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Original Paper

Optimizing Nitrogen and Phosphorus Fertilizer Rates for Bread Wheat (*Triticum aestivum L.*) Yield in the Highlands of North Gondar, Ethiopia

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***Abstract*—Wheat production in Ethiopia is lacking in addressing domestic issues, due to many limiting factors, among this N and P are the two major plant nutrients that limit wheat productivity. A two-year field experiment was conducted in the Debark district, North Gondar Zone, northern Ethiopia. The study aimed to determine optimum N and P rates for bread wheat (cv. ALIDERO) and to find economically appropriate rates. The treatments consisted of factorial combinations of four levels of N (69, 92, 115, and 138 kg ha^{-1}) and three levels of P (23, 46, and 69 P2O5 kg ha-1) arranged in RCBD with three replications. The result of the study indicated that the application of N and P has a significant effect on all traits. The highest grain yield (4.81 ton ha^{-1}) and lowest (2.88 ton ha-1) were obtained due to the application of 138 kg N ha-1 and 46 kg P2O5 ha-1, and 69 kg N ha^{-1} and 23 kg P2O5 ha^{-1}, respectively. Pearson correlation analysis revealed strong positive relationships between grain yield and key yield components. The treatment that received 138 kg N ha^{-1} and 46 kg P2O5 ha^{-1} yielded the highest MRR birr ha-1, according to the partial budget analysis. Therefore, the combined application of 138 kg N ha^{-1} and 46 kg P2O5 ha^{-1} is an advisable and acceptable rate for wheat production in Debark and similar agroecologies. However, further multi-location and multi-season validation is required before wider recommendations.**

***Keywords*—Biomass, Grain yield, Nitrogen, Phosphorus, Wheat**

I. INTRODUCTION

Wheat is one of the world's most significant staple food crops, supplying 20% of humanity's dietary energy supply and acting as the major source of protein in developing nations. It is a staple food for around one-third of the world's population [1], and marketed cereal crops account for 15% of total cereal crop planting areas worldwide [2]. In Ethiopia, wheat is mostly produced in the highlands, which lie between 6 and 16° N latitude and 35 and 42° E longitude, at elevations ranging from 1500 to 2800 m above sea level, with typical low temperatures of 6 to 11°C [3]. Ethiopia is one of the world's major wheat producers in terms of both planted area and production. With a total of 4.54 million smallholder farmers cultivating wheat throughout 1.87 million acres. It ranks third among cereals in terms of area farmed annually and production, after tef (*Eragrostis tef Zucc*) and maize (*Zea mais*) [4]. Ethiopia is a major wheat grower in sub-Saharan Africa. However, wheat yield levels remain low, with a national average of roughly 2.2 t ha^{-1}, which is significantly lower than yields collected from research stations in 2017, which were 5 t ha^{-1} [5].

Wheat grains are traditionally utilized in the preparation of domestic bread, beverages, and pancakes. Despite Ethiopia's expanding demand for bread wheat, production and productivity remain low at 2.5 t ha^{-1}, compared to the global average of 3.4 t ha^{-1} [6]. The primary cause of Ethiopia's low wheat productivity is the absence of better agronomic techniques. The North Gondar zone has a low wheat production, similar to other parts of Ethiopia. One of the major causes of low wheat output is declining soil fertility. Declining soil fertility, caused by soil erosion, continuous cropping of the same land year after year, and inadequate replenishment of nutrients lost through different pathways through the application of organic and inorganic fertilizers, are the main challenges not only to wheat production but also to crop production in general [7]. To preserve soil nutritional quality and achieve good crop yields, the use of mineral fertilizers is essential. The two most crucial nutrients for crop productivity, particularly the increase in wheat yield, are nitrogen and phosphorus [2]. It is a major worry in the study areas since soil nutrient depletion is worsening with time, and little is being done to reverse the situation. However, the response of wheat to fertilization and the economically feasible rates of nitrogen and phosphorus for wheat production have not been studied in these areas (Debark districts of North Gondar zone). Therefore, this research aims to determine the optimum nitrogen and phosphorus fertilizer rate for wheat at Debark district.

