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Research article

Effects of phosphorus and sulfur on yield and nutrient uptake of wheat (*Triticum aestivum* L.) on Vertisols, North Central, Ethiopia

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ABSTRACT

Deficiency of phosphorus (P) and sulfur (S) is increasingly being reported in soils of Ethiopia. While some studies have shown significant response of wheat to P and S application, information on the response of wheat to P and S application interactively is conspicuously lacking. In this regard, we evaluated the response of wheat to P and S application interactively in the study area. A field experiment was conducted at two locations to determine the effects of P and S, on yield, uptake and P, S use efficiency of bread wheat. A factorial combination of four levels of P (0,11,22 and 44 kg h^{-1}) and three levels S (0, 15 and 30 kg ha^{-1}) laid out in Randomized Complete Block Design with three replications. Results revealed that interacted application of P and S at 22 and 15 kg ha^{-1} respectively increased grain yield of wheat by 40.1 % over control. The corresponding increase with straw was 53.4 % over control. Wheat yield obtained with combined application of P and S greater than single application of P or S indicating synergistic between them. The maximum grain N (56.3 kg ha-1), P (12.8 kg ha-1) and S (4.2 kg ha-1) uptakes were obtained due to combined application of P and S at 22 P and 15 kg ha-1. Agronomic efficiencies of P and S decreased as the rates of P and S application increased. Combined fertilization of S and P is necessary in the study district and 15 kg S combined with 22 kg P ha^{-1} produced the highest yield. Thus, this treatment is found to be recommended for bread wheat production in Vertisols of the district. While, partial budget analysis result revealed that, combination of 22P and 15S kg ha^{-1} produced the highest MMR (54.9 %) and thus, this treatment is found to be economically feasible treatment for bread wheat production in study area of the district. We recommend further experiments on different combination of P with S in different agro-ecologies and soil types are required for confirmation of results and the residual effect of P and S on the following crop is needed to study the long-term effect of P and S.

1. Introduction

Wheat is the most important food security crop in the world with a production of 750 million tons (MT) on about 220 million hectares (Mha) (Tadesse et al., 2018). Worldwide, the demand of wheat by the year 2020 is forecast at around 950 million tons per year. This target can be achieved only, if the global wheat production is increased approximately with 2.5 percent per annum (Bairwa D. et al., 2018). More than 25 million tons of wheat on 10 Mha produced in Africa. Sub-Saharan Africa (SSA) produced a total of 7.5 MT on a total of 2.9 Mha accounting for 40 and 1.4 percent of wheat production in Africa and at global levels, respectively (FAO, 2017). Bread wheat, which accounts for 95 percent of the wheat production at the global level, is also the dominant wheat type produced in sub Saharan Africa (Tadesse et al., 2018). Ethiopia, South Africa, Sudan, Kenya, Tazania, Nigeria, Zimbabwe and Zambia are the most important wheat producing countries in SSA in descending order. Ethiopia accounts for the largest production area (1.7 Mha) followed by south Africa (0.5 Mha) (Tadesse et al., 2018). In Ethiopia wheat consumption is increasing due to population growth and gradual change of life style in urban areas (Abu, 2012). The current average productivity of wheat in Ethiopia is 2.76-ton ha^{-1} (CSA, 2019). The average yield of wheat in the country is lower, compared to potential yield which is 5-ton ha^{-1} (Birhan et al., 2016).

Wheat is a staple food that provides around 20% of protein and calories consumed worldwide (FAOSTAT, 2015) and is a major source of energy and protein for the highland population of Ethiopia. It is

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consumed in many forms like bread, cakes, biscuits, bakery products and many confectionery products. Its straw is used as animal feed and also for manufacturing paper (Iqtidar et al., 2006).

In Sub Saharan Africa including Ethiopia wheat production constrained by a number of biotic and abiotic stresses at different levels of intensity across rain fed and irrigated environments. The most important abiotic stresses in the rain-fed environment that hinder wheat production are drought, soil acidity, erosion, poor soil fertility, water logging and preharvest sprouting. Such constraints are most common in the East African, highlands of Ethiopia, Eritrea, Kenya, Tanzania, Uganda, Rwanda and Burundi (Tadesse et al., 2018). Comparatively lower productivity in Ethiopia can be explained by several constraints like depletion of soil fertility which is caused by intensive cropping, imbalanced fertilization, limited application of organic manures and soil erosion (Birhan et al., 2016). Nutrient mining due to sub optimal fertilizer use in one hand and unbalanced fertilizer uses on other have favored the emergence of multi nutrient deficiency in Ethiopian soils. For the last five decades, Ethiopian agriculture depended solely on imported fertilizer products, only urea and di-ammonium phosphate (DAP), sources of N and P. However, recently it is perceived that the production of such high protein cereals like wheat can be limited by the deficiency of sulfur (S) and other nutrients.

Phosphorus (P) is one of the most limiting plant nutrients in crop production next to N, in most agricultural soils (Akande et al., 2010). It is one of the most limiting elements in the majority of the soils of Ethiopia. Wheat experiments has been conducted in Ethiopia in major wheat growing areas and results revealed that increased yield and yield component with successive application of P fertilizer (Minale et al., 2006; Bereket et al., 2014; Tilahun et al., 2006).

Like P, S deficiency is also being reported in soils of Ethiopia. Sulfur is a nutrient most overlooked in Ethiopian agriculture and major prone areas of S deficiency are the central highlands. Assefa Mena (2016) studied the response of wheat to S application and reported that wheat significantly responded to S fertilizer application. Soils in this study had S content below the critical level (11–13 mg kg^{-1} SO_4^{-2}-S) for optimum production of crop.

