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RESEARCH ARTICLE

Improving food barley productivity in nutrient depleted Ethiopian soils *via* blended NPSB fertilization

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Food barley is an important crop in the southern highlands of Ethiopia, playing a key role in the local food supply. However, its productivity is limited due to the lack of improved high-yield varieties and the decline in soil quality caused by nutrient depletion. A field trial was, therefore, conducted in the Gorche district during the 2021–022 cropping season to investigate the effectiveness of blended NPSB fertilization and assess economically feasible rates for enhancing food barley productivity. A factorial combination of four fertilizer rates (0, 50, 100, and 150 kg NPSB ha^{-1}) and four barley varieties (Adoshe, HB-1307, EH-1493, and HB-1966) was used in a randomized complete block design with three replications. The results revealed that days to emergence were only affected by varieties. Days to heading, maturity, tillers m^{-2}, grain weight, spike length, height, kernels spike-1, and harvest index were influenced by both NSPB fertilizer and variety. The main and interaction effects notably influenced the total tillers m^{-2}, aboveground dry biomass, grain yield, and straw yield. Of all the combinations, the HB-1307 variety with 150 kg NPSB ha^{-1} produced the highest grain yield of 4.86 t ha^{-1} and an economic return of 73,403.20 Ethiopian birr (ETB) ha^{-1}. This combination also had an acceptable marginal rate of return of 2,729.92% when compared to other fertilizer and variety combinations. Based on these results, farmers in Gorche district and similar agroecological areas in Ethiopia are advised to use the combination of HB-1307 variety with 150 kg NPSB ha^{-1}, to achieve better crop productivity, food security, and higher economic returns.

Keywords: Economic return, Food cereal, Inorganic fertilizer, Growth, Phenology, Yield.

Key Points

- The results indicated that utilizing a blended NPSB fertilizer enhanced the yield of food barley and increased economic profits.
- The four barley varieties showed different responses to the application of inorganic fertilizer.
- Improved crop varieties and optimal use of inorganic fertilizers can help small-scale farmers enhance their crop yields and attain food security.
- The combined use of 150 kg N ha^{-1} and HB-1307 variety was recommended for food barley production in Ethiopia.

Introduction

In Ethiopia, soil fertility continues to decline, posing a challenge to crop production and food security. Several studies have been conducted at the national and international levels to combat soil nutrient depletion and improve household food security (Van Beek et al., 2016; Abuye et al., 2021). The main causes of soil nutrient depletion include continuous cultivation, reduced fertilizer application, removal of crop residues and animal manure for fuelwood, and erosion associated with low inherent soil fertility (Mulualem and Yebo, 2015; Tilahun et al., 2017). Hence, it is imperative to implement strategic measures to replenish soil fertility and improve nutrient levels for various crops. In this context, chemical fertilizers play a crucial role in increasing agricultural productivity and safeguarding food security for farming communities (Weldegebriel et al., 2018).

For plants to grow and reproduce successfully, they require an adequate and balanced supply of essential nutrients (Weldegebriel et al., 2018). These nutrients can be obtained from both organic and inorganic sources.

However, in the country, the focus on fertilizer use since the early 1970's has been mainly on the application of Nitrogen (N) and Phosphorus (P) fertilizers, specifically urea and DAP respectively, to almost all crops (Abebe et al., 2022).

Since then, little or no attention has been paid to other macro- and micronutrients, resulting in unbalanced fertilization, poor nutrient management, and poor crop quality (Tena and Beyene, 2011). Such an imbalanced use of plant nutrients can exacerbate the depletion of other important nutrients in soils (Assefa et al., 2014). Moreover, the country's fertilizer usage does not adhere to recommended levels and is not based on the findings of soil tests.

Furthermore, the recommended soil management techniques are not being fully adopted by farmers, resulting in a decline in crop yield, depletion of soil nutrients, and a rise in the number of people experiencing food insecurity (Diriba et al., 2019; Wawire et al., 2021). Recent soil analysis results revealed a deficiency in most nutrients, including N (86%), P (99%), S (92%), B (65%), and Zn (53%), in Ethiopian soils and study areas (Bekele et al., 2022). Although micronutrient levels rise as soil pH falls, it is worth noting that B deficiency is severe in acidic soils in the southern highlands, limiting grain yield (Elias, 2019). Hence, implementing appropriate soil management practices, such as balanced fertilization and soil amendment strategies, can help replenish the essential nutrients and mitigate the negative impacts of these deficiencies on crop production (Penuelas et al., 2023). In this regard, the Ministry of Agriculture has introduced a new NPSB fertilizer containing 18.9% N, 37.7% P_2O_5, 6.95% S, and 0.1% B. This fertilizer aims to offer farmers essential nutrients as an alternative to the conventional DAP fertilizer. Besides, using improved crop varieties has great potential to enhance the food security and livelihoods of the smallholder farmers in the country. However, these agronomic practices are not scaled down to the farmer level in the district and rely heavily on conventional production methods. Hence, this study aims to evaluate the effects of blended NPSB fertilization on agronomic parameters and identify the optimal NPSB fertilization rates and varieties to improve food barley yield in the Gorche district of Sidama region, Ethiopia.