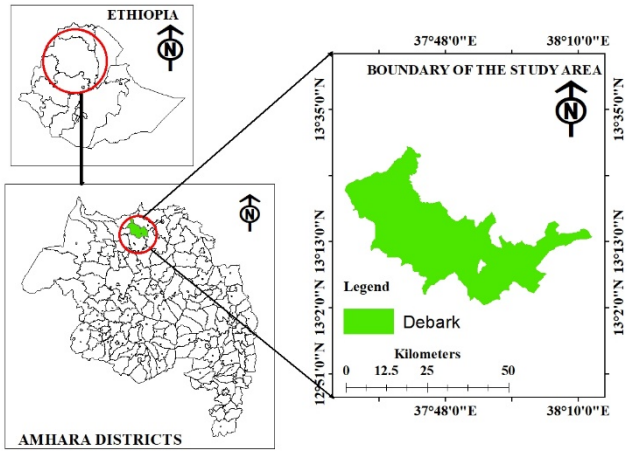


Fig. 1. Map of the study area

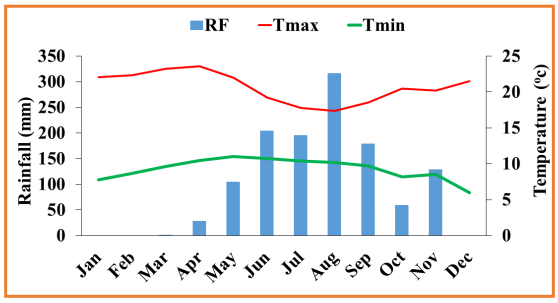


Fig. 2. Climate conditions of Debark at the 2019 cropping season.
Source: Ethiopia Meteorological Agency

II. Materials and Methods

A. Description of the study area

This study was conducted across four experimental sites in debark district during the 2019 and 2020 main growing seasons. Debark is situated at an elevation of 2,885 meters above sea level (13.13°N, 37.9°E). The major crops that are grown in this district are wheat, barley, lentil, faba bean, and chickpea.

B. Climatic Condition

The study area receives an average annual rainfall of approximately 1221.4 mm and 1283.1mm in the 2019 and 2020 main season respectively, with a unimodal distribution that occurs between April and October (Figure 2 and 3). The average monthly maximum temperature was recorded at 20.7°C in 2019 and 20.2°C in 2020, while the minimum temperature averaged 9.3°C and 8.8°C in the 2019 and 2020 main cropping season respectively. Figure 2 and 3 illustrate the mean monthly rainfall along with the maximum and minimum temperatures during the period from 2019 to 2020. The soils at all study sites are categorized as cambisol. Rainfall distribution across the sites is concentrated from April to September, with the highest precipitation typically occurring in July and August [7].

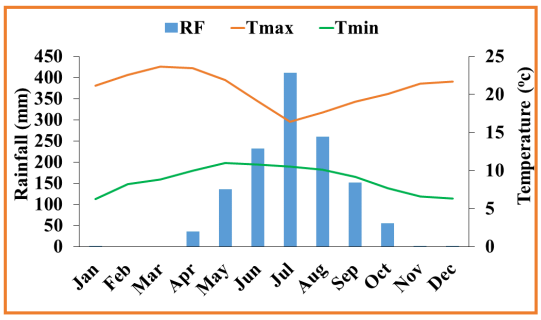


Fig. 3. Climate conditions of Debark at 2020 cropping season
Source: Ethiopia Meteorological Agency

C. Treatments and Experimental Design

The treatments consisted of factorial combinations of four levels of N (69, 92, 115, and 138 kg ha^{-1}) and three levels of P_2O_5 (23, 46, and 69 P_2O_5 kg ha^{-1}) arranged in RCBD with three replications, resulting in 12 treatments. Each plot consisted of 15 rows, which were 20 cm apart, and the gross plot size was 3 m in length and 3 m in width (9 m2). The harvestable size was 7.8 m^2 because one row was excluded on each plot to minimize border effects. Urea (NH4)2CO3 and triple super phosphate (TSP) were used as the source of N and P fertilizers, respectively.

D. Land Preparation and Experimental Procedure

The experimental field was prepared based on the conventional tillage practice of the area. It was manually leveled and then divided into blocks and plots; the blocks, plots, and rows were separated by 1.5 m, 1 m, and 0.2 m, respectively. The full dose of TSP fertilizer was applied during sowing, while urea was applied in the split as a 1/3 urea (i.e., as per treatment) was applied uniformly in rows at planting. The remaining 2/3 of each nitrogen fertilizer treatment was side-dressed after 45 days from sowing. The selected wheat variety (Alidero) seeds were sown manually at equal spacing between rows with a seed rate of 150 kg ha-1 and depth (3-5 cm) midway on the row and slightly covered by soil. The weeds observed in the plots were controlled manually at the same time for all treatments during the growth period of wheat. All other typical agronomic practices of the area were performed uniformly on all plots. Harvesting for the experiment was done by hand using a sickle, and threshing was also executed manually by labor.