Sulfur interacts with P as phosphate ion is more strongly bound than sulphate (Hedge and Murthy, 2005). Application of P fertilizer results in increased of anion adsorption sites by phosphate, which releases sulphate ions into the soil solution (Tiwari and Gupta, 2006). Both synergistic and antagonistic relationship between P and S but their relationship depends on their rate of application and crop species (Sinha et al., 1995). Grain and biological yield of wheat increase significantly with increase both P and S levels and protein content increase by increasing the level of sulfur (Ibrahim et al., 2012). Deficiency of phosphorus (P) and sulphur (S) is increasingly being reported in soils of Ethiopia. While some studies have shown significant response of wheat to P and S application, information on the response of wheat to P and S application interactively is conspicuously lacking in the study district. The present experiment was conducted to study the effects of P and S application on yield, nutrient uptake, nutrients use efficiency and to determine economic feasibility of P and S fertilizer application of wheat grown at Moretina Jiru and Sya debr ena Wayu district.

2. Materials and methods

2.1. Description of the study areas

The field experiment was conducted in 2017/18 cropping season on two locations. The locations are found in Moretina Jiru (Gerba) and Saya deber ena wayu (Deneba) district of north Shewa. Geographically, the study locations lie between 09° 46′ 53.3″ to 09° 52′ 07.5″ N and 039° 10' 38.1″ to 039° 11′ 28.3″ E. The altitude of the study locations lies between 2600 to 2700 m.a.s.l. The mean annual minimum and maximum temperature ranging from 5.9-11.6 °C and 17.4–31.2 °C respectively. The study locations and the district as a whole are characterized by having a uni-modal rainfall pattern and receives an average annual rainfall of 921.2 mm. Vertisols is the dominant soil type occurring in the districts. Major crops grown in the locations are wheat, tef, lentil, faba bean, chickpea, field pea and grass pea in decreasing orders of area cultivated under these crops. Figure 1 indicated monthly total rainfall, average maximum and minimum temperatures in the growing season and Figure 2 indicated location map of the study districts.

2.2. Description of soil horizon and soil classification of study district

The soil profile pit was dug on representative site. The soil profile description made according to FAO system was recorded on standard form for soil profile description (FAO, 2006). The soil type of the study area was classified as Eutric Vertisol (FAO-WRB 2014 update of 2015). *The soil of the study district described as follows.*

2.2.1. Profile description

Ap-horizon (0–30 cm depth)- Very dark grayish brown (10YR3/2) dry and very dark brown (10YR2/2) moist, clay; strong coarse prismatic; Very closely spaced cracks; sticky plastic wet, firm moist, very hard dry; common fine interstitial pores; common fine roots; clear and smooth boundary.

A-horizon (30–75 cm depth)- Black (10YR2/1) dry and moist, clay; strong coarse angular blocky; very sticky very plastic wet, firm moist, very hard dry; common fine interstitial pores; few fine roots; clear and wavy boundary.

B1-horizon (75–150 cm depth)- Very dark brown (10YR2/2) moist, clay; strong coarse angular blocky; very sticky very plastic wet, friable moist; common prominent slickensides and pressure faces; few fine interstitial pores; clear and wavy boundary.

Btc-horizon (150–200 cm depth)- Very dark grayish brown (10YR3/2) moist, clay; strong coarse angular blocky; sticky plastic wet, friable moist; common prominent slickensides and pressure faces; few fine interstitial pores; common CaCO3 concretions.

2.3. Soil sampling and analyses

Before planting of the wheat crop, soil samples were collected from each site for the analyses of selected physicochemical properties. The composite soil samples were taken from each experimental site from a depth of 0–30 cm using augur randomly from 15 spots by walking in a zigzag pattern. After carefully mixing the composite samples, 1 kg of subsample was taken and brought to Debre Berhan agricultural research Centre soil laboratory. The submitted sample was air dried and grounded to pass 2 mm mesh sized sieve.

The soil texture was analyzed by using Bouyoucous hydrometer method (Bouyoucos, 1962). The soil reaction (pH) was measured using pH-water method by making soil to water suspension of 1: 2.5 ratio and was measured using a pH-meter. The soil organic carbon (OC) content was determined by wet digestion method which developed by Walkley and Black (1934). Total nitrogen (TN) was determined by using the modified micro Kjeldhal method (Cottenie, 1980), available P (ava. P) was analysed by using Olsen's calorimetric method (Olsen et al., 1954), and exchangeable potassium (Ex. K) in the soil was extracted with 1 N NH_4OAc and the amount was estimated using a flame photometer (Jones, 2001). Soil available sulphur (ava. S) in the soil was determined turbidmetrically using a spectrophotometer (Singh et al., 1999). Cation exchange capacity (CEC) was measured after saturating the soil with 1N NH_4OAc and displacing it with 1N NaOAc (Chapman, 1965).

2.4. Selected soil physical and chemical properties

The soil analyses data before planting for selected physicochemical properties collected from experimental locations at Moretina Jiru (Gerba) and Sayadeber Ena Wayu (Deneba) are summarized in Table 1. The soils of both experimental sites were belonging to clay textural class.

