DOI: https://doi.org/10.20372/afnr.v3i1.1531
Journal of Agriculture, Food and Natural Resources
J. Agric. Food Nat. Resour. Jan-Apr 2025, 3(1): 41-49
Journal Home page: https://journals.wgu.edu.et

Original Research

Effects of NPS Fertilizer Rates on Yield and Yield Components of Malt Barley (*Hordeum vulgare* L.) Varieties in Gitlo, Horro Guduru Wallaga Zone, Ethiopia

Temesgen Fasika*and Birki Binalfew

Department of Plant Sciences, Faculty of Agriculture, Wallaga University, Shambu Campus, Ethiopia

Abstract

A field experiment was conducted during the 2022/23 cropping season at Gitlo, Horro District, Horro Guduru Wollega Zone, to evaluate the effects of NPS fertilizer rates on the yield and yield components of malt barley (Hordeum vulgare L.) varieties. The study employed a randomized complete block design in a factorial arrangement with three replications, testing three malt barley varieties (HB1963, Holker, and IBON174/03) under five NPS fertilizer rates (0, 23, 46, 69, and 92 kg ha $^{-1}$*). Significant varietal differences (P < 0.05) were observed for days to 50% heading, number of seeds per spike, and spike weight. The earliest maturing variety was IBON174/03 (112 days), whereas Holker exhibited the longest duration to 50% heading (78 days). Application of NPS fertilizer significantly increased the number of seeds per spike, with the highest value (33 seeds) recorded at 92 kg ha* $^{-1}$*. The interaction between varieties and NPS fertilizer rates significantly influenced days to maturity, plant height, and yield components. HB1963 achieved the tallest plant height (95.8 cm) at 92 kg ha* $^{-1}$ *NPS, while Holker produced the highest grain yield (5429 kg ha* $^{-1}$*) at the same fertilizer rate, indicating a strong positive response to increased nutrient input. These findings suggest that malt barley productivity in the study area can be enhanced by combining the Holker variety with 92 kg NPS ha* $^{-1}$*; however, further multi-season and multi-location studies are recommended to validate these results and to develop region-specific fertilizer and variety recommendations.*

Article Information

Article History:

Received: 10-04- 2025

Revised: 28-04-2025

Accepted: 28-04-2025

Keywords:

Blended fertilizer

Grain yield

Malt barley

Varieties

***Corresponding Author:**

E-mail:

temes.fesika86imire@gmail.com

INTRODUCTION

Barley (*Hordeum vulgare* L.), a member of the Poaceae family, is one of the world's major cereal crops, ranking fifth in global production after tef, maize, sorghum, and wheat (Lapitan et al., 2009). It is classified into three primary types based on spike morphology and floret fertility: (1) *Hordeum vulgare*, the six-rowed barley, characterized by three fertile spikelets at each rachis node; (2) *Hordeum distichum*, the two-rowed barley, with fertile central florets and sterile lateral florets; and (3) *Hordeum irregulare*, a less cultivated form exhibiting an irregular pattern of fertile and sterile lateral florets (Ceccarelli & Grando, 2000). Barley's origin and domestication remain topics of ongoing debate, with estimates suggesting it was first cultivated around 3000 BCE in northwestern Europe (Harlan, 1976). Despite its ancient cultivation, pinpointing the exact center of domestication remains elusive due to the lack of trade records from its early history (Harlan, 1976).

In Ethiopia, barley is a staple crop, particularly in the highland regions where it serves as both a key food grain and a critical crop for malting purposes. It is particularly significant for smallholder farmers, who rely on malting barley as a source of income (Yirga et al., 1998). Ethiopia accounts for over 26% of Africa's total barley production, ranking second only to Morocco (Shahidur et al., 2015). Barley is cultivated across approximately 959,273 hectares, with an annual output of around 2.03 million metric tons. However, despite its importance, the national average barley yield remains low, averaging only 2.1 tons per hectare (CSA, 2020). Factors such as poor cultivars and insufficient fertilizer application contribute to the underperformance of barley yields (Mulatu & Grando, 2011).

Barley cultivation in Ethiopia is concentrated in the Oromia National Regional State, where the average yield is approximately 1.09 tons per hectare, significantly lower than the global average of 2.4 tons per hectare (CSA, 2020). This disparity in yield is attributed to factors including low fertilizer use and reliance on small-scale farming, which constitutes only 0.1% of the total planted area (Taffesse et al., 2011). Notably, malt barley has substantial potential for growth, particularly in light of the expansion of Ethiopia's brewing industry (Berhane, 2011). However, despite its potential, the domestic supply of malt barley has struggled to meet the growing demand, with approximately 69% of malt consumption being met through imports (ORDA, 2015a).

The low availability of essential nutrients, particularly nitrogen (N), phosphorus (P), and sulfur (S), in Ethiopian soils poses a significant challenge to barley productivity (Assefa et al., 2017). Effective fertilizer management, especially nitrogen, is crucial to optimizing both the yield and quality of malt barley. Studies have shown that adjusting nitrogen application based on soil conditions and cultivar requirements is essential for improving productivity (Edney et al., 2012; McKenzie et al., 2005). Moreover, excessive fertilizer application can adversely affect malt quality, emphasizing the need for balanced nutrient management (O'Donovan et al., 2011; Edney et al., 2012).

