Soil type and fertilizer rate affects wheat (*Triticum aestivum* L.) yield and nutrient use efficiency in Ayiba, northern Ethiopia

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Soil fertility depletion is among the most important cause for declining crop yields in the Ethiopian highlands. Bread wheat (*Triticum aestivum*) is the most important staple crop, but yield levels are woefully low, with the national average of 2.9 t ha^{-1}. The blanket approach of fertilizer recommendation over the past five decades did not bring a significant change on crop productivity. Accordingly, a new fertilization approach for soils was very much needed, and with this premise, currently, blended fertilizers are introduced to substitute conventional inputs. Here, we examine the effect of NPSZnB blended fertilizer on bread wheat yield, quality traits and use efficiency in two soil types under rainfed conditions in Ayiba, northern Ethiopia. Treatments were a factorial combination of two soil types (Vertisol and Cambisol) and eight rates of fertilizers (0, 50, 75, 100, 125, 150, 175 kg NPSZnB ha^{-1} and 100/100 kg Urea/DAP ha^{-1}). The field experiment in each soil type was laid out in a Randomized Complete Block Design (RCBD) replicated three times. Relevant agronomic data were recorded from each plot for analysis. The two seasons pooled data analysis of variance revealed a significant ($p<0.001$) variation on all the agronomic and grain quality traits due to the main and interaction effects of soil type and fertilizer treatment factors. Most agronomic and quality characteristics recorded the highest result in the highest treatment applications (175 and 150 kg NPSZnB ha^{-1}) in both soils. Yield and grain quality traits of bread wheat were also found better under fertilized plots than control. In both soil types increasing application of the new blended fertilizer rate from 50-175 kg NPSZnB ha^{-1} showed an increasing trend in grain yield from 1.6 to 4.3 and 2.5 to 5.4 t ha^{-1} in Vertisol and Cambisol soils, respectively. This result demonstrated differences in response to NPSZnB blended fertilizer across soils, indicating that soil-specific fertilization is vital for enhancing productivity. Based on the partial budget analysis, the highest net benefit with the highest marginal rate of return was obtained in Vertisol plots treated with 100 kg NPSZnB ha^{-1} and in Cambisol plot treated with 125 kg NPSZnB ha^{-1}, respectively. Therefore, we conclude that to produce optimum bread wheat yield under rainfed conditions in Ayiba: fertilizing Vertisol with 100 kg NPSZnB ha^{-1} and fertilizing Cambisol with 125 kg NPSZnB ha^{-1} is recommended.

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ABSTRACT

Soil fertility depletion is among the most important cause for declining crop yields in the Ethiopian highlands. Bread wheat (Triticum aestivum) is the most important staple crop, but yield levels are woefully low, with the national average of 2.9 t ha^{-1}. The blanket approach of fertilizer recommendation over the past five decades did not bring a significant change on crop productivity. Accordingly, a new fertilization approach for soils was very much needed, and with this premise, currently, blended fertilizers are introduced to substitute conventional inputs. Here, we examine the effect of NPSZnB blended fertilizer on bread wheat yield, quality traits and use efficiency in two soil types under rainfed conditions in Ayiba, northern Ethiopia. Treatments were a factorial combination of two soil types (Vertisol and Cambisol) and eight rates of fertilizers (0, 50, 75, 100, 125, 150, 175 kg NPSZnB ha^{-1} and 100/100 kg Urea/DAP ha^{-1}). The field experiment in each soil type was laid out in a Randomized Complete Block Design (RCBD) replicated three times. Relevant agronomic data were recorded from each plot for analysis. The two seasons pooled data analysis of variance revealed a significant ($p<0.001$) variation on all the agronomic and grain quality traits due to the main and interaction effects of soil type and fertilizer treatment factors. Most agronomic and quality characteristics recorded the highest result in the highest treatment applications (175 and 150 kg NPSZnB ha^{-1}) in both soils. Yield and grain quality traits of bread wheat were also found better under fertilized plots than control. In both soil types increasing application of the new blended fertilizer rate from 50-175 kg NPSZnB ha^{-1} showed an increasing trend in grain yield from 1.6 to 4.3 and 2.5 to 5.4 t ha^{-1} in Vertisol and Cambisol soils, respectively. This result demonstrated differences in response to NPSZnB blended fertilizer across soils, indicating that soil-specific fertilization is vital for enhancing productivity. Based on the partial budget analysis, the highest net benefit with the highest marginal rate of return was obtained in Vertisol plots treated with 100 kg NPSZnB ha^{-1} and in Cambisol plot treated with 125 kg NPSZnB ha^{-1}, respectively. Therefore, we conclude that to produce optimum bread wheat yield under rainfed conditions in Ayiba: fertilizing Vertisol with 100 kg NPSZnB ha^{-1} and fertilizing Cambisol with 125 kg NPSZnB ha^{-1} is recommended.

Key Words: *Blanket application, grain quality, Kingbird wheat variety, NPSZnB Blended fertilizer, nutrient use efficiency, Yield*

1. INTRODUCTION

Ethiopia is one of the countries where agricultural sector is the chief source of livelihood (Elias, 2016). Crop production contributes approximately 28% to the nation's GDP (NBE, 2019). Cereals are the primary staple crops in terms of cultivated area (81.46%) and production volume (88.52%) within the crop sector. Bread wheat (*Triticum aestivum*) is one of the major cereals, along with maize (*Zea mays*), teff (*Eragrostis teff Zucc*), barley (*Hordeum vulgare*) and sorghum (*Sorghum bicolor*). Wheat accounts for 13.91% of the total cultivated area under cereals and 81% of the total volume of food production (CSA, 2020). Ethiopia is the largest wheat producer in sub-Saharan Africa but remains a net importer (Hodson et al., 2020). In Ethiopia, for the past five decades, research works were highly concerned and limited to fertilizer recommendation of Urea (46%N) and DAP (18%N-46%P_2O_5) as blanket application considering the only limiting nutrient of Ethiopian soils (Alemu et al., 2016; Desta and Almayehu, 2020; Elias et al., 2019; Fisseha et al., 2020). However, wheat yields are woefully low, with a national average of 2.97 t ha^{-1} under farmers conditions, while the average yield from research stations is 5.5 t ha^{-1} (Elias et al., 2019). Amongst the reasons for the low levels of wheat, yields are declining soil fertility caused by low levels of fertilizer application and soil quality deterioration (Abebe, 2021; Elias et al., 2019; Gebreselassie et al., 2016; Kiboi et al., 2021). However, stagnating productivity in Ethiopia is multi allied in the wheat-growing segments (Abera and Kassa, 2017; Elias et al., 2019; Mulugeta et al., 2017; Walsh et al., 2020).

The current national average wheat yield (2.97 t ha^{-1}) is far below the potential yield (Yp = 9.6 t ha^{-1}), the water-limited potential yield (Yw = 8.3 t ha^{-1}) (http://www.yieldgap.org/Ethiopia), and world average (4.39 t ha^{-1}) (Purdy and Langemeier, 2018). As a result, millions of households face chronic food insecurity annually, and their survival depends on relief food assistance (Elias et al., 2019; Elias and Van Beek, 2015). In addition, at present, population rising and dietary pattern shifting linked to urbanization are causing to surpasses the demand for national wheat supply (6.3 Mt demand Vs. 4.6 Mt supply). The low supply then makes the current production insufficient to meet domestic needs and forcing the country to import up to 50% to fill the gap from the Black Sea region for the last several years (Elias et al., 2019; Hodson et al., 2020; Minot et al., 2019). Although demand and production are not related yet, there is a potential to increase wheat productivity with proper extension support and adequate inputs (Habte et al., 2020; MoA, 2019). Consequently, the government recently declared to narrow the yield gap (van Ittersum et al., 2013) and reduce wheat import from 1.7 million metric tons in 2019 to zero in

2023 (MoA, 2019). Thus, increasing domestic wheat production is a national primacy for becoming self-sufficient (Simret, 2019). The government envisioned achieving this goal by acid soil and Vertisols management, intensification, expanded use of irrigation, and mechanization with private sector partnership (Getachew, 2020). Moreover, to achieve this goal, it will be imperative to apply balanced amounts of the most limiting essential nutrients to obtain the highest yield while minimizing nutrient losses, that is, when fertilization is fine-tuned to local soil chemical conditions and crop requirements (Elias et al., 2019; Roy et al., 2006).

The problem with fertilization indicated that the need for great potential to include deficient essential minerals in the fertilizing practice. By doing so it is possible to increase the nutrient use efficiency and possibly intensify the yield by considering all essential plant nutrients in the fertilizer sources and fertilization strategies (Bindraban et al., 2015; Dimkpa and Bindraban, 2016). Micronutrients like boron, iron, manganese, zinc, and copper, although required in small quantities, are essential for plant health and growth (Waqeel and Khan, 2022). Currently, soil scientists noted that problem of undernourishment starts from not feeding the soil, which continues to devastate many populations by the ‘hidden hunger’ of essential minerals and vitamins (Shekhar, 2013; von Grebmer et al., 2014), which is very common and chronic in Sub-Saharan Africa (SSA) countries due to socioeconomic and geospatial setting reasons (Gashu et al., 2021).

The complex interplay between the local environment and locally relevant crops makes soil testing and critically soil-test-based recommendations site-specific (Kedir et al., 2021). The blanket recommendation mentioned earlier often fails to consider differences in resource endowment (soil type, labor capacity, climate risk) or allow dramatic changes in input/output price ratio, thereby discouraging farmers from fertilizer application. Likewise, studies confirmed that the blanket reference nutrients were not well balanced agronomical, and their continued use was also gradually exhausting soil nutrient reserves (Elias, 2016; Elias and Van Beek, 2015; Tewolde et al., 2020). Other studies also revealed that different plant species respond differently to fertilizer rates and combinations in different soil types and require balanced fertilizers to maximize growth, yield, quality, and efficiency (Akamine et al., 2007; Chowdhury et al., 2008). Hence, soil test-based application of fertilizer rather than a blanket recommendation, especially those blended with S, B, Zn, and other nutrients, is recommended in averting problems caused due to nutrient-deficient soil (ATA, 2016). Studies from different parts of the country also confirmed major grain crops' positive responses to blended fertilizer application instead of using NP alone (Desta and Almayehu, 2020; Fayera et al., 2014; Li et al., 2019; Tesfay and Gebresamuel, 2016), as the absence of one or more nutrients besides NP can depress yield significantly. Accordingly, Ethiopia currently launches a strategy to use different blended fertilizer sources to curb the productivity constraints and become self-sufficient in crop production (ATA, 2016).

As reported by EthioSIS (2017), the Emba Alaje district (Fig. 1), where our study site - Ayiba - is part, requires five types of blended fertilizers (Fig. 1a) plus potash fertilizer (Fig. 1b). From the five recommended lists, NPSZnB blend fertilizer has wide coverage indicated that this compound fertilizer is needed to be supplied to support production (Fig. 1a). Hence, the site-soil-specific trial's rationale is to generate fertilizer recommendations specific to the soil type of each microclimate location, based on their inherent fertility status (Elias, 2018). Finally, this site-specific management optimizes profitability through higher crop yield and protects the environment from degradation (Teklu and Michael, 2007).

Fig. 1. (a) List of recommended blended fertilizer types, and (b) recommended potash fertilizer for Emba-Alaje district, including the study area (015: Ayiba) (EthioSIS, 2017).

Balanced fertilization is necessary to sustain crop productivity. Investigating the impact of the new blended fertilizer sources on different crops under different soil types is a vital theme to research in Ethiopia. Because, following the production of soil fertility atlas and new blended fertilization system, information is still lacking on site-soil-specific to recommend the optimum rates of the blended fertilizers for different crop-specific. Thus, to the best of our knowledge, the effect of different NPSZnB blended fertilizer rates on bread wheat productivity in different soil types is not yet investigated in the Ayiba highland, where we have used it as a case study. Hence, a field experiment was conducted under the rainfed condition to respond to the following questions: (i) how the selected test crop responds to the increasing rate of NPSZnB blended fertilizer in Vertisol and Cambisol soil types?, and (ii) what looks the NPSZnB blended fertilizer comparative advantage against the conventional NP recommendation in both soils. The finding will guide farmers of the area to strategically implement fertilizer sources in areas with heterogeneous soil types. It will amplify also the achievement of SDGs 1 and 2 of hunger and poverty eradication. This research, therefore, seeks to assess the following objectives: (a) to explore how soil type affects bread wheat yield and grain quality response to NPSZnB blended fertilizer application; (b) to determine and recommend optimum rate of NPSZnB blended rate for wheat production on different soil types of Ayiba under rainfed condition.

