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The search for best fertilizer combination to increase wheat (*Triticum aestivum* L.) yield in north-western Ethiopia

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ABSTRACT

Wheat is among the major cereals of wider importance in the mid-altitudes and highlands of Ethiopia. But wheat yield is quite lower than what could be achievable. To address this gap, Ethiopia introduced the use of blended fertilizer in 2015. However, the response of wheat to these new fertilizers is not known. In this study, we evaluated changes in wheat yield resulting from the application of blended fertilizers relative to common practice. The study also aimed at identifying the rate of blended fertilizer appropriate for wheat production and to evaluate how the inclusion of potassium (K), boron (B), and zinc (Zn) to the blend affects wheat yield. For this study, two groups of treatments were set using RCBD design in two locations over two seasons. While the first group composed of no fertilizer application and five levels of NPSZnB blended fertilizer, the second group contains an additional three different fertilizer rates; including modest rate of NPS compound fertilizer alone and NPS blended with K, B, and Zn. A 100 kg/ha urea was uniformly applied to all treatments, except for the control plots. The findings showed that the new blended fertilizer resulted in significantly lower wheat grain yield compared to the common practice. A closer look at the treatments containing the blended fertilizers showed that the highest wheat grain yield was produced with the application of 300 kg/ha NPSZnB at both Burie (3460 kg/ha) and Farta (2290 kg/ha) sites. Compared with the NPS compound fertilizer at a rate of 100 kg/ha, there was no significant wheat yield advantage following the inclusion of Zn and B in the blend fertilizer. However, the inclusion of K resulted in a substantial increase of wheat grain yield at Farta site, while it significantly reduced yield at Burie site. Though wheat responded to blend fertilizer, the move from application of DAP and urea to the blended fertilizers does not result in significant yield increase as it was intended. Regardless of the quality of grain produced by the application of micronutrients, the inclusion of Zn and B to the blends did not increase wheat grain yield either. However, site-specific application of K is required as wheat significantly responded to K at Farta, but the application negatively affected yield at Burie site.

1. Introduction

Wheat (*Triticum eaestivum* L.) is a versatile cereal crop that thrives at altitudes ranging from 1500 to 3000 m above sea level, making it a particularly important cash and food security crop in the highlands and mid-altitude areas of Ethiopia [1]. The crop covers about 13.33 % of cultivated land area and contributes to 15.81 % of the total grain production in Ethiopia [2]. The Amhara region alone contributes to about 27 % of the total national wheat production [3]. Ethiopia's wheat production remains significantly below its potential, primarily due to prevalent yield gaps that hinder achieving global average productivity levels [4,5]. Irrespective of the potential for wheat production, the country is forced to import wheat every year [4] as a result of low productivity, which remains far below the global average due to several constraints [5].

Wheat production at smallholder farmer is a factor of interactive and complex effect of biotic, abiotic, and socioeconomic factors [6]. The most significant constraints driving high yield gaps in Ethiopian wheat

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production systems are low soil fertility and suboptimal use of mineral fertilizers [7], although diseases, insect pests [6], weeds, and erratic rainfall distribution in lower altitude areas [1] have been considered as contributing factors. Other major determining factors to low wheat yields in Ethiopia are no/minimal access to improved seeds, poor agronomic practices, cultivation of marginal lands, and terminal drought stress [5,8,9]. Efforts to alleviate soil fertility problems through the application of mineral fertilizer have been ongoing for more than five decades. As a result of different agricultural extension efforts like the Comprehensive Package Approach in the 1960s, the Peasant Agricultural Development Extension Projects (PADEP) in the 1970s, and the relatively recent Participatory Demonstration and Training Extension Systems (PADETES), farmers have started to apply fertilizer to increase production [10]. However, rates have not been differentiated for various crops and soil properties, and thus 'blanket recommendations' were considered containing only nitrogen and phosphorus fertilizers [11]. The nationally recommended application was initially 100 kg/ha Di-ammonium phosphate (DAP) for all crops and later revised to 100 kg DAP and 100 kg/ha urea [12,13]. The average national fertilizer application is as low as 43 kg/ha urea and 65 kg/ha DAP [14]. For other plant nutrients, such as potassium, there has been a general understanding that Ethiopian soils already contain high levels, and therefore no need to apply fertilizers containing potassium [15,16]. But, some localized studies in Ethiopia indicated that application of N and P fertilizers, without considering other nutrients such as K and micro-nutrients, have led to the depletion of other soil nutrients such as calcium, magnesium, potassium, sulfur and the micronutrients [17,18].

Recently however, evidence on the status of nutrient other than N and P in Ethiopian soils has increased and reports confirmed that nutrients such as K and micronutrients can limit crop growth. In 2014, a landmark change was made by the Ethiopian government in the fertilizer sector to include compound fertilizer NPS (19N–38 P_2O_5 – 7S) [14], blended with Zn, B and K nutrients in an effort to increase crop production in Ethiopia [11,12]. Currently, limited information is available regarding wheat response on farmers' fields to these newly released fertilizers. Whereas concrete evidence of wheat response to the blended fertilizers in different localities can guide site- and crop-specific blended fertilizers for the farming communities. Therefore, the objectives of this study were (i) to evaluate whether the move from the previous practice of applying DAP and urea to the recent recommendation of applying blended fertilizers resulted in wheat yield increase, (ii) What would be the yield response of bread wheat to different rates of the blended fertilizers, and (iii) is there a yield advantage because of the inclusion of K and micronutrients (Zn and B) in to the blends for wheat growing farmers at Burie and Farta districts of the Amhara region, northwestern Ethiopia.