Research on the agronomic requirements for malt barley cultivation in Ethiopia, particularly in regions like Horro District, remains limited. Suboptimal practices, such as insufficient fertilizer application and the use of low-yielding cultivars, continue to hinder production (Mulatu & Lakew, 2011). There is a critical need for targeted studies to determine the appropriate fertilizer levels and optimize production practices for different barley cultivars in the region. This study aims to evaluate the effects of NPS fertilizer rates on the yield and yield components of malt barley varieties in Gitlo, Horro Guduru Wallaga Zone, Ethiopia, to address the gaps in malt barley production and support its potential as a high-value industrial crop.

MATERIALS AND METHODS

Description of the Study Area

The Gitlo location was the site of the experiment. Approximately 340 kilometers separate Gitlo from Addis Ababa, the capital of Oromia National Regional State, which is situated in the Horro Guduru Wollega zone. It is located at a height of 2900 meters above sea level. In addition to mixed farming, the primary crops grown at Gitlo are wheat, barley, oats, faba beans, field peas, potatoes, and rapeseed. The area's farmers rely on crop-livestock production for both cash income and food security. The site is a clay loam soil type with high land agro-ecology. The average yearly rainfall and temperature in the research area are 1900–2200 mm and 18–23°C, respectively (unpublished data from Horro Agriculture Bureau, 2008).

Experimental material

The test crops were malt barley cultivars HB1963, Holker, and IBon which were made available by the Holeta Agricultural Research Center. The HB 1963 had a grain yield of 4.0–6.0 tons per hectare and an altitude of 2300–2600 meters above sea level and was released in 2016. In 1979, Holker was released with a grain yield of 2.4–3.1 tons per hectare and an altitude of 2300–3000 meters above sea level. In contrast, IBon was issued in 2012 with a grain yield of 3.0-5.7 tons per hectare and an altitude of 2300–2800 meters above sea level. All types required 500–800 millimeters of rainfall at the time of release (MoA, 2012).

Treatments and Experimental Design

A factorial combination of five blended NPS fertilizer rates (0, 23, 46, 69, and 92 kg ha^{-1}) and three malt barley types (HB1963, Holker, and IBon) was used in the experiment. There were therefore fifteen (15) treatments in total. Three replications of the experiment were carried out using a randomized complete block design. The experimental units within a block were thus randomly assigned to the treatments, including the control treatment. A field layout was created in compliance with the design parameters, and experiment plots within each block were randomly assigned to each treatment. Whereas the plots were within 0.5 m of one another, the blocks were separated by a 1 m wide open region. The total area of the plot was 12 m^2 (3 m × 4 m). Ten rows made up each plot, and the rows were separated by 30 cm. The net plot size was 2 m x 3 m (6 m^2) after removing the two outermost rows from each plot's sides and leaving a 0.5 m row length on both ends of each plant row. This was done to prevent border effects.

Experiment procedures

Using an oxen-drawn local plow (Maresha), the experimental field was tilled three times to prepare the seedbeds finely. This was followed by manual bed preparation for field layout. Manually plant malt barley varieties in rows at the suggested seed rate of 125 kg/ha for the broadcasting method. When summer rainfall started, the seeds were sown at a depth of 2 cm by the prescribed spacing for each treatment. During crop planting, the entire fertilizer dosage was administered in the drill. To handle this experiment, all suggested cultural methods were used, such as weeding 30 to 35 days following crop emergence, etc., for the production of malt barley.

Data Collection and Measurements

Soil sampling and analysis

Soil samples were collected from representative locations across the experimental field (0–20 cm depth) before planting to create a single composite sample. Similarly, surface soil samples were collected from five locations within each plot at the same depth shortly after harvest for each treatment. Soil analyses, focusing on parameters relevant to the current study, were performed by the Bedele Soil Laboratory. The pre-planting soil samples were analyzed for total nitrogen using the Kjeldahl method, available phosphorus using the Olsen method, exchangeable potassium (cmol(+)/kg soil), organic carbon through the Walkley-Black method, and soil pH using a pH meter in a 1:2.5 soil-to-water ratio. Organic matter was estimated as % OM = % organic carbon × 1.72. Similarly, post-harvest analysis of total nitrogen, available phosphorus, exchangeable potassium, organic carbon, organic matter, and soil pH was performed on a per-plot basis.

Phenological parameters

Days to 50% emergence: The days to 50% emergence were determined by counting the number of days from sowing until 50% of the plants had emerged.

Days to 50% Heading: The duration, measured in days, from planting to the point at which 50% of the plants have reached the heading stage.

Days to 95% Maturity: The duration, measured in days, from planting to the point at which 95% of the plants have attained physiological maturity.

Grain filling period: The number of days from heading to maturity.

Growth parameters

Plant height was measured by randomly selecting five plants per plot.

Spike length was measured in centimeters from ground level to the top of the spike, excluding the awns, using ten randomly selected pre-tagged plants within the net plot at maturity.

Number of tillers per plant: The average number of tillers per plant was calculated by counting them from two locations within the net plot, each measuring 0.5 meters in length.

The number of productive tillers per plant was determined by counting the tillers bearing plants at the time of harvest. This was done by selecting two representative sections, each 0.5 meters in length, from the net plot area, and then calculating the average number of productive tillers.

Yield and yield components

The thousand-seed weight was determined by measuring the weight of 1,000 kernels sampled from the grain yield of each net plot. The kernels were counted using an electronic seed counter and weighed with a sensitive electronic balance. The weight was subsequently adjusted to a moisture content of 12.5%.