Materials and Methods

Description of the study site

A field trial was conducted during the 2021-2022 cropping season in Ethiopia's southern highlands, Gorche district, Sidama regional state. The site is located at 6°52′30″ north latitude and 38°35′30″ east longitude, at an altitude of 2620 meters above sea level. It is situated 45 kilometers away from Hawassa, which is the regional capital (Figure 1). The site receives an average annual rainfall of 1324.3 mm, with the lowest and highest temperatures recorded at 8.16°C and 22.2°C, respectively. The area experiences an average relative humidity of 65%, with the primary rainy season occurring from June to September and contributing to 66% of the total annual rainfall. Conversely, the shorter rainy season from February to May receives the lowest amount of precipitation. Peak rainfall received in July and August coincided with barley sowing and cultivation. According to the Ethiopian agro-ecological classification, the experimental site is classified as 'Dega' or subhumid with a bimodal rainfall pattern. Mixed farming and livestock rearing are the primary agricultural activities in the area. In the highlands, mixed farming focuses on the intensive cultivation of cereals, pulses, tubers, and vegetables. The predominant soil type in the region is clay loam.

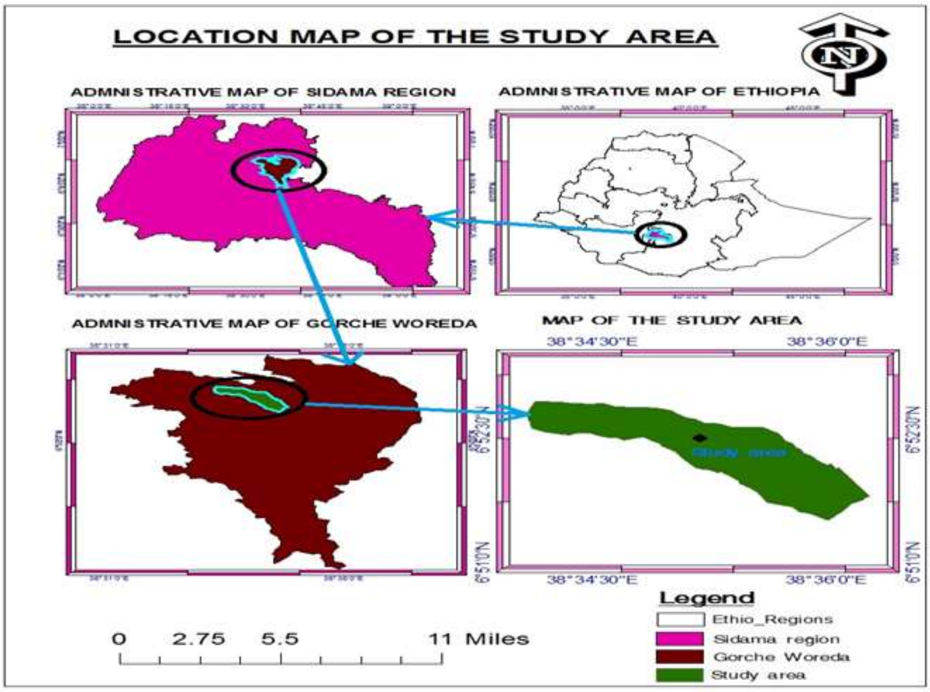

Figure 1. Study area.

Description and source of the experimental materials

The experiment involved selecting four different barley varieties (Adosha, HB-1307, HB-1966, and EH-1493) from the Werabe Agricultural Research Center. These specific varieties were chosen because they share similar adaptation areas and growing seasons. NPSB fertilizer, which includes 18.9% N, 37.7% P_2O_5, 6.95% S, and 0.1% B, was used during the experiment at planting time.

Treatments, experimental design, and field management

The treatments studied included four fertilizer rates (0, 50, 100, and 150 kg NPSB ha^{-1}) and four food barley varieties (Adosha, HB-1307, HB-1966, and EH-1493). The experiment followed a randomized complete block design with a factorial combination and three replicates. Hence, it included 16 treatments with 48 plots. The size of each plot was (3.2 m x 1.5 m=4.8 m^2). The distance between plots was 0.5 m, while the distance between blocks was 1 m. The plot consisted of 16 rows planted 20 cm apart and covered with soil by hand. To prevent potential border interference, barley plants in the outermost rows on both sides, within 10 cm of the borders, were labeled as border plants and excluded from the data analysis. The net area of the plot used for data collection was 14 rows (2.6 m x 1.5 m=3.9 m^2).

The research area was prepared for experimentation using a traditional local plow (Maresha) following the farmers' conventional cultivation methods. After hand preparing and smoothing the seedbed, rows were carefully set up in each plot. Subsequently, designated plots within a block were randomly assigned to each treatment. The specified amounts of each fertilizer rates were applied for all treatments according to randomization. The experiment involved using 46 kg N ha^{-1} in the form of urea. Half of this amount, or 23 kg, was applied during sowing for all treatments. The remaining half was applied after 35 days of planting to prevent N loss through leaching. All agronomic practices, such as weeding, cultivation, roughening, and pest control, were performed accordingly.

