertilization level on selected agronomic parameters and quality of malting barley grown in southeastern Ethiopian highlands

| Effects | Seedling density (No.) | Harvest index (%) | Grain yield (kg ha$^{-1}$) | Biomass yield (kg ha$^{-1}$) | Kernel weight (g) | Kernel protein (%) |
|---|---|---|---|---|---|---|
| Year | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Location | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Replication | 0.2771 | 0.315 | 0.1911 | 0.8007 | 0.9555 | 0.8596 |
| Seed rate (SR) | <0.0001 | <0.0001 | <0.0001 | 0.0456 | <0.0001 | 0.9908 |
| Nitrogen rate (N) | 0.4319 | 0.868 | <0.0001 | <0.0001 | 0.6457 | 0.0091 |
| SR*N | 0.8007 | 0.5887 | 0.0864 | 0.0302 | 0.8353 | 0.736 |
| Mean | 207.45 | 40.77 | 3307.65 | 8197 | 43.2 | 10.29 |
| CV | 31.58 | 13.18 | 26.27 | 26.74 | 11.61 | 10.28 |

## Effect of seeding rate

Seeding rate had a significant effect on grain ($P \leq 0.001$) and biomass ($P \leq 0.05$) yields of malting barley. Figures 1a and 1b showed that malting barley grain and biomass yields increased as the level of seeding rate increased up to 150 kg ha$^{-1}$, however, beyond 150 kg ha$^{-1}$, yields decreased and reached to the lowest value at 200 kg ha$^{-1}$. Malting barley sown at a rate of 150 kg ha$^{-1}$ gave the highest grain (3488 kg ha$^{-1}$) and biomass (8498 kg ha$^{-1}$) yields. Seeding malting barley at rates of 125 and 175 kg ha$^{-1}$ gave 3336 and 3485 kg ha$^{-1}$ grain yields, and 8301 and 8379 kg ha$^{-1}$ biomass yields, respectively, which were statistically not different from 150 kg ha$^{-1}$. Compared to 100 kg ha$^{-1}$, malting barley sown at rates of 125, 150 and 175 kg ha$^{-1}$ provided grain yield advantages of 173 kg (5%), 326 kg (10%) and 323 kg (10%), respectively. The corresponding increments for biomass yield were 417 kg (5%), 615 kg (8%), and 495 kg (6%), respectively. The lowest grain (2765 kg ha$^{-1}$) and biomass (7592 kg ha$^{-1}$) yields were obtained from seeding malting barley at the highest rate, 200 kg ha$^{-1}$. Significant grain and biomass yield responses to seeding rates were also reported by Lafond (1994), McKenzie et al. (2005), O'Donovan et al. (2011) and Spaner et al. (2001).

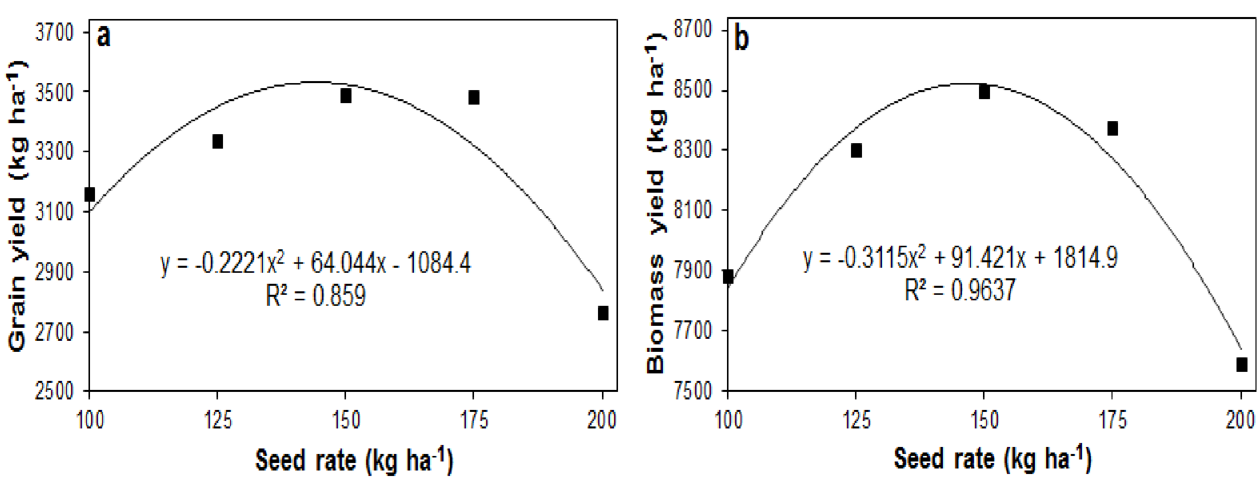


Figure 1: Effect of seedling rate on the grain (a) and biomass (b) yields of malting barley in the southeastern Ethiopian highlands