Spike Weight: The average weight of individual spikes was measured from the main tillers.

Number of Seeds per Spike: The average number of seeds produced per spike was calculated by averaging the counts from 10 randomly selected spikes from the net plot area.

Dry Biomass: Dry biomass was determined from plants harvested from the net plot area, followed by sun drying until a constant weight was achieved. The biomass was then converted to kilograms per hectare.

Grain Yield: Grain yield was determined by harvesting, sun drying, and threshing the grains from the net plot area. The yield was adjusted to a moisture content of 12.5%.

Straw Yield: Straw yield was calculated as the difference between the total above-ground dry biomass and the grain yield.

Harvest Index: The harvest index was computed on a plot basis as the ratio of grain yield to total above-ground biomass yield and expressed as a percentage.

$$HI(\%) = \frac{Grain\ yield/plot}{Aboveground\ dry\ biomass/plot} x100$$

Data Analysis

Statistical analysis of variance (ANOVA) was performed on the data using SAS software (SAS, 2004). Using LSD (least significant difference), significant differences between and within treatments were identified. The simple correlation coefficient between phonological growth, yields, and yield components is found by correlation analysis. The same biometrical equations were used and interacted with following Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Specific Chemical Characteristics of the Soil for the Field Test Location

Table 1 lists the chemical characteristics of the soil in the experimental field. According to Tekalign (1991), the soil in the experimental field has a severely acidic pH, a high percentage of total nitrogen, and a very low amount of accessible phosphorus. Phosphorus and nitrogen may also be yield-limiting factors for local malt production. The percentages of organic matter and organic carbon were lowest at control and highest at 92 kg NPS per hectare. Tekalign (1991) and Westerman (1990) defined organic carbon and organic matter as a medium.

Table 1. Lists the physical and chemical characteristics of the Gitlo experimental site both before and after harvest.

Soil depth (0-20 cm)	PH (H_2O)	MCF	OC (%)	O M (%)	TN (%)	Av. P	Exch. K^+
Before Sowing	4.82	1.051	5.465	9.34	0.309	2.165	1.142
After Harvest (NPS kg ha^{-1})							
Control	4.87	1.044	5.090	8.75	0.270	1.984	0.574
23	4.84	1.056	5.972	10.27	0.281	2.112	0.459
46	4.85	1.056	5.697	9.79	0.303	1.690	0.473
69	4.80	1.029	5.351	9.20	0.303	1.935	0.540
92	4.65	1.033	6.043	10.34	0.249	2.087	0.000

OC = Organic carbon, OM = Organic matter, TN = Total nitrogen, Av.P = Available phosphorus, MCF= Moisture correction factor, and Exch. K^+= Exchangeable of potassium

The variance analysis

Results showed that spike weight (P<0.01), number of seeds per spike (P<0.05), and days of 50% heading were all significantly impacted by types (P<0.001) (Table 2). The quantity of seeds per spike, however, was the only variable where NPS had a significant impact (P<0.05).

Similarly, days to maturity (P<0.05), grain filling period (P<0.01), plant height (P<0.01), number of productive tillers (P<0.01), thousand seed weight (P<0.01), and above-ground dry biomass yield, seed yield, straw yield, and harvest index (P<0.001) were all significantly impacted by the interaction effect of varieties depending on NPS rate.

Table 2. Mean square values for different agronomic traits as affected by varieties, fertilizer rates and the interaction of varieties and fertilizer rates of Malt barley varieties.

Parameters	REP (DF=2)	VAR (DF= 2)	FER (DF=4)	VARXFER (DF=8)	ER (DF=16)
Days to 50% emergence	0.60^{ns}	0.20^{ns}	0.64^{ns}	0.39^{ns}	0.55
Days to heading	20.55^{ns}	461.35^{***}	54.83^{ns}	32.55^{ns}	20.03
Days to maturity	188.02^{ns}	152.95^{ns}	307.31^{*}	247.09^{*}	78.95
Grain filling period	228.28^{ns}	135.02^{ns}	136.27^{ns}	237.41^{**}	65.21
Plant height (cm)	5.24^{ns}	42.10^{ns}	165.04^{ns}	130.25^{**}	58.98
Number of seeds per spike	2.95^{ns}	14.41^{*}	29.09^{***}	7.45^{ns}	2.71
Spike length	0.33^{ns}	0.47^{ns}	0.26^{ns}	0.35^{ns}	0.51
Number of tillers	10.33^{ns}	2.69^{ns}	14.22^{ns}	15.16^{ns}	6.13
Number of productive tillers	4.31^{ns}	2.23^{ns}	6.41^{ns}	6.08^{**}	2.66
Thousand Seed weight	4.54^{ns}	29.04^{ns}	9.32^{ns}	33.31^{**}	14.92
Spike weight	2.77^{ns}	5.17^{**}	5.05^{ns}	1.28^{ns}	1.65
Above ground dry biomass	1427691.0^{ns}	180597.2^{ns}	60994414.9^{***}	4438774.3^{***}	932330.1
Grain yield	657069.36*	1105291.10ns	9623493.16***	1729448.43***	255463.40
Straw yield	182495.1ns	1993066.1ns	28533033.8**	6134760.0***	706733.0
Harvest index	19.96ns	214.27ns	407.70***	335.67***	29.57