Soil sampling and analysis

Soil samples were randomly collected from multiple locations using an auger to a depth of 30 cm before planting. The samples were combined and thoroughly mixed to form a composite sample, which was air dried at room temperature under shade and ground to pass through a 2 mm sieve. The soil's physicochemical properties were then determined using a 1 kg subsample at the Arekka Agricultural Research Center. The submitted sample was, then analyzed for particle distribution (soil texture), soil pH, Cation Exchange Capacity (CEC), organic carbon and matter, available S, P, and B, as well as total N. Soil texture was determined using Bouyoucos' hydrometric method (Bouyoucos, 1951; Orhan and Kılınç, 2020) and the texture triangle system described in (Beretta et al., 2014). Soil pH was measured with a glass electrode connected to a digital pH meter at a 1:2.5 (mass/volume) dilution ratio (Schofield and Taylor, 1955). The CEC and exchangeable K were measured after saturating the medium with 1 N Ammonium Acetate (NH_4OAC) and displacing it with 1 N NaOAC (Jaremko and Kalembasa, 2014). Soil organic C content was determined using the Walkley and Black method, and organic matter content was calculated by multiplying the percentage of organic C by a factor of 1.724. The available S content in turbid soils was measured spectrophotometrically (Chesnin and Yien, 1951), while the Olsen method was employed to determine available P levels. Available B content was determined using the hot water method, and the Kjeldahl method was used to determine total soil N.

Agronomic data collection

Days to emergence were calculated as the number of days between seeding and when seedlings in each plot had covered 50% of the soil. Days to heading were estimated as the number of days between seeding and when plants reached 50% heading. Days to physiological maturity were computed by determining the number of days between planting and when plants reached 90% maturity. At physiological maturity, ten plants were randomly selected from the central plots, and their height was measured from the soil surface to the top of the ear, excluding the awns. Spike length was determined by averaging the spike lengths of ten randomly selected premarked plants and dividing the sum by the number of plants per plot.

The total number of tillers m^{-2} was calculated by counting the number of seedlings in the designated area of each plot (0.5 m x 0.4 m=0.2 m^2) after all seedlings had emerged. The productive tillers m^{-2} were determined by counting the effective tillers from each plot's 0.5 m x 0.4 m=0.20 m^2 area, which was used to calculate the total number of tillers m^2. The difference between the counts taken before and after flowering gives the number of effective tillers. When selecting high yielding varieties for agronomic purposes, tillers m^{-2} are preferable to tillers $plant^{-1}$. The average kernel $spike^{-1}$ was calculated using ten randomly selected spikes from the net plots. The weight of 1000 kernels was measured by counting 1000 seeds from each treatment's total grain yield with an electronic seed counter. The weight was measured with an electronic balance and then adjusted to a moisture content of 12.5%. Grain yield was measured on central rows of 3.9 m^2, weighed with a sensitive balance, adjusted to a moisture content of 12.5%, and expressed in t ha^{-1}. The straw yield was estimated by subtracting the grain yield from the total aboveground biomass. Aboveground dry biomass was computed from plants harvested from the net plot area after sun drying to a consistent weight and converted to tons per hectare. The harvest index was calculated as the ratio of grain yield to total aboveground biomass yield and was multiplied by 100% at harvest in each plot.

Economic analysis

An economic analysis was carried out to determine the benefits of using NPSB fertilizer and different varieties using a partial budget analysis, as described by CIMMYT. The input expenses were determined by combining fertilizer costs and labor for applying fertilizer. Nevertheless, the remaining operational and fixed expenses were presumed to be uniform across the board and were not factored into the computation.

Statistical analysis

The collected data underwent analysis of variance using SAS statistical software version 9.3. Duncan's multiple range test was used to separate treatment means for measured traits at a 5% significance level. Additionally, correlation analysis was used to determine the relationship between agronomic parameters, considering the influence of NPSB fertilizer application and variety.

Results and Discussion

Soil physicochemical properties of the experimental site

Table 1 shows the soil analysis results from the experimental site before planting. According to the soil texture triangle, the site had 36% clay, 31% silt, and 33% sand, making it a clay loam. The soil's textural composition offers valuable insights into its capacity for water storage and infiltration, aeration, root penetration, and soil fertility. The optimal pH range for most crops and fertile soils tends to be between 5 and 8. As a result, the pH of the experimental site was slightly acidic, making it suitable for cereal crops, including barley. Most crops in Ethiopian soils require an N content of around 0.2% for optimal production. Unfortunately, the total N at the testing site was below this ideal percentage. This issue may arise due to insufficient plant coverage, frequent soil disturbance, or the absence of crop residue in the field. Soil aggregates, formed by organic matter, are crucial in reducing soil bulk density and compaction. Likewise, it provides energy to soil microbes and fauna. Apparently, this investigation was performed in an experimental site with limited organic matter content. The primary cause of this deficiency is the removal of crop residues. The available P content was found to be low, according to Olsen. Heavy metal ions and intensive decomposition of agricultural fields may have contributed to the low available P content. Similarly, realized low available P levels in farmer fields due to fixation and degradation. The estimated values of S and B were 19.43 ppm and 0.25 ppm, respectively, which fell within the low range. Inadequate use of mineral fertilizers containing S and B, limited application of organic fertilizers, and changes in cropping systems can all be linked to lower levels of these essential elements. Furthermore, the CEC value was low, indicating that the tested soil lacked adequate nutrient levels and should be improved using appropriate agricultural practices (Table 1).

Table 1. Selected soil physical and chemical characteristics of the study area before sowing.