2. MATERIALS AND METHODS

2.1. Site description: location, climate, soil and husbandry

The study was conducted in farmers' fields in the Ayiba watershed (4099.14 ha) of Emba-Alaje district, southern Tigray, northern Ethiopia. Geographically the area lies between 12°51′18″–12°54′36″N and 39°29′24″–39°35′24″E. The altitude ranges from 2722 to 3944 meters above sea level. The area is among the potential wheat-producing regions in Tigray furnished with tepid to cool semi-arid agro-ecological zone (Amanuel et al., 2015; Elias, 2016; Negash and Israel, 2017). The total amounts of rainfall received during the 2017 and 2018 cropping seasons were 417 and 479 mm, respectively (Mesfin et al., 2020). The mean minimum and maximum temperatures were 12.6 and 23.3ºC for the 2017 cropping season and 11.6 and 22.3ºC for the 2018 cropping season, respectively (Mesfin et al., 2020). The area's annual potential evapotranspiration (PET) is about 1411 mm (Elias, 2016).

In the study area, volcanic trap-rocks are common parent materials, having mainly a basalt lithology, on which Vertisols, Cambisols, Regosols, and Leptosols have been developed (Amanuel et al., 2015; Elias, 2016) with dominant clay texture mostly developed from fluvial and alluvial sediments (Table 1). The soil nutritional characteristics of the studied topsoil are presented in Table 3. The main farming system is mixed farming (Seifu et al., 2021). Major crops such as sorghum (*Sorghum bicolor*), teff (*Eragrostis teff*), maize (*Zea mays*), wheat (*Triticum* spp.), barley (*Hordeum* spp.), faba-bean (*Vicia faba* L.), field pea (*Pisum sativum* L.), Dekeko (*Pisum sativum* var. *abyssinicum*), linseed (*Linum usitatissimum*), and some other vegetables and fruits like an onion (*Allium cepa*), pepper (*Piper nigrum*), cabbage (*Brassica oleracea*) (Girmay et al., 2014) and apple (*Malus Domestica* L.) are grown in the study area. Natural pasture is the primary animal feed source in the area where farmers practice intensive pasture land grazing with a higher stocking rate, which leads to poor natural pastureland management (Atsbha et al., 2020).

2.2. Experimental set up: treatments, design and parameters evaluated.

The field experiments were carried out in two different soil types, viz. Vertisol and Cambisol (Table 1) to develop an optimal NPSZnB blended fertilizer application rate for bread wheat productivity. The experimental treatment included eight levels of fertilizers: (T_1) control (no fertilizer), (T_2) Urea + DAP (each 100 kg ha^{-1}) and ($T_{3\text{-}8}$) Six NPSZnB blended fertilizer rates (50, 75, 100, 125, 150, and 175 kg ha^{-1}) (Table 2) which were laid out under Randomized Complete Block Design (RCBD) having three replications. The blanket NP fertilizer application was included in this field experiment as a positive control for comparison. The intention is to substitute the traditional experience with the new NPSZnB blended fertilizer. Each block consisted of eight plots measuring 3 × 3 m with 1 m between blocks and 0.5 m between plots. The experimental fields were maintained with 15 rows, each spaced with 0.2 m (CIMMYT, 2013). All agronomic practices were kept uniform for all treatments per the specific recommendation for bread wheat cultivation (EIAR, 2007). Before sowing whole doses of NPSZnB, DAP and KCl fertilizers were applied as basal fertilizers. At the same time, urea was applied in a split method as 60% was used as a basal dressing at sowing. The remaining 40% applied as a top-dressing one month after the day of sowing and after weeding with optimum moisture condition or after rain. Wheat seed was used at the rate of 125 kg ha^{-1} and sowing was done using hand drill under rainfed semi-arid cool conditions.

Bread wheat variety *King-bird* (ETBW 8512) was used as a test crop. The variety was selected based on its early maturity and yield performance, good bread-making quality, multi-disease resistance attribute, and adaptability to broad agro-ecological conditions (low to mid-altitude) (BGRI, 2015; CIMMYT, 2015). Seed and fertilizers were bought from the farmers' cooperative union of Ayiba. Finally, the following yield and quality parameters were evaluated: *Total tillers (TT) and productive tiller (PT), number of kernels per spike (NKS), thousand kernel weight (TKW), grain yield (GY), straw yield (SY), Biological yield (BY), harvest index (HI), grain protein content (GPC), and hectoliter weight (HLW).* The agronomic data were collected based on the national standard (Abera et al., 2020a). The GPC and HLW parameters were determined by AACC methods of 46-11.02 and 55.10.01, respectively (AACC International, 2002).

Table 1. Information on on-farm experimental fields.

Table 2. The nutrient share of each element in each treatment.

2.3. ***Soil sampling and analysis***

Before starting the experiment, soil samples from topsoil (0-30 cm) were taken using the grid sampling technique from the study farms. They were bulked together, air-dried and sieved using a 2-mm sieve and their physical and chemical characteristics were determined. A total of 18 soil samples (i.e., 9 augers x 2 soil types) were collected from the experimental blocks of each soil type using an auger. Samples for each soil type were thoroughly mixed. A kilogram of the composited sample through the quartering process (Abera et al., 2020a) was taken from each soil type for laboratory analysis.

A hydrometer was used to determine soil texture (Bouyoucos, 1962). Textural class, field capacity (FC), permanent wilting point (PWP), and saturation percentage were estimated using SPAW-hydrology software (USDA-NRCS, 2013) based on the soil texture result. Plant available water capacity (AWC) was determined as the difference between FC and PWP (Estefan et al., 2013). A combined glass electrode was used to measured soil pH and electric conductivity (EC) in a suspension of soil and deionized water (1:2.5 w/v) (Mclean, 1983; Rhoades, 1996). Soil organic carbon was estimated following the Walkley-Black method (Estefan et al., 2013). Total N was determined by the micro-Kjeldahl digestion method (Bremner, 1996). Available phosphorus (AP) was determined following the Olsen extraction method (Olsen and Sommers, 1982). Mehlich 3 extraction was used to determine bioavailable Sulfur and Boron (Mehlich, 1984). Their concentrations in soil digests were measured using Perkin Elmer Optima 8300 Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES). Soil micronutrients (Fe and Zn) were extracted with Diethylene Triamine Penta acetic Acid-triethanolamine (DTPA-TEA) method as described by Lindsay and Norvell (1978), and their concentration in the soil digests was measured using ICP-MS (Inductively Coupled Plasma mass spectroscopy; Perkin-ElmerNexion 300x). Ammonium acetate (NH_4OAC, pH-7) leaching (Ross and Ketterings, 1995) was used to estimate cation exchange capacity (CEC). Laboratory works were done at Tigray Soil Laboratory Centre, Mekelle (Ethiopia), Plant Nutrition Laboratory, College of Environmental Science Resources, Zhejiang University, Hangzhou (China).

2.4. Nutrient use efficiency

Nutrient use efficiency (NUE) is a critically important concept in the evaluation of crop production systems. The objective of nutrient use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses from the field (Fixen et al., 2015). Two indicators were used to evaluate nutrient use efficiency (NUE) in this study: (i) Agronomic efficiency of NPSZnB (AE) and (ii) partial factor productivity of NPSZnB (PFP) were calculated (Fageria and Baligar, 2003). Agronomic efficiency (AE) and Partial factor productivity (PFP) is a valuable measure of nutrient use efficiency indices as they provide an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system (Yadav, 2003). The AE indicates the economic production obtained per unit of NPSZnB blended nutrient applied (Elias et al., 2020). The PFP, a ratio of the grain yield to the applied nutrient, is a valuable measure of nutrient-use efficiency as it provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system, including native soil nutrients and nutrients from applied fertilizers (Dobermann, 2005; Yadav, 2003). They were calculated using the following equations, respectively:

$$AE\ (\frac{kg\ grain}{kg\ NPSZnB}) = \frac{G_{NPSZnB} - G_{NP}}{Na} \qquad \text{(Eq.3)}$$

$$PFP\ (\frac{kg\ grain}{kg\ NPSZnB}) = \frac{Nn}{Na} \qquad \text{(Eq.4)}$$

Where; G_{NPSZnB} = grain yield obtained from plots fertilized with NPSZnB blended fertilizer; G_{NP} = grain yield obtained from plots fertilized with NP fertilizer (Urea and DAP); Nn = the total grain yield obtained from each treatment; and Na = the quantity of nutrients applied.

2.5. Partial budget and marginal rate of return analysis

Partial budget analysis was computed using the CIMMYT (1988) procedure to determine the economic feasibility of NPSZnB blended fertilizer for optimal bread wheat productivity under rainfed conditions in Ayiba soils. The 10% down adjusted grain and straw yield data were used with local filed prices of 13.5 and 3.5 ETB kg^{-1}, respectively. Marginal rate of return analysis (MRR) was executed on non-dominated treatments to pinpoint treatments with the highest return to farmer’s investment, considering MRR of 100% is realistic for the recommendation.

2.6. *Statistical analysis*

The data obtained from lab analysis were checked to test the data sets' normality with the Shapiro-Wilk normality test, and the normality assumption was not violated. All results were reported as means ± standard error (SE) for three replicates. Statistical analysis was conducted with Two-way ANOVA to obtain the effect of the model in R software (R Core Team, 2020) using package '*doebioresearch*' version 0.1.0 (Popat and Banakara, 2020). The analysis of variance used the Fisher's least significant difference (LSD) at 5% level in the *doebioresearch package* of the R programming language hosted in R studio. The Pearson's correlation coefficients were calculated between the analyzed agronomic parameters in each soil type using the R '*corrplot package*' (Wei and Simko, 2021). All bar graphs were drawn using the OriginPro software (OrginPro, version 2019b).

3. RESULT AND DISCUSSION

3.1. Pre-planting soil physicochemical analysis of the experimental fields

The result of pre-planting soil physicochemical analysis of the experimental fields (Table 3) indicated in the Vertisol and Cambisol soil types that the soil textural class was clay and neutral with pH of 7.4 and 7.3, respectively. The bulk density of the studied soils varied from 1.2 to 1.4 g $cm^{-3,}$ which was found ideal for plant growth (Hazelton and Murphy, 2016). The electrical conductivity (EC) rate in the two soils was low, indicating non-saline. According to EthioSIS rating (Karltun et al., 2013), available Boron (B) was found in a very low rate in Vertisol and optimum rate in Cambisol. Vertisol was found low in SOC and TN and very low in Av Olsen P. whereas, Cambisol was found optimum in SOC and TN and low in Av Olsen P. Available Sulfur (S) was found in very low status in both soils. Both soils recorded high cation exchange capacity (CEC), indicating that both have commendable water holding capacity (Weil and Brady, 2017), optimum exchangeable K^+, high Manganese (Mn) and Iron (Fe), and low Zinc (Zn) micronutrients. The rating for most soil chemical properties discussed above was done based on Elias (2016).

Table 3. The physicochemical properties of the experimental fields before sowing in 2017.

3.2. Descriptive and analysis of variance statistics

Figure 2 represents the mean statistical evaluation of the obtained agronomic data and quality trait results. Table 4 summarized the basic descriptive statistics for all agronomic and quality parameters of bread wheat to measure the range of variability. The descriptive statistics showed considerable variation for all agronomic data between the soil types treated with different NPSZnB blended and blanket NP fertilizers. Accordingly, Cambisol was found superior in tillering capacity and recorded 30.15% and 39.55% higher in total and productive tillers m^{-2} than Vertisol. Likewise, higher biological yield (BY), grain yield (GY), harvest index (HI), and grain protein content (GPC) was recorded in Cambisol. Whereas, in Vertisol soil highest straw yield (SY) and hectoliter weight (HLW) was recorded by 16.46% and 3.93%, respectively, than Cambisol.