*DF= degrees of freedom; REP= replication; VAR = varieties; FER= fertilizer rate; VARX FER= interaction of Variety and fertilizer rates; ER=mean square of error; ns=non-significant; *, **, *** indicate significant difference at probability levels of 5%, 1% and 0.1% respectively.*

Treatment effects on malt barley phenological parameters

Number of Days to 50% Emergence

Statistical analysis indicated that there was minimal variation in the days to emergence among the different components. Table 2 presents the varieties, NPS treatments, and their interaction, with the varieties emerging after an average of five days. During germination, seedlings predominantly rely on their stored reserves rather than external nutrients. Consequently, fertilizer application is unlikely to significantly affect the time to emergence. This observation aligns with the findings of Shrivastava *et al*. (1992), who reported that plants predominantly utilize stored food for germination, with minimal reliance on external nutrients. Furthermore, Zeidan (2007) emphasized that seedling emergence typically occurs within a week after the onset of germination, depending on the availability of stored reserves, soil temperature, moisture, and sowing depth.

Days to 50% heading

The days to 50% heading of malty barley showed a highly significant ($p<0.01$) difference due to varieties (Table 2). Holker took the longest date (98.80) to reach 50% heading as compared to HB1963 (97.80 days) and IBon (88.73 days) (Table 3). This might be due to the difference in genetic makeup of the varieties. Similarly, Daniel (2010), Getachew *et al*. (2014), and Mekonnen (2016) reported that days to heading were significantly affected by varieties, whereas non-significant difference in 50% heading ($p>0.05$) due to the fertilizer applications (Table 3). The interaction of variety and fertilizer was not significantly affected by days of 50% heading. Similarly, Esayas (2015) reported that the application of NPS fertilizer had no significant difference on days to the heading of wheat.

Days to 95 % physiological maturity

There was a highly significant ($p < 0.01$) impact on days to physiological maturity from the interaction between NPS levels and malt barley cultivars (Table 2). Holker cultivars with a fertilizer rate of 69 kg NPS/ha^{-1} took the longest (135.00) days to reach 90% physiological maturity, while Holker types without fertilizer showed the quickest (108.66) days to physiological maturity. This could be explained by the way the fertilizer NPS speeds up crops' vegetative growth, which delays physiological maturity (Table 3). Furthermore, crops may need a long time to reach maturity to make use of the soil's available moisture and nutrients. The shortest days to physiological maturity and high fertilizer rates were also reported by Woinshet (2007). Malt barley cultivars' physiological maturity was delayed by the maximum NPS kg/ha fertilizer rate. Extended vegetative growth rather than slightly green reproductive growth could be the cause of this outcome. Wakene *et al.* (2014) observed a similar finding: fertilizers, nitrogen, and phosphorus combined with other essential nutrients delayed the number of days until barley reached maturity and the delay in maturity time increased with the number of fertilizer combinations. These findings also support those of Bekalu and Mamo (2016), who found that fertilizer rate, had a substantial impact on wheat's days to maturity.

Table 3. Main Effect of Different NPS Fertilizer Rates and Varieties on Yield related Parameters of Malt Barley Varieties at Gitlo.

Malt barley Varieties	DE(day)	DH(day)	NSS	SL(cm)	NT	SW(g)
HB1963	5.46	97.80	25.74	7.91	11.94	9.76
Holker	5.26	98.80	27.61	7.82	12.33	8.93
IBon	5.46	88.73	27.20	8.17	11.48	10.06
LSD (5%)	Ns	3.34	1.23	Ns	Ns	0.96
Fertilizer rate (kgha^{-1})						
0 (Control)	5.77	99.00	23.94	8.10	10.00	8.38
23	5.55	95.44	27.30	8.00	11.94	9.55
46	5.22	95.11	26.48	8.14	12.40	10.22
69	5.11	93.33	28.00	7.72	11.80	10.22
92	5.33	92.66	28.53	7.88	13.46	9.55
LSD (5%)	Ns	Ns	1.59	Ns	Ns	Ns
CV (%)	13.76	4.70	6.13	8.97	20.77	13.40
Mean	5.40	95.11	26.85	7.97	11.92	9.58

Ns=non-significant

Days to grain filling period

The main effect of cultivars and NPS fertilizer rate was non-significant, but their interaction had a substantial ($p < 0.005$) impact on the number of days till the grain filling period (Table 2). The Holker variety and a 0 kg NPS ha^{-1} fertilizer rate (control) had the lowest grain filling period (11.66), whereas the variety IBon had the longest (41.00) at a 69 kg/ha NPS rate. Both types demonstrated a steady upward trend in days to grain filling with rising nitrogen fertilizer rates, despite minor fluctuations (Table 3). The outcome was consistent with Sofonyas (2016), who reported that rates of NPS in wheat showed a consistent upward trend in the grain-filling time. Moreover, Wakene *et al.* (2014) found that the use of NPS considerably extended the barley grain-filling period as well as the days to heading and maturity.