Parameters	Unit	Values	Rating
Sand	(%)	33	
Silt	(%)	31	
Clay	(%)	36	
Textural class			Clay loam
pH (1:2.5 H_20)	Potent metric	5.36	Moderately acidic
Total nitrogen	%	0.16	Low
Organic matter	%	2.31	Low
Available phosphorous	ppm	9.42	Low
Available sulfur	ppm	19.43	Low
Available boron	ppm	0.25	Low
Cation exchange capacity	(cmol kg^{-1})	19.15	Low

Treatments effect on the phenological parameters

The days to heading and maturity were significantly influenced by the variety and the blended NPSB fertilizer rates, whereas the days to emergence were influenced solely by the variety (Table 2). The longest days to heading and maturity were recorded at 150 kg NPSB ha^{-1}, while the shortest days for these parameters were observed in the control (0 kg NPSB ha^{-1}). The delayed heading caused by NPSB fertilization could be attributed to the high N content, which promotes vegetative development before the onset of the reproductive phase and is thus responsible for an extended period of heading and maturation. Similarly, Kefale and Hawassa found a significant difference in heading time between the highest and lowest N fertilizer rates for malt barley, with a noticeable delay observed in the former. Moreover, the presence of P in the soil triggers the growth of lateral and fibrous roots, leading to enhanced nutrient uptake. On the other hand, S plays a crucial role in facilitating the absorption of vital nutrients by the plants. Studies by Grover, et al., and Desta and Almayehu have highlighted these significant contributions of P and S in plant development. Additionally, it has been observed that the overall S content in leaves tends to rise with an increase in sulfate availability. Leaves that are actively involved in photosynthesis exhibit the highest concentrations of S, thereby supporting robust vegetative growth before the initiation of the reproductive phase. Thus, the prolonged phenological traits of food barley due to supplied fertilizer blends might be attributed to the availability of these nutrients essential for the overall functions of the plants. Seedlings rely mainly on their internal nutrient reserves rather than external sources for germination. As a result, no significant variation was observed in days to emergence owing to NPSB fertilizer application (Table 2). In line with these findings, Abtew, et al., noticed that plants rely on stored food rather than external nutrients for germination.

Of the barley varieties, the HB-1307 variety took the longest days for emergence, heading, and maturity, while the EH-1493 variety required the shortest duration to complete these stages (Table 2). Genetic variations in the stored nutrients in the endosperm may account for the differences in days to emergence among cultivars. These variations can influence the germination rate of barley seeds in comparable environmental conditions, including climate and soil. In line with this result, different varieties showed variations in the number of days it took for emergence. Similarly, Alem and Legese noted significant differences in the days to heading and physiological maturity among barley varieties. Additionally, there have been reports of notable disparities in physiological maturity among the various barley varieties.

Table 2. Effect of NPSB fertilizer rates on phenological parameters of food barley varieties during the 2021/2022 cropping season.

Treatments	Days to 50% emergence	Days to 50% heading	Days to 90% maturity
NPSB kg ha^{-1}			
0	7.38	70.30^{d}	98.61^{d}
50	7.39	74.20^{c}	106.66^{c}
100	7.39	78.70^{b}	115.93^{b}
150	7.41	84.10^{a}	126.35^{a}
LSD (5%)	NS	2.43	3.45
Variety			
Adosha	7.23^{b}	76.80^{b}	112.02^{b}
HB-1307	8.20^{a}	79.30^{a}	114.97^{a}
HB-1493	6.87^{c}	74.30^{c}	107.93^{c}
HB-1966	7.26^{b}	77.00^{b}	112.63^{b}
LSD 0.05	0.33	2.26	2.2
CV%	11.5	7.01	9.03
F values			
NPSB	0.46^{ns}	423.17*	1716.58*
Variety	3.71*	48.98*	102.71*
NPSB × variety	0.01^{ns}	3.98^{ns}	6.54^{ns}

Note: Means in columns followed by the same letters are not significantly different as judged by LSD test at 5% level of significance; CV: Coefficient of Variation

Effect of NPSB fertilizer on growth and yield-related traits of barley varieties

Plant height and spike length: NPSB fertilizer rate and variety significantly ($p<0.05$) affected growth related parameters of food barley. However, their interactions did not affect these traits (Table 3). As the rate of fertilizer increased, there was a corresponding increase in plant height and spike length. The tallest plant and longest spike were measured at a rate of 150 kg NPSB ha^{-1}, while the shortest values were recorded in the control. The positive effect of N on plant growth can be attributed to its role in increasing the production of macromolecules such as proteins, enzymes, pigments, and hormones. It also accelerates important processes like photosynthesis, cell division, elongation, and internode lengthening. Thus, it helps plants grow by providing the necessary building blocks and energy. Consistent with this finding, Sigaye, et al., reported that plant growth showed a consistent pattern of increase as the application rates of NPSB increased. Similar findings were reported by Tigre, et al., who found an increase in plant height as NPSB rates increased from 0–69/30 kg ha^{-1}. The spike's length increases proportionally with NPSB fertilizer rates. This can be attributed to enhanced root development and nutrient absorption. The increased availability of P promotes growth and stimulates cell division. As a result, this synergistic effect increases the overall impact of nutrients, ensuring that they work optimally. Furthermore, Abebe and Manchore found a significant effect of the optimal fertilizer rate on spike length. Consistent with these findings, Menamo and Masebo reported the longest spike length in barley at 50/150 kg N/P_2O_5 ha^{-1}. HB-1966 outperformed the other varieties in terms of plant height and spike length. Adosha, on the other hand, exhibited the lowest values for these characteristics (Table 3). Differences in plant traits and growth patterns can be linked to the genetic composition of different plant varieties. In agreement with this finding, Ghaffar et al., reported differences in plant height and spike length among wheat cultivars owing to differences in their genetic makeup. Similarly, several studies have reported variations in plant growth among genotypes.