Moreover, median values were almost near the mean values, representing the nonappearance of outliers in calculating the central tendency for the agronomic data analysis (Table 4). In Table 5 are summarized values of the mean squares with *p*-values of the effects of soil type (st), fertilizer rate (fr), and their interactions (st*fr) for all traits evaluated for this study. The analysis of variance (Table 5) showed statistically significant variation among agronomic data due to the main factor's effect and their interaction (except straw yield) in Ayiba under rainfed conditions.

Fig. 2. Bar graph showing the mean±SD of agronomic and grain quality data measured for (a) Vertisol and (b) Cambisol soils. The data are pooled of two cropping seasons (2017-18). Bars indicated that standard deviation (SD).

Table 4. Descriptive statistics of bread wheat agronomic parameters (two seasons pooled data: 2017-2018) grown in different soils.

Table 5. Mean square and *p*-value computed for yield and quality traits (two seasons pooled data: 2017-2018).

3.3. Response of Wheat yield components, yield and quality attributes

According to the analysis of variance results presented in Table 5 above, the interaction effect of soil types and fertilizer rate significantly ($p<0.001$) affected TT (m^{-2}), PT (m^{-2}), NKS (grains $spike^{-1}$), TKW (g), BY (t ha^{-1}), GY (t ha^{-1}), HI (%), GPC (%), and HLW (k hl^{-1}). At the same time, straw yield (t ha^{-1}) was not significantly affected by the interaction effect. However, it was significantly affected by the main effect of soil type ($p<0.001$) and fertilizer rate ($p<0.01$). The average value of the agronomic parameters and GPC was higher in Cambisol than Vertisol, indicating that Cambisol was better in soil nutrient availability. However, the average HLW was high in Vertisol than Cambisol, indicating that grain harvested from Vertisol brings the best price and provides the best quality, which is more valuable to the end-user. The lower HLW in Cambisol compared to Vertisol may be due to endured stress at some point during the grain-filling period or when frost ends the growing season before physiological maturity, which is a common problem in the study area. The model's analysis showed a highly statistically significant relationship between the measured bread wheat agronomic and quality parameters and the independent factors. Therefore, about 74.3-99.3% (R^2) of the agronomic and quality measures variations can be attributable to variations in soil type and fertilizer application. The R^2 indicated that the variation present in the agronomic and quality parameters explained by the model. Results are presented in Figures 3 - 6 and Tables 6 - 8.

3.3.1. Total and productive tillers (m^{-2})

Tillering capacity is an essential trait of plant architecture for grain yields, and the number of tillers per plant determines spike number and affects grain production directly (Naruoka et al., 2011; Shang et al., 2021; Tesfaye et al., 2021). In this study, the analysis of variance revealed a highly significant ($p<0.001$) interaction effect between soil type and fertilizer rate for both total and productive tillers (m^{-2}) of wheat (Table 5). The result indicated that the highest number of total and productive tillers (m^{-2}) was observed in T_8 for Vertisol and Cambisol soils, which was also statistically at parity with T_5 and T_2 in Vertisol and with the two predecessor treatments in Cambisol (Fig. 3). The increase in the number of tillers in response to an increasing rate of NPSZnB blended fertilizer indicated the importance of balanced nutrients for better vegetative growth and crop development. In addition, all fertilized treatments significantly improved wheat total and productive tillers compared to the unfertilized control.

The finding of this study revealed that under Ayiba condition, application of NPSZnB blended fertilizer: $\geq$100 kg ha^{-1} in both soils produced significantly higher total tillers (m^{-2}) and productive tillers (m^{-2}) than the conventional NP application. Besides, the highest mean total and productive tillers (m^{-2}) recorded in Vertisol was 27.8% and 27.7% higher and in Cambisol was 19.5% and 16.6% higher, respectively, compared to the NP blanket application. The highest record in both soils indicated that the application of blended fertilizer has an advantage on tillering capacity of bread wheat over the conventional application under Ayiba conditions. The lower numbers of total and productive tillers (m^{-2}) were produced from control treatment in both soils, at par with T_3 in Cambisol (Fig. 3). The variation in tillering capacity as a function of blended fertilization between soil types proved that the NP blanket recommendation was wrongly used without considering the limitation of other elemental soil nutrients, which play a significant role in plant growth and development. However, the part of NP that stimulates the formation of new tillers and prevents abortion of formed tillers is indispensable. Therefore, soil-specific fertilization practice seems a very meaningful approach in the study area for telling capacity.

The present study result agrees with the findings of Abera et al. (2020b). They reported the highest TT and PT for durum wheat varieties (Mangudo and Utuba) treated with NPSB blended fertilizer in central Ethiopia. Similarly, the highest number of tillers per plant of wheat due to the combined application of 200 kg NPS + 92 kg N ha^{-1} was reported by Seyoum et al. (2017). Other research findings also indicated that the application of NPK fertilizers had a potential role in the number of TT and PT production of wheat (Abera et al., 2020b; Baque et al., 2006; Getachew and Dechassa, 2014; Malghani et al., 2010) due to their positive role in stimulating vegetative growth and development. In tools of southern Ethiopia, the higher number of TT and PT from the combined effect of NPS and KCl was reported than the unfertilized plots (Tesfaye et al., 2021). Similarly, the highest number of TT (421 tillers m^{-2}) and PT (375.7 tillers m^{-2}) were reported with the application of NPSB supplied with N in central highland Ethiopia (Desta and Almayehu, 2020). Leghari et al. (2016) and Abayu (2012) reported a significant and highest tillering in wheat and Teff with NPKB and NPSZnMg blended fertilizers. In agreement with our findings, Jan et al. (2011) also reported significantly higher PT m^{-2} with the application of 30 Mg FYM ha^{-1} + 90 kg N ha^{-1}. The PT per hill of rice was significantly higher in integrated nutrient management than chemical fertilizer alone in the Indian Agricultural Research Institute, New Delhi, India (Singh et al., 2013).

Fig.3. Interaction effects of soil type and fertilizer rate on (a) total tillers (m^{-2}) and (b) productive tillers (m^{-2}) of bread wheat (two seasons pooled data: 2017-2018). Values followed by similar letters are not significantly different at $p<0.05$ according to the LSD test. Error bars indicate the standard error of the mean.

3.3.2. Number of kernels per spike and thousand kernels weight

The number of kernels per spike (NKS) and thousand kernel weight (TKW) are important yield contributing parameters and directly affect wheat grain yield. The two-year average data showed that NKS varied from 37.42 to 52.48 grains per spike in Vertisol and 38.03 to 60.38 grains per spike in Cambisol. Likewise, TKW varied from □36 to 50.4g in Vertisol and 39.2 to 50.2g in Cambisol. The highest mean NKS and TKW were recorded with the application of 175 kg

NPSZnB ha^{-1} in both Vertisol (52.5 grains per spike, 50.4g) and Cambisol (60.4 grains per spike, 50.2g) soils (Fig. 4). At the same time, the minimum NKS and lighter TKW were recorded in the control treatment in both soils. In general, the mean value of NKS and TKW has displayed an increasing trend as the application rate of blended fertilizer increased (Fig. 4) in both soils, reflecting the importance of NPSZnB in wheat NKS and TKW.

In this field experiment, bread wheat grown on fertilized plots showed 7.4 - 28.7% and 6.3 - 28.7% higher in NKS and TKW over the control treatments at Vertisol and Cambisol soils, respectively. The highest NKS and TKW may be due to the provision of balanced nutrients, which enhanced spike elongation and accumulation of assimilating in the grains and thus resulting in more spikelets per spike and heavier grains. Explicitly, the TKW is an essential indication of flour yield where wheat can be classified according to its grain weight as 15-25g (very small), 26-35g (small), 36-45g (medium), 46-55g (large) and over 55g (very large) (Williams et al., 1986). Accordingly, TKW obtained in this study fall under medium to large size in both soils. The larger seed size was produced by applying >125 kg NPSZnB ha^{-1} in both soils. According to the overall mean, Cambisol produced higher TKW by □3% than Vertisol. Compared to NP recommendation, application of blended fertilizer >100 kg ha^{-1} and >125 kg ha^{-1} in Vertisol produced significantly higher NKS and TKW, respectively. Whereas, application of NPSZnB >75 kg ha^{-1} produced significantly higher NKS and TKW in Cambisol soil (Fig. 4). The variation in NKS and TKW in both soil types as a function of fertilization indicated that different soils have various responses to different fertilizer rates and types.

In agreement with the present study, Desta and Almayehu (2020) reported the highest (50.07) NKS under combined application of 150/92 kg NPSB/N ha^{-1} fertilizer rates. Increasing NKS was also reported by Malghani et al. (2010) and Tesfaye et al. (2021) due to the increasing rate of NPKS fertilizer. Debnath et al. (2011) and Muhammad et al. (2009) also reported that Boron application significantly affected wheat's NKS. Similarly, a substantial difference with the application of fertilizers blended by macro/micronutrient nutrients which significantly increased TKW of teff, was also reported by Fayera et al. (2014). The present result also agrees with the finding of Yasir et al. (2015) in Pakistan. Recent studies on NPS and K (Tesfaye et al., 2021) and NPKSZn (Brhane et al., 2017) demonstrated that adding these nutrients together improved photosynthetic activity and enhanced sink transport the grain and resulted in heavier grains. In the sub-humid environment, Mubeen et al. (2021) found similar result as highest NKS and heavier TKW was recorded in plots where the integrated application of natural and synthetic sources at equal dose were used. However, Liu et al. (2021) revealed that excessive nitrogen fertilizer use and high planting density reduce kernel number per spike and TKW in wheat.

Fig.4. Interaction effects of soil type and fertilizer rate on (a) number of kernels per spike and (b) thousand-grain weight of bread wheat (two seasons pooled data: 2017-2018). Values followed by similar letters are not significantly different at $p<0.05$ according to the LSD test. Error bars indicate the standard error of the mean.

3.3.3. Biological yield (BY), grain yield (GY) and harvest index (HI)

The result revealed that mean BY varied from 7.2 to 11.9 t ha^{-1} (at Vertisol) and from 7.6 to 11 t ha^{-1} (at Cambisol), and mean GY varied from 1.6 to 4.3 t ha^{-1} (at Vertisol) and 2.5 to 5.4 t ha^{-1} (at Cambisol). The result also indicated that application of NPSZnB blended >100 kg ha^{-1} in Vertisol produced higher BY (6.9 – 28.8%), higher GY (19 - 50.8%) and higher HI (13 – 30.9%) compared to the application of NP alone. Likewise, in Cambisol soil, higher BY (□10 – 16.2%), GY (11.9 – 21.5%) and HI (5.9%) were recorded with the application of >100, >125, and 175 kg NPSZnB ha^{-1}, respectively compared to the application of NP alone. Plots treated with NPSZnB gave 10.7 - 63.5% and 15.9 - 53.5% higher GY in Vertisol and Cambisol compared to the control plot, respectively. The highest yield could be attributed to the relatively balanced nutrients in NPSZnB, resulting in enhanced yield due to better nutrient use efficiency and the synergistic effect of nutrients in the new compound fertilizer.

The highest and lowest BY and GY were produced in both soil types in T_8 and control plots, respectively (Table 6). The highest BY and GY attained from high blended fertilizer than the positive control NP is due to the presence of S, Zn, and B minerals which play a vital role: in metabolic processes, synergistic utilization of other nutrients by plants, enzyme activation, enhancement of photosynthesis and assimilate transport processes from source to sink during the growth period. We also observed that the average BY, GY, and HI increased in most, as both soil types increased the NPSZnB blended fertilizer rate applications. The result enumerated that BY, GY and HI of wheat responded to varying application rates of NPSZnB blended fertilizer in the experimental soils, indicating that soil-specific fertilization is an important approach. Bread wheat grain yields in most plots receiving NPSZnB blend and NP fertilizers in both soil types were significantly greater than in control plots (Table 6).