Growth Parameters

Height of Plants

The interaction impact of NPS fertilizer with cultivars resulted in highly significant ($P<0.01$) changes in malt barley plant height (Table 2). The HB1963 variety with the application of NPS 92 kg NPS ha^{-1} fertilizer rates had the highest mean plant height (95.60 cm) (Table 3), whereas the HB1963 variety with the control had the lowest plant height (72.96 cm). The two other cultivars were outperformed by the HB1963 variety; this could be because of genotypic behavior combined with environmental factors that made the HB1963 more suited than the other kinds (Holker and IBon). Because nitrogen, phosphorus, and sulfur are essential for the structure of chlorophyll and are involved in the energy transfer for cellular metabolism, a sufficient supply of nutrients may be the cause of the increase in plant height observed with increasing NPS fertilizer. This outcome was consistent with what Giday *et al*. (2014) found. In a similar vein, using NPS as blended fertilizers resulted in noticeably taller plants on wheat and was comparable to the general fertilizer recommendation. For a similar reason, the height spike length of the plant also grew. High photosynthetic production and the accretion of dry matter result from Feyera *et al.* (2013)'s balanced fertilizer application and effective nutrient use, which ultimately raises plant height. This finding also supports that of Minale *et al.* (2011), who found that barley plant height rose when NPS rates rose.

Table 4. The interaction effect of Varieties by Fertilizer rate on different phenology and growth parameters of malt barley varieties at Gitlo.

Varieties X NPS rate (kgha^{-1})	**DM(days)**	**GF(days)**	**PH (cm)**	**NPT**
HB1963@Control	133.66	30.00	72.96	6.50
HB1963@23	130.00	35.66	75.93	8.36
HB1963@46	133.00	30.33	78.36	7.13
HB196@69	118.33	23.66	93.54	8.66
HB1963@92	117.00	23.33	95.60	11.26
Holker @Control	108.66	11.66	80.30	7.20
Holker@23	119.00	19.33	83.73	8.53
Holker@46	125.00	29.66	86.33	9.66
Holker@69	135.00	32.00	92.80	8.20
Holker@92	134.00	35.00	81.60	7.00
IBon @Control	131.33	40.00	80.56	8.40
IBon @23	111.66	19.33	83.56	8.33
IBon @46	115.00	27.66	84.40	9.73
IBon @69	128.33	41.00	81.78	7.33
IBon@92	114.33	29.66	77.70	10.60
LSD (5%)	15.48	14.54	12.41	2.77
CV (%)	7.18	25.28	9.22	19.30
Mean	123.62	28.55	83.27	8.46

HB1963, Holker, and IBon are the kinds of malt barley; the NPS rates are 0 kg/ha, 23 kg/ha, 46 kg/ha, 69 kg/ha, and 92 kg/ha; @=at the rate of; DM = days to maturity; GF = grain filling period; PH = plant height; NPT = number of productive tillers; ns = non-significant difference.

Spike Length

Fertilizer administration, variety, and their interaction did not significantly ($p>0.05$) alter the spike length of malt barley (Table 2). Although it was statistically insignificant, the application of NPS fertilizer to malt barley varieties resulted in a commensurate increase in spike length malt. This could be because of the accessible space, which in turn provides a favorable growing environment for an active plant. Rashid *et al.* (2007) provided support for this finding, stating that overuse of N fertilizer has a detrimental effect on barley growth, causing stunted growth and shorter spike length.

Number of Tillers

The most significant characteristic is the average number of malty barley tillers per plant. The application of various NPS fertilizer amounts, malt barley types, and their interaction did not substantially alter the number of tillers per plant of malty barley (p>0.005) (Table 2). When fertilizer amounts of 23, 46, 69, and 92 kg blended NPS ha^{-1} were applied, the Holker variety produced the most tillers per plant, although the difference was not statistically significant (Table 2). The use of fertilizers may be to blame for this; in particular, fertilizers containing nitrogen, phosphorus, and sulfur have a favorable effect on the vegetative growth of plants from malt barley varieties. According to Maqsood *et al.* (2009), the well-established contribution of nitrogen, phosphorus, and sulfur to the rapid vegetative growth of genetic diversity may also be the reason for the rise in the number of tillers as fertilizer levels rise.

Number of Productive Tillers per Plant at Maturity Stage

There was a highly significant difference (P<0.05) in the number of productive tillers per malt barley plant due to the interaction impact of NPS fertilizer amounts and cultivars (Table 4). The application of 92 kg NPS ha^{-1} from the HB1963 variety produced the highest number of productive tillers (11.26) at the maturity stage, whereas the control group produced the lowest number of productive tillers (6.50) at the maturity stage. The reason for this could be that NPS fertilizer speeds up plant vegetative development and promotes tillering, which may be brought on by its impact on cytokine/protein synthesis (Table 2). Abdullatif *et al.* (2010) reported that fertilization increased the number of productive tillers, and the results supported their findings.

Impact of NPS Fertilizer Variety and Rate on Yield and Parts of Yield

Number of seeds per spike

The application rates and types of NPS fertilizer had the most significant impact on the number of seeds per spike in malt barley, with substantial variations observed (P < 0.005). However, the interactions between these factors were not found to be significant (Table 3). Accordingly, the variety Holker had more seeds per spike (27.61) than IBOn (27.20) and HB1963 (25.74) (Table 3). Comparing control and fertilized plots, the former had fewer seeds per spike (23.94). In malty barley, the number of seeds per spike was raised from 0 to 92 kg NPS ha^{-1}. Despite this discrepancy, the plots fertilized with a 92 kg NPS ha^{-1} fertilizer rate produced the highest number of seeds per spike (28.53), which was statistically equivalent to the fertilizer rate (Table 3). The findings supported those of Tayebeh et al. (2010), who claimed that the number of seeds spiked increased significantly when NPS rates were raised to optimal levels. The best measure of barley's reaction to fertilizers is the quantity of seeds per spike, which Assefa *et al.* (2017) found to be boosted by fertilizers. The quantity of seeds per spike varied from variety to variety. Thus, the variance in the number of seeds per spike was due to barley genotype diversity. In agreement with this finding, Biruk and Demelash (2016) revealed genotypic differences in barley spikelet per spike, which resulted in more seeds per spike.