2. Materials and methods

2.1. Description of the study sites

Experiments were conducted on farmers' fields at Farta and Burie districts of the Amhara Region (Fig. 1) for two consecutive main cropping seasons in 2017 and 2018. Geographically, Farta is situated between 11°32′–12°03′ N latitude and 37°31′–38°43′ E longitude, with an altitude ranging from 1900 to 4035 m above sea level [19]. On the other hand, Burie is situated between 10°17′–10°49′ N latitude and 37°00′–37°11′ E longitude, with an average elevation of 2100 m above sea level and temperature that ranges between 18 and 27 °C [20]. These sites were representative of the soils and agro-ecological conditions that

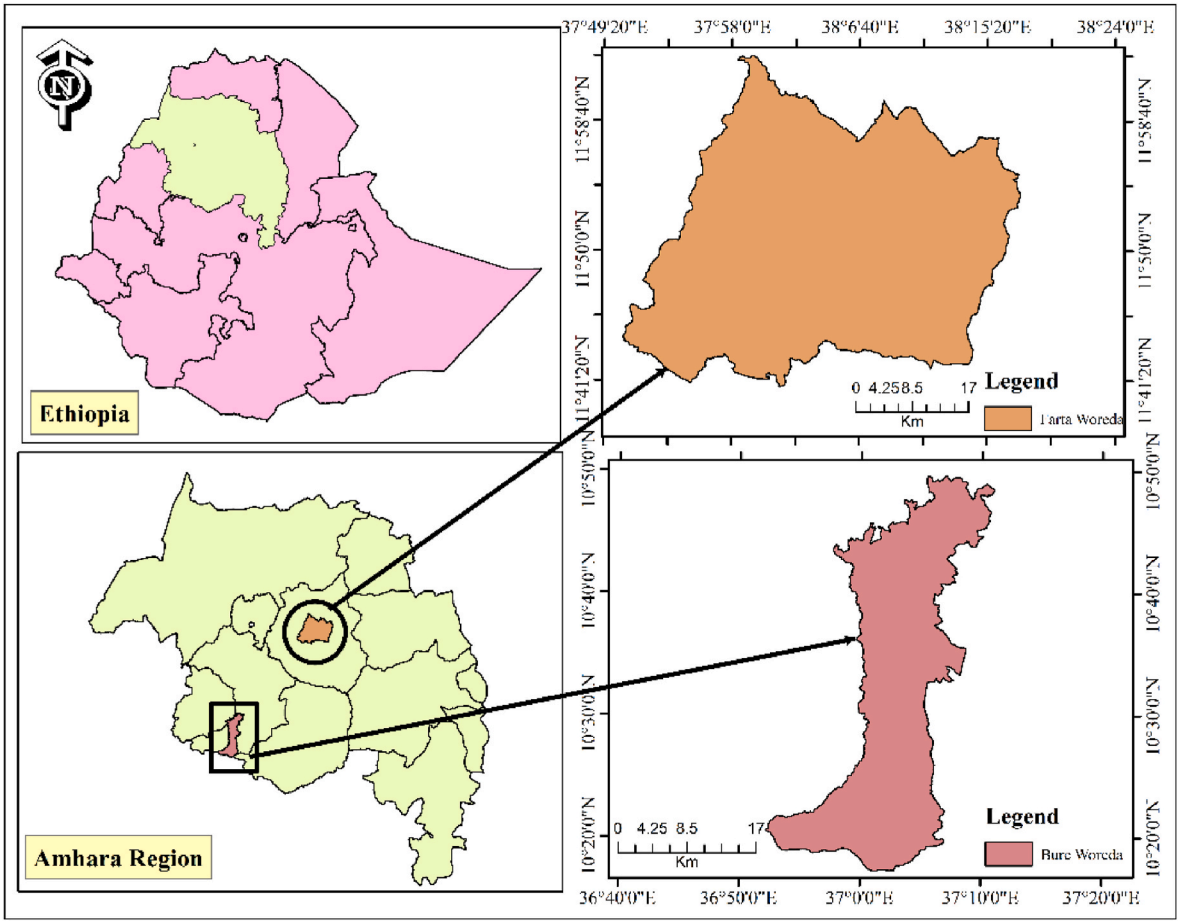

Fig. 1. Map of the study areas.

are most suitable for bread wheat production in the Amhara region. The rainy season in these sites is between May and October, with the maximum rain falling between June and August. The period from February to May is the hottest, while from September to January is the coldest. Although Alisols, Nitisols, Vertisols, Cambisols, Regosols, and Leptosols are common soil types in the Amhara region, Luvisols at Farta [21] and Nitisols at Burie district are the dominant soil types [22].

2.2. Treatments and experimental design

A control and five levels of the newly introduced blended fertilizers containing Zn and B were compared using *Danda'a* bread wheat variety at a seeding rate of 125 kg/ha. The treatments were control – no fertilizer (T_1), 50 kg NPSZnB (T_2), 100 kg NPSZnB (T_3), 150 kg NPSZnB (T_4), 200 kg NPSZnB (T_5), and 300 kg/ha NPSZnB (T_6). To see the effect of K, B and Zn inclusion into the blend, two additional treatments; 100 kg/ha NPS (T_7) and T_3 + 100 kg/ha KCl (T_8) were also included to the treatment set up. The second batch of the treatments were set at a relatively modest level of fertilizer rate to clearly see the effect of the inclusion of other nutrients to the base compound (NPS) fertilizer. Urea, at a rate of 100 kg/ha, was uniformly applied to all plots to satisfy the nitrogen demand of the test crop, except the control plots that did not receive any fertilizer. The nutrient content of each of the treatments is indicated in Table 1.