Malting barley stand density was significantly ($P \leq 0.001$) affected by seeding rate. The stand density increased as seeding rate increased, and vice versa implying a direct relationship (Figure 2). The maximum malting barley population per square meter (311) was recorded from the plots seeded at a rate of 200 kg ha$^{-1}$. A similar effect of seeding rate on stand density of barley was documented previously by O'Donovan et al. (2011).

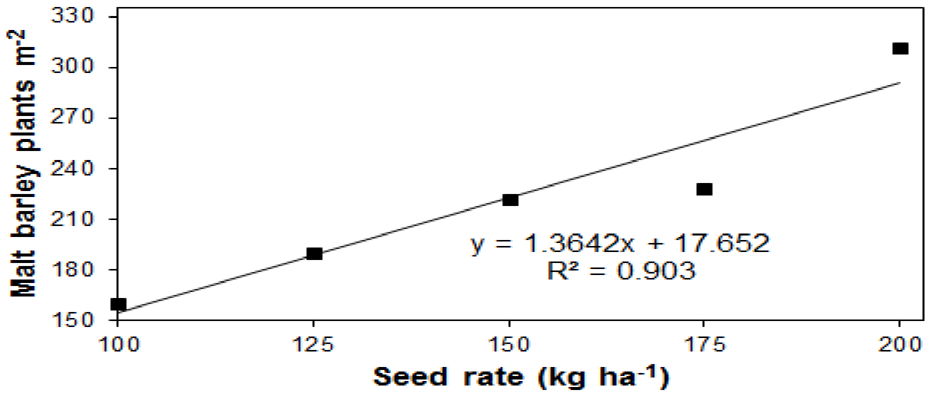


Figure 2: Effect of seedling rate on plant population of malting barley in the southeastern Ethiopian highlands

The inferior grain and biomass yield at 100 kg ha$^{-1}$ could be attributed to the inability of tillering to fully compensate for the inadequate plant population. However, increasing seeding rate beyond 150 kg ha$^{-1}$ may have brought competition among the plants for the limited resources and resulted in the reduced grain and biomass yields. The results clearly showed that seeding malting barley between 125-150 kg ha$^{-1}$ could maintain an adequate plant population enabling farmers to increase the malting barley productivity in the southeastern highlands of Ethiopia and other areas with similar agro-ecologies.

Seeding rate also highly significantly ($P \leq 0.001$) affected the harvest index of malting barley. The harvest index of malting barley increased as the level of seeding rate increased until 175 kg ha$^{-1}$; however, it showed significant decline at 200 kg ha$^{-1}$ (Figure 3a). The highest harvest index (42%) was obtained from seeding malting barley at a rate of 175 kg ha$^{-1}$. This result was, however, statistically similar with seeding malting barley at rates of 100, 125 and 150 kg ha$^{-1}$. The lowest harvest index (37.4%) was recorded at a seeding rate of 200 kg ha$^{-1}$. The inferior harvest index at the highest seeding rate, 200 kg ha$^{-1}$, could be attributed to the significant reductions in malting barley grain and biomass yields. This result is similar to that of Hajighasemi et al. (2016), who reported that the response of harvest index to the rising seeding rate was quadratic; increasing seeding rates from 400 to 600 seeds m$^{-2}$ improved harvest index although further increments resulted in reduced harvest index.

The kernel weight of malting barley was significantly ($P \leq 0.001$) affected by seeding rate, but the kernel protein content was not significantly affected by seedling rate. The kernel weight of malting barley inversely related to seeding rate; increasing seeding rates resulted in reduced kernel size of malting barley (Figure 3b). As the level of seeding rate increased from 100 to 200 kg ha$^{-1}$, the kernel weight of malting barley decreased from 44.4 to 38.5 mg. The highest kernel weight (44.4 mg) was recorded from seeding malting barley at a rate of 100 kg ha$^{-1}$. However, this result was statistically similar with all rates other than 200 kg ha$^{-1}$, which gave the lowest kernel weight of malting barley (38.5 mg). Several researchers including Kirby (1969), Lafond

(1994), O'Donovan et al. (2011) and Wade and Froment (2003) also reported reduced kernel size with increased seeding rate. Bigger kernel sizes at lower seeding rates are due to the enhancement of tillering at the corresponding lower seeding rates (Wade and Froment 2003). Both low and high seeding rates had adverse effects on the seed size distribution of malting barley since they resulted in large and small kernels, respectively. Generally, a plump kernel is required as it contains more starch and results in a higher percent of extract, which in turn produces a greater amount of beer from a given weight of malt and vice versa (BMBRI, 2010). Thus, seeding malting barley at intermediate rates could improve malting barley quality despite the relative reductions in kernel size and plumpness.