Thousand seed weight

Varieties and NPS fertilizer rates had no significant effect on thousand seed weight (p<0.01), but their interaction resulted in a significant difference in malty barley (Table 5). The IBOn variety generated the maximum thousand seed weight (57.50g) with 92 kg NPS ha^{-1}, while the HB1963 variety produced the lowest thousand seed weight (46.65g) with 0 kg NPS ha^{-1}. This could be because the IBOn variety's genetic behavior matched the environmental conditions, increasing the rate of photosynthesis and causing the grain to accumulate carbohydrates, resulting in heavy grains and higher grain weight per spike (Table 5). According to Yetsedaw *et al.* (2013), the data supported the idea that barley genotype influences the variation in thousand-grain weight.

Spike Weight

A highly significant effect (p < 0.01) on the spike weight of malt barley was observed due to the main effect of variety. However, neither the fertilizer rate nor the interaction between variety and fertilizer rate showed a significant effect. (Table 2). Holker variety gave significantly the lowest spike weight per plant as compared to IBOn and HB1963 varieties (Table 3). The highest spike weight (10.06) was recorded in the case of the IBOn variety due to the presence of a high number of seeds per spike. The finding is consistent with the results of Namoobe et al. (2014), who reported that varietal differences had a significant effect on the spike weight of malt barley.

.

Dry biomass yield

The main effect of varieties on dry biomass yield was not statistically significant (P > 0.05). However, both the interaction between NPS fertilizer rates and varieties, as well as the main effect of NPS fertilizer application, exhibited highly significant differences (P < 0.001). The application of 69 kg NPS ha^{-1} from the HB1963 variety of malty barley resulted in the mean maximum dry biomass (11208 kg ha^{-1}), whereas the application of 0 kg NPS ha^{-1} produced the lowest dry biomass (3313 kg ha^{-1}). In comparison to control, this may be because of the genetic behavior of the HB1963 variety when the greatest fertilizers (69 kg NPS ha^{-1}) are applied. This promotes the vegetative growth of malt barley crops, delaying senescence and ultimately increasing biological production. Particularly at larger doses, fertilizer promotes plants' vegetative growth. Furthermore, sulfur increased the formation of chlorophyll and promoted vegetative growth, and P aided in N absorption, all of which contributed to the notable rise in above-ground dry biomass. According to Gebrekidan and Seyoum (2006), distinct applications of blended fertilizers showed a comparable and noteworthy increase in biomass yield. They attribute this increase to proportional vegetative growth, particularly plant height.

In addition, Alemu *et al.* (2016) reported that, in addition to spike and plant height, the enhanced biomass yield is a result of the number and size of secondary branches and leaves that were developed during the grain-filling period. These findings are further supported by Tareke *et al.* (2013), who obtained heavier spike-bearing culms and more productive tillers, both of which boosted biomass.

Table 5. The interaction effect of Varieties and NPS Fertilizer rate on yield and yield components of malt barley varieties at Gitlo.

Varieties by NPS Fertilizer rate (kg ha^{-1})		Thousand seed weight (g)	Dry Biomass (Kg ha^{-1})	Grain Yield (Kg ha^{-1})	Straw Yield (Kg ha^{-1})	Harvest Index (%)
	0	46.65	3562.5	1512.9	2049.6	42.32
	23	54.90	5833.3	2077.7	3755.6	35.56
HB1963	46	51.66	5187.5	2474.2	2713.3	47.94
	69	55.33	11208.3	4114.2	7094.2	37.01
	92	50.56	10954.2	3676.3	7277.9	33.62
	0	52.43	3312.5	1546.5	1766.0	46.68
	23	52.53	7012.5	1657.1	5355.4	23.94
Holker	46	56.06	8379.2	2446.9	5932.3	29.07
	69	50.70	9429.2	3475.4	5953.8	36.77
	92	49.10	8562.5	5428.8	3133.8	63.42
	0	55.26	3841.7	1630.4	2211.3	41.97
	23	50.90	7375.0	2609.6	4765.4	35.43
IBon	46	54.96	7583.3	2230.8	5352.5	29.63
	69	53.30	9658.3	1864.2	7794.2	19.35
	92	57.50	9129.2	3583.8	5545.4	39.37
LSD (5%)		6.29	1638.4	885.88	1366.7	8.96
CV (%)		7.31	13.04	18.79	17.83	14.51
Mean		52.79	7401.94	2688.57	4713.37	37.47

Grain yield

The impact of the interaction between NPS fertilizer application rates and cultivars on malty barley grain production was shown to be highly significant (P<0.001) (Table 2). With the application of 46, 69, and 92 kg NPS ha^{-1}, the HB-1963 variety performed better in terms of grain yield; this could be because these varieties have the highest reaction to NPS and use efficiency. The Holker variety produced the highest grain yield (54298 kg ha^{-1}/ha) when 92 kg of NPS ha^{-1} fertilizer was applied at a rate of 1, whereas the HB1963 variety produced the lowest grain yield (15139 kg ha^{-1}) when no NPS fertilizer was applied. The wide range of grain yields amongst barley varieties under various NPS rate treatments may aid in the selection of superior cultivars for various NPS supply conditions. The mean grain yield rapidly rose in response to increasing NPS fertilizer rates, which ranged from 0 to 92 kg NPS ha^{-1} (Table 5). In a similar vein, Amare (2015) found that raising NPS fertilizer levels significantly increased the grain yields of malt barley crops.