E. Soil Sampling, Preparation and Analysis Methods

Before planting, soil samples were taken from up to 20 cm around the entire field. Using a zigzag sampling technique, 15 subsamples from each experimental site were combined to create the composite samples. Following standard procedure, Gondar Soil Laboratory examined the prepared and collected samples for texture, pH, organic carbon, total nitrogen, available P, and Cation exchange capacity (EEC). To prevent N volatilization losses, collected samples were dried for five days in the shade. Clods and broad aggregates were crushed and mixed after the samples were dried. Then the crushed material was further ground using a pestle and mortar

to pass a 2 mm sieve. The sedimentation technique was used to determine soil texture [8]. Determination of soil pH was done using the potentiometric method to determine the pH of the soil [9]. The Walkley-Black extraction and titration method was used to analyze the SOC content [10]. The total N in the soil (%) was determined by the Micro-Kjeldahl digestion method [11]. The Olsen extraction approach was used to analyze Ava. P [12] and measured by a spectrophotometer. CEC was assessed following soil saturation with ammonium acetate (NH4OAC) and displacement using NaOAC [13].

F. Data Collection

Plant Height (cm): Upon reaching maturity, ten plants were randomly selected from the central rows. Their heights were measured from the base of the plant to the tip of the spike using a meter tape. The average of these measurements was then calculated and recorded as the plant's height.

Spike Length (cm): At maturity, ten plants were randomly chosen from the central rows, and the length of their spikes was measured from the base to the tip of the spike using a meter tape. The average of these measurements was determined and used as the spike length for a plant.

Thousand-Grain Weight (g): A random sample of 1,000 grains was taken from each treatment once the grain reached a moisture level of 12%. The weight of these grains was then carefully measured using a highly sensitive balance.

Above-Ground Dry Biomass (t ha^{-1}): At maturity, the thirteen central rows of plants were harvested and placed into sacks. These were dried under the sun until completely dry, after which their weight was determined using a sensitive balance. This weight was then converted into tons per hectare (t ha-1).

Grain Yield (t ha^{-1}): The sun-dried biomass was threshed within the sacks using sticks to separate the grains. After cleaning, only the grain weight was recorded, and this measurement was subsequently converted into tons per hectare (t ha-1) to determine the grain yield.

Straw Yield (t ha^{-1}): The straw yield was measured after threshing and measuring the grain yield by subtracting the grain yield from the dry biomass yield.

G. Data analysis

The analysis of crop yield and related traits was conducted using analysis of variance (ANOVA) using the R software, following the statistical procedures. To compare the mean values of wheat yield and crop responses obtained from different nitrogen-phosphorus (NP) application rates, the least significant difference (LSD) test was utilized.

H. Partial Budget Analysis

This study performed a partial budget analysis by considering all variable costs and benefits, such as straw and grain yield. The variable costs accounted for the expenses of fertilizers used in different combinations, as well as their application costs. Specifically, fertilizer costs were determined based on the price of DAP at 18.45 ETB per kg and Urea at 14.5 ETB per kg. The application cost was fixed at 90 ETB for every 100 kg of fertilizer applied. Furthermore, the analysis incorporated the average market prices of straw and wheat grain yields at the time of harvest in the study district, which were set at 20 and 3.21 ETB per kg, respectively.

TABLE I. PHYSIOCHEMICAL SOIL PROPERTIES OF STUDY SITES

Location	**Site 1**	**Site 2**	**Site 3**	**Site 4**
pH (H2O)	6.44	6	6.25	5.65
OC (%)	1.69	2.2	2.09	2.28
Total N (%)	0.18	0.24	0.25	0.22
Ava. P (ppm)	5.45	21.45	7.61	9.77
CEC(cmol kg-1)	45.24	41.62	47.62	35.29
Exch. K+(cmol kg-1)	0.32	0.5	0.31	0.35
Sand	32	36	34	24
Silt	35.3	25.3	37.3	43.3
Clay	32.7	38.7	28.7	32.7
Textural class	Clay loam	Clay loam	Clay loam	Clay loam

III. RESULTS AND DISCUSSION

A. Soil Properties of the Experimental Sites Before Sowing

The soil texture in the study area is primarily characterized by a dominance of clay particles, classifying it as clay loam according to the USDA textural triangle (Table 1). This high clay content suggests the soil has a strong capacity to retain water and essential nutrients, which is advantageous for crop growth. Soil pH levels across the experimental sites were slightly acidic, ranging from 5.65 to 6.44 [14], falling within the optimal range (4–9) for most crops [15]. However, despite favorable pH conditions, the soil exhibited very low organic matter (OM) content (1.69–2.28%) and low available phosphorus (P) levels (5.45–11.45 ppm), as determined by [16]. Notably, total nitrogen (N) levels were relatively low (0.18–0.25%), indicating a potential imbalance in nutrient availability. The low P content, despite pH levels conducive to P solubility, suggests inherent phosphorus deficiency in the soil, likely due to natural geological factors rather than acidity constraints. Collectively, these properties—combined with the clay loam texture and suitable pH—indicate that the soil is generally well-suited for wheat cultivation, though targeted fertilization strategies may be necessary to address P and OM limitations for optimal productivity.