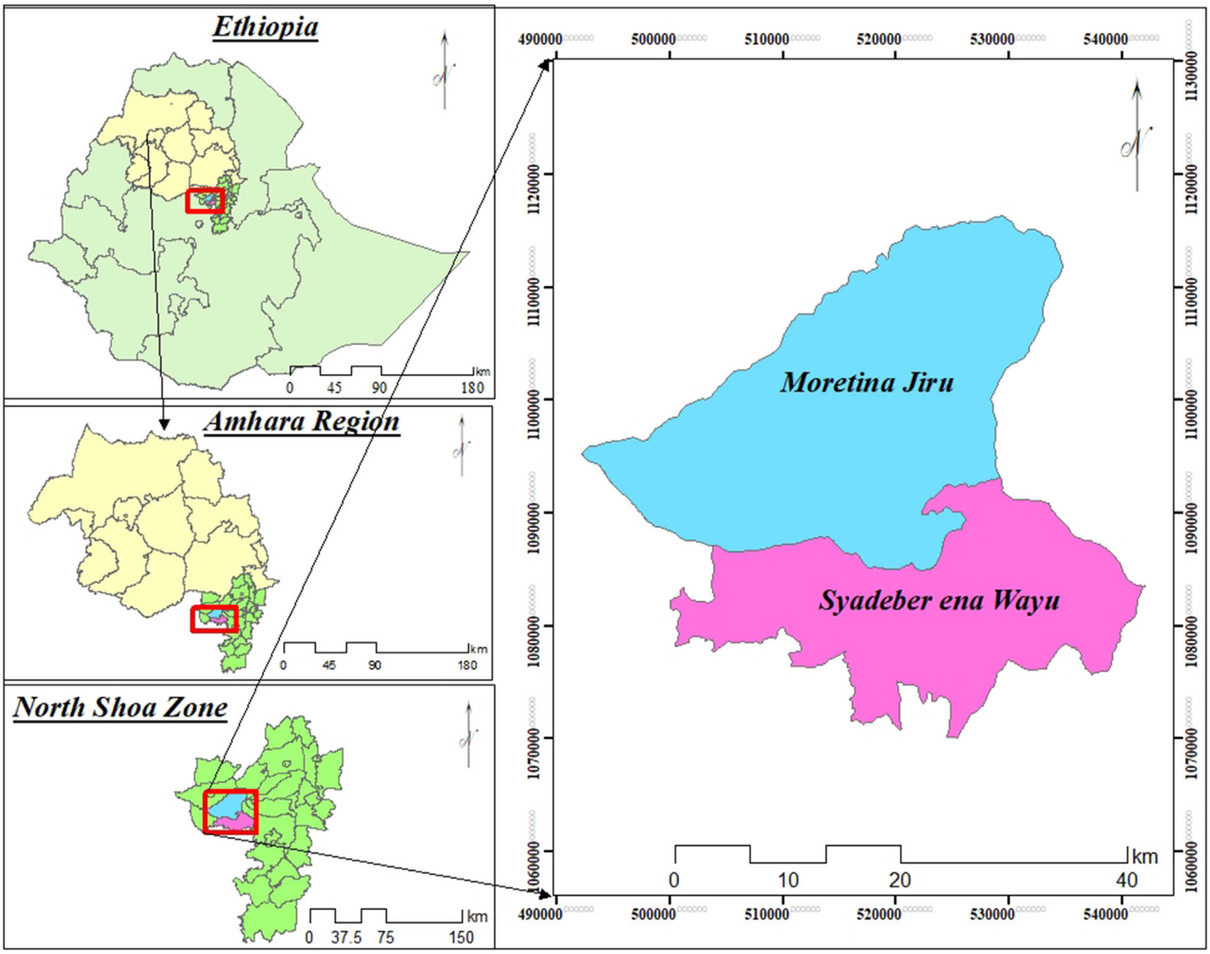

Figure 1. Location map of the study sites.

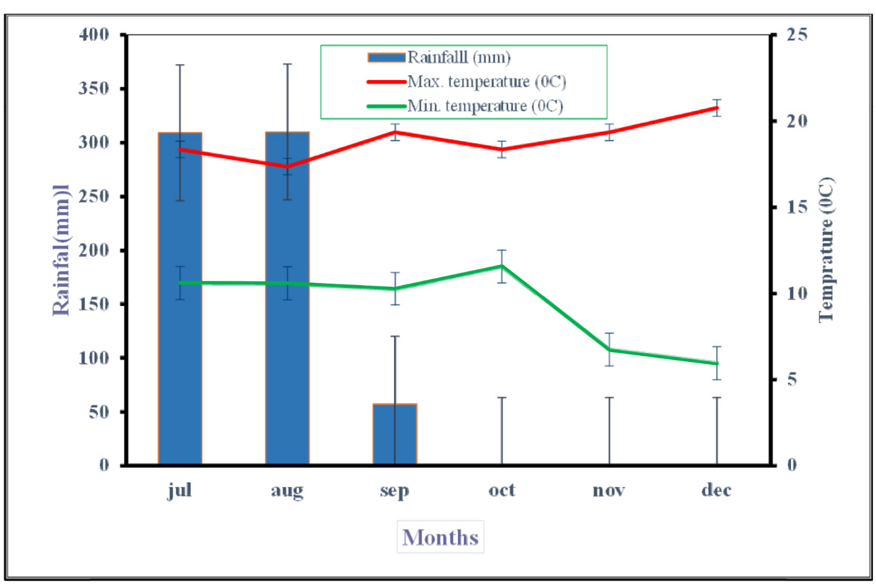

Figure 2. Monthly total rainfall and average maximum and minimum temperatures.

Soil reaction (pH) at Gerba and Deneba location is near to neutral and slightly alkaline respectively. The soil organic matter (SOM) and Total nitrogen content of both locations are in low categories (Jones, 2001). The available P content of both locations are slightly higher than 5 mgk^{-1}, which is far lower than the critical soil available P value established for some Ethiopian soils which is 10 mg kg^{-1} (Tekalign and Haque, 1991). The available S content of both soils were also found below the critical value of S which is 10–13 mg kg^{-1} SO_4^{-2}-S (Tandon, 1991).

Table 1. Pre-planting selected physicochemical properties of experimental soils.