Straw Yield

There were significant ($p \leq 0.001$) differences among their interactions of varieties and NPS fertilizer application rates for a straw yield of malt barley (Table 5). The highest straw yield (7794 kg ha^{-1}) was obtained from the application of 69 kg NPS ha^{1} from the IBon variety, while the minimum straw yield (1766kg ha^{-1}) was obtained from the Holker variety without fertilizer (Table 5). This might be due to genetic variation, and the application of NPS fertilizer enhances the vegetative growth of barley crops that delay senescence, which ultimately increases straw yield. The observed increase in straw yield can be primarily attributed to the significant effects of nitrogen (N) application on key growth parameters, including plant height, spike length, and the number of fertile tillers. Barley straw is an essential feed resource during the dry season for Ethiopia's large livestock population, highlighting its importance in supporting livestock nutrition (Tilahun *et al*., 1996).

The Harvest Index

One measure of a variety's capacity to divide dry matter into economic (grain) production is its malt barley harvest index, which changed considerably (p < 0.001) between the interaction impact of varieties and NPS fertilizer rate (Table 5). With a 92 kg NPS ha^{-1} application, the Holker variety produced the highest harvest index (63.42%), whereas the IBOn variety, which applied 69 kg NPS ha^{-1}, produced the lowest value (19.35%) (Table 5). Due to barley's inherent heterogeneity, the mean harvest index varied throughout barley varieties, but it exhibited an upward trend as fertilizer rates increased. With higher fertilizer rates, there may be a greater grain yield per plant, which could explain the higher malt barley harvest index. Increased assimilation to the grain would increase the harvest index and decrease the amount of dry matter generated, according to Tahir *et al.* (2009).

Relationships between grain yield and yield components

The product of the yield components determines the grain yield in cereals. As a result, there is a strong correlation between malt barley's grain yield and its yield components, including the of seeds per spike, dry biomass yield, and harvest index (Table 6). The harvest index, number of seeds per spike, and dry biomass all had positive correlations with the grain yield, which was significant (P<0.01). The number of seeds per spike had a correlation coefficient of r=0.53, which was followed by the dry biomass yield, which had a stronger correlation (r=0.66). As a result, a highly substantial positive association between biomass yield and grain yield was discovered. Correlations between dry biomass, harvest index, and straw yield were also found to be positive and significant. Ortiz *et al*. (2002) also reported strong associations between barley grain yield and its yield components.

Table 6. The correlation of different phenology, growth, yield and yield components on the malt barley

	DH	**DM**	**PH**	**NSS**	**TSW**	**SW**	**AGB**	**GY**	**SY**
DH									
DM	0.444*								
PH	-0.094 ^{ns}	-0.38*							
NSS	-0.26 ^{ns}	-0.29 ^{ns}	0.31 ^{ns}						
TKW	-0.419*	-0.002 ^{ns}	-0.033 ns	0.175 ^{ns}					
SW	-0.379*	-0.182 ^{ns}	0.090 ^{ns}	0.205 ^{ns}	0.113 ^{ns}				
AGB	-0.431*	-0.443*	0.566**	0.623**	0.156 ^{ns}	0.431*			
GY	-0.106 ^{ns}	-0.250 ^{ns}	0.352 ^{ns}	0.530**	-0.109 ^{ns}	0.116 ^{ns}	0.661**		
SY	-0.491*	-0.424*	0.522*	0.492*	0.264 ^{ns}	0.485 ^{ns}	0.90 **	0.27 ^{ns}	
HI	0.355*	0.241 ^{ns}	-0.187 ns	-0.075 ns	-0.364*	-0.329 ^{ns}	-0.293 ns	0.504**	-0.668**

*DH=Days to heading, DM= Days to maturity; PH= Plant height; NSS=Number of seed per spike, TSW= Thousand Seed weight; SW=Spike weight, AGB= above ground dry biomass; GY= Grain yield; SY= Straw yield; HI= Harvest index; LSD=least significance difference ns=non-significant different. *, **, *** indicate significant difference at probability levels of 5%, 1% and 0.1% respectively.*

CONCLUSION

Developing a lucrative and sustainable malt barley production strategy requires knowledge of crop response to NPS rates and improved varieties. At the Horro District, Gitlo location, the goal was to boost malt barley production's yield and yield components using good, manageable agronomic techniques. Another objective of the study was to evaluate the effects of NPS fertilizer application on the growth, yield, and yield components of different malt barley cultivars. Higher rates of NPS fertilizer significantly enhanced the harvest index, above-ground dry biomass, number of seeds per spike, plant height, days to maturity, and straw yield. In contrast, days to emergence, spike length, and the number of tillers per plant were not significantly different from the control treatment. However, above-ground dry biomass, harvest index, grain yield, straw yield, plant height, number of productive tillers, thousand seed weight, days to maturity, and grain filling period exhibited statistically significant improvements compared to the control. Correlation analysis indicated a positive association between grain yield and the evaluated growth and yield parameters. Two malt barley types that performed well were Holker and HB-1963. However, 92 kg NPS/ha^{-1} fertilizer rates with the Holker type produced the best grain yield. Thus, it was suggested that 92 kg NPS ha^{-1} rates and the Holker variety be applied together for broader use in the study area and comparable agro-ecologies in Ethiopia's highlands. Future improvements in malt barley production in the central highlands of Ethiopia will depend on increasing yields of premium-quality grain across diverse varieties through the application of sound agronomic practices. However, fertilizer recommendations are often based primarily on soil nutrient analyses, without fully accounting for environmental variability. A major limitation is that absolute crop yields can fluctuate considerably between years due to differences in weather conditions, even under similar site characteristics, crop types, and management practices. Given that the present study was conducted at a single location over one growing season, formulating definitive recommendations would be premature. Therefore, further research, replicated across multiple seasons and locations, is necessary to develop agronomically optimal fertilizer management strategies and achieve sustainable improvements in malt barley yield and quality.