B. Growth Parameters

1) Plant Height (cm) A two-year ANOVA analysis showed that N levels significantly affected plant height ($p < 0.05$), while P levels did not ($p > 0.05$) (Appendix Table I). However, the interaction between N and P had a highly significant effect ($p < 0.01$), indicating a synergistic impact on wheat plant height. The highest plant height (105.89 cm) was recorded when N was applied at a rate of 138 kg ha^{-1} in combination with applied at 23 kg P_2O_5 ha^{-1}. In contrast, the shortest plant height (87.07 cm) was observed when nitrogen was applied at a lower rate of 69 kg ha^{-1}, paired with the same phosphorus rate of 23 kg P_2O_5 ha^{-1} (Appendix Table II). These findings highlight the importance of optimizing N application rates for achieving maximum plant height in wheat, particularly when combined with an appropriate level of phosphorus fertilization. This could likely be attributed to the fact that nitrogen supply enhances

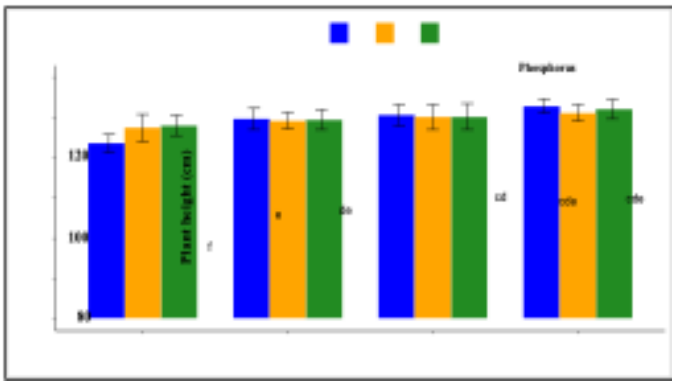


Fig. 4. Interaction effect of NP Fertilizer rate on plant height of bread wheat at Debark

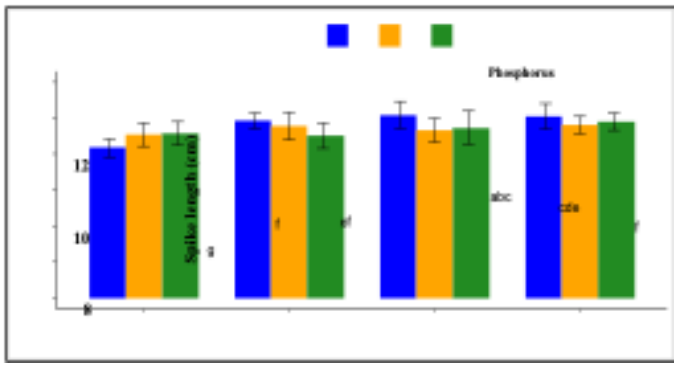


Fig. 5. Interaction effect of nitrogen and phosphorus fertilizer rate on spike length of bread wheat at Debark

photosynthetic activities, promoting more vigorous growth in plants [17]. Similarly, phosphorus plays a crucial role in influencing dry matter yield and various plant characteristics, such as plant height, the number of leaves, and leaf area [18]. Ref [19] reported a significant increase in the plant height of wheat with the application of nitrogen (N). Additionally, adequate phosphorus (P) plays a crucial role in enhancing various physiological processes, including the fundamental mechanisms of photosynthesis, which directly contribute to plant growth [20]. These findings are consistent with the results reported by [21, 22], who observed that plant height increased significantly with the combined application of nitrogen and phosphorus (NP). This highlights the synergistic effect of N and P in promoting wheat growth. Likewise, [23] found a similar result.