Table 3. Main effect of NPSB rates on growth parameters of food barley varieties during the 2021/2022 cropping season.

Treatments	Plant height (cm)	Spike length (cm)
NPSB kg ha^{-1}		
0	74.90^{d}	4.37^{d}
50	77.97^{c}	5.40^{c}
100	80.30^{b}	6.42^{b}
150	83.50^{a}	6.74^{a}
LSD (5%)	2.05	0.2
Variety		
Adosha	78.37^{d}	5.66^{b}
HB-1307	69.80^{c}	5.61^{b}
HB-1493	83.32^{b}	5.80^{ab}
HB-1966	86.2^{a}	5.87^{a}
LSD 0.05	2.05	0.2
CV%	6.48	6.02
F values		
NPSB	49.96*	13.76*
Variety	658.98*	0.19*
NPSB × variety	3.43^{ns}	0.04^{ns}

Note: Means in columns followed by the same letters are not significantly different as judged by LSD test at 5% level of significance; CV: Coefficient of Variation.

Number of total tillers: Tillers are secondary shoots that grow from the base of the main stem in grasses such as barley. They contribute to the crop's overall yield and productivity by producing more heads, which eventually mature into grains. The results revealed that fertilizer rates, varieties, and their interactions had a significant ($p<0.05$) influence on the total number of tillers m^{2}. The HB-1307 variety exhibited the highest tiller count with 150 kg NPSB ha^{-1} application. In contrast, the Adosha variety produced the fewest total tillers without fertilization treatment (Table 4). When NPSB fertilization was not applied, the total number of tillers decreased in all barley varieties, highlighting the importance of using effective fertilization strategies to boost tiller yield. On the other hand, the increase in tillers with higher fertilizer rates demonstrates the importance of providing a balanced nutrient supply for optimal plant growth and development. Furthermore, increased N availability at the highest NPSB fertilizer rate may have aided cytokinin synthesis and cell division, accelerating plant vegetative growth.

This could also be attributed to the positive role of P found in NPSB fertilization in emerging radicles and seminal roots during seedling establishment in food barley, which promotes N uptake and assimilation by growth points triggering tillers, resulting in overall plant growth and an increase in total tillers of food barley. In line with this finding, Tesfaye, et al., reported an increase in the total number of tillers m^{-2} as NPSB fertilizer rates increased. Similarly, Abera et al. (2020) reported the highest tiller count in plants treated with the highest rate of 150 kg NPSB ha^{-1}. Having a higher number of tillers in a crop results in a stronger stand, which brings benefits such as reduced lodging, improved light interception, enhanced nutrient absorption, and better weed control. Ultimately, these advantages contribute to higher yields, making a higher tiller count a valuable trait for crop productivity.

Table 4. Interaction effects of blended NPSB fertilizer rates and varieties on the total number of tillers per m^2 during the 2021/2022 cropping season.

Treatments	NPSB (kg ha^{-1})			
	0	**50**	**100**	**150**
Varieties				
Adosha	88.33^{h}	129.71^{fg}	183.78^{cd}	189.78^{de}
HB-1307	92.22^{h}	139.08^{fg}	200.00^{bcd}	241.67^{a}
EH-1493	88.67^{h}	137.09^{fg}	191.78^{de}	194.61^{cde}
HB-1966	88.34^{h}	145.08^{f}	208.78^{bc}	209.02^{b}
CV (%)	9.58			
LSD (5%)	14.51			

Note: Mean values followed by the same letters in each column and treatment showed no significant difference ($p<0.05$). *Shows significant differences at the 0.05 probability level.

Productive tillers, kernels spike^{-1}, and thousand kernel weight

The applied fertilizer rate and variety had a significant ($p<0.05$) effect on productive tillers m^{-2}, kernel spike^{-1}, and thousand kernel weight, but their interaction did not significantly affect these parameters (Table 5). The increase in these parameters was directly proportionate to the higher application rates of blended NPSB fertilizer. Supplying blended NPSB fertilizer at higher rates resulted in improved yield related characteristics. Among the various application rates, the 150 kg NPSB ha^{-1} showed the highest values for these traits, while the control group showed the lowest values. Nitrogen is essential for many physiological processes, including photosynthesis, protein synthesis, and enzyme activity. By providing adequate N, plants can perform these processes more efficiently, resulting in improved overall plant health.

This could also be related to N's well-known role in promoting plant vegetative growth. In addition, increased productivity of tillers with higher N application rates can be attributed to improved tiller survival, as they have the resources to withstand environmental stresses, diseases, and pests. In addition, the NPSB fertilizer not only contains N, but also includes P, S, and B. Phosphorus is important for energy transfer, root development, and flowering. Sulfur is necessary for amino acid synthesis, protein production, and plant defense mechanisms. Boron, although needed in small amounts, is crucial for cell wall formation, pollen germination, and fruit development. Hence, it provides a well-balanced combination of these nutrients, ensuring that plants have all the essential elements for optimal growth and development.

The increase in kernel spike^{-1} caused by blended NPSB fertilization could be attributed to P, which is required for flower initiation and grain development. It's also possible that the availability of B-containing fertilizer aids grain filling, reducing sterility and increasing the number of spike^{-1} grains. Similarly, Nadim, et al., reported that P and B are responsible for the translocation of food materials in plants; therefore, they play a vital role in grain setting and the production of a higher number of grains in wheat. The increase in kernel weight might be due to the supply of adequate and balanced nutrients, which enhances the accumulation of assimilates in the grains, resulting in good grain filling and the development of larger kernels. In line with this result, Rahman, et al., reported the maximum thousand kernel weight for wheat in two consecutive years with the application of 120 kg N ha^{-1}.