Although several previous research findings (Gessesew et al., 2015; Rurinda et al., 2020; Vanlauwe et al., 2015) reported that increasing NP fertilizers stimulate growth and development and increase the uptake of other nutrients from the soil. However, their sole application trend over time bring adverse side effects on the soil nutrient stock, environmental and health concerns, cost and availability of the exclusive mineral fertilizers unless transformed to new fertilizer formulations (Agegnehu et al., 2014; Bindraban et al., 2012; Elias, 2018; Mugwe et al., 2019; Vanlauwe et al., 2015). They used micronutrients to increase crop productivity, especially when conventional NPK fertilizers are not efficient (Dimkpa and Bindraban, 2016). The present results regarding yield attributes follow the findings of others (Abera et al., 2020c; Desta and Almayehu, 2020; Tola et al., 2020), who reported that the highest wheat and maize grain yield was attained from the application of blended fertilizer at Ambo and Toke Kuyaye districts of Ethiopia. Similarly, a recent study also reported higher wheat and maize grain yield response for soil test-based fertilizer recommendations than the NP blanket application alone (Elias et al., 2020; Rurinda et al., 2020). Earlier studies have reported that combined application of mineral and organic fertilizer resulted in synergistic effects and improved synchronization of nutrient release and uptake by plants leading to higher grain yield (Abdou et al., 2016; Jan et al., 2011; Rezig et al., 2013; Saha et al., 2008).

Our result is in accord with findings reported in the studies by others (Desta and Almayehu, 2020; Hřivna et al., 2015; Muhammad et al., 2009; Tola et al., 2020), who stated that the application of fertilizers blended with micronutrients enhanced the vegetative growth of bread wheat, and ultimately increased biomass production due to sufficient assimilation process as a result of synergistically balanced nutrient supply. In southern Ethiopia, Elka and Laekemariam (2020) reported increased BY of haricot beans with an increase in the rate of NPS and organic fertilizers. The result is also in agreement with the research findings of others (Astatke et al., 2004; Singh and Wanjari, 2014; Tesfaye et al., 2021) reported in different soil types. As Amanullah and Inamullah (2016) reported, applying P + Zn increases totaled dry matter accumulation and partitioned more significant amounts into the reproductive plant parts (panicles), resulting in a higher harvest index. In accord with the present finding, significantly higher HI results were attained from the application of blended fertilizers, as reported by Dejene and Chala (2021) and Fisseha et al. (2020) in Ethiopia. Besides, significant variations were detected in HI of winter wheat in Southern Bavaria, Germany (Sticksel et al., 2000). Mubeen et al. (2021) reported that integrated application of natural and synthetic sources each @ 60 kg ha^{-1} produced maximum GY in a sub-humid environment. Increased HI in rice was also reported with combined application of P and Zn than sole application (Amanullah and Inamullah, 2016; Mafi et al., 2013). Significantly higher GY was obtained with the combined application of S and P than their sole application (Assefa et al., 2021). However, contrary to the present result, Amare et al. (2019) reported that K, Zn, and B did not bring a significant difference in BY compared to the blanket application and Lemma and Tana (2015) and Desta and Almayehu (2020) also reported as the application of blended fertilizer has no significant effect on HI of wheat.

Table 6. The interaction effect of soil type and fertilizer rates on yield attributes of bread wheat (two seasons pooled data: 2017-2018).

3.3.4. Straw yield

The two-season pooled data on straw yield (SY) revealed that it was significantly affected by the main effect of soil type and fertilizer treatments (Table 5). The straw yield produced from Cambisol was higher by 14.1% over Vertisols irrespective of fertilizer effect treatment, which could be due to better nutrient availability in Cambisols than Vertisols for bread wheat growth (Table 7). Regarding the effect of fertilizer treatment, the higher SY was recorded with application 175 kg ha^{-1}which was at par with treatment 3, 5, 6, and 7; whereas, the lowest was recorded at control which was statistically similar with treatment 1, 2 and 4 (Table 7). Compared to the conventional NP recommendation (T_2), the application of NPSZnB >150 kg ha^{-1} produced higher SY (Table 7). The advantage on SY attribute by NPSZnB blended fertilizer was probably caused by greater availability and uptake of macro/micronutrients that might have resulted in higher photosynthesis, tissue differentiation, and translocation assimilation turn, leading to better vegetative growth.

Table 7. The main effect of soil type and fertilizer treatments on wheat straw yield.

Previous studies reported that blended fertilizer was found vital to increase straw yield. The present study result is in line with the finding of Tekle and Wassie (2018) and Jafer (2018). They reported that the SY of teff and maize was found highest in blended fertilizers compared to the NP blanket recommendation. The positive response of NPS fertilizer to achieve food security in Ethiopia was also reported by Tamene et al. (2017). The present finding was also in line with that of Tesfay and Gebresamuel (2016). They reported that SY of teff was significantly affected by the application of blended fertilizer and exceeds 7% and 490% over the recommended NP and control plots, respectively. Others (Mubshar et al., 2012; Soni et al., 1996; Ullah et al., 2018) also found that SY of wheat and rice increased significantly with increasing Mn and B application rates. Straw yields of *Tef* were also reported significantly increased due to the application of NPSB on Vertisols of Hatsebo, central Tigray (Tewolde et al., 2020), and application of K in Vertisols of central highland Ethiopia (Demïss et al., 2020). The current finding by Lakshmi et al. (2021) revealed a significantly higher SY where wheat was treated with 10 kg Zn ha^{-1} in calcareous soil. Application of Sulfur on Vertisol and Cambisol soil types reported improving straw yield in central highland Ethiopia (Assefa et al., 2020).

3.3.5. Grain protein content (GPC)

Increasing grain protein and its strength has recently received greater attention due to their positive effect on bread and pasta products (Johansson et al., 2004; Kinyua et al., 2006). The protein content in grain (flour) is the main quality criterion, especially for bread-producing wheat (García-Molina and Barro, 2018) that determines flour's water-absorbing ability, stability, resistance, and elasticity. In this study, increased GPC with increased NPSZnB quantity in both soils is observed. In Vertisols and Cambisols, GPC ranged from 9.93% to 14.4% and 9.38% to 17.95%, respectively, of which all are almost within the acceptable range, which proves the response of wheat to NPSZnB and NP fertilization. Both soils recorded the highest and lowest GPC in T_8 (175 kg ha^{-1}) and T_1 (controls. The Mean GPC for overall treatments was 12.1% and □13% in Vertisols and Cambisols, respectively (Table 8). The result indicated that the increased application of NPSZnB led to a subsequent increase in total GPC, thereby suggesting that an increase in multi-nutrient (mainly N and S: the significant constituents of protein) availability in the rhizosphere ultimately increases the rate of uptake, translocation, assimilation in leaves and reassimilation into developing grains.

According to the ISO-20483 method of test (https://www.iso.org/standard/59162.html) treatment, 7 and 8 in Vertisols and treatment 5 to 8 in Cambisols produced grade 1 standard grain, which can be considered the best quality for baking. The other treatments in both soils made grade 2 to 4 standard grain, except control treatments produced below grade 4 standards. This indicates that wheat production under Ayiba conditions requires soil-specific fertilization to have quality grain that fills the maximum standard limit set by ISO-20483 for protein content.

The plausible reasons for variation in GPC between soils (locations) could be attributed to available soil N and S contents. Studies conducted so far to analyze the effect of N fertilizer on grain quality traits have also revealed significant increases in total GPC of rice, wheat, maize, and barley under an increased rate of N application (Chandel et al., 2010; Nishizawa, 2005). According to Couch et al. (2017), of the N absorbed by the plant, 31-60% remobilizes to capsules and seeds, that why nitrogen is a ubiquitous nutrient in the environment. Sulfur is also an essential component of amino acids (like cysteine and methionine) crucial to protein formation and improves cereal crops' milling and baking quality (Clarkson and Hanson, 1980). Zinc is also engaged in more than 300 enzymes for protein and carbohydrate metabolism with a significant constitute for human immunity enhancement (Lakshmi et al., 2021).

Table 8. The interaction effect of soil type and fertilizer treatments on bread wheat grain quality parameters (two seasons pooled data: 2017-2018).

More importantly, research findings indicated that the deposition of protein in grains depends on the plethora of interconnected metabolic pathways involved in the uptake of N, S, Zn, and other elements with synergistic effects from the soil, their transport to source tissues such as leaves and mobilization and remobilization to developing grains (Chandel et al., 2010; Grusak, 2002). The present study results were similar to many other reports, which explained that the GPC of wheat increased with increasing N fertilizer rates (Bereket et al., 2014; Dargie et al., 2020; Fisseha et al., 2020). Similarly, Abera et al. (2020b) reported the highest GPC from the highest NPSB blended fertilizer application. The highest crude protein content was recorded in southwestern Ethiopia with the application of 200 kg NPSB ha^{-1} + 46 kg P ha^{-1} + 128 kg N ha^{-1} as reported by Zewide et al. (2021). The results obtained in this study also substantiate with Tao et al. (2018), who noted that sulfur fertilization increased grain and protein yields, grain weight, and total starch.

3.3.6. Hectoliter weight (HLW)

Hectoliter weight (HLW) is a general physical indicator of grain quality in all wheat grading systems (Brennan et al., 2012; Dexter and Marchylo, 2000). Higher HLW usually means higher quality grain; therefore, more valuable to the end-user. The highest HLW (74.3 kg hL^{-1}) was recorded from the highest NPSZnB rate (175 kg ha^{-1}) for Vertisol, while the lowest HLW (62.2 kg hl^{-1}) was recorded from the control treatment for Cambisol (Table 8). Both soils showed significant differences in their HLW, but it was found as Vertisol > Cambisol based on the average result. The result showed, 66.7% of the NPSZnB blend fertilizer treatment at Vertisol and 16.7% at Cambisol produced wheat grain with HLW above 70 kg hL^{-1} (Table 8). According to the ES ISO-7971/2 method of the test (ES, 2017) for the wheat standard of quality (kg hl^{-1}), treatment 8 in Vertisols produced grade 3 standard grain. Treatment 5 to 7 in Vertisol and treatment 8 in Cambisol also produced grade 4 standard grain. The other treatments in both soils were below grade 4-grain quality standards. The higher HLW with the application of the highest NPSZnB fertilizer might be due to the role of balanced nutrients on wheat quality, such as flour yield and protein content. This indicates that wheat production under Ayiba conditions requires more soil-specific balanced fertilization than the highest setting to produce quality grains that fill the maximum standard limit set by ES ISO-7971/2 for hectoliter weight. Abera et al. (2020b) reported the highest HLW (80.2 kg hl^{-1}) with the application of 183 kg NPSB ha^{-1}. Others also reported HLW of 78.5 - 83.4 kg hl^{-1} for durum wheat varieties in Ethiopia (Fana et al., 2012; Woyema et al., 2012). Our result is also close to the findings of other researchers (Muhammad et al., 2009; Seyoume, 2006; Soboka et al., 2017) who reported HLW variations from 68.3 to 82.5 kg hl^{-1} in different Pakistan and Ethiopian wheat varieties. The variation in hectoliter weight reported differs probably due to varieties, soil type, climate, and agronomic practices.

3.4. Nutrient use efficiency indices

There has been poor synchrony between crop nutrient demand and nutrient supply because of a limited understanding of the nutrient uptake-yield relationship. Hence, developing an integrated soil-crop system management strategy that simultaneously increases grain yield and nutrient use efficiency (NUE) is required. In this study, the nutrient use indices of agronomic efficiency (AE) and partial factor productivity (PFP) for bread wheat were found to vary among treatments and soil types in the Ayiba condition. The two season's average grain yield, AE, and PFP data exhibit variation among the soil types (Table 9). In Vertisol and Cambisol soils, bread wheat treated with 175 kg NPSZnB ha^{-1} gave maximum AE of 13.01 and 6.8 kg grains kg^{-1} NPSZnB, respectively. The lowest AE results (negative) were recorded at the NPSZnB rate of 50-75 kg ha^{-1} (for Vertisol), and rate 50-100 kg ha^{-1} (for Cambisol) compared to the blanket application rate (Table 9).

Table 9. Effect of NPSZnB blended fertilizer rate on AE and PFP of bread wheat grown under two soil types (two seasons pooled data: 2017-18).