2) Spike Length (cm) The results of the combined ANOVA showed that the main effects of nitrogen (N) and phosphorus (P) fertilizer levels had a highly significant ($p < 0.001$) and significant ($p < 0.05$) effect, respectively, on the spike length of wheat. Furthermore, the interaction between these two factors was also found to be highly significant ($p < 0.001$) (Appendix Table I). The maximum spike length of 10.19 cm was achieved with the use of 115 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1}, while the minimum spike length of 8.36 cm was observed in the plot treated with 69 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} (Appendix Table II). This could likely be attributed to the release of sufficient nitrogenous compounds, primarily nitrates and ammonium that are easily absorbed by vascular plants. The nitrogen uptake promotes spike length increase by stimulating stem elongation through enhanced cell division and expansion [24]. These results indicated that the application of P fertilizer alone does not significantly influence the spike length of wheat. Consistent with these findings, [25] reported that the optimal application of both N and P fertilizers plays a significant role in promoting spike length growth. The findings of this study are consistent with the results reported by [26], who demonstrated that the combined application of N and P fertilizers resulted in the longest spike length in wheat plants. This suggests that the synergistic effect of both nutrients is crucial for optimizing spike development, as opposed to the application of either nutrient alone. In contrast, [22] reported that non-significant differences were observed in spike length due to N.

C. Yield and Yield Related Traits

1) Thousand seed weight (g) The analysis of variance revealed that thousand-seed weight was significantly influenced by nitrogen rates ($p < 0.01$), while the interaction between nitrogen and phosphorus fertilizers had no significant effect (Appendix Table I). The maximum thousand seed weight (39.6 g) was observed at a nitrogen application rate of 138 kg N ha^{-1}, which was not significantly different from the thousand seed weight at 92 kg N ha^{-1}. The minimum thousand-seed weight (37.24 g) was recorded at 69 kg N ha^{-1} (Appendix Table III). Moreover, the findings revealed a positive relationship between nitrogen application and the weight of a thousand seeds, indicating that higher nitrogen levels led to larger seeds, which could improve both grain yield and quality. The present findings are consistent with those reported by [27], who observed that the maximum thousand-seed weight was achieved at a nitrogen application rate of 138 kg N ha^{-1}. This suggests that optimal nitrogen levels play a crucial role in enhancing thousand-seed weight. Similarly, this result is in line with [28], who reported that when N -level application increases, there is a positive impact on the yield component of wheat crop, especially on 1000 seed weight. The current results contradict those of [22], who reported that the application of N and P fertilizers, as well as their interaction, had no significant influence on the thousand kernel weight.

2) Grain Yield (t ha^{-1}) The analysis of variance revealed that the main effects of phosphorus and nitrogen, as well as their interaction, had significant effects on the grain yield of bread wheat ($p < 0.05$). In addition, the site × nitrogen (Site × N) interaction was highly significant ($p < 0.001$) (Appendix Table I).The highest grain yield (4.8 t ha^{-1}) was obtained from the combined application of 138 kg N and 46 kg P_2O_5 ha^{-1}. The result indicated that this nutrient combination appears to have optimized the growth and productivity of the crop, leading to significantly higher yields. In contrast, the lowest (2.48 t ha^{-1}) was recorded from the plot that received 69 kg N

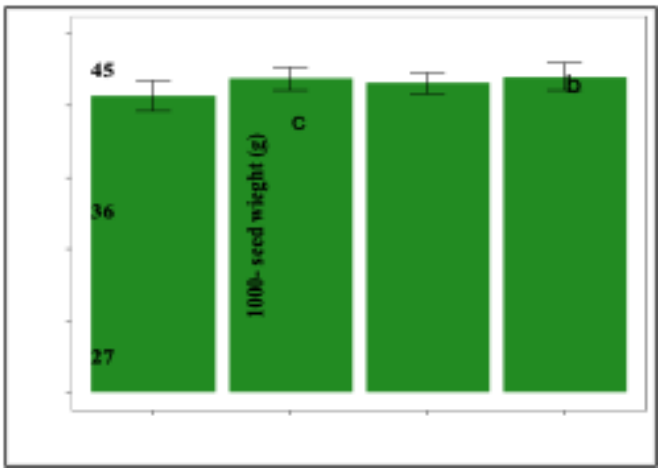


Fig. 6. Main effect of nitrogen fertilizer rate on thousand seed weight of bread wheat.

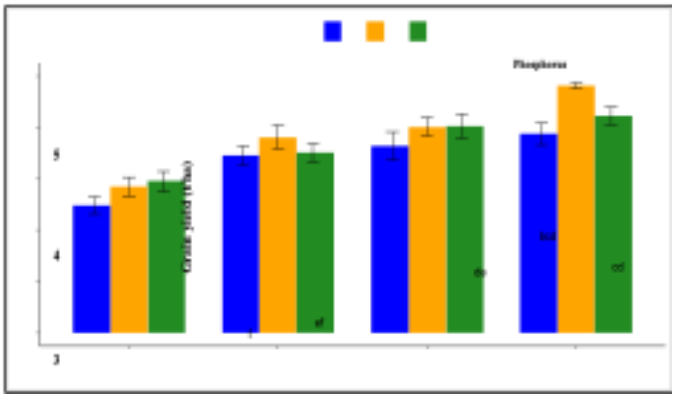


Fig. 7. Interaction effect of nitrogen and phosphorus fertilizer rate on grain yield of bread wheat at Debark