Competing Interests Statement
The authors declare that there are no conflicts of interest associated with this work.

Data Availability Declaration
The supporting data for this study are available from the corresponding author upon reasonable request.

REFERENCES

Assefa, G., Tsegaye, D., & Tesfaye, K. (2017). Integrated soil fertility management technologies on barley productivity in Ethiopia: A review. *Journal of Biology, Agriculture and Healthcare*, *7*(7), 1–6.

Berhane, G. (2011). Constraints to efficient and inclusive barley value chains in Ethiopia. In *Barley research and development in Ethiopia* (pp. 233–251). International Center for Agricultural Research in the Dry Areas (ICARDA).

Ceccarelli, S., & Grando, S. (2000). Barley landraces from the Fertile Crescent: A lesson for plant breeders. In S. Brush (Ed.), *Genes in the field: On-farm conservation of crop diversity* (pp. 51–76). Lewis Publishers.

Central Statistical Agency (CSA). (2020). *Agricultural sample survey: Report on area and production of major crops (Private Peasant Holdings, Meher Season)*. Statistical Bulletin 586. Addis Ababa, Ethiopia.

Edney, M. J., O'Donovan, J. T., Turkington, T. K., Clayton, G. W., McKenzie, R. H., Juskiw, P. E., Lafond, G. P., Brandt, S. A., Harker, K. N., & Smith, E. G. (2012). Effects of nitrogen fertilizer rate and timing on malting barley yield and quality. *Agronomy Journal*, *104*(5), 1230–1239. https://doi.org/10.2134/agronj2012.0005

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley & Sons.

Harlan, J. R. (1976). Barley. In N. W. Simmonds (Ed.), *Evolution of crop plants* (pp. 93–98). Longman.

Lapitan, N. L. V., Chen, X., & Haber, E. (2009). Breeding for durable resistance to biotic stresses in barley. *Critical Reviews in Plant Sciences*, *28*(4), 189–209. https://doi.org/10.1080/07352680903035400

McKenzie, R. H., Middleton, A. B., Bremer, E., & Moulin, A. P. (2005). Fertilizer management for malt barley production. *Canadian Journal of Soil Science*, *85*(1), 101–110. https://doi.org/10.4141/S04-042

Ministry of Agriculture (MoA). (2012). *Crop variety register* (Issue No. 15). Addis Ababa, Ethiopia.

Mulatu, B., & Grando, S. (2011). Barley research and development in Ethiopia: Introduction. In S. Grando & M. H. Gomez (Eds.), *Barley research and development in Ethiopia* (pp. 1–8). ICARDA.

Mulatu, B., & Lakew, B. (2011). Barley research and development in Ethiopia—An overview. In S. Grando & M. H. Gomez (Eds.), *Barley research and development in Ethiopia* (pp. 1–8). ICARDA.

O'Donovan, J. T., Edney, M. J., Turkington, T. K., Clayton, G. W., McKenzie, R. H., Juskiw, P. E., Lafond, G. P., Brandt, S. A., Harker, K. N., & Smith, E. G. (2011). Nitrogen and plant density effects on barley malting quality and yield. *Agronomy Journal*, *103*(1), 155–165. https://doi.org/10.2134/agronj2010.0290

Organization for Rehabilitation and Development in Amhara (ORDA). (2015a). *Barley value chain development interventions in Ethiopia*. ORDA Press.

SAS Institute. (2004). *SAS/STAT user's guide, version 9.1*. SAS Institute Inc.

Shahidur, R., Gautam, M., & Mekonnen, D. (2015). *Barley value chain and poverty reduction in Ethiopia*. World Bank Group.

Taffesse, A. S., Dorosh, P., & Gemessa, S. A. (2011). Crop production in Ethiopia: Regional patterns and trends. In P. Dorosh & S. Rashid (Eds.), *Food and agriculture in Ethiopia: Progress and policy challenges* (pp. 53–83). University of Pennsylvania Press.

Tekalign, M. (1991). *Soil, plant, water, fertilizer, animal manure and compost analysis manual*. International Livestock Research Centre for Africa (ILCA).

Westerman, R. L. (1990). Soil testing and plant analysis: An overview. In R. L. Westerman (Ed.), *Soil testing and plant analysis* (3rd ed., pp. 1–6). Soil Science Society of America.

Yirga, C., Alemu, H., & Yami, A. (1998). The role of research in the development of barley production in Ethiopia. In H. Alemu, A. Getachew, & K. Belay (Eds.), *Barley research in Ethiopia: Past work and future prospects* (pp. 1–8). IAR/ICARDA