This implies that application of NPSZnB blended <75 kg ha^{-1} (in Vertisol) and <100 kg ha^{-1} (in Cambisol) have little agronomic value than the blanket application in Ayiba condition. As Tamene et al. (2017) explained, fertilizer efficiency should be improved by applying a balanced and appropriate fertilizer mix, increasing crop yield, improving soil health, and increasing the revenue from fertilizer application. Thus, application of NPSZnB blended >100 kg ha^{-1} (in Vertisol) and >125 kg ha^{-1} (in Cambisol) showed better agronomic value on wheat than the NP alone in Ayiba condition. Similarly, Puniya et al. (2019) reported that higher uptake of Fe, Mn, Cu, and Zn were obtained with combined FYM and NPK application compared to mineral sources of NPK alone. Now, emphasis is also placed on improving the use efficiency of fertilizers through the 4R nutrient stewardship principle (i.e., right source, right rate, right time, and right placement) (IPNI, 2014). Singh et al. (2013) also found the seed quality parameters like germination rate and vigor indexes and N uptake and soil organic carbon content were higher in integrated nutrient management than chemical fertilizer alone. Another study by Chandel et al. (2010) confirms that soil contained balanced nutrient composition in the rhizosphere enhances the uptake, translocation, and redistribution of nutrients into grains.

On the other hand, Gupta and Khosla (2012) and Ruisi et al. (2015) reported that the crop was not effectively utilizing 50-60% of applied N fertilizer. Hence, increasing N use efficiency in cereal cropping systems by just 10% could result in an annual savings of US$5 billion and substantial improvement in environmental quality (Gupta and Khosla, 2012). Given the regional differences, it is also feasible to primarily identify a regional soil nutrient status and then adjust according to the actual site conditions to increase NUE. In this field study, the observed negative average AE in both soil types indicated that NPSZnB blended fertilizer has no advantage compared to the conventional application. However, it is evident that N fertilization is crucial in increasing grain productivity and quality; but, to achieve maximum profitable production and minimize negative environmental impact, improving N use efficiency by applying other limited micronutrients together should be considered.

Regarding PFP, the average PFP showed a positive relationship with the NPSZnB blended fertilizer rate (Table 8). Maximum PFP of 25.61 (38.4% higher than T_2) and 32.72 (4.7% higher compared to T_2) kg grains kg^{-1} NPSZnB blend was detected when bread wheat was treated with 175 kg NPSZnB ha^{-1} in Vertisol and with 125 kg NPSZnB ha^{-1} in Cambisol, respectively. Bread wheat treated with NPSZnB blended treatments provided higher PFP than NP fertilizer in Vertisol soil while varied in Cambisol soil (Table 8). This indicates that in Vertisol soil type, bread wheat was positively responding to NPSZnB blended fertilizer rates.

3.5. Correlations among agronomic and grain quality parameters

The correlation analysis was determined to observe the degree of relationship among agronomic and grain quality traits (Fig. 5). Correlation coefficients among most of the characteristics were statistically significant and revealed a noticeable association among the parameters measured in both soil types. The correlation analysis among the agronomic and grain quality parameters is presented in Fig. 5 (a) for Vertisol and in Fig. 5 (b) for Cambisol soils, respectively. Specifically, the correlation results: at Vertisol farm among parameters were positive and significant (Fig. 5a), and at Cambisol soil, most parameters exhibited considerable positive correlation, except SY with HI revealed negative and significant correlation (Fig. 5b). Correspondingly others (Getachew and Dechassa, 2014; Tesfay and Gebresamuel, 2016; White and Wilson, 2006) also reported similar results on teff and wheat.

Fig. 5. Pearson's correlation matrix graph for agronomic data of bread wheat grown in (a) Vertisol and (b) Cambisol soils of the Ayiba area, northern Ethiopia. Color intensity is proportional to the correlation coefficients.

3.6. Partial budget and marginal analysis

Partial budget and marginal rate of return analysis of NPSZnB blended fertilizer rate and blanket recommendation NP fertilizer across the studied two soil types are summarized in Table 10. For partial budget economic analysis, the grain and straw yields were reduced by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. Accordingly, all treatments produced a higher positive net benefit (NB) than the control in both soil types. In both Vertisol and Cambisol soils, the highest net benefit of 45940.7 ETB ha^{-1} and 72714.9 ETB ha^{-1} with MRR of 6717.2% and 2644.3% was obtained from the application of 100 kg ha^{-1} and 125 kg ha^{-1} NPSZnB blended fertilizer, respectively (Table 10). The result suggests that for every 1 ETB invested in fertilizer in Vertisol and Cambisol, farmers (producers) can expect to recover the 1 ETB and obtain an additional 45.9 and 72.7 ETB, respectively.

The MRR results are ranked, and the three highest consecutive alternatives are highlighted in boldface for optional recommendation (Table 10). Therefore, the application of blended fertilizer: 100 kg NPSZnB ha^{-1} in Vertisol and 125 kg NPSZnB ha^{-1} in Cambisol soils are recommended for farmers in the Ayiba area. This study further proved that the application of NP alone was not profitable but can be an optional alternative in Vertisol soils. The highest net benefit in response to applying NPSZnB blended fertilizer could be attributed to incorporating additional soil nutrients rather than NP alone; thereby, the productivity of bread wheat increased. Hence, implementing the recommended soil-specific blended fertilizer in the Ayiba area would create a pathway to wheat self-sufficiency. Moreover, as Elias et al. (2019) noted, such investment in the national wheat sector would create more job opportunities in agricultural value chains.

Table 10. Partial budget and marginal rate of return analysis of bread wheat productivity by NPSZnB blended fertilizer rate experiment for Ayiba Vertisol and Cambisol soils (two seasons pooled data: 2017-2018).

4. CONCLUSION

Nutrient depletion and disproportionate fertilizer use are backing the appearance of multi-nutrient deficiency in Ethiopian soils. The country has been importing only urea and DAP fertilizers to enhance soil productivity for the last five decades. However, the half-century thrives on these fertilizers did not detach the farming livelihood from the poverty circle. The core reason behind failure was (i) using unbalanced input, (ii) ignoring to consider the status of other essential plant nutrients in the fertilization strategy perceiving they are sufficient, and (iii) soil degradation. Current findings indicated that the reverse was true regarding the status of other essential plant nutrients, and new soil-specific fertilizers blended with the macro/micronutrients in an area were introduced to improve soil and crop productivity. In addition, there is also a need to increase the fertilizer use efficiency to obtain more yields per unit of fertilizer applied. With this background, a field experiment was done in Ayiba, Northern Ethiopia, to investigate the response of bread wheat to the application of NPSZnB blended fertilizer rates on two different soil types (i.e. Vertisol and Cambisol) in 2017 and 2018 cropping seasons under rainfed conditions.

The study assessed the influence of soil type and fertilizer rate on wheat yield and quality attributes. The result of the current study indicated that the application of NPSZnB blended fertilizer in both soil types was found as a critical fertilization practice for increasing bread wheat yield, yield component, and quality traits. The two-season combined analysis of the results revealed that TT, PT, NKS, TKW, BY, GY, HI, GPC, and HLW were significantly ($p<0.001$) affected by the application rate of NPSZnB blended fertilizer in both soils (Table 5). Cambisol soil provided a higher grain yield of bread wheat than Vertisol soil. In this study, NPSZnB blended fertilizer application promoted yield and yield components of bread wheat in all soils under rainfed conditions in Ayiba. This indicated that the soil's inherent nutrient contents were not enough to regulate the function of growth and yield. Hence, applying high NPSZnB blended fertilizer resulted in the highest yield of bread wheat in both soil types. The two season's average AE and PFP data also exhibit variation among the soil types. Accordingly, in Vertisol and Cambisol soils, bread wheat treated with 175 kg NPSZnB ha^{-1} gave maximum AE of 13.01 and 6.8 kg grains kg^{-1} NPSZnB, respectively. The observed negative average agronomic nutrient efficiency (AE) in both soil types indicated that applying the NPSZnB blended fertilizer has no advantage compared to the conventional Urea and DAP fertilizers.

Regarding PFP, a Maximum PFP of 25.61 (38.4% higher than T_2) and 32.72 (4.7% higher than T_2) kg grains kg^{-1} NPSZnB blend was detected when bread wheat was treated with 175 kg NPSZnB ha^{-1} in Vertisol and with 125 kg NPSZnB ha^{-1} in Cambisol, respectively. This study suggests that adopting a soil-specific fertilization strategy is better for wheat cultivation in the study area. Therefore, under Ayiba conditions, applications of 100 and 125 kg NPSZnB ha^{-1} were effective and economically profitable in Vertisol and Cambisol soils, respectively. The partial budget analysis revealed that these rates produced the highest marginal rate of return (6717.2% and 2644.3%, respectively). Furthermore, to improve the response of bread wheat to blended fertilizers, testing at a higher rate and identifying nutrients synergism are another obvious management strategy that needs further study to increase wheat yield and fertilizer use efficiency.

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Table 1(on next page)

Information on on-farm experimental fields.

[1] Elias (2016) [2] Amanuel et al. (2015)

Table 1. Information on on-farm experimental fields.

Farms	Geographical location			Crop history	Soil parent material [1,2]	Soil type
	Latitude (N)	Longitude (E)	Altitude (m)			
Farm - 1	12°52'28.1"	39°32'38.1"	2219	Teff	Aluvial	Haplic Vertisol
Farm - 2	12°54'04.5"	39°32'16.1"	2468	Field bean	Fluvial	Haplic Vertisol
Farm - 3	12°53'49.1"	39°32'56.6"	2744	pea	Fluvial	Haplic Cambisol
Farm - 4	12°53'54.6"	39°31'23.3"	2468	Teff	Aalluvial	Haplic Cambisol

[1]Elias (2016) [2]Amanuel et al. (2015)

Table 2(on next page)

The nutrient share of each element in each treatment.

Compiled Based on *NPSZnB* blend = 17.8 N - 35.7 P_2O_5 - 7.7 S - 0.1 B -2.2 Zn, Urea = 46-0-0, and DAP = 18-46-0. Urea was added for all *NPSZnB* treatment to adjust to its recommended rate of 64 kg ha^{-1}, TNA: total nutrient applied per treatment.

Table 2. The nutrient share of each element in each treatment.

Code	Treatments (kg ha^{-1})	Nutrient composition						TNA
		N (total)	P_2O_5	K_2O	S	Zn	B	
T_1	Control (no fertilizer)	0	0	0	0	0	0	0
T_2	100 DAP+50 KCl +100 Urea	64	46	25	0	0	0	135
T_3	50 NPSZnB+50 KCl+119.8 Urea	64	17.9	25	3.9	1.1	0.05	111.95
T_4	75 NPSZnB+50 KCl+110 Urea	64	26.8	25	5.8	1.7	0.08	123.38
T_5	100 NPSZnB+50 KCl+100.4 Urea	64	35.7	25	7.7	2.2	0.1	134.70
T_6	125 NPSZnB+50 KCl+90.7 Urea	64	44.6	25	9.6	2.8	0.13	146.13
T_7	150 NPSZnB+50 KCl+81.1 Urea	64	53.6	25	11.6	3.3	0.15	157.65
T_8	175 NPSZnB+50 KCl+71.3 Urea	64	62.5	25	13.5	3.9	0.18	169.08

Compiled Based on *NPSZnB* blend = 17.8 N - 35.7 P_2O_5 - 7.7 S - 0.1 B -2.2 Zn, Urea = 46-0-0, and DAP = 18-46-0. Urea was added for all *NPSZnB* treatment to adjust to its recommended rate of 64 kg ha^{-1}, TNA: total nutrient applied per treatment.

Table 3(on next page)

The physicochemical properties of the experimental fields before sowing in 2017.

BD: bulk density, FC: field capacity, PWP: permanent wilting point, AWC: available water content, SOC: soil organic carbon, TN: total nitrogen, CEC: cation exchange capacity

Table 3. The physicochemical properties of the experimental fields before sowing in 2017.