ha-1 and 23 kg P_2O_5 ha^{-1} (Appendix Table II). It was visually observed that wheat plants in plots with the lowest NP levels were slender, with small spikes, short height, and pale color. Conversely, plants in the fertilized plots, particularly those with the highest NP levels, displayed thick, strong stems, a vibrant green hue, and noticeably larger spikes. This finding is nearly similar to [26], who reported that applying 92 kg N ha^{-1} in combination with 200 kg P ha^{-1} resulted in the maximum grain yield (6832 kg ha^{-1}). Similarly, the highest grain yield (5182 kg ha^{-1}) was obtained from the maximum application of 270/52.5 kg N/P ha^{-1}, while the lowest yield was obtained at the lowest NP rate [29]. Correspondingly, fertilizer applications of 138–46 kg N–P_2O_5 ha^{-1} at Farta and 123–46 kg N–P_2O_5 ha^{-1} at Laie-Gaient in northwestern Ethiopia were found to be economically viable, with bread wheat grain yield consistently increasing as NP application reached the highest levels [30]. Likewise, on-farm trials conducted in the mid-highland Vertisol districts of the Arsi zone indicated that applying 92–46 kg N–P_2O_5 ha^{-1} resulted in optimal bread wheat yield, achieving an agronomic efficiency (AE) of 13.3 kg of grain per kg of applied nitrogen [27].

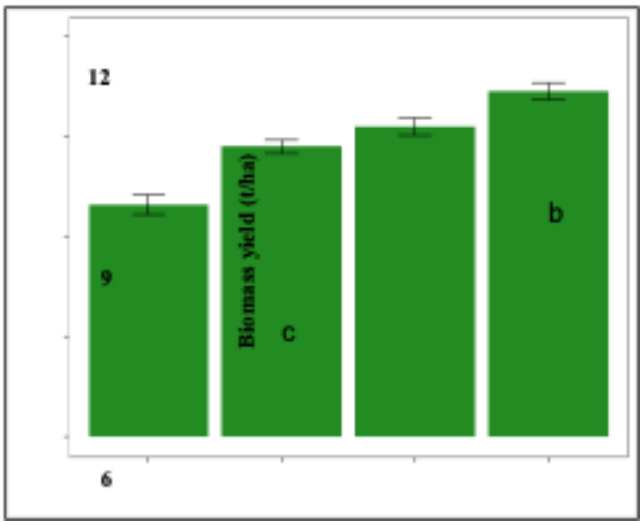


Fig. 8. Main effect of nitrogen fertilizer rate on aboveground biomass yield of bread wheat.

3) Aboveground Biomass (t ha^{-1}) The biomass yield was significantly influenced by the main effect of nitrogen (N) levels and site × N interaction ($p < 0.01$), while neither the main effects of phosphorus (P) fertilizer rates nor their interaction with N and site × P interaction had a significant impact on biomass production (Appendix Table I). The findings revealed that biomass yield increased as N levels rose. It indicating that the critical role nitrogen plays in determining the biomass yield of the crop being studied. The highest biomass yield (10.36 t ha^{-1}) was achieved at the maximum nitrogen application rate (138 kg N ha^{-1}), whereas the lowest biomass yield (6.97 t ha^{-1}) occurred at the minimum nitrogen level (69 kg N ha^{-1}) (Appendix Table III). The increase in biological yield at the highest nitrogen rates may be attributed to an adequate nitrogen supply, which promotes vegetative growth in wheat plants by enhancing leaf area and leaf area index. This leads to improved light interception, resulting in greater total dry matter production at different growth stages [31]. These findings align with those of [21, 22], who reported the highest biological yield from plots receiving the maximum nitrogen levels. The highest biomass yield of 21,100 kg ha^{-1} was achieved in plots receiving nitrogen fertilizer at a rate of 184 kg ha^{-1}, indicating that biomass yield increased with higher nitrogen application rates [32]. Similarly, a study by [33] found that biomass yield rose with increasing nitrogen levels, with the maximum yield of 10,818 kg ha^{-1} recorded at a nitrogen application rate of 92 kg ha^{-1}, while the lowest yield of 7,388.1 kg ha^{-1} was observed in the control plots where no nitrogen was applied.

4) Straw Yield (t ha^{-1}) Biological yield holds particular importance for farmers, as they prioritize not only grain but also straw production. In highland regions, wheat straw is especially valuable, serving dual purposes as livestock feed and a means of nutrient cycling to sustain soil fertility.