Locations	Physical Properties				Chemical properties						
	Sand	Clay	Silt	Textural Class	pH	SOM	TN	Ava.P	Ava.S	Ex. K	CEC
	%					%		Mg kg^{-1}		(Cmol kg^{-1})	
Gerba	6	76	18	Clay	6.8	1.55	0.087	6.95	5.62	0.88	40.0
Deneba	8	74	18	Clay	7.3	1.79	0.088	6.36	4.98	0.82	39.0

pH = soil reaction, SOM = soil organic matter, ava. P = available phosphorus, ava. S = available sulphur, Exch. K = exchangeable potassium, CEC = Cation exchange Capacity. TN = Total nitrogen.

The exchangeable K content of both soils was very high (Jones, 2001). The Cation exchange Capacity of both soils was also in high category (Landon, 1991). Based on the soil analysis, the result from Table 1, indicated that, the study area soil is deficient in N, P and S which needs N, P and S fertilizer application for optimum crop production.

2.5. Treatments, design and experimental procedure

An experiment consisting of four levels of phosphorus (0, 11, 22 and 44 kg ha^{-1}) and three levels of sulfur (0, 15 and 30 kg ha^{-1}) was laid out in *Randomized Complete Block Design (RCBD)* with three replications. Potassium sulphate (K_2SO_4) and Triple super phosphate (TSP) was used for S and P fertilizer sources respectively. The wheat variety used for the study was Menze (HAR-3008)*,* which was released by Debre berhan Agricultural Research Centre (DBARC, 2007). The variety is high yielding and disease resistant. The seed was planted in a unit plot size of 3.6 × 3.4m with row spacing of 20 cm apart at a rate of 150 kg ha^{-1}. The whole doses of potassium Sulfate (K_2SO_4) and Triple super phosphate (TSP) fertilizers were applied at basal in both sides of rows just before planting as per the treatment. To compensate potassium (K) applied along with S fertilizer source in S treatment plots, K was applied in the form of potassium chloride (KCl). The recommended dose of nitrogen (N) fertilizer for wheat production around the study area 167 kg N ha^{-1} (Adamu, 2018) was applied uniformly to all plots in the form of urea. The Urea-N was split applied in which one half of N was applied at planting and the remaining one half was applied 45 days after planting and first weeding. All agronomic management of the trails was done as per the recommendation for the crop (EIAR, 2007). Data on grain and straw yield, nutrient uptake (NU), Grain Protein content (GPC) and nutrient use efficiency were collected and calculated at appropriate time pertinent for each parameter.

2.6. Plant tissue sampling and analysis

Ten (10) randomly selected wheat plants were harvested from six central rows at physiological maturity and partitioned into grain and straw. The grain and straw samples were separately oven-dried at 70 °C for 24 h to a constant weight and ground to pass through 1 mm sieve for analysis of N, P and S in grain and straw. Total nitrogen (N) in grain and straw subsamples were quantitatively determined by kjeldahl procedure developed by Bremner and Mulvarey (1982). Phosphorus in grain and straw subsamples were determined by using Meta vanadate method (NSL, 1994). Sulfur was determined by magnesium nitrate dry ashing method (Benjamin, 1982). After the determination of N, P and S concentration, in grain and straw uptake of N, P and S in the grain and straw of wheat was determined by using the following formula as described by Sharma et al. (2012).

$$Nutrient\ uptake\ (kgha^{-1}) = \frac{Nutrient\ content\ (\%) * yield\ (kgha^{-1})}{100} \quad \text{Equation 1}$$

2.7. Phosphorus and sulfur use efficiency

Based on the results of plant tissue analysis, phosphorus and Sulfur use efficiency indices were computed (Rakshit et al., 2015).

Agronomic efficiency (AE): is the economic production obtained per unit of nutrient applied and expressed in kg/kg. It can be calculated by using the following equation:

$$AE\ (Agronomic\ efficiency)\ (kgkg^{-1}) = \frac{Gf - Gu}{Na} \quad \text{Equation 2}$$

Where: *Gf* is the grain yield of the fertilized plot (kg), GU is the grain yield of the unfertilized plot (kg), and Na is the quantity of P applied (kg).

Apparent Recovery efficiency (ARE): is defined as the quantity of nutrient uptake per unit of nutrient applied. Expressed as percent (%).

$$ARE\ (Apparent\ recovery\ efficiency)\ (\%) = \frac{Nf - NU}{Na} \quad \text{Equation 3}$$

Where: Nf and Nu are nutrient uptakes (grain plus straw) from fertilized unfertilized plots (kg), respectively, and Na is the quantity of nutrient applied (kg).

Determination of protein content

$$Protein\ conten\ (\%) = N\ content\ (\%) * 5.7 \quad \text{Equation 4}$$

2.8. Data analysis

The collected data were subjected to ANOVA. After verifying the homogeneity of error variances and normal distribution, combined analysis of variance was done using the procedure of SAS software version 9.3 (SAS, 2011). Mean comparisons were done by Duncan's multiple range tests (Gomez and Gomez, 1984) at the 5% level.

2.9. Economic analyses

Partial budget analyses were done to determine economic feasibility of P and S fertilizers as well as their combinations for wheat production around the study areas following procedures described in CIMMYT (1998). The mean grain and straw yield data of wheat was employed in the analyses. Furthermore, the grain yield and straw yield obtained from each treatment were adjusted down by 10 % in order to narrow the possible yield gap that may happen due to difference in field management by researcher and famers. This is because usually, researcher managed field give higher yield than famer managed field.