Among the varieties, HB-1307, followed by HB-1966, produced the highest productive tiller m^{-2}, kernel spike^{-1}, and thousand kernel weight, whereas HB-1493 produced the lowest for these parameters (Table 5).

The differences in the yield components of barley varieties could be attributed to genetic makeup. In agreement with this finding Massigoge, et al., there was significant variation in yield components among the tested varieties. Several studies have highlighted significant variations in yield components caused by genetic differences among cultivars.

Table 5. Main effect of NPSB rates on yield parameters of food barley varieties during the 2021/2022 cropping season.

Treatments	Number of productive tillers m^{-2}	Number of kernels $spike^{-1}$	Thousand kernel weight (g)
NPSB kg ha^{-1}			
0	60.00^{d}	31.25^{d}	30.75^{d}
50	114.78^{c}	36.17^{c}	37.50^{c}
100	163.68^{b}	41.25^{b}	42.48^{b}
150	181.67^{a}	45.67^{a}	47.23^{a}
LSD (5%)	9.12	1.12	0.94
Variety			
Adosha	126.66^{bc}	38.33^{b}	38.92^{b}
HB-1307	138.59^{a}	39.83^{a}	40.61^{a}
HB-1493	121.38^{c}	36.75^{c}	37.69^{c}
HB-1966	133.50^{ab}	39.41^{ab}	40.05^{a}
LSD 0.05	9.03	1.15	0.9
CV%	12.3	9.59	7.24
F values			
NPSB	35746.1^{*}	467.61^{*}	596.75^{*}
Variety	686.0^{*}	22.72^{*}	7.758^{*}
NPSB × variety	168.5^{ns}	3.63^{ns}	2.294^{ns}

Note: Means in columns followed by the same letters are not significantly different as judged by the LSD test at the 5% level of significance; CV: Coefficient Of Variation.

Aboveground dry biomass: Blended NPSB fertilizer rates, variety, and their interaction significantly ($p<0.05$) influenced aboveground dry biomass production. The HB-1307 variety produced the highest yield at 150 kg NPSB ha^{-1}, followed by EH-1493 at the same rate. Conversely, the Adosha variety without fertilization showed the lowest yield (Table 6).

Table 6. Interaction effects of blended NPSB fertilizer rates and varieties on aboveground dry biomass during the 2021/2022 cropping season.

Treatments	**NPSB (kg ha^{-1})**			
	0	**50**	**100**	**150**
Varieties				
Adosha	3.65^{p}	5.25^{m}	8.28^{h}	9.15^{g}
HB-1307	5.15^{n}	7.15^{i}	10.13^{e}	13.85^{a}
EH-1493	4.65^{o}	6.53^{k}	9.72^{f}	11.45^{b}
HB-1966	6.05^{l}	6.87^{j}	10.65^{d}	11.15^{c}
CV (%)	7.28			
LSD (5%)	0.08			

Note: Mean values followed by the same letters in each column and treatment showed no significant difference ($P<0.05$).
*Significant differences at 0.05 probability levels.

The substantial increase in biomass production was due to the increased NPSB rate, which enhanced nutrient availability. This, in turn, promoted root growth and improved nutrient absorption by plants from the soil, resulting in robust plant growth and development. Additionally, the increased absorption of nutrients allowed crops to thrive by providing them with a greater supply of essential elements. As a result, there was an increase in tillering, which involved the production of additional shoots or stems emerging from the base of the plant. The increased tillering rate led to a thicker and more efficient crop, boosting the total biomass yield. Furthermore, the four nutrients' synergistic effects most likely contributed to the delay of leaf senescence. With adequate nutrition, the leaves remained vibrant and functional for an extended period, allowing for longer photosynthesis and continuous energy and biomass production. Moreover, N enhances vegetative growth and yield, whereas P plays a fundamental role in metabolism and energy production, resulting in enhanced biomass yield.

In addition, longer spike length, higher kernels spike^{-1}, productive tillers, and grain yield due to supplied N resulted in improved aboveground dry biomass yield. On the other hand, Demissie, et al., reported that supplying optimum NPSB at a rate of 150 kg ha^{-1} resulted in higher aboveground dry biomass than in the control. Moreover, Sigaye, et al., reported a marked effect of blended NPSB fertilizer on aboveground dry biomass, of which the maximum aboveground biomass was obtained from 200 kg NPSB ha^{-1}. In agreement with this result, Jasemi, et al., reported that vegetative growth and biological yields are highly dependent on the consumption of chemical fertilizers; the application of fertilizers led to an increase in the biological yield of barley.

Grain yield: The NPSB fertilizer rate, variety, and their interaction had a significant ($p<0.05$) effect on grain yield. The combination of variety HB-1307 and 150 kg NPSB ha^{-1} produced the highest yield, surpassing the Adosha variety and the no-fertilization treatment by 84.5% (Table 7). This could be explained by the varietal response to NPSB blended fertilizer and its high fertilizer utilization efficiency. The differences observed in this case can be explained by the crop variety's response to NPSB blended fertilizer and its efficient utilization. Moreover, the presence of P can impact crop grain filling and nutrient usage. When these four nutrients are combined, root growth, nutrient uptake, and overall plant development can be improved, resulting in increased yield components and final harvest.