The ANOVA results indicated that the straw yield of wheat was highly significantly ($p<0.01$) affected by the main

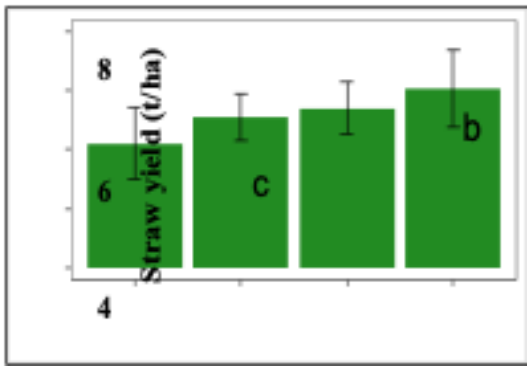


Fig. 9. Main effect of nitrogen fertilizer rate on straw yield of bread wheat.

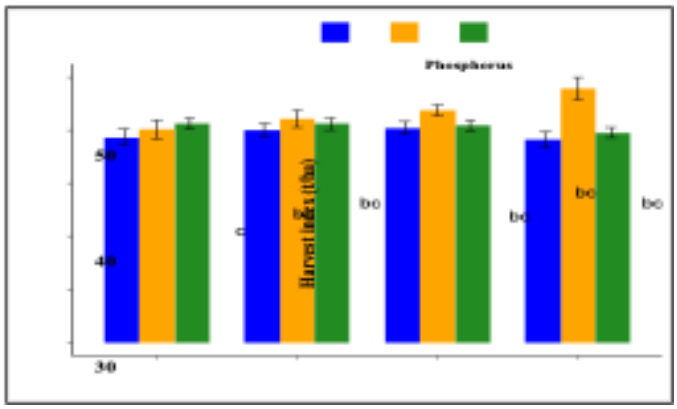


Fig. 10. Interaction effect of nitrogen and phosphorus fertilizer rate on harvest index of bread wheat at Debark

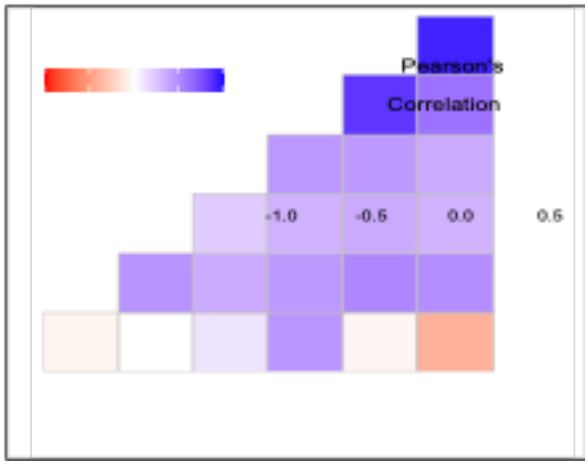


Fig. 11. Pearson correlation coefficients of the main characters of bread wheat.

effects of N and site × N interaction whereas the main effects P, site × P and N×P interaction had no significant effect (Appendix Table I). The greatest straw yield, measuring 6.08 t ha^{-1}, was achieved in plots fertilized with 138 kg N ha^{-1}. This significant yield highlights the positive impact of optimal nitrogen supplementation on crop productivity. In contrast, the lowest straw yield, at 4.21 t ha^{-1}, was recorded in the plot, which received 69 kg N ha^{-1}, demonstrating the limitations in straw yield potential when nitrogen levels are suboptimal (Appendix Table III). The result showed that increasing nitrogen fertilizer from 69 to 138 kg/ha resulted in a significant and consistent rise in straw yield, demonstrating the crucial role of optimal nitrogen in enhancing crop productivity and vegetative growth. Similarly, research by [34] indicated that straw yield increased as nitrogen application rates rose, with the lowest yield observed in control plots (6,991.8 kg ha^{-1}) and the highest yield recorded in plots receiving 184 kg N ha^{-1} (7,735.5 kg ha^{-1}). Additionally, [32] reported that applying 92 kg ha^{-1} to durum wheat plants resulted in a maximum straw yield of 8000 kg ha^{-1}, representing an 88% increase compared to untreated control plots. Research by [35] indicated that nitrogen fertilizer significantly influenced straw yield. The highest straw yield was recorded in plots treated with 69 kg N ha^{-1}, resulting in a 172.2% increase compared to the control.