3. Results

The data on response of grain and straw yield, nitrogen uptake, phosphorus uptake, sulfur uptake, phosphorus use efficiency and sulfur use efficiency indices of wheat under phosphorus and sulfur interaction are shown graphically in Figures 3, 4, 5, 6, and 7. The grain protein content of wheat due to main and interaction effect of P and S are presented in Table 2. All the above-mentioned parameters are discussed here after in sub sections. While the response of grain and straw yield, N, P, and S uptake, P and S use efficiency indices under main effect of P and S are presented in Tables 3 and 4 and the correlation coefficient of among each paraments presented in Table 5.

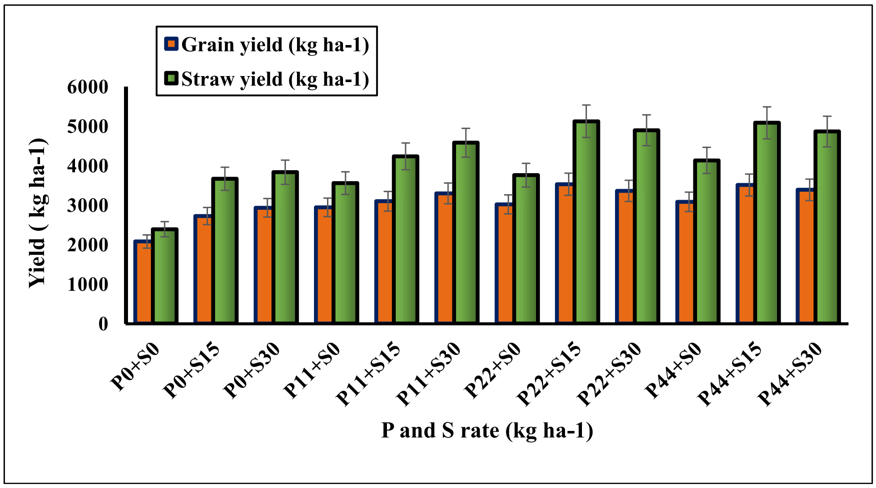

Figure 3. Interaction effects of P and S, on yield of Wheat.

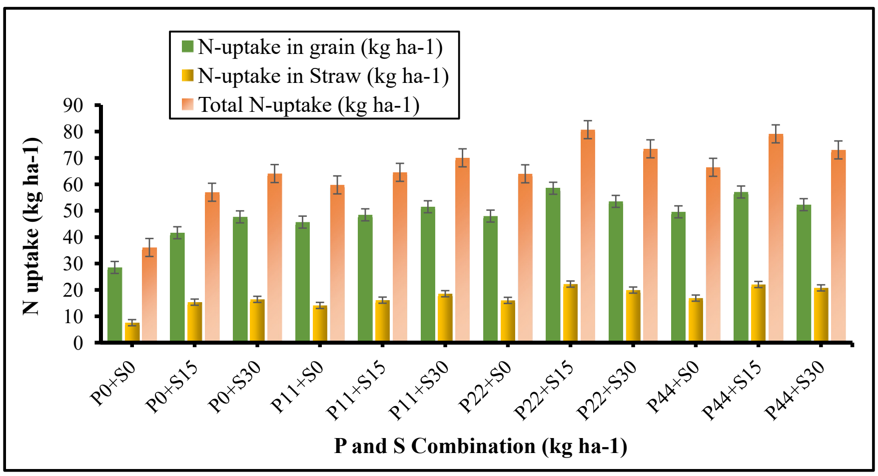

Figure 4. Interaction effects of P and S, on Nitrogen Uptake of Wheat.

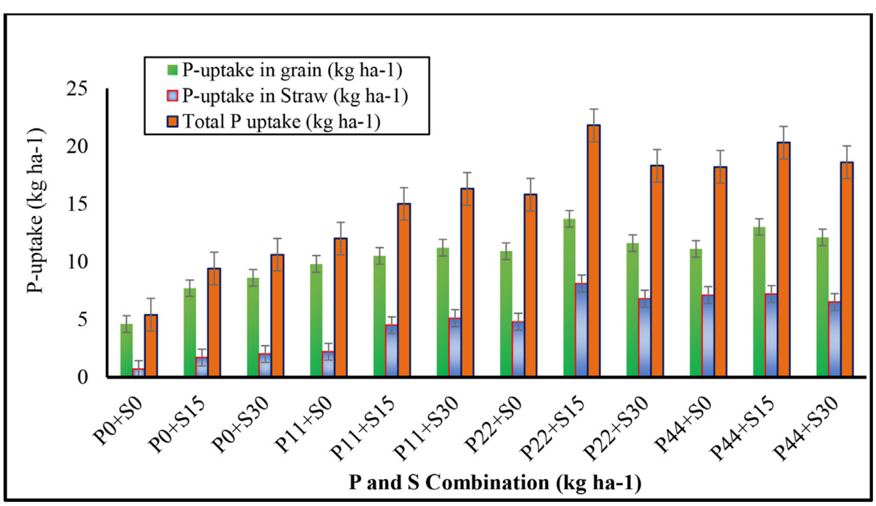

Figure 5. Interaction effects of P and S, on Mean Phosphorus Uptake of Wheat.