After collecting all the necessary data, the treatments were analyzed twice by fitting two separate models. The first model was fitted to compare wheat response to the newly introduced blend fertilizer application (treatments T_1-T_6) and the second model was fitted for a careful comparison between the treatments T_1, T_3, T_7, and T_8 to see the effects of fertilizers containing K and micronutrients (Zn and B), which were blend of NPS compound fertilizer. The treatments were implemented in randomized complete block design (RCBD) with three replications. Farmers' fields were considered as replications in each district or site. Based on the design requirements, a field layout was prepared, and each treatment was assigned randomly to the experimental plots of each farmer's field. The plot sizes were 5 m × 5 m, separated by 0.5 m wide open space; the rows were separated 0.2 m apart from each other. Two border rows were not considered during harvest to avoid border effects.

2.3. Trial management

The experimental fields were prepared using conventional tillage practices before planting in both seasons. The land was leveled using human labor. One composite soil sample from each of the farmers' fields was collected before planting and samples were analyzed following standard laboratory procedures. Ditches and bunds were constructed around the fields to avoid overflooding. Planting is usually done in late July at Burie and mid-June at Farta. Planting followed the practices in each district. Basal application of NPSZnB, KCl and NPS was made at sowing, while urea was split-applied twice, with one-third applied at sowing and the remaining two-thirds applied at tillering stages. Two rounds of manual hand weeding were carried out to keep the plots free from weeds.

Table 1
Nutrient contents of the treatments (kg/ha).

Treatments	Fertilizer rates (kg/ha)	Nutrient rates (kg/ha)					
		N	P	S	Zn	B	K
T1	Control – no application	0.0	0.0	0.0	0.0	0.0	0.0
T2	50 NPSZnB + 100 urea	54.5	8.3	3.5	1.1	0.3	0.0
T3	100 NPSZnB + 100 urea	63.0	14.9	7.0	2.2	0.6	0.0
T4	150 NPSZnB + 100 urea	71.5	22.3	10.5	3.3	0.9	0.0
T5	200 NPSZnB + 100 urea	80.0	29.8	14.0	4.4	1.2	0.0
T6	300 NPSZnB + 100 urea	97.0	44.6	21.0	6.6	1.8	0.0
T7	100 NPS +100 urea	65.0	16.6	7.0	0.0	0.0	0.0
T8	100 NPSZnB + 100 urea +100 KCl	63.0	14.9	7.0	2.2	0.6	49.8

2.4. Initial soil data analysis

Before planting, soils representing the plow layer (top 20 cm) of each farmers' field were properly sampled following 'X' pattern using Edelman auger. The soil sampled from different corners of the field were later bulked in one container and properly mixed to create homogenous sample. A field representative sample was then sub-sampled from the properly mixed soil, properly tagged and submitted to laboratory to understand the initial condition of each farmers' field.

According to Landon [23], averaged over the farmers that were considered as replications, the pH in the initial soil (before planting) at Burie site was very strongly acidic, total nitrogen was sufficient, available phosphorous was very low, available Sulfur was low, Zn content was high and the organic carbon was medium. Similar conditions prevailed at Farta except the available phosphorous and exchangeable bases that was found to be very high and high, respectively. Table 2 shows the initial soil conditions before planting at both Burie and Farta sites.

2.5. Agronomic data collected

At physiological maturity, five plants in each plot from the five central rows were randomly selected/tagged for recording of growth and yield related parameters. The main spikes from the randomly tagged plants were measured and averaged to represent the spike length in centimeters for each plot. The number of seeds per spike was also counted from these randomly tagged plants and their average was considered as plot reading. The aboveground biomass yield was obtained from the five central rows, sun-dried to a constant weight and weighed. The sun-dried aboveground biomass was threshed to separate the grain from the straw, cleaned and weighed (in kilogram) for each plot in the field. The grain yield of each plot weighed in the field was adjusted to 12.5 % moisture content.

2.6. Secondary data collection

To see the comparative yield advantage of the blend fertilizer against practices that were common to farmers and researchers in the country, bread wheat yield response from different regions, on different soil types, different varieties, under nitrogen (N) and phosphorous (P) fertilizer treatments were searched from published journal articles and compared against the maximum yield obtained from the new blend treatments. While searching, "Wheat", "Nitrogen", "Phosphorous" and "Ethiopia" were used as key words for the search in Web of Science, Scopus and Google scholar search engines. In doing so, treatments containing fertilizers, other than N and P, were excluded because urea and DAP fertilizers were the most dominant/common fertilizer types used in the country before the blends came in. As a result, data representing 7 districts, from 9 different varieties, and constituting 52 data points were used for the comparison (see Table 3). Reliance on secondary data was a must as DAP was out of the market during experimental period to include common previous practices in the treatment setup.

2.7. Agronomic efficiency

The agronomic efficiency of nutrient applied is an indicator of additional yield gain because of additional fertilizer application and

Table 2
Initial soil condition collected from each farmer before planting.