Physical properties	Soil type Vertisol	 Cambisol	 Mean	Chemical properties	Soil type Vertisol	 Cambisol	 Mean
Sand (%)	22.5	26.2	24.4	pH	7.4	7.3	7.4
Silt (%)	29.5	17.5	23.5	EC (dSm^{-1})	0.2	0.2	0.2
Clay (%)	48	46.5	47.3	SOC (%)	1.4	2.1	1.8
Textural class	Clay	Clay	Clay	TN (%)	0.1	0.2	0.2
BD (g cm^{-3})	1.4	1.2	1.3	C:N	8.5	11.7	10.1
FC (%)	38.5	41.3	39.9	P (mg kg^{-1})	14.4	21.4	17.9
PWP (%)	24.4	28.7	26.6	S (mg kg^{-1})	0.7	1.1	0.9
AWC (%)	14.1	13.6	13.9	B (mg kg^{-1})	0.4	1.8	1.1
Saturation (%)	49.3	49.4	49.4	Zn (mg kg^{-1})	0.2	0.4	0.3
-	-	-	-	Mn (mg kg^{-1})	9.6	13.5	11.6
-	-	-	-	Fe (mg kg^{-1})	20.7	19.5	20.1
-	-	-	-	K^+ ($cmol_{(+)}$ kg^{-1})	0.7	0.6	0.7
-	-	-	-	CEC ($cmol_{(+)}$ kg^{-1})	41.8	36.9	39.4

BD: bulk density, FC: field capacity, PWP: permanent wilting point, AWC: available water content, SOC: soil organic carbon, TN: total nitrogen, CEC: cation exchange capacity

Table 4(on next page)

Descriptive statistics of bread wheat agronomic parameters (two seasons pooled data: 2017-2018) grown in different soils.

Min.: minimum, Max.: maximum, SD: standard deviation

Table 4. Descriptive statistics of bread wheat agronomic parameters (two seasons pooled data: 2017-2018) grown in different soils.

Parameters	Min.	Median	Mean	Max.	SD
Haplic Vertisol					
Total tillers per meter square (TT)	89.25	169.25	161.14	243.25	50.4
productive tillers per meter square (PT)	53.55	101.55	96.48	145.5	30.3
Number of kernels per spike (NKS)	36.5	45.36	45.04	53.6	5.01
Thousands Kernel Weight (g) (TKW)	35.12	43.39	43.17	51.45	4.77
Biological yield (t ha^{-1}) (BY)	6.5	8.88	9.13	12.3	1.43
Grain yield (t ha^{-1}) (GY)	1.4	2.35	2.63	4.6	0.9
Straw yield (t ha^{-1}) (SY)	5.1	6.48	6.51	7.7	0.59
Harvest Index (%) (HI)	20.25	26.52	28.04	37.4	5.41
Grain protein content (%) (GPC)	9.75	12.21	12.1	14.6	1.38
Hectoliter weight (kg hl^{-1}) (HLW)	60.5	70.65	69.1	74.7	4.26
Haplic Cambisol					
Total tillers per meter square (TT)	176.3	225.5	230.7	283.5	34.8
productive tillers per meter square (PT)	117.4	159.3	159.6	198.4	23.9
Number of kernels per spike (NKS)	35.3	47.75	48.47	67.4	7.95
Thousands Kernel Weight (g) (TKW)	36.9	44.98	44.5	52.35	3.78
Biological yield (t ha^{-1}) (BY)	6.7	9.85	9.65	11.9	1.34
Grain yield (t ha^{-1}) (GY)	2.43	4.2	4.07	5.38	0.93
Straw yield (t ha^{-1}) (SY)	4.04	5.7	5.59	6.83	0.75
Harvest Index (%) (HI)	29.22	42.04	41.77	51.19	6.07
Grain protein content (%) (GPC)	9.2	12.82	12.99	21.2	2.70
Hectoliter weight (kg hl^{-1}) (HLW)	61.5	65.7	66.49	71.6	3.04

Min.: minimum, Max.: maximum, SD: standard deviation

Table 5(on next page)

Mean square and p-value computed for yield and quality traits (two seasons pooled data: 2017 - 2018).

Note: DF: Degree of freedom, TT: total tillers, PT: productive tillers, NKS: number of kernels per spike, TKW: thousand kernels weight, BY: Biological yield, GY: grain yield, SY: straw yield, HI: harvest index, GPC: grain protein content, HLW: hectoliter weight, *, **, and *** denotes significant at $p<0.05$, 0.01, and 0.001, respectively and ns is not significant at $p<0.05$.

Table 5. Mean square and p-value computed for yield and quality traits (two seasons pooled data: 2017 - 2018).

F-test source	DF	Mean squares and significance									
		TT	PT	NKS	TKW	BY	GY	SY	HI	GPC	HLW
Soil type (st)	1	58015***	47784***	141.02***	21.3**	3.32***	24.85***	10***	2262.41***	9.49***	81.64***
Fertilizer rate (fr)	7	11318***	4465***	227.64***	100.61***	10.56***	5.22***	1.15**	161.99***	24.96***	77.81***
st*fr	7	739***	247***	18.65*	8.24*	0.66*	0.22***	0.48ns	20.3*	2.79***	9.67***
Residuals	30	49	35	7.64	2.74	0.24	0.01	0.26	7.06	0.57	0.59

Note: DF: Degree of freedom, TT: total tillers, PT: productive tillers, NKS: number of kernels per spike, TKW: thousand kernels weight, BY: Biological yield, GY: grain yield, SY: straw yield, HI: harvest index, GPC: grain protein content, HLW: hectoliter weight, *, **, and *** denotes significant at $p < 0.05$, 0.01, and 0.001, respectively and ns is not significant at $p<0.05$.

Table 6(on next page)

The interaction effect of soil type and fertilizer rates on yield attributes of bread wheat (two season pooled data: 2017-2018).

Results are Mean ±SE, means followed by different letters in a column and row are significantly different according to LSD ($p < 0.05$) test, LSD: least significant difference, CV: coefficient of variation

Table 6. The interaction effect of soil type and fertilizer rates on yield attributes of bread wheat (two season pooled data: 2017-2018).

Treatments (kg ha^{-1})	Biological yield (t ha^{-1})		Grain yield (t ha^{-1})		Harvest Index (%)	
	Vertisol	Cambisol	Vertisol	Cambisol	Vertisol	Cambisol
T_1	7.22±0.36^{i}	7.58±0.47^{hi}	1.58±0.10^{j}	2.49±0.04^{h}	21.92±0.48^{h}	33.23±2.73^{ef}
T_2	8.50±0.23^{efg}	9.20±0.44^{defg}	2.13±0.12^{i}	4.21±0.04^{cd}	25.06±0.08^{gh}	46.11±2.68^{ab}
T_3	8.12±0.13^{gh}	8.67±0.33^{efg}	1.77±0.09^{j}	2.96±0.02^{g}	21.76±0.93^{h}	34.22±1.13^{e}
T_4	8.33±0.22^{fgh}	8.87±0.55^{defg}	2.07±0.09^{i}	3.76±0.07^{e}	24.88±1.59^{gh}	42.78±3.45^{bc}
T_5	9.13±0.17^{def}	10.22±0.30^{bc}	2.63±0.15^{h}	4.12±0.08^{d}	28.81±1.28^{fg}	40.37±0.54^{cd}
T_6	9.65±0.08^{cd}	10.90±0.35^{b}	3.23±0.07^{f}	4.78±0.08^{b}	33.5±0.56^{e}	43.95±1.66^{bc}
T_7	10.18±0.07^{bc}	10.87±0.23^{b}	3.27±0.06^{f}	4.86±0.02^{b}	32.08±0.61^{ef}	44.74±0.84^{abc}
T_8	11.93±0.20^{a}	10.98±0.37^{b}	4.33±0.15^{c}	5.36±0.02a	36.29±0.60^{fde}	48.86±1.54^{a}
Mean	9.13	9.66	2.63	4.07	28.04	41.77
CV	5.22		3.56		7.61	
LSD$_{5\%}$	0.82		0.2		4.43	
R^2(%)	92.1		99.3		94.4	

Results are Mean ±SE, means followed by different letters in a column and row are significantly different according to LSD ($p < 0.05$) test, LSD: least significant difference, CV: coefficient of variation

Table 7(on next page)

The main effect of soil type and fertilizer treatments on wheat straw yield.

Results are mean±SE, Values followed by similar letters along column are not significantly different at p = 0.05 according to LSD test, LSD: least significant difference, CV: coefficient of variation.

Table 7. The main effect of soil type and fertilizer treatments on wheat straw yield.

Soil type	Straw yield (t ha^{-1})
Vertisol	5.59±0.39^{b}
Cambisol	6.51±0.14^{a}
LSD$_{5\%}$	0.3
Fertilizer treatments (kg ha^{-1})	
Control (no fertilizer)	5.36±0.21^{c}
100 DAP+50 KCl +100 Urea	5.68±0.21^{bc}
50 NPSZnB+50 KCl+119.8 Urea	6.03±0.21^{ab}
75 NPSZnB+50 KCl+110 Urea	5.69±0.21^{bc}
100 NPSZnB+50 KCl+100.4 Urea	6.30±0.21^{a}
125 NPSZnB+50 KCl+90.7 Urea	6.26±0.21^{ab}
150 NPSZnB+50 KCl+81.1 Urea	6.46±0.21^{a}
175 NPSZnB+50 KCl+71.3 Urea	6.61±0.21^{a}
LSD$_{5\%}$	0.61
CV	8.48
R^{2}(%)	74.3

Results are mean±SE, Values followed by similar letters along column are not significantly different at $p = 0.05$ according to LSD test, LSD: least significant difference, CV: coefficient of variation.

Table 8(on next page)

The interaction effect of soil type and fertilizer treatments on bread wheat grain quality parameters (two season pooled data: 2017-2018).

Results are Mean ±SE, means followed by different letters in a column and row are significantly different according to LSD ($p < 0.05$) test, LSD: least significant difference, CV: coefficient of variation.

Table 8. The interaction effect of soil type and fertilizer treatments on bread wheat grain quality parameters (two season pooled data: 2017-2018).

Fertilizer rate (kg ha^{-1})	Grain Protein Content (%)		Hectoliter Weight (kg hl^{-1})	
	Vertisol	Cambisol	Vertisol	Cambisol
Treatment 1	9.93±0.1^{g}	9.38±0.18^{g}	63.92±0.25^{g}	62.23±0.38^{h}
Treatment 2	12.43±0.1^{de}	12.43±0.10^{de}	62.07±0.85^{h}	65.00±0.79^{fg}
Treatment 3	10.58±0.13^{fg}	10.17±0.27^{g}	66.53±0.19^{e}	63.90±0.29^{g}
Treatment 4	11.56±0.1^{ef}	12.08±0.16^{de}	69.95±0.20^{d}	65.30±0.26^{ef}
Treatment 5	11.93±0.12^{ef}	13.28±0.16^{cd}	71.28±0.09^{c}	65.75±0.83^{ef}
Treatment 6	12.67±0.2^{de}	14.58±0.21^{b}	71.95±0.35^{bc}	68.98±0.34^{d}
Treatment 7	13.25±0.2^{cd}	14.00±0.10^{bc}	72.83±0.14^{b}	69.45±0.22^{d}
Treatment 8	14.40±0.1^{bc}	17.95±1.63^{a}	74.25±0.43^{a}	71.30±0.17^{c}
Mean	12.09	12.98	69.10	66.49
CV	6		1.14	
LSD$_{5\%}$	1.26		1.28	
R^{2} (%)	92.3		97.5	

Results are Mean ±SE, means followed by different letters in a column and row are significantly different according to LSD ($p < 0.05$) test, LSD: least significant difference, CV: coefficient of variation.

Table 9(on next page)

Effect of NPSZnB blended fertilizer rate on AE and PFP of bread wheat grown under two soil types (two seasons pooled data: 2017-18).

TNA: total nutrient applied (according to Table 2), GY: grain yield, AE: agronomic efficiency, PFP: partial factor productivity.

Table 9. Effect of NPSZnB blended fertilizer rate on AE and PFP of bread wheat grown under two soil types (two seasons pooled data: 2017-18).

Treatments		Vertisol			Cambisol		
(kg ha^{-1})	TNA	GY	AE	PFP	GY	AE	PFP
Treatment 1	0	1.58	-	-	2.49	-	-
Treatment 2	135	2.13	-	15.78	4.21	-	31.19
Treatment 3	112	1.77	-3.21	15.80	2.96	-11.16	26.43
Treatment 4	123.4	2.07	-0.49	16.77	3.76	-0.36	30.47
Treatment 5	134.7	2.63	3.71	19.52	4.12	-0.67	30.59
Treatment 6	146.1	3.23	7.53	22.11	4.78	3.90	32.72
Treatment 7	157.7	3.27	7.23	20.74	4.86	4.12	30.82
Treatment 8	169.1	4.33	13.01	25.61	5.36	6.80	31.70

TNA: total nutrient applied (according to Table 2), GY: grain yield, AE: agronomic efficiency, PFP: partial factor productivity.