3.1. The effects of P and S on grain and straw yield of wheat

Grain and Straw yield were significantly influenced by the main effects of P, **S**, as well as their interaction rate (Table 6). The grain yield as influenced by different levels of P and S are presented in Figure 3. The addition of 22 kg P ha^{-1} with 15 kg S ha^{-1} produced maximum grains yield (3526.8 kg ha^{-1}) which was significantly differed from other treatment combination except, 22P+30S, 44P+15S and 44P+30

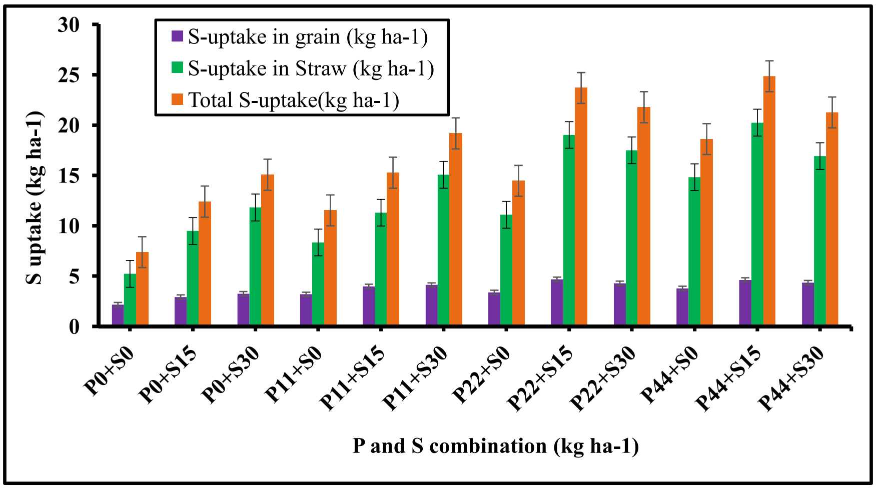

Figure 6. Interaction effects of P and S, on Mean Sulfur Uptake of Wheat.

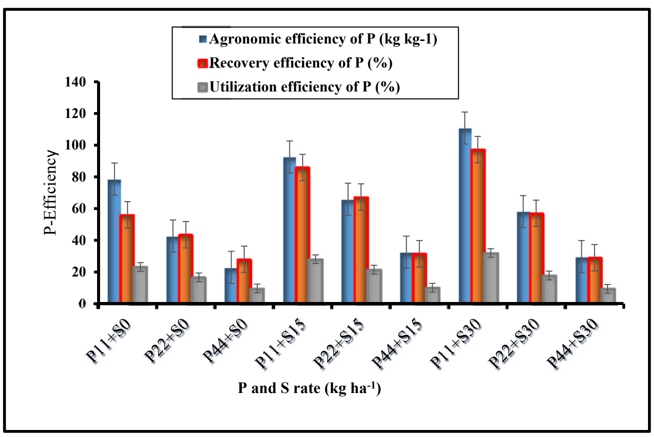

Figure 7. Effect of P and S rate on Phosphorus efficiency indices of wheat.

S kg ha^{-1}. This treatment has a yield advantage of 40.1% over control treatment. However, grain yield become decreased numerically as interactive application rate of P and S beyond 22P and 15S kg ha^{-1}. The minimum grains yield (2076.7 kg ha^{-1}) was recorded in control plot (untreated with P and S) shown in Figure 3. The straw yield of wheat was also influenced significantly ($P \leq 0.01$) by different levels of P and S application interactively. The higher straw yield (5120.0 kg ha^{-1}) was produced where treatment receiving 22 kg P ha^{-1} and 15 kg S ha^{-1} interactively (Figure 3) which have straw yield advantage of 53.4 % over control treatment. Similar trends were also observed like grain yield due to the influence of different P and S application rates. The minimum straw yield (2385.6 kg ha^{-1}) was recorded in control plot.

Table 2. Effects of P and S on grain protein contents of wheat.

S-Levels kg ha^{-1}	P-Levels kg ha^{-1}				Mean
	0	11	22	44	
0	7.8b	8.6ab	9.3ab	9.4a	8.77b
15	9.1ab	9.1ab	9.3ab	9.4a	9.2a
30	9.1ab	9.4ab	9.8a	9.77a	9.5a
Mean	8.7c	9.0b	9.5a	9.6a	
CV (%)	**6.25**				

3.2. The effects of P and S on nutrient uptake

3.2.1. Nitrogen uptake

Nitrogen uptake due to main effect of P and S as well as interaction of P and S rate in grain, straw was significantly ($P < 0.01$) different (Table 6). Interaction effect of P with S significantly increased the uptake of N in grain, Straw and total (Figure 4). Combined application of 22 kg P with 15 S kg ha^{-1} gave the highest N uptake (56.3 kg ha^{-1}) in grain over lower rates and control, more uptake of N was observed in grain compared to straw. It might be due to higher concentration of N in grain compared to straw. Similarly, N uptake by straw increased with increasing combined application P and S. However, the uptake N was not significantly different beyond the application of 22 kg P with 15 kg S kg ha^{-1}. The maximum total N uptake was observed with integrated application of P and S at 22 kg P with 15 kg S ha^{-1}. This might be due to the fact that favorable effect of P and S, on N absorption and biomass production of wheat.

3.2.2. Phosphorus uptake

Phosphorus uptake in grain, straw and total were significantly ($p < 0.01$) influenced by main effects of various level of P and S and their interaction (Table 6). Phosphorus uptake due to different levels of P and S application interactively in grain, straw and total P uptake presented in Figure 5. Combined application of P and S at 22P and 15S kg ha^{-1} gave the highest P uptake of 12.8 & 6.9 kg ha^{-1} in grain and straw respectively. However, it is statistically similar as the combined application of P and S increased above 22P with 15S kg ha^{-1}. More uptake of P was noted in grain compared to straw. It also might be due to higher concentration of P in grain compared to P concentration in straw. In case of total P uptake, there was also maximum P uptake noted with interaction application of P and S at of 22 kg P and 15 kg S ha^{-1}.