Sites	Rep.	Soil properties										
		pH (H_2O)	TN (%)	Av. P (mg/kg)	Av. S (mg/kg)	Zn (mg/kg)	B (mg/kg)	Ca (cmolc/kg)	Mg (cmolc/kg)	K (cmolc/kg)	OC (%)	C/N
Burie	1	5.12	0.12	6.22	11.81	1.55	0.15	20.85	10.41	*0.68*	1.90	15.81
	2	5.17	0.19	3.62	12.51	1.78	0.23	8.58	2.31	0.53	2.11	11.11
	3	4.91	0.16	4.75	20.70	1.84	0.29	9.15	2.85	0.51	1.88	11.73
	Average	**5.07**	**0.16**	**4.86**	**15.01**	**1.72**	**0.22**	**12.86**	**5.19**	**0.57**	**1.96**	**12.88**
Farta	1	5.08	0.18	29.87	14.27	1.26	0.28	8.47	2.58	0.41	1.78	9.88
	2	5.12	0.17	21.80	16.77	1.27	0.39	8.68	2.63	0.39	1.85	10.85
	3	5.54	0.22	39.22	11.21	1.57	0.58	9.19	3.73	0.36	2.40	10.90
	Average	**5.25**	**0.19**	**30.30**	**14.08**	**1.36**	**0.41**	**8.78**	**2.98**	**0.39**	**2.01**	**10.55**

Table 3
Wheat yield response to N and P fertilizers in different woreda/districts constituting different varieties from secondary sources to compare with the response of the new blend fertilizer.

S.No	Woreda	Varieties	Data points	Sources
1	Doyoena	3	9	Solomon and Anjulo [24]
2	Welmera	1	5	Agegnehu et al. [25]
3	Enewari	1	9	Molla [26]
4	Ofla	2	18	Harfe [1]
5	Dedessa	3	3	Ibrahim [27]
6	Akaki	1	4	Geleto et al. [28]
7	Robe	1	4	Geleto et al. [28]
Total	**7**	**9**	**52**	**6**

usually expressed in kg/kg. It is the yield difference between the fertilized and the control fields divided by the amount of fertilizer applied [29] and is also expressed as follows:

$$AE = \left(Y_f - Y_C\right) / F_{applied} \quad \text{eq (1)}$$

where: AE is the agronomic efficiency, Y_f is the yield from fertilized plots, Y_C is the yield from the control, and $F_{applied}$ is the applied fertilizer, say nitrogen for nitrogen efficiency [29].

2.8. Data analysis

The data collected from the experiment was fitted to a linear mixed model analysis of variance (LMM) using R statistical software [30] and package lme4 [31]. Treatment and site were considered fixed effects, while the variation between years and farmers' practices were modeled as random effects (equation (2)).

$$Y_{ijkl} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + \delta_l + (\gamma\delta)_{kl} + \varepsilon_{ijkl} \quad \text{eq (2)}$$

Where: Y_{ijkl} is yield response; μ is the overall mean; α_i is the year effect as random factor; $\beta_{j(i)}$ is the block effect in each year as random factor; γ_k is treatment effect as fixed factor; δ_l is site effect as fixed factor; $(\gamma\delta)_{kl}$ is the interaction between treatment and site as fixed factor; ε_{ijkl} is the error term. In this model, the random factors were treated in such a way that farmers/replications were nested in years. Regression summary with maximum likelihood was requested using Satterthwaite's approximation for the degree of freedom to compare the different treatments. Finally, Tukey's Honestly Significant Difference test (HSD) at 5 % probability level was used to group treatment means according to the effect of the different fertilizer treatments at the two sites with the help of the package emmeans in R [32]. The comparison between the new blend fertilizer and the previous practices were made using one-sample *t*-test after the yield reported from secondary data was power transformed using second degree polynomial to maintain the assumption of *t*-test.

For the economic analysis, treatments in the first group were subjected to partial budget analysis to determine the treatment combination that would give acceptable returns at low risk to farmers [33]. During the partial budget analysis, the mean grain and straw yield data for the different locations were averaged over years and adjusted down by 10 % to mimic the farmers' condition. Partial profit was calculated using the formula [(grain yield × grain sale price) – (fertilizer amount × fertilizer cost)] for each site. The budget analysis was performed using Ethiopian Birr (ETB) as a common denominator during the time of input use and wheat grain yield at the time of harvest in the local market (1$ ≈ 29 Birr). All costs and benefits were calculated on a per hectare basis. The average cost of 1 kg NPSZnB was considered 12.49 Birr at Farta and 13.33 Birr at Burie. Urea was not included in the calculation as the same amount was applied to all the fertilized plots. The price of 1 kg of wheat grain was considered 10.25 and 10.75 Birr respectively at Farta and Burie sites. Straw prices were 3.5 Birr at Farta and 1.25 Birr/kg at Burie. The costs that varied for each treatment were ranked in ascending order of variable costs. Dominance analysis was used to eliminate those treatments with high cost, but low benefit resulting in negative net benefit. The marginal rate of return (MRR) was calculated for two non-dominated treatments (say 1 & 2) using the formula in equation (3).

$$MRR = \frac{Change\ in\ NB(NB_2 - NB_1)}{Change\ in\ TVC(TVC_2 - TVC_1)} * 100 \quad \text{eq (3)}$$

where NB is the net benefit and TVC is the total variable costs. Therefore, 100 % MRR indicates that for every one Birr invested in fertilizer application, there is one Birr return on investment.