Furthermore, Klikocka and Marx found that in addition to a 3.58% increase in grain yield from S fertilization, the highest grain yield was achieved with the application of 80 kg N ha^{-1}, resulting in a 13.1% increase compared to the control. Besides that, increased grain production can be attributed to B's role in various plant processes such as hormone production, carbohydrate metabolism, and DNA synthesis, which leads to increased growth and yield. Likewise, adding B to wheat during the tillering, jointing, booting, and anthesis stages resulted in a marked increase in grain yield. According to Mekonnen and Woldekiros, applying P fertilization had a noticeable effect on the grain yield of food barley, resulting in a 15.12% increase even at the lowest application rate. Similarly, Eshetu, et al., reported that nutrients such as K, S, Zn, Mg, and B significantly increased grain yield and yield components compared to the control. Moreover, Malla, et al., reported a 22.40% grain yield increment over the recommended NP fertilizer application and a 48.0% yield increment over the control treatment owing to the synergistic effect of nutrients found in NPSB fertilizers.

Table 7. Interaction effects of blended NPSB fertilizer rates and varieties on grain yield during the 2021/2022 cropping season.

Treatments	NPSB (kg ha^{-1})			
	0	**50**	**100**	**150**
Varieties				
Adosha	0.75^{l}	1.32^{i}	3.31^{f}	3.48^{e}
HB-1307	1.05^{k}	2.08^{h}	4.20^{cd}	4.86^{a}
EH-1493	0.89k^{l}	2.05^{h}	4.16^{d}	4.43^{b}
HB-1966	1.21i^{j}	2.70^{g}	4.16^{d}	4.33^{bc}
CV (%)	6.42			
LSD (5%)	0.16			

Note: Mean values followed by the same letters in each column and treatment showed no significant difference ($P<0.05$).
*significant differences at 0.05 probability levels.

Straw yield: The results revealed that the blended NPSB fertilizer rate and variety, along with their interaction, had a significant impact on the straw yield of barley. The HB-1307 variety produced the highest straw yield at 150 kg NPSB ha^{-1}, while the Adosha variety produced the lowest yield without fertilization (Table 8).

The considerable increase in straw production when using the highest dosage of blended NPSB may be due to the combined effect of nutrients in promoting the growth and development of the plant's vegetative parts. In addition, it might be due to the higher biomass yield with the HB-1307 variety compared to the others due to its relatively late maturing nature (Table 2). Moreover, Fageria, et al., stated that nutrient accumulation in cereals is associated with dry matter production.

Furthermore, optimal nutrient application resulted in increased grain and straw yields. Similarly, Gul, et al., realized that a higher nitrogen application rate of 160 kg ha^{-1} resulted in a substantial increase in straw yield production over the control treatment.

Table 8. Interaction effects of blended NPSB fertilizer rates and varieties on straw yield during the 2021/2022 cropping season.

Treatments	NPSB (kg ha^{-1})			
	0	**50**	**100**	**150**
Varieties				
Adosha	2.9^{m}	3.93^{k}	4.97^{g}	5.67^{f}
HB-1307	4.10^{j}	5.07^{g}	5.93^{e}	8.99^{a}
EH-1493	3.75^{l}	4.47^{i}	5.55^{f}	7.02^{b}
HB-1966	4.84^{h}	4.16^{j}	6.39^{d}	6.82^{c}
CV (%)	5.26			
LSD (5%)	0.13			

Note: Mean values followed by the same letters in each column and treatment showed no significant difference (P<0.05). *Significant differences at 0.05 probability levels.

Harvest index: The results showed that both the blended NPSB fertilizer rates and variety had a significant (p<0.05) effect on the harvest index. However, there was no marked interaction effect between the two factors on the harvest index (Table 9). The data indicated a trend of increasing values with higher application rates of blended NPSB fertilizer. The highest harvest index was observed at a rate of 150 kg NPSB ha^{-1}, while the control group had the lowest harvest index. Gul, et al., reported that a higher transfer of assimilates to the grain maximizes the harvest index and reduces the proportion of dry matter produced. Moreover, the maximum harvest index at the highest blended NPSB rate could be attributed to greater photoassimilate production and its greater partitioning into grains compared to partitioning into straw; hence, the grain yield was proportionally higher than the vegetative biomass yield. Similarly, Duressa and Ayana found that the plots treated with 100 kg NPSZnB ha^{-1} had the highest harvest index, whereas the control plots had the lowest values of this parameter. The average harvest index values ranged from 30.92% to 34.32% among the various barley varieties (Table 9). In particular, the HB-1307 variety showed higher values compared to the Adosha variety, possibly due to its superior ability to allocate dry matter to sink organs more efficiently. This observation aligns with the results of Woyema, et al., who also reported marked differences in harvest index among barley varieties due to their genetic differences.

Table 9. Main effect of NPSB rates on the harvest index of food barley varieties during the 2021/2022 cropping season.

Treatments	Harvest index (%)
NPSB (kg ha^{-1})	
0	20.03^{d}
50	31.25^{c}
100	38.74^{b}
150	40.85^{a}
LSD at (5%)	1.94
Varieties	
Adosha	32.58^{ab}
HB-1307	34.32^{a}
EH-1493	30.92^{b}
HB-1966	33.06^{a}
CV (%)	7.11
LSD at 5%	1.92
F values	
NPSB	1062.38*
Variety	23.81*
NPSB × variety	6.24 ^{ns}

Note: Means in columns followed by the same letters are not significantly different as judged by the LSD test at the 5% level of significance; CV: Coefficient of Variation.