3.2.3. Sulfur uptake

Sulphur uptake was significantly ($P < 0.01$) influenced by main effect of P and S in wheat grain and straw. Similarly, their interaction effect was significantly influenced S uptake by grain and straw and, total at $P < 0.05$, and $P < 0.01$ respectively (Table 6). Data regarding to S uptake by grain, straw and total presented in Figure 6. The S uptake varied from 1.8 to 4.2 and 3.8–14.8 kg ha^{-1} in, grain and straw respectively due to interacted application of P and S. The highest S uptake (4.2 kg ha^{-1}) in grain was obtained with combined application of P and S at 22 kg P and 15 kg S ha^{-1} followed by 44 kg P and 15 kg S ha^{-1} (4.1 kg ha^{-1}), while, the lowest one (1.8 kg ha^{-1}) was recorded in treatment that don't received any P and S fertilizers (control). The maximum S uptake (14.8 kg ha^{-1}) in straw was produced by combined application of P and S, at 44

Table 3. Main effect of different P and S levels on yield and nutrient uptake of wheat.

P Levels (kg ha^{-1})	GY	STY	NUG	NUS	TNU	GPC	PUG	PUS	TPU	SUG	SUS	TSU
0	2575.7c	3294.6c	37.4c	11.5c	48.9c	8.2c	6.5c	1.2c	7.6c	2.3c	6.7d	9.0d
11	3110.7b	4121.8b	46.9b	14.7b	61.6b	8.6b	10.1b	3.6b	13.7b	3.3b	8.9b	12.2b
22	3299.6a	4589.6a	51.1a	16.8a	67.9a	8.8a	11.5a	5.7a	17.2a	3.6a	12.0b	15.6b
44	3324.1a	4690.6a	0.6a	17.3a	67.9a	8.7a	11.6a	6.3a	17.9a	3.7a	13.3d	17.0a
S Levels (kg ha^{-1})												
0	2779.1b	3456.2b	40.9b	12.6b	53.5b	8.3b	8.5b	3.4b	11.9b	2.6b	7.6b	10.3b
15	3212.5a	4525.5a	49.3a	16.4a	65.7a	8.7a	10.6a	4.7a	15.3a	3.6a	11.3a	14.8a
30	3240.9a	4540.8a	49.3a	16.2a	65.5a	8.7a	10.5a	4.5a	15.1a	3.5a	11.8a	15.2a
CV (%)	5.2	6.1	7.1	11.5	5.7	5.5	7.7	21.8	9.1	10.0	15.49	11.95

BY = Biomass yield, GY = grain yield, STY = Straw yield, NUG = Nitrogen uptake by straw, NUS = Nitrogen uptake by straw, TNU = Total Nitrogen uptake, PUG = Phosphorus uptake by grain, PUS = Phosphorus uptake by straw, TPU = Total Phosphorus uptake, SUG = Sulfur uptake by grain, SUS = Sulfur uptake by straw, TSU = Total Sulfur uptake.

Table 4. Main effect of different P and S levels on P and S use efficiency of wheat.

P-Levels (kg ha^{-1})	AEP (kg kg^{-1})	REP (%)	PUE (%)	AES (kg kg^{-1})	RES (%)	SUE
0	-	-	-	23.8c	16.0c	5.2c
11	94.0a	79.7a	27.8a	36.2b	25.6b	8.5b
22	55.6b	55.9b	18.6b	46.4a	41.4a	12.9a
44	28.3c	29.5c	9.7c	46.3a	42.3a	13.3a
S-Levels (kg ha^{-1})						
0	36.0b	31.9b	12.3	-	-	-
15	47.7a	46.2a	14.9	75.7a	61.8a	19.6a
30	49.7a	45.8a	14.8	38.8b	32.2b	10.4b
CV (%)	22.0	20.7	27.1	17.8	24.2	26.8

CV = Coefficient of Variation, AEP = Agronomic efficiency of phosphorus, REP = Recovery efficiency of phosphorus, PPE, Physiological phosphorus efficiency, PUE = Phosphorus utilization efficiency, AES = Agronomic efficiency of Sulfur, RES = Recovery efficiency of Sulfur, SUE = Sulfur utilization efficiency, GPC = grain protein content.

Table 5. Correlation coefficients of each parameters.

	GY	STY	NUG	NUS	TNU	PC	PUG	PUS	TPU	SUG	SUS	TSU	PAE	PRE	SAE	SRE
GY	1															
STY	0.823**	1														
NUG	0.948**	0.845**	1													
NUS	0.739**	0.927**	0.774**	1												
TNU	0.925**	0.920**	0.975**	0.896**	1											
PC	0.528**	0.583**	0.766**	0.562**	0.736**	1										
PUG	0.952**	0.827**	0.912**	0.767**	0.911**	0.518**	1									
PUS	0.742**	0.800**	0.746**	0.748**	0.787**	0.473**	0.84**	1								
TPU	0.885**	0.848**	0.866**	0.79**	0.887**	0.517**	0.961**	0.958**	1							
SUG	0.835**	0.873**	0.861**	0.836**	0.899**	0.579**	0.84**	0.757**	0.833**	1						
SUS	0.657**	0.869**	0.724**	0.875**	0.817**	0.559**	0.704**	0.737**	0.751**	0.857**	1					
TSU	0.698**	0.887**	0.760**	0.886**	0.846**	0.573**	0.739**	0.754**	0.778**	0.896**	0.997**	1				
PAE	0.489**	0.33*	0.456**	0.253*	0.409**	0.244*	0.492**	0.311*	0.42**	0.402**	0.137ns	0.182ns	1			
PRE	0.530**	0.449**	0.510**	0.380**	0.492**	0.294*	0.584**	0.495**	0.564**	0.497**	0.284*	0.323*	0.948**	1		
SAE	0.613**	0.595**	0.596**	0.465**	0.582**	0.333*	0.550**	0.418**	0.506**	0.570**	0.403**	0.437**	0.256*	0.304**	1	
SRE	0.600**	0.749**	0.638**	0.661**	0.681	0.436**	0.604**	0.545**	0.599**	0.700**	0.699**	0.713**	0.189ns	0.29*	0.875**	1

kg P and 15 kg S ha^{-1} and followed by 22 kg P and 15 kg S ha^{-1} (17.1 kg ha^{-1}). Based on total S uptake, interacted application of P and S at 44 kg P and 15 kg S ha^{-1} gave the highest S uptake; but it was statistically similar with S uptake obtained by application of P and S at 22 kg P and 15 kg S ha^{-1}. Generally, interaction of different P and S levels increased the uptake of S significantly over control.