Table 10(on next page)

Partial budget and marginal rate of return analysis of bread wheat productivity by NPSZnB blended fertilizer rate experiment for Ayiba Vertisol and Cambisol soils (two season pooled data: 2017-2018).

FR: Fertilizer Rate, AGY: adjusted Grain Yield, ASY: Adjusted straw Yield, FC, Fertilizer cost, SC: seed cost, TVC: total variable cost, MC: marginal cost, TGFB: total gross field benefit, NB: net benefit, ETB: Ethiopian Birr, MNB: marginal net benefit, MRR: marginal rate of return, D: dominated (**N.B:** DAP and NPSZnB = 15.5 ETB kg^{-1}, Urea = 12 ETB kg^{-1}, wheat grain = 13.5 ETB kg^{-1}, wheat straw = 3.5 ETB kg^{-1}).

Table 10. Partial budget and marginal rate of return analysis of bread wheat productivity by NPSZnB blended fertilizer rate experiment for Ayiba Vertisol and Cambisol soils (two season pooled data: 2017-2018).

soil type	FR (kg ha^{-1})	AGY (kg ha^{-1})	ASY (kg ha^{-1})	FC (Birr ha^{-1})	SC (Birr ha^{-1})	TVC (Birr ha^{-1})	MC	GFBG (Birr ha^{-1})	GFBS (Birr ha^{-1})	TGFB (Birr ha^{-1})	NB = TGFB-TVC	MNBC	MRR (%)	Rank
Vertisol	0	1422	3717	0	1440	1440	-	19197	13009.5	32206.5	30766.5	-	-	-
	50	1917	4023	2257.1	1440	3697.1	2257.1	25879.5	14080.5	39960	36262.9	5496.4	243.5	6
	75	1593	4527	2549.3	1440	3989.3	292.2	21505.5	15844.5	37350	33360.8	D	D	-
	NP	1863	5337	2750	1440	4190	200.8	25150.5	18679.5	43830	**39640**	6279.3	**3127.9**	**3**
	100	2367	5220	2843.8	1440	4283.8	93.8	31954.5	18270	50224.5	**45940.7**	6300.7	**6717.2**	**1**
	125	2907	5778	3137.2	1440	4577.2	293.4	39244.5	20223	59467.5	54890.4	8949.7	3050.8	4
	150	2943	6363	3431.7	1440	4871.7	294.6	39730.5	22270.5	62001	57129.3	2239	760.1	5
	175	3897	6903	3723.9	1440	5163.9	292.2	52609.5	24160.5	76770	**71606.2**	16715.8	**5721.7**	**2**
Cambisol	0	2241	4995	0	1440	1440	-	30253.5	17482.5	47736	46296	-	-	-
	50	3789	4788	2257.1	1440	3697.1	2257.1	51151.5	16758	67909.5	64212.4	17916.4	793.9	4
	75	2664	5031	2549.3	1440	3989.3	292.2	35964	17608.5	53572.5	49583.3	D	D	-
	NP	3384	5220	2750	1440	4190	200.8	45684	18270	63954	59764	D	D	-
	100	3708	5481	2843.8	1440	4283.8	93.8	50058	19183.5	69241.5	**64957.7**	745.3	**794.7**	**3**
	125	4302	5490	3137.2	1440	4577.2	293.4	58077	19215	77292	**72714.9**	7757.2	**2644.3**	**1**
	150	4374	5292	3431.7	1440	4871.7	294.6	59049	18522	77571	72699.3	D	D	-
	175	4824	5625	3723.9	1440	5163.9	292.2	65124	19687.5	84811.5	**79647.7**	6932.8	**2373**	**2**

FR: Fertilizer Rate, AGY: adjusted Grain Yield, ASY: Adjusted straw Yield, FC, Fertilizer cost, SC: seed cost, TVC: total variable cost, MC: marginal cost, TGFB: total gross field benefit, NB: net benefit, ETB: Ethiopian Birr, MNB: marginal net benefit, MRR: marginal rate of return, D: dominated (**N.B:** DAP and NPSZnB = 15.5 ETB kg^{-1}, Urea = 12 ETB kg^{-1}, wheat grain = 13.5 ETB kg^{-1}, wheat straw = 3.5 ETB kg^{-1}).

Figure 1

(a) List of recommended blended fertilizer types, and (b) recommended potash fertilizer for Emba-Alaje district, including the study area (015: Ayiba) (EthioSIS, 2017) .

EthioSIS: Ethiopia Soil Information System

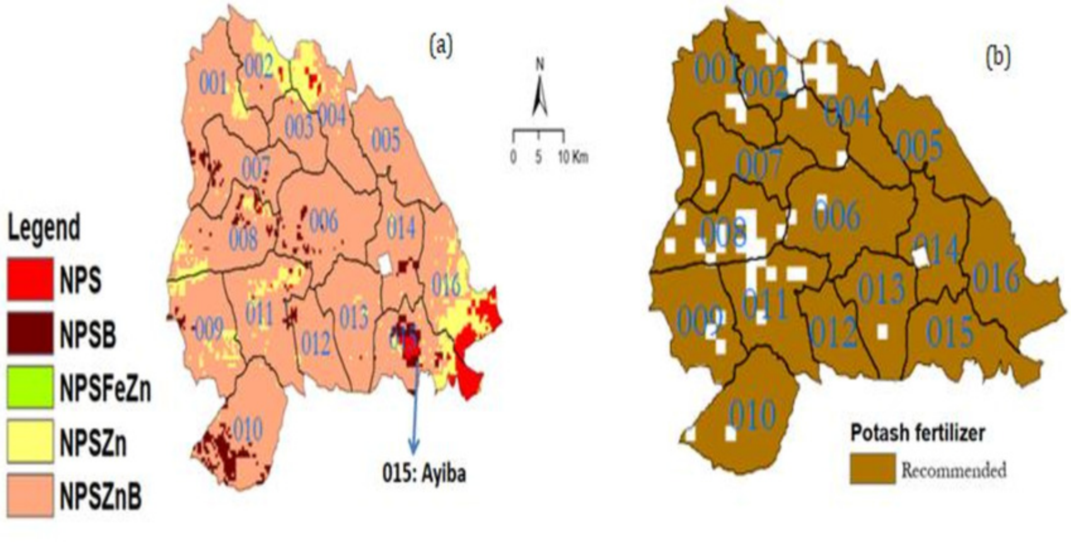

(a)
Legend
NPS
NPSB
NPSFeZn
NPSZn
NPSZnB
001
002
003
004
005
006
007
008
009
010
011
012
013
014
015
016
015: Ayiba
N
0 5 10 Km
(b)
Potash fertilizer
Recommended

Fig. 1. (a) List of recommended blended fertilizer types, and (b) recommended potash fertilizer for Emba-Alaje district, including the study area (015: Ayiba) (EthioSIS, 2017).

Figure 2

Bar graph showing the mean±SD of agronomic and grain quality data measured for (a) Vertisol and (b) Cambisol soils.

The data are pooled of two cropping seasons (2017-18). Bars indicated that standard deviation (SD). The colors in the legend showed the different parameter types evaluated (BY: biological yield, GPC: Grain Protein content, GY: grain yield, HI: harvest index, HLW: hectoliter weight, NKS: number of kernels per spike, PT: productive tillers, SY: straw yield, TKW: thousand kernel weight, and TT: total tillers)

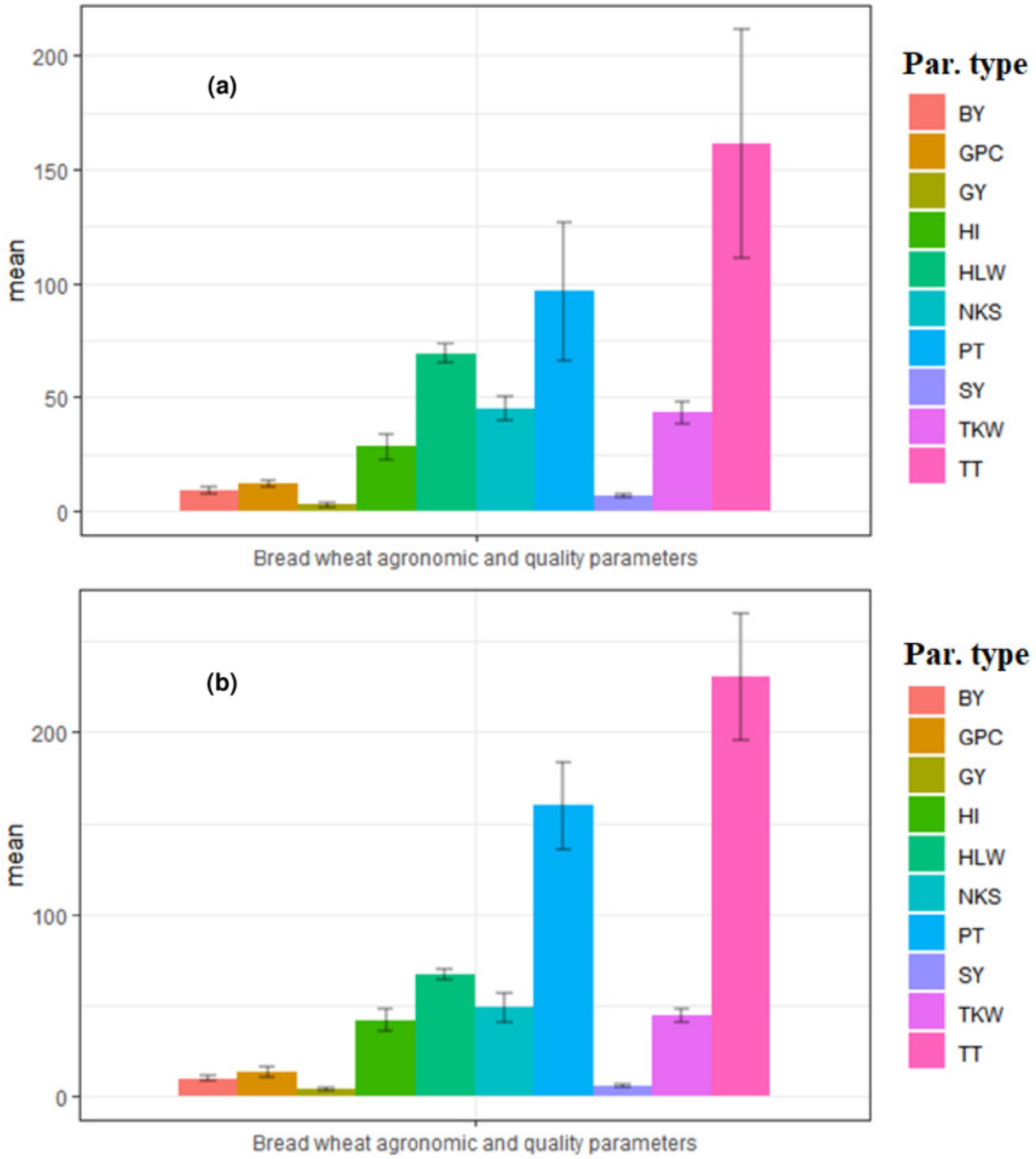


Fig. 2. Bar graph showing the mean±SD of agronomic and grain quality data measured for (a) Vertisol and (b) Cambisol soils. The data are pooled of two cropping seasons (2017-18). Bars indicated that standard deviation (SD).

Figure 3

Interaction effects of soil type and fertilizer rate on (a) total tillers (m^{-2}) and (b) productive tillers (m^{-2}) of bread wheat (two seasons pooled data: 2017-2018).

Values followed by similar letters are not significantly different at $p<0.05$ according to LSD test. Error bars indicate standard error of the mean.