5) Harvest index The analysis of variance showed that the harvest index was significantly ($p<0.05$) affected by the interaction effects of N and P fertilizer application (Appendix Table I). The highest harvest index (47.87%) was obtained from the integrated application of 138 kg N and 46 kg P_2O_5 ha^{-1}. In contrast, the lowest (38.32%) was recorded from the plot that received 138 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} (Appendix Table II). This result indicates that insufficient phosphorus application can limit the efficiency of nitrogen utilization and reduce the crop's ability to convert biomass into grain yield. The findings of this study are consistent with the results reported by [36], who observed that balanced NP fertilization significantly increases grain yield and often improves harvest index compared with unfertilized or single-nutrient treatments. Similarly, [37] demonstrated that the application of NPK fertilizer enhances the yield components of wheat, particularly in terms of the harvest index and grain yield.

D. Correlation Analysis

Bread wheat yield and its related characteristics showed a significant ($p\leq0.001$) positive, negative, and linear connection (Figure 11). The findings revealed a substantial positive association between grain yield and plant height (r=0.44***), spike length (r=0.33***), harvest index (r=0.46***), biomass yield (0.86***), thousand seed weight (r=0.45***), and straw yield (r=0.65***). This shows that when the thousand-seed weight and spike length grow, grain yield increases dramatically. This is due to a significant increase in grain output as a result of improved vegetative growth, increased reproductive development, and more efficient nutrient and resource utilization. Key characteristics such as spike length and thousand-seed weight are critical for maximizing the plant's grain yield. Furthermore, plant height (r=-0.05ns) and aboveground biomass (r=-0.05ns) revealed a negative and non-significant relationship with the harvest index in bread wheat. Furthermore, plant height, spike length, aboveground biomass, and grain production all demonstrated a positive and significant relationship with straw yield.

E. Partial budget analysis

According to the partial budget analysis (Table II), the treatment with 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} had

TABLE II. PARTIAL BUDGET ANALYSIS OF BREAD WHEAT

TRT (N/P kg ha^{-1})	AGY (kg ha^{-1})	AST (kg ha^{-1})	TVC (Birr)	TB (Birr)	NB (Birr)	DA	MRR (%)
69/23	2234	3660	3215	56457	53242		
92/23	3107	4658	3965	77675	73710		2729.07
69/46	2566	3921	4180	64288	60108	D	
92/46	3425	4676	4930	84690	79760		2620.27
69/69	2652	3800	5145	65943	60798	D	
115/23	3280	4747	5465	81648	76183		4807.81
92/69	3155	4485	5895	78385	72490	D	
138/23	3481	5614	6215	87805	81590		2843.75
115/46	3606	4620	6430	88572	82142		256.744
138/46	4328	4912	7180	105047	97867		2096.67
115/69	3623	5216	7395	90127	82732	D	
138/69	3803	5846	8145	95346	87201		595.867

NB: Adjusted Grain Yield (AGY), Adjusted Straw Yield (ASY), Total Variable Cost (TVC), Total Benefit (TB), Net Benefit (NB), Dominance Analysis (DA), Marginal Rate of Return (MRR)

the largest net benefit of 97867 birr ha^{-1}. In contrast, the treatment fertilized with 69 kg N ha^{-1} and 23 kg P_2O_5 ha^{-1} had the lowest net benefits of 53247 birr ha^{-1}. The minimal acceptable rate of return (MRR) for a treatment to be regarded as worthy by farmers is between 50 and 100% [38]. The maximum MRR (1687%) in this case was achieved using 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}. Other treatments showed MRRs more than 100%, although they were much lower than the 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} rates. As a result, applying 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} is profitable and suggested for farmers in Debark and other locations with comparable agroecological circumstances. Despite these findings, additional research should be undertaken across diverse locations and agroecological conditions to evaluate the applicability and consistency of the results.

IV. CONCLUSSION AND RECOMMENDATION

Based on the findings of this study, the integrated application of 138 kg nitrogen (N) per hectare and 46 kg phosphorus (P_2O_5) per hectare emerges as an optimal and economically viable fertilizer treatment. This advice is based on the crucial relevance of increasing grain and biological yields, which have a direct impact on farmers' economic returns and agricultural production. The partial budget analysis performed as part of this study further confirms this fertilizer mixture, indicating its capacity to increase profitability by balancing input costs with yield improvements. However, it is critical to recognize that regional differences in soil qualities, meteorological circumstances, and crop management approaches may limit the general validity of these results. As a result, while the recommended rates appear promising under the evaluated conditions, more study across various agro-ecological zones and agricultural systems is required to refine and generalize these suggestions. Such studies should also look at the long-term effects on soil health and environmental sustainability to ensure that the recommended approaches are consistent with larger ecological and agronomic aims.

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