3. Results

3.1. Model output and significance of the different blend fertilizer levels

The random component of the model comparing the different rates of NPSZnB blend fertilizer shows that there is significant variance ($\chi^2 = 0.004$) between the years, while the blocking effect within the year does not exist. The random intercept of the year further indicated that wheat yield in 2017 was lower by 213.09 kg compared to the yield in 2018. On the other hand, both the treatment ($F = 54.33$, $P < 0.001$), site ($F = 57.87$, $P < 0.001$), and their interaction ($F = 12.19$, $P < 0.001$) showed significant effect on wheat grain yield. A closer look into the treatments by including K, Zn, and B also showed significant treatment ($F = 49.80$, $P < 0.001$) and interaction ($F = 13.87$, $P < 0.001$) effect, while the site effect was non-significant ($F = 1.28$, $P = 0.265$). There is also significant variance ($\chi^2 = 0.028$) from the random component 'year', but there is no blocking effect from the addition of K, Zn, and B. The random intercept from the year also shows wheat yield was significantly lower (170.11 kg) in 2017 compared to the succeeding year.

3.2. Grain yield response of bread wheat to different levels of blended fertilizers

Giving due attention to the interaction effect, wheat grain yield from different farmers' fields were significantly affected by the application of blended fertilizers. With no fertilizer application, wheat grain yield was higher at Farta site compared to Burie. However, the application of NPSZnB fertilizer increased yield at both sites compared to the without fertilizer. Though increased fertilizer application improved yield, there is no statistical difference between the different rate of fertilizer applied at Farta site (Fig. 2). The performance of all the fertilized farmers' fields at Farta site is lower compared to fields from Burie site. On the other hand, application of blended fertilizer sharply increased wheat grain yield compared to the no application (control) at Burie site and there is also significant yield difference between the different rates of fertilizer application. Increased fertilizer application was followed by increased wheat yield and the largest harvest (3460 kg/ha) was obtained by the application of 300 kg/ha NPSZnB. This was significantly higher compared to the two lower rates, but no significant difference was observed compared to the other two higher rates preceding the maximum application rates. All the yield from fertilized fields at Burie are higher than the fertilized field from Farta (Fig. 2).

3.3. Wheat yield response to inclusion of K, Zn, and B to the blended fertilizers

As indicated under section 3.2., wheat yield was better at Farta site when there is no fertilizer applied, but there is sharp increase following fertilizer (NPS) application at Burie site. At both sites, there is yield increase following the inclusion of Zn and B to the compound NPS fertilizer. However, the increased yield was not statistically significant compared to the compound fertilizer at both sites. To the contrary, the inclusion of K to the compound fertilizer showed contrasting effect at the two sites. While it significantly improved wheat grain yield at Farta, it significantly decreased yield at Burie site (Fig. 3).

3.4. Wheat yield advantage of using blended fertilizers compared to previous practices

One of our objectives was to see whether the shift from the existing practice to a new practice has a yield advantage that can be reflected in wheat grain yield in the two sites of Amhara region. A one sample *t*-test comparison of the highest average yield from the largest NPSZnB rate and harvested from Burie site (3.46 t/ha) against wheat yield reported by researchers in the country from different regions, different variety, and with use of different rates of N and P fertilizers (the only plant nutrients used to be applied in the form of Urea and DAP in the country for long time), showed that there is no yield advantage by shifting from the previous practice to the new practice, i.e the use of blended fertilizer ($t = 2.48$, $P = 0.018$, $df = 33$). The *t*-test also showed that the mean wheat yield from the different areas reported by researchers is 3.81 t/ha, which is significantly higher than the highest yield harvested using the new blend fertilizers.

3.5. Economic and agronomic efficiency of the blends

Regardless of the constant costs of inputs and price of farm products averaged over the two seasons, economic benefits calculated through partial budget analysis indicated that the net benefit was the highest (33422.8 Birr) when T_4 was used at Burie site. This is a 627 % MRR, which means six Birr and 25 cents return for every Birr invested on fertilizer purchase (Table 4). At Farta, the highest benefit (20594.7 Birr) was obtained with the application T_5. The high-level application of fertilizer used at Farta even reduced the MRR to only 191.8 %, which means nearly two Birr returns for every one Birr investment on fertilizer.

On the other hand, the agronomic efficiency of the major plant nutrient (nitrogen) indicated that T_4 resulted in the highest agronomic efficiency of nitrogen at Burie (Fig. 4). To the contrary, the agronomic efficiency of nitrogen remained more or less the same regardless of the amount of nitrogen applied at Farta. The agronomic efficiency of phosphorous was the highest for plots treated with low-level of fertilizer at both Burie and Farta site. However, P efficiency is lower at Farta compared to Burie site and it diminishes with increased fertilizer application.