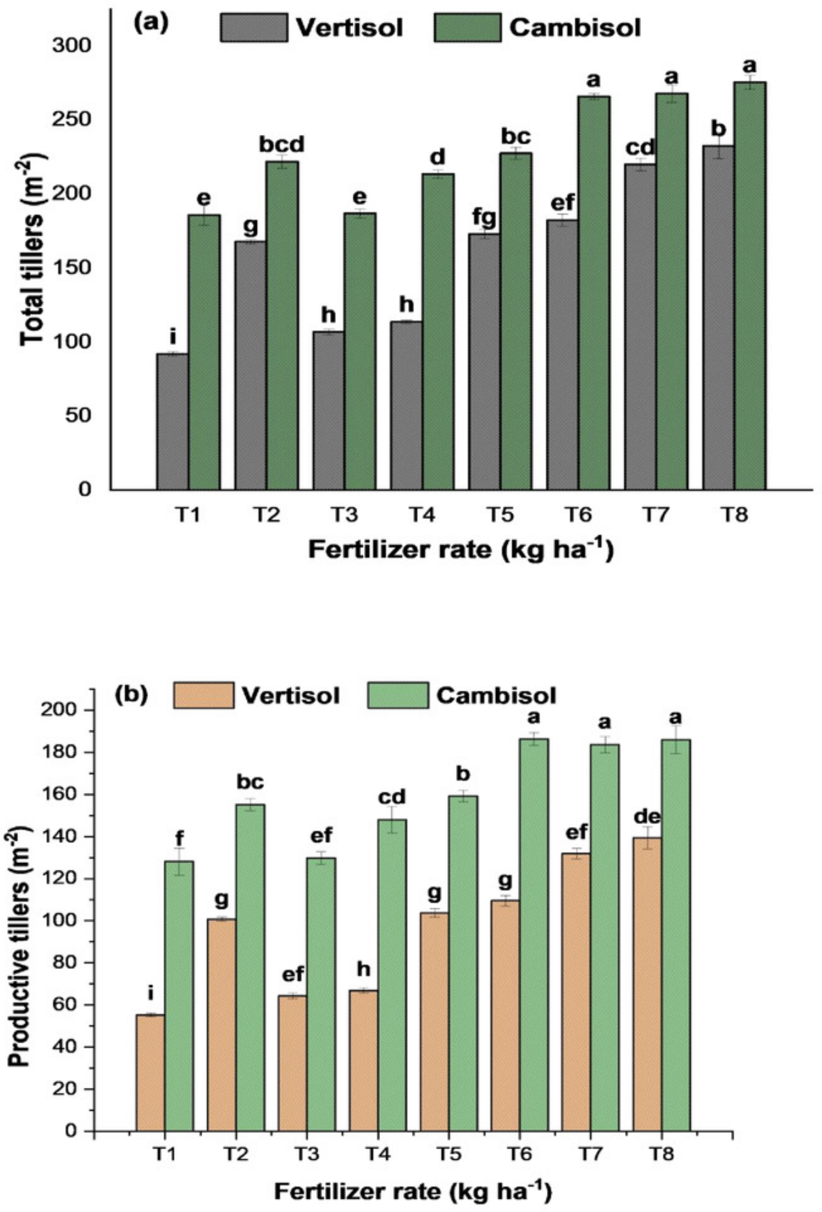


Fig.3. Interaction effects of soil type and fertilizer rate on (a) total tillers (m^{-2}) and (b) productive tillers (m^{-2}) of bread wheat (two seasons pooled data: 2017-2018). Values followed by similar letters are not significantly different at $p<0.05$ according to LSD test. Error bars indicate standard error of the mean.

Figure 4

Interaction effects of soil type and fertilizer rate on (a) number of kernels per spike and (b) thousand grain weight of bread wheat (two seasons pooled data: 2017-2018).

Values followed by similar letters are not significantly different at $p<0.05$ according to LSD test. Error bars indicate standard error of the mean.

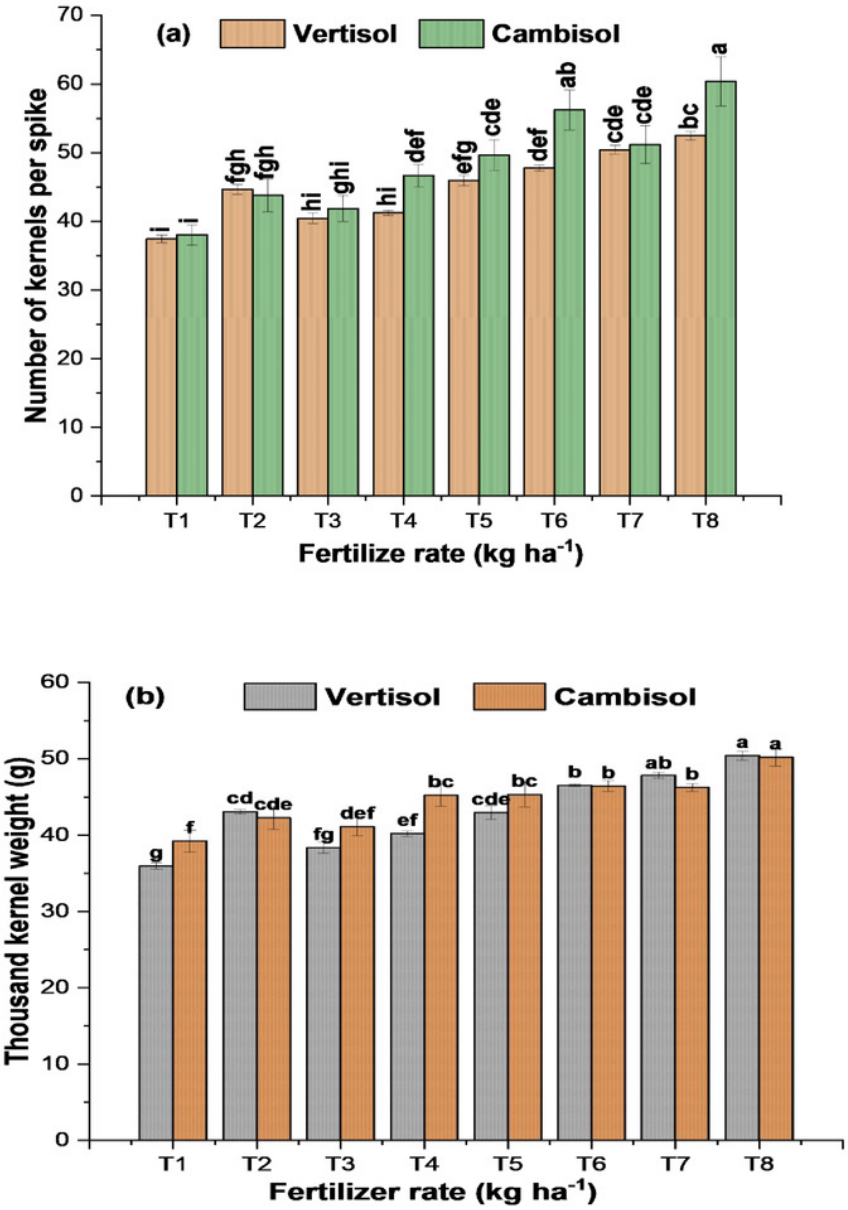
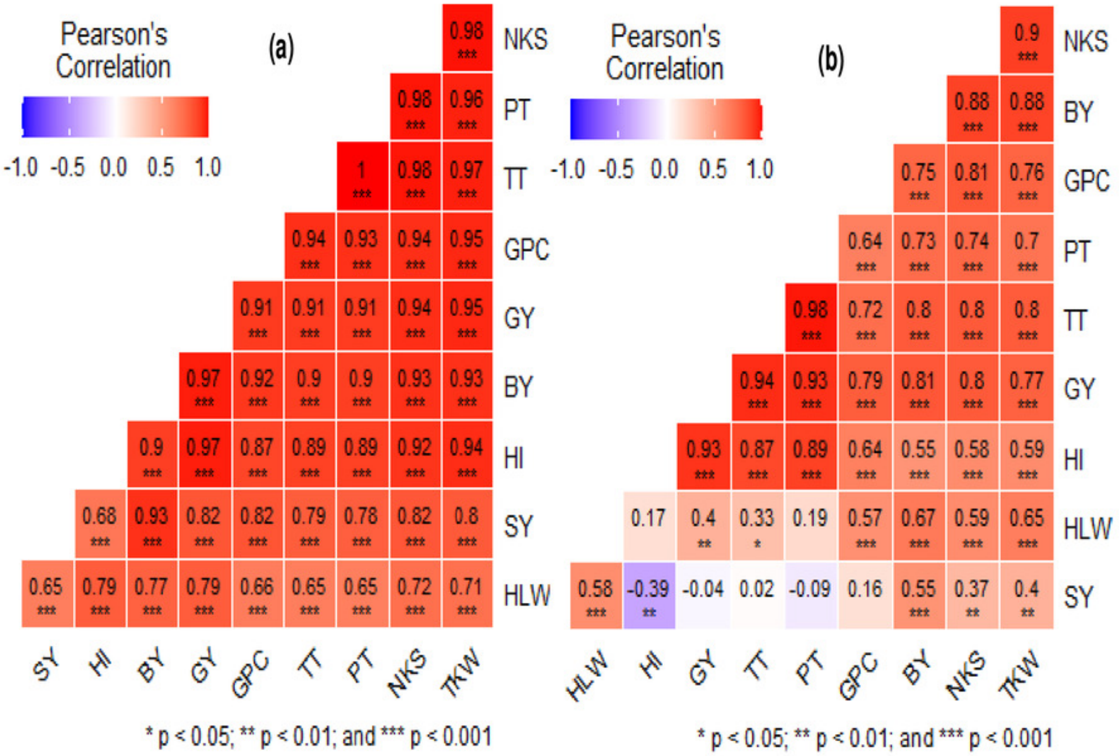


Fig.4. Interaction effects of soil type and fertilizer rate on (a) number of kernels per spike and (b) thousand grain weight of bread wheat (two seasons pooled data: 2017-2018). Values followed by similar letters are not significantly different at *p*<0.05 according to LSD test. Error bars indicate standard error of the mean.

Figure 5

Pearson’s correlation matrix graph for agronomic data of bread wheat grown in (a) Vertisol and (b) Cambisol soils of the Ayiba area, northern Ethiopia.

Color intensity is proportional to the correlation coefficients.



(a)

	SY	HI	BY	GY	GPC	TT	PT	NKS	TKW
NKS									0.98 ***
PT								0.98 ***	0.96 ***
TT							1 ***	0.98 ***	0.97 ***
GPC						0.94 ***	0.93 ***	0.94 ***	0.95 ***
GY					0.91 ***	0.91 ***	0.91 ***	0.94 ***	0.95 ***
BY				0.97 ***	0.92 ***	0.9 ***	0.9 ***	0.93 ***	0.93 ***
HI			0.9 ***	0.97 ***	0.87 ***	0.89 ***	0.89 ***	0.92 ***	0.94 ***
SY		0.68 ***	0.93 ***	0.82 ***	0.82 ***	0.79 ***	0.78 ***	0.82 ***	0.8 ***
HLW	0.65 ***	0.79 ***	0.77 ***	0.79 ***	0.66 ***	0.65 ***	0.65 ***	0.72 ***	0.71 ***

* p < 0.05; ** p < 0.01; and *** p < 0.001

(b)

	HLW	HI	GY	TT	PT	GPC	BY	NKS	TKW
NKS									0.9 ***
BY								0.88 ***	0.88 ***
GPC							0.75 ***	0.81 ***	0.76 ***
PT						0.64 ***	0.73 ***	0.74 ***	0.7 ***
TT					0.98 ***	0.72 ***	0.8 ***	0.8 ***	0.8 ***
GY				0.94 ***	0.93 ***	0.79 ***	0.81 ***	0.8 ***	0.77 ***
HI			0.93 ***	0.87 ***	0.89 ***	0.64 ***	0.55 ***	0.58 ***	0.59 ***
HLW		0.17	0.4 **	0.33 *	0.19	0.57 ***	0.67 ***	0.59 ***	0.65 ***
SY	0.58 ***	-0.39 **	-0.04	0.02	-0.09	0.16	0.55 ***	0.37 **	0.4 **

* p < 0.05; ** p < 0.01; and *** p < 0.001

Fig. 5. Pearson's correlation matrix graph for agronomic data of bread wheat grown in (a) Vertisol and (b) Cambisol soils of the Ayiba area, northern Ethiopia. Color intensity is proportional to the correlation coefficients.