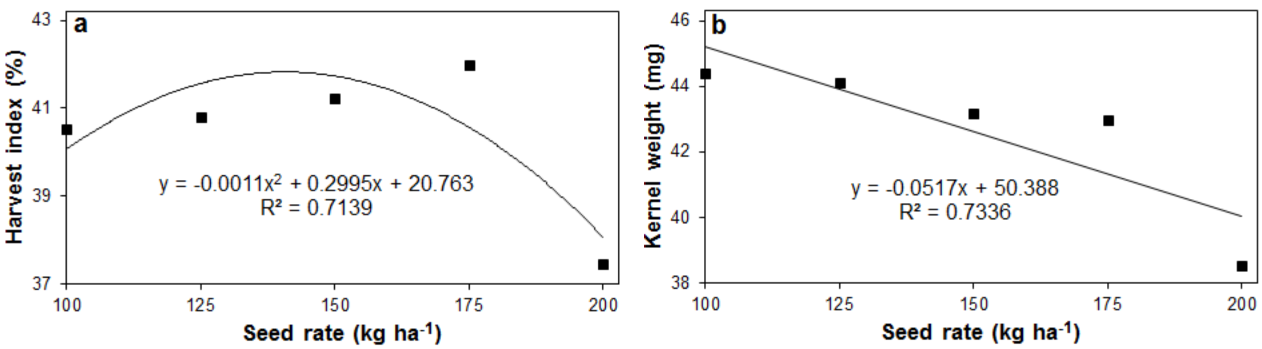


Figure 3: Effect of seeding rate on the harvest index (a) and kernel weight (b) of malting barley in the southeastern Ethiopian highlands

## Effect of nitrogen fertilizer rate

Similar to seeding rate, N fertilizer rate also highly significantly affected most of the measured variables including grain yield ($P \leq 0.001$), biomass yield ($P \leq 0.001$) and kernel protein concentration ($P \leq 0.01$). Stand density, harvest index and kernel weight were not significantly affected by N fertilization during this study.

The grain and biomass yields of malting barley increased linearly as the level of N fertilizer increased from 0 to 54 kg ha$^{-1}$(Figures 4a and 4b). The highest grain (3587 kg ha$^{-1}$) and biomass (8864 kg ha$^{-1}$) yields of malting barley were attained from the application of the corresponding highest rate of N, 54 kg N ha$^{-1}$. Likewise, application of 36 kg N ha$^{-1}$ also gave statistically equivalent grain (3438 kg ha$^{-1}$) and biomass (8578 kg ha$^{-1}$) yields of malting barley. The lowest grain (2948 kg ha$^{-1}$) and biomass (7267 kg ha$^{-1}$) yields were obtained from seeding malting barley without N fertilizer. The application of 18, 36 and 54 kg N ha$^{-1}$ gave grain yield advantage of 309 kg ha$^{-1}$ (10%), 490 kg ha$^{-1}$ (17%) and 639 kg ha$^{-1}$ (22%), respectively compared to the control. The corresponding increases for the biomass yield of malting barley were 816 kg ha$^{-1}$ (11%), 1311 kg ha$^{-1}$ (18%) and 1597 kg ha$^{-1}$ (22%), respectively. The cutoff point for the optimum rate of N was not attained in this study since yield of malting barley increased as the rate of N increased from 0 to 54 kg ha$^{-1}$ indicating the need for further study. In order to balance maximum yields with optimum levels of protein concentration, application of N fertilizer for malting barley production needs to consider the available residual soil N. Therefore, limiting N application at sowing and additional applications at the end of tillering may be required to compromise maximum yields at acceptable kernel protein content. The current result is in agreement with Agegnehu et al. (2014), Derebe et al. (2018), Halvorson and Reule (2007), McKenzie and Jackson (2005), O'Donovan et al. (2011), Spaner et al. (2001) and Upendra et al. (2013), who all reported increased malting barley yield with increased N fertilization rates.