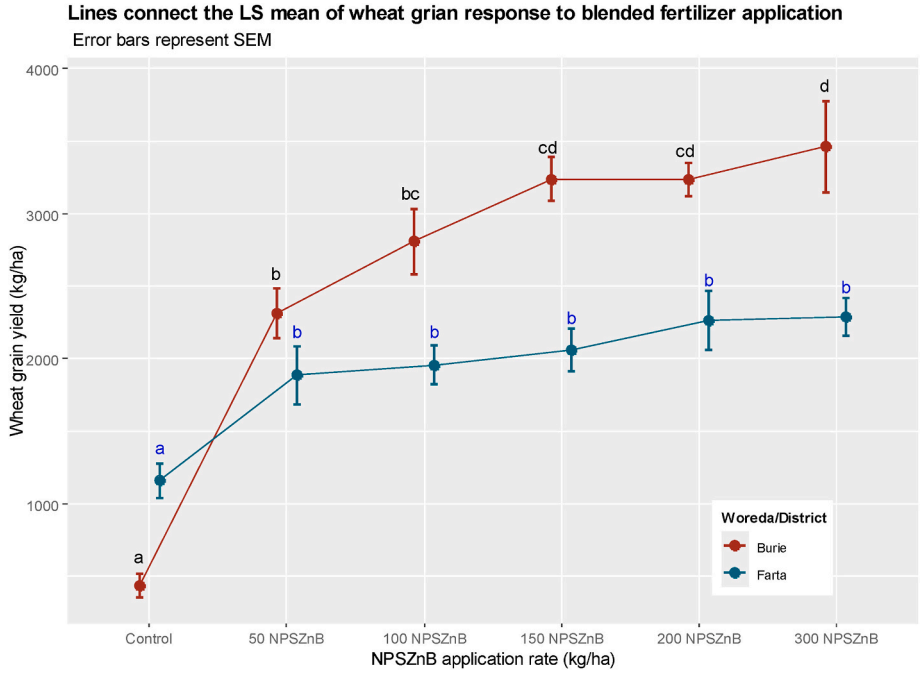

Fig. 2. Wheat fertilizer response at Farta and Burie sites of Amhara region.

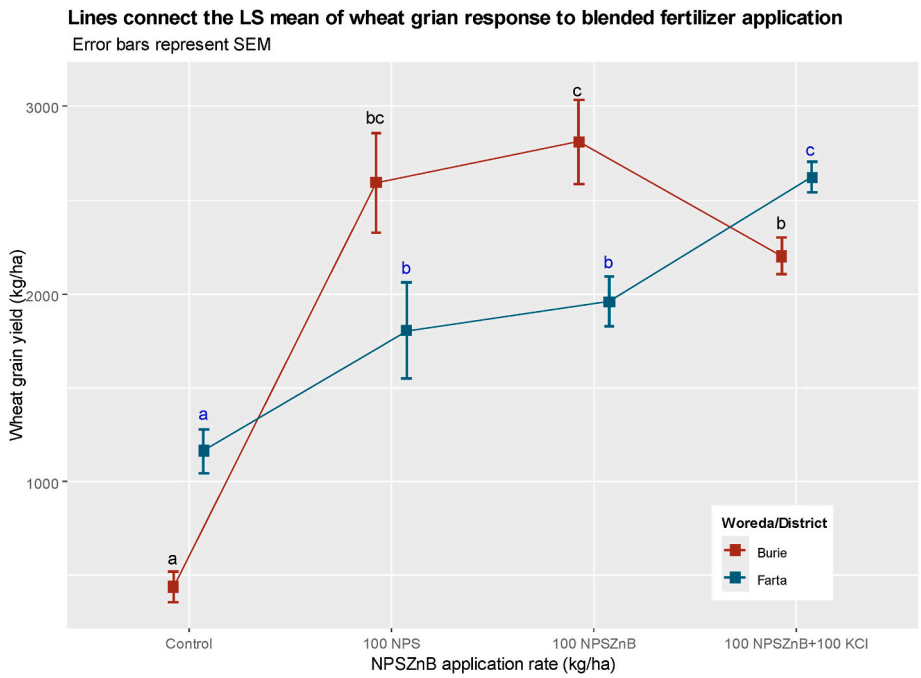

Fig. 3. The effect of application of K, Zn, and B to the NPS compound fertilizer on wheat grain yield at Farta and Burie sites of Amhara region.

Table 4
Economic return of the blends using partial budget analysis for the two sites.

Site	NPSZnB (Kg/ha)	GY (kg/ha)	Adj.GY (Kg/ha)	Gr.B (ETB/ha)	SY (kg/ha)	Adj.SY (Kg/ha)	SB (ETB/ha)	GB (ETB/ha	TVC (ETB/ha	NB (ETB/ha	MRR (%)
Burie											
	0	438	394.2	4237.7	999	899.1.0	1123.9	5361.5	0	5361.5	–
	50	2312	2080.8	22368.6	2720	2448.0	3060.0	25428.6	666.3	24762.4	2911.9
	100	2810	2529.0	27186.8	3013	2711.7	3389.6	30576.4	1332.5	29243.9	672.6
	150	**3238**	**2914.2**	**31327.7**	**3639**	**3275.1**	**4093.9**	**35421.5**	**1998.8**	**33422.8**	**627.2**
	200	3239	2915.1	31337.3	4094	3684.6	4605.8	35943.1	2665.0	33278.1	**D**
	300	3460	3114.0	33475.5	4040	3636.0	4545.0	38020.5	3997.5	34023.0	55.9
Farta											
	0	1162.0	1045.8	10719.5	1823.0	1640.7	1640.7	12360.2	0.0	12360.2	–
	50	1888.0	1699.2	17416.8	2364.0	2127.6	2127.6	19544.4	624.5	18919.9	1050.4
	100	1958.0	1762.2	18062.6	2519.0	2267.1	2267.1	20329.7	1249.0	19080.7	25.7
	150	2058.0	1852.2	18985.1	2539.0	2285.1	2285.1	21270.2	1873.5	19396.7	50.6
	200	**2262.0**	**2035.8**	**20867.0**	**2473.0**	**2225.7**	**2225.7**	**23092.7**	**2498.0**	**20594.7**	**191.8**
	300	2290.0	2061.0	21125.3	3035.0	2731.5	2731.5	23856.8	3747.0	20109.8	**D**

Note: D = dominated treatment; ETB = Ethiopian Birr, GY = grain yield; Adj.GY = adjusted grain yield; Gr.B = benefit from grain; SY = straw yield; Adj.Sy = adjusted straw yield; SB = benefit from straw; GB = gross benefit; TVC = total variable cost; NB = net benefit; MRR = marginal rate of return; and ha = hectare.