Correlation between food barley yield and yield components: The grain yield of cereals is determined by a multitude of factors and components that collectively contribute to the overall yield. The results of the correlation analysis between the parameters showed that grain yield was positively correlated with plant height, spike length, total number of tillers, fertile tiller number, kernel spike^{-1}, dry biomass, and thousand kernel weight (Table 10). Grain yield was positively and significantly associated with spike length, number of kernels per spike, total number of tillers m^{-2}, effective number of tillers m^{-2}, thousand kernel weight, aboveground dry biomass, straw yield, and the harvest index. In line with the present findings, Negash, et al., reported that the grain yield of barley was significantly associated with its yield components. Similarly, Alemayehu and Momina reported increased grain yield owing to the improved yield components of malt barley. Similarly, Rodrigues, et al., reported that the main component associated with grain yield was the number of grains m^{-2} because the higher number of spikes per m^2 associated with a greater contribution of tillers in modern cultivars.

Table 10. Correlation between the food barley yield and yield components.

Parameters	Significance	
	R-value	**P value**
Grain yield *vs.* spike length	0.9165	***
Grain yield *vs.* total number of tillers per m^{-2}	0.9265	***
Grain yield *vs.* productive number of tillers m^{-2}	0.907	***
Grain yield *vs.* kernel per spike	0.8999	***
Grain yield *vs.* Thousand kernel weight	0.9325	***
Grain yield *vs.* Above ground biomass yield	0.8932	***
Grain yield *vs.* Straw yield	0.6325	***
Grain yield *vs.* Harvest Index	0.8348	***

Partial budget analysis: The results of the partial budget analysis showed that the highest net benefit of ETB (78,403.20 ha^{-1}) and marginal yield rate (2729.92%) were obtained in the combined application of 150 kg NPSB ha^{-1} with the food barley variety HB-1307 (Table 11). Hence, this treatment combination was more profitable than the other treatments when the net economic benefits were considered. Therefore, the net positive benefit obtained by applying 150 kg NPSB ha^{-1} to the HB-1307 variety was economically profitable and could be recommended to farmers in the study area and other areas with similar agroecological and edaphic conditions.

Table 11. Partial budget analysis of food barley varieties yield as influenced by blended NPSB fertilizer application rates (kg ha^{-1}).

Varieties	NPSB rate	Mean	AGY	TGB	TVC	NB	MRR
	(kg/ha)	GY(kg)	(kg)	(ETbirr)	(ETbirr)	(ETbirr)	(%)
Adoshe	0	750	675	19256.25	2736.35	16519.9	-
HB1307	0	1050	945	22803.75	3055.25	19748.5	1012.4
EH1493	0	850	765	19697.85	3065.35	16798.5	D
HB1966	0	1210	1089	26408.25	3098.75	23309.5	838
Adoshe	50	1320	1188	27290.25	4325.35	22964.9	D
HB1307	50	2008	1807.2	42012.75	4360.15	37652.6	1137.07
EH1493	50	2050	1845	40609.71	4394.65	36215.06	D
HB1966	50	2700	2430	40522.21	4802.45	35719.76	D
Adoshe	100	3310	2979	50937	5498.25	45471.75	687.03
HB1307	100	4200	3780	52355	5600.23	46754.77	1258.1
EH1493	100	4160	3744	53435.54	5703.15	47732.39	949.88
HB1966	100	4160	3744	54481.79	5820.75	48661.04	789.66
Adoshe	150	3480	3132	53669.75	6620.15	47049.6	D
HB1307	150	4860	4374	85313.25	6910.23	78403.2	2729.92
EH1493	150	4430	3987	75700.71	6920.15	68780.56	D
HB1966	150	4330	3897	73689.75	6967.35	66722.39	D

Note: AGY: Adjusted grain yield: MGY: Mean Grain Yield; TGB: Total Gross Benefit; TVC: Total Variable Cost; NB: Net Benefit;

NPSB cost: 18 Birr kg^{-1}; Urea cost: 14.20 Birr kg^{-1}, Seed cost: EH1493: 25.35 Birr kg^{-1}; HB130724.90 Birr kg^{-1}; Adoshe24.35 Birr $kg^{-1}$and HB1966: 25.60 Birr kg^{-1}, Labor cost: 130 Birr 2 manday's^{-1}; Sales of price of food barley grain: 18 Birr kg^{-1}; Straw sales price: 1.25 Birr kg^{-1}, MRR(%): Marginal Rate of Return; D: Dominated treatment; UD: Undominated treatment; 0: Unfertilized treatment.

Conclusion

Among the barley varieties tested, the HB-1307 variety had a higher yield performance than the other experimental varieties. Moreover, the same variety with 150 kg ha^{-1} NPSB fertilizer gave a maximum grain yield of 4.86 t ha^{-1} and a net benefit of ETB 78,403.20, with a marginal yield rate of 2,729.92% compared with the other fertilizer and variety combinations. It can be concluded that the application of 150 kg NPSB ha^{-1} along with variety HB-1307 could be a better choice for farmers in the study area to achieve high yields with higher returns.

Data Availability

The raw data collected and used to support the findings of this study are available upon request from the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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