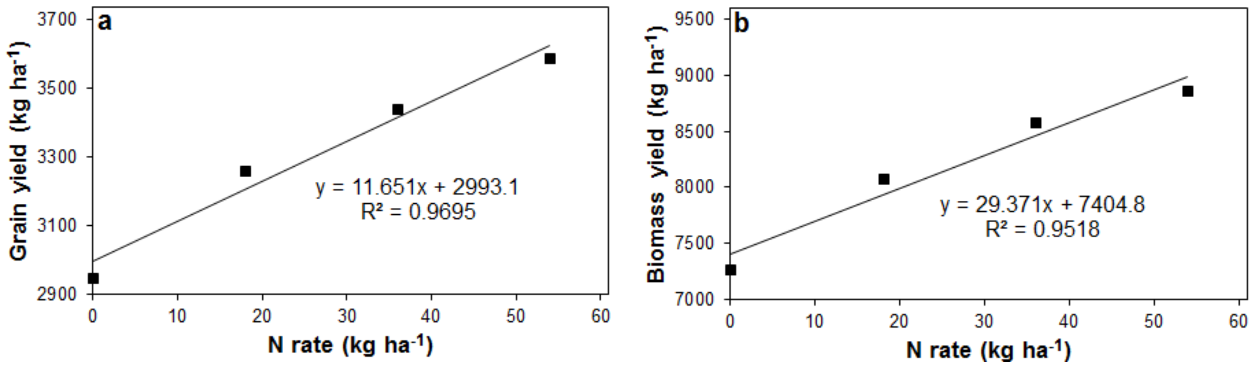


Figure 4: Effect of nitrogen fertilizer on the grain (a) and biomass (b) yields of malting barley in the southeastern Ethiopian highlands

The kernel protein concentration increased with increasing rate of N (Figure 5) indicating a direct impact of N fertilizer on the quality of malting barley. The highest kernel protein content (10.8%) was recorded from the application of the corresponding highest rate of N, 54 kg N $ha^{-1}$. Likewise, application of N at a rate of 36 kg N $ha^{-1}$ also gave statistically similar kernel protein concentration (10.4%). The lowest kernel protein concentration was recoded from the application of zero (9.9%) and 18 kg N $ha^{-1}$ (10%) with insignificant difference between them. The rises in the kernel protein concentrations of malting barley due to applications of 18, 36 and 54 kg N $ha^{-1}$ were 0.07, 0.41 and 0.85% respectively indicating the slow rate of growth. Thus, increasing the rate of N fertilization up to 54 kg $ha^{-1}$ did not surpass the threshold level of grain protein (9 – 11.5%). This implies that the possibility of rejection of malting barley grain by malting factories due to the surpass of the threshold for protein levels in response to application of N up to 54 kg $ha^{-1}$ is less likely. However, the increase in the rate of N beyond 54 kg $ha^{-1}$ to achieve higher yield of malting barley needs due attention because the kernel protein concentration may exceed the threshold level. Thus, to balance maximum yield with optimum level of kernel protein concentration, the rate of N fertilizer application needs to consider the available residual soil N and limiting N applications based on soil test results. The consistent increase in kernel protein concentration of malting barley with increased level of N fertilizer was also reported by Agegnehu et al. (2014), Derebe et al. (2018), Halvorson and Reule (2007), McKenzie et al. (2005), O'Donovan et al. (2014), Potterton and McCabe (2017) and Upendra et al. (2013).

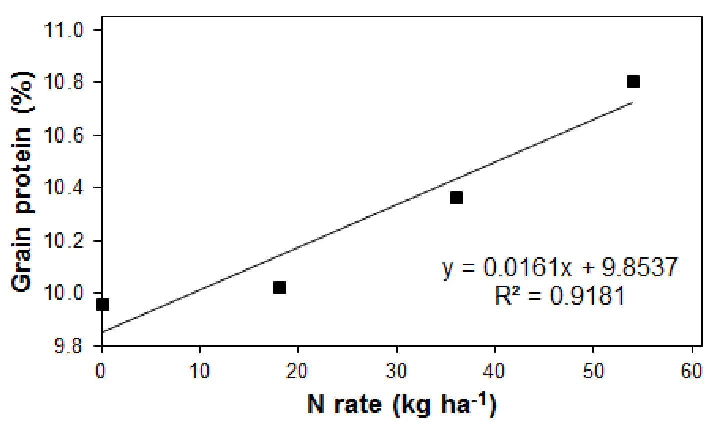


Figure 5: Effect of nitrogen fertilizer on the grain protein concentration of malting barley in the southeastern Ethiopian highlands.