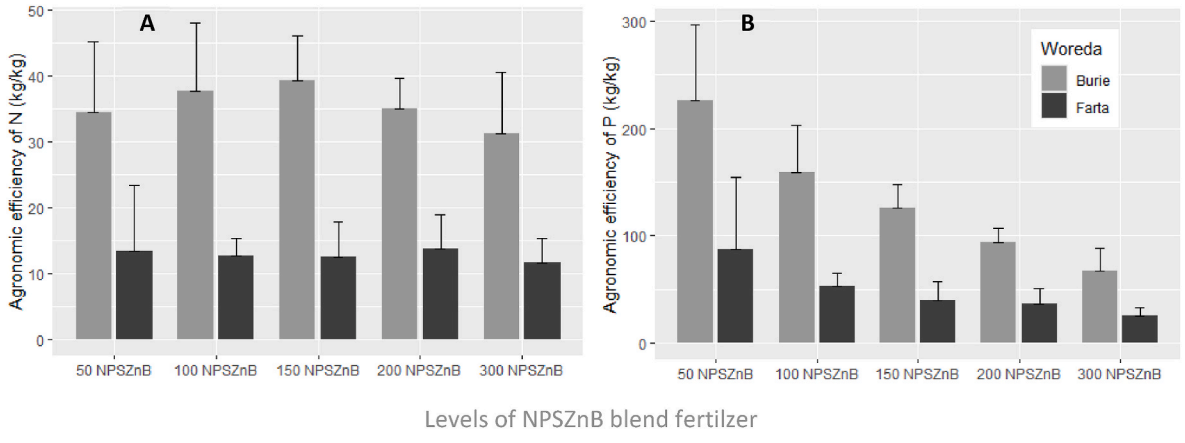

Fig. 4. Agronomic efficiency of nitrogen (A) and phosphorous (B) for the blended fertilizers (kg/kg) averaged over two seasons.

4. Discussion

4.1. Did the shift to the new blended fertilizers result in higher wheat yield?

Until recently, wheat domestic production has never been able to meet consumption needs in Ethiopia and the country has been forced to import nearly 50 % of national demand [14,34]. In order to transform the agricultural sector, through its Ethiopian Soil Information System (EthioSIS) project, the Agricultural Transformation Institute (ATI) of Ethiopia recommended different soil test-based blend fertilizers for the country [35]. Accordingly, different types of blended fertilizers were recommended by ATI to the study areas. This was a major shift from blanket recommendation of Urea and DAP (that farmers accepted conventionally) to the use of compound and blended fertilizers. This raised an important question of whether this move from the conventional fertilizer application to the use of new NPS compounds and their blend fertilizers have resulted in wheat yield increase or not in Ethiopia.

Comparison of the farmers'/researchers' practice from different regions in the country to the different blend levels and compound fertilizers indicated that previous practices (the use of DAP and urea fertilizer) outperformed all the other treatments. It is also true that macro-nutrients, especially nitrogen, are the most limiting nutrients in terms of wheat production [1]. In addition, macro-nutrients such as phosphorus and potassium can also be retained in the soil system to the level that they can affect crop yield [36]. Above all, research has revealed that Ethiopian soils are significantly different in their phosphorus absorption capacity and do not respond when P is applied at low levels [37]. However, as indicated in Table 1, macro-nutrients applied in the blended fertilizers are lower when compared to conventional practice, particularly nitrogen. Many researchers in Ethiopia have recommended high rates of N and P per hectare, far beyond what has been included in the blends. For example, the amount recommended at Farta (138 kg N and 38.18 kg/ha P) for optimal wheat production [38] is much higher than what is found in the blends. The reason for this was the fact that S, B and Zn were added in the blends by reducing the amount of N and P. These may be some of the reasons why previous farmers'/researchers' practices outperformed the newly introduced compounds and the blended fertilizers at both Farta and Burie districts/sites of the Amhara region.

4.2. Wheat response to NPSZnB blended fertilizers

According to ATA [39], the blend containing NPSZnB was recommended for the vast majority of the Amhara region, including Farta and Burie districts. The recommended rates vary between 100 and 200 kg/ha and they are based on soil nutrient deficiency level for critical limits of the nutrient, and none of the recommendations are based on crop responses. Although the amount of fertilizer used by Ethiopian farmers is low [35], some argue that more fertilizer is used to produce wheat and *teff* than other crops in the country [40]. Since the national demand for wheat has not yet been met, the search for alternative mechanisms to increase yield is normal. However, serious revisions on application rates and their economic profitability must be made so that the fertilizer recommendations are aligned with the differences in soils, agroecology and farmers' endowments [17].

In this study we found that application of blend fertilizer at the T_6 resulted in the highest wheat yield at both sites. However, the production function portrayed in Fig. 2 above clearly showed that the performance of the blended fertilizer was different at different sites and the yield increase was not statistically significant. Wheat responded better to the blends at Burie compared to Farta. The initial soil sample analysis revealed that, except for available P and the exchangeable bases, other soil parameters were more or less similar at both sites. According to the soil property rating indicated by Landon [23], averaged over the three replicates, the pH of the soils in the study area was strongly acidic, total nitrogen was sufficient, and organic carbon was medium. However, for soil sampled before planting from both sites, basic cations (including potassium) was medium for Farta, while they were high for Burie. To the contrary, available phosphorous was very high at Farta, but acutely deficient at Burie site (Table 2). This could be the potential reason why soil at Burie was more responsive to the fertilizer applied compared to those at Farta. In addition, there might be issues such as soil depth and structural disturbance that can seriously affect crop response to fertilizer application, as the soil fertility problem in the country goes beyond chemical fertilizer application [17]. The difference in agronomic efficiency is also another indicator that shows there is a clear difference between the two sites. For the same amount of blended fertilizer application, lower nitrogen and phosphorous agronomic efficiency at Farta site shows uptake problem or losses of the applied nutrients through, e.g phosphorous fixation and K leaching, which further reduces farm profitability [41].