## Effect of environment

Though the same management practices were applied to all experimental sites throughout the whole period, environmental factors caused variations and significantly ($P \leq 0.0001$) affected the variables. The grain yields varied from 2634 – 4497 kg ha$^{-1}$ (Figure 6a) and biomass yields from 5970 – 10976 kg ha$^{-1}$ (Figure 6b). The harvest index, grain protein concentration and kernel weight varied from 33.8 – 48.8%, 9.6 – 10.9% and 36.2 – 49.3 mg, respectively. These variations among locations could be due to differences in soil fertility statuses and previous land and crop management practices of the testing sites. There were also significant differences in many factors, such as rainfall patterns, even within nearby sites.

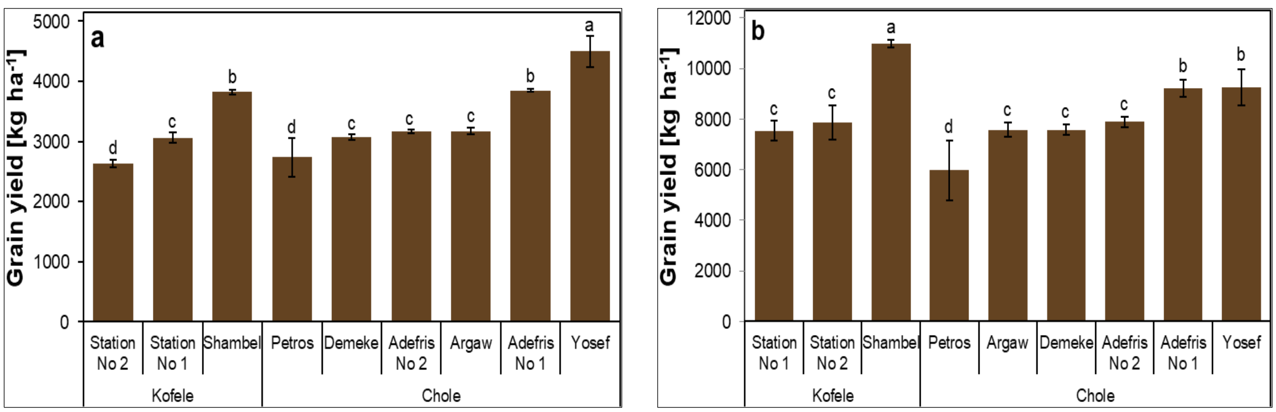


Figure 6: Effect of location on the grain (a) and biomass (b) yields of malting barley in the southeastern Ethiopian highlands

## Economic analysis

Malting barley sown at rates of 125 and 150 kg ha$^{-1}$ could enable farmers to earn higher economic returns per unit of their investment as well as higher yields (Table 2). However, increasing the seeding rate beyond 150 kg ha$^{-1}$ could not bring equivalent economic return to farmers since their marginal rates of return (MRR) were less than 100%. The maximum benefit of US$6.58 for every US$1.00 investment was obtained from seeding malting barley at 125 kg ha$^{-1}$. Malting barley sown at a rate of 150 kg ha$^{-1}$ also gave a profitable economic return of US$4.15 for every unit investment on seed (Table 2).

Table 2: Evaluation of the economic feasibility of the use of different seeding rates for malting barley production in southeastern highlands of Ethiopia

| Seed rate [kg ha$^{-1}$] | Adjusted grain yield [kg ha$^{-1}$] | Adjusted straw yield [kg ha$^{-1}$] | Gross field benefit [US$ ha$^{-1}$] | Total costs that vary [US$ ha$^{-1}$] | Net benefits [US$ ha$^{-1}$] | Marginal rate of return |
|---|---|---|---|---|---|---|
| 100 | 2846 | 4249 | 3,410.60 | 97.00 | 3,313.60 | |
| 125 | 3002 | 4469 | 3,594.30 | 121.25 | 3,473.05 | 6.58 |
| 150 | 3140 | 4509 | 3,719.30 | 145.50 | 3,573.80 | 4.15 |
| 175 | 3137 | 4404 | 3,691.79 | 169.75 | 3,522.04 | D |
| 200 | 2488 | 4344 | 3,132.69 | 194.00 | 2,938.69 | D |

“D” means dominated demonstrating treatments with higher variable cost, but lower net benefits

Seeding malting barley at N rates of 18 – 54 kg ha$^{-1}$ was found to be economically profitable in Kofele and Chole districts, as they gave acceptable rates of return in excess of 100% (Table 3). The maximum MRR of US$8.14 for every US$1.00 investment was attained from the application of 18 kg N ha$^{-1}$. Applications of 36 and 54 kg N ha$^{-1}$ also provided profitable returns of US$4.44 and US$2.78 for every unit investment on N fertilizer. The economic profitability is generally in conformity with the agronomic results. Similar results were also reported in the work of Kassie and Tesfaye (2019), who stated a higher MRR of US$9.76 for every unit investment for the application of 48 kg N ha$^{-1}$ for malting barley (cv *Holker*) production in Lemu-Bilbilo district in the southeastern highlands of Ethiopia.

Table 3: Evaluation of the economic feasibility of the use of different nitrogen fertilizer rates for malting barley production in southeastern highlands of Ethiopia

| Nitrogen rate [kg ha$^{-1}$] | Adjusted grain yield [kg ha$^{-1}$] | Adjusted straw yield [kg ha$^{-1}$] | Gross field benefit [US$ ha$^{-1}$] | Total costs that vary [US$ ha$^{-1}$] | Net benefits [US$ ha$^{-1}$] | Marginal rate of return |
|---|---|---|---|---|---|---|
| 0 | 2653 | 3887 | 3,161.60 | 0.00 | 3,161.60 | |
| 18 | 2932 | 4343 | 3,504.86 | 37.57 | 3,467.29 | 8.14 |
| 36 | 3094 | 4626 | 3,709.38 | 75.13 | 3,634.25 | 4.44 |
| 54 | 3228 | 4749 | 3,851.55 | 112.70 | 3,738.85 | 2.78 |

Given the likely rise in price of input costs in the years to come, sensitivity analyses were also conducted. Results revealed that the MRR values were still above 100% indicating that the same recommendations could be made in the future should seed and N fertilizer prices increase. If the market price of improved seed increases by 30% in the next three years, farmers who sow malting barley at rates of 125 and 150 kg ha$^{-1}$ can earn US$4.83 and US$2.97, respectively for every US$1.00 invested. Similarly, if the price of N fertilizer rises by 30% within the coming 3 years, farmers who can make the decision to apply 18, 36 and 54 kg N ha$^{-1}$ can obtain economic benefits of US$6.03, US$3.19 and US$1.91, respectively for every unit investment in the Kofele and Chole districts.

## Conclusion and recommendations

The results showed that optimising seeding and nitrogen fertilizer rates significantly improved the productivity, quality and economic profitability of malting barley. Malting barley sown at rates of 125 and 150 kg ha$^{-1}$ gave grain yield increases of 173 (6%) and 326 (10%) kg ha$^{-1}$, and economic benefits of US$6.58 and US$4.15 for every US$1.00 investment, respectively relative to 100 kg ha$^{-1}$. Similarly, grain yields of malting barley increased by 309 kg ha$^{-1}$ (10%), 490 kg ha$^{-1}$ (17%) and 639 kg ha$^{-1}$ (22%), and economic benefits enhanced by US$8.14, US$4.44 and US$2.78 for every unit investment due to applications of 18, 36 and 54 kg N ha$^{-1}$, respectively, when compared to the control without having detrimental effects on the grain protein concentration. Therefore, seeding malting barley at a rate of 125–150 kg ha$^{-1}$ along with 18–54 kg N ha$^{-1}$ is recommended for growers in Kofele and Chole districts, southeastern highlands of Ethiopia and other similar agroecologies for optimum grain yield, acceptable kernel protein concentration and economic benefit. In order to avoid the adverse effects of increased protein concentrations, nitrogen application should be limited to 54 kg N ha$^{-1}$ regardless of its reduced yield compared to applications at higher rates.

Because of the diversities in agroecological zones, application of nitrogen fertilizer should be based on soil test results to achieve optimum malting barley yields. Since excessive protein concentration is a major factor in the rejection of barley for malting, breeders in their future studies are recommended to focus on screening of new malting barley cultivars that maintain higher yields and relatively low protein concentration in response to nitrogen application. Growers should also be aware of the tradeoff of high yield with relatively low protein content. Studies are also recommended to investigate new agronomic packages that could improve productivity, quality and economic profitability of malting barley in line with the requirement of malting factories and breweries.

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