The type of fertilizer application is another factor affecting uptake of applied pant nutrients and finally the yield. The blends containing Zn and B were in the form of granular, which are commonly applied by the farmers as side dressing. However, researches indicated that micronutrient applications is more effect when applied as foliar application [42,43]. The side dressing of Zn and B may limited the yield response of wheat to the applied fertilizer. Furthermore, it was reported that monocotyledons in general are less sensitive to micronutrient deficiency such as B [44].

As indicated in the result section, increased fertilizer application resulted in increased wheat yield at both sites at a diminishing rate. However, the highest grain yield recorded at Burie (3460 kg/ha) and Farta (2290 kg/ha) with the application of T_6 (i.e 300 kg/ha NPSZnB) is much lower than the experimental yield of wheat (>5 t/ha) reported by different researchers in the country [11,17,45]. In addition to the low content of N and P in the blends, the other reason for the low wheat yield is the low pH (strongly acidic) at both sites that can limit the fertilizer response. Low levels of organic fertilizer application in the area are also a problem, as farmers have limited knowledge of composting, and they use minimal amounts of cow dung and crop residue for soil fertility management because of their alternative utilities [40]. For example, the use of cow dung as a source of energy and for plastering of house floors are among the most competing practices for animal manure in most part of the Amhara region. Therefore, the move to Integrated Soil Fertility Management (ISFM), combining organic and inorganic fertilizers, could be a potential solution to increasing wheat productivity under such conditions.

4.3. Wheat response to K containing fertilizer

Plants require potassium (K) in large amounts next to N and P. It is an essential macronutrient because it is vital in many plant physiological processes. For example, it transports prepared food from leaves to other parts of the plants, affects the quality of seeds and fruits, and strengthens plant roots, stems and branches, thereby reducing lodging [11,46]. Although the major source of K in modern agricultural system is the application of K containing mineral fertilizers, farmers globally often overlook it, influenced by the wrong belief that K-containing fertilizers do not significantly affect yield [46]. Until very recently, it was believed that Ethiopian soils are rich in K [47], hence the farming systems in the country were free of K-containing fertilizer application [48]. As a result, there are very limited studies on plant responses to K fertilizers in the country.

However, since 2014, with the ambition of utilizing balanced fertilizers that is reflected in soil test results, ATI has recommended K fertilizers and K-containing blends to different parts of the country. According to ATA [39], the vast majority of the study areas require potash. In the current study, it was found that the application of micronutrients such as Zn and B had similar effects at the two sites. Conversely, the application of KCl resulted in a yield advantage at Farta,

but significantly penalized yield at Burie. The initial soil analysis before planting revealed that there was a relatively low base forming cations in Farta soils compared to Burie (Table 2). Which means the relatively K hungry soil at Farta responded for the applied K compared to Burie. In addition, because of their antagonistic nature [49,50], the application of K containing fertilizer on a soil containing relatively larger soil K may hinder the uptake of Mg and can reduce wheat yield at Burie.

Like our finding from Farta site, other researchers also reported cereals such as wheat and barley respond to K-fertilization in Ethiopia. For example, research in the northern part of the country revealed that wheat responds to K-containing blended fertilizer application, but the amount of K in the blends currently distributed in the country does not satisfy the crop demand [11]. Not only the amount, but the balance between the exchangeable cations is also important while applying K containing fertilizers [50], calling for the need for a site-specific application.

5. Conclusions

Although yield response to fertilizer application varies based on many factors, fertilizer application increases yield to a certain level and gradually levels off. It is apparent that underutilization of fertilizer causes yield reduction and excess application incurs cost to farmers, the environment, and even reduces yield. Guided by this truth, a new policy direction has been implemented in Ethiopia to shift from the use of DAP and Urea to NPS compound fertilizer blended with different plant nutrients such as K, B and Zn. In this study, an attempt was made to investigate whether the recent change has increased wheat yield compared to previous practice of farmers, which has been in effect for more than half a century. The results confirmed that application of the blended fertilizers up to 300 kg/ha did not outperform the common practice of the farmers. This shows the move from application of DAP and urea to the blended fertilizers does not satisfy nutrient demand of the crop and increased yield as it was intended. Even if the move from a blanket recommendation to blended fertilizers is appreciated, other plant nutrients included in the formula came at the expense of macronutrients and the blends require revision in terms of N and P content. Though additional verification trials are imperative and regardless of the quality of crop produced with the application of micronutrients, inclusion of Zn and B to the blends also did not increase wheat yield in the study site. However, site-specific application of K is required as wheat grain yield positively responded to K at Farta, but not at Burie site. In general, wheat responded to the blended fertilizers differently in different locations, calling for location specific fertilizer recommendation.

CRediT authorship contribution statement

Gizachew Kebede Biratu: Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Eyasu Elias:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization. **Abebe Worku:** Writing – review & editing, Supervision, Resources, Project administration, Data curation. **Yihenew G. Selassie:** Writing – review & editing, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Samuel Gameda:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis. **Tesfaye Shiferaw Sida:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation.

Declaration of competing interest

The author declares that there's no financial/personal interest that can potentially affect the work reported in this document.

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Data availability

Data will be made available on request.

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