3.3. The effects of P and S on P and S use efficiencies

3.3.1. Phosphorus use efficiency

Agronomic of Efficiency (AE) is an economic term which indicated that the direct production impact of an applied fertilizer on the production of crops. The AE of P on wheat was statistically significant ($P < 0.01$)

Table 6. Mean squares of combined analysis of variance for the effects of P and S level on different parameters of bread wheat.

Parameters	Mean squares for sources of variation with respective degrees of freedom in parenthesis								
	L (1)	Rep in L (2)	P (3)	S (2)	P*S (6)	L*P (3)	L*S (2)	L*P*S (6)	Error (46)
GY	316325**	11538	2178333**	1607309**	151955**	28159^{ns}	57317^{ns}	29746^{ns}	21512
STY	9452024**	100113	7293954**	9279709**	268525**	216326*	639151**	160578*	58930
NUG	292.1**	17.9	725.8**	571.3**	66.8**	2.2^{ns}	0.3^{ns}	9.1^{ns}	10
NUS	318.9**	0.4	124.7**	110.3**	6.8^{ns}	6.1^{ns}	19.7**	3.8^{ns}	3.0
TNU	1221.3**	23.4	1442.7**	1182.9**	113.3**	15.3^{ns}	18.4^{ns}	15.8^{ns}	12.2
GPC	2.2**	0.3	1.2**	1.2**	0.4^{ns}	0.3^{ns}	0.3^{ns}	0.2^{ns}	0.2
PUG	17.2**	0.4	104.4**	34.4**	2.9**	0.01^{ns}	0.5^{ns}	0.4^{ns}	0.6
PUS	20.3**	1.8	97.5**	11.4**	4.7**	1.3^{ns}	0.9^{ns}	0.2^{ns}	0.8
TPU	74.8**	1.6	398.3**	85.5**	8.8**	1.6^{ns}	1.1^{ns}	0.8^{ns}	1.6
Parameters	**L (1)**	**Rep in L (2)**	**P (3)**	**S (2)**	**P*S (6)**	**L*P (3)**	**L*S (2)**	**L*P*S (6)**	**Error (46)**
SUG	17.9**	0.2	7.2**	6.3**	0.2^{ns}	0.01^{ns}	0.012^{ns}	0.01^{ns}	0.1
SUS	727.4**	2.1	161**	122.9**	12.9**	15.3**	15.7**	2.4^{ns}	2.5
TSU	973.6**	3.5	231.5**	183.8**	16.1**	16.4**	16.1**	2.2^{ns}	2.6
GPC	22.012	0.942	3.628**	2.352**	1.946**	5.513**	0.019^{ns}	0.433^{ns}	0.331
AES	54.7^{ns}	721.5	2066.2**	34406.7**	1065**	86.7^{ns}	17.4^{ns}	22.5^{ns}	46
RES	4448.8**	151.9	2941**	22944**	1635**	305.3**	1537.9**	177.2**	57.4
SUE	283.8**	45.3	271.1**	2316.2**	167.5**	17.9^{ns}	103.1**	9.6^{ns}	7.7
GPC	22.012	0.942	3.628**	2.352**	1.946**	5.513**	0.019^{ns}	0.433^{ns}	0.331

BY = Biomass yield, GY = grain yield, STY = Straw yield, NUG = Nitrogen uptake by straw, NUS = Nitrogen uptake by, straw TNU = Total Nitrogen uptake, PUG = Phosphorus uptake by grain, PUS = Phosphorus uptake, by straw TPU = Total Phosphorus uptake, SUG = Sulfur uptake by grain, SUS = Sulfur uptake by straw, TSU = Total Sulfur uptake, AEP = agronomic efficiency of Phosphorus, REP = recovery efficiency of phosphorus, PUE = phosphorus utilization efficiency, AES = agronomic efficiency of Sulfur, RES = recovery efficiency of sulfur, SUE = sulfur utilization efficiency = GPC = grain protein.

due to different levels of P and S application (Table 6). Agronomic efficiency decreased as the rates of P application increased in all observed treatments. Data regarding to phosphorus agronomic efficiency presented on Figure 7. The results revealed that lower AE of P was seen at higher P rates and vice versa. The maximum AE of P (110.8 kg kg^{-1}) was observed at 11 kg P combined with 30 kg S ha^{-1} and it decreased significantly at higher P rates. This revealed that combined application of phosphorus with sulfur enhanced agronomic efficiency of wheat over control and main effect of P. However, the least AE of P value (22.9 kg kg^{-1}) was noted at maximum dosage of P (44 kg ha^{-1}) without sulfur.

Apparent recovery efficiency (ARE) is another nutrient use efficiency index and commonly defined as the difference in nutrient uptake in above-ground parts of the plant between the fertilized and unfertilized crop relative to the quantity of nutrient applied. The present study revealed that ARE of P significantly ($P < 0.01$) varied in response to P, S and their interaction (Table 6). Data regarding to apparent recovery efficiency of P presented on Figure 7. The highest apparent recovery efficiency of 97.2% was obtained with application of 11 kg P with 30 kg S ha^{-1} and lowest one (28.0%) with application of 44 kg P ha^{-1} without S. Apparent recovery efficiency of P was considerably affected by S levels at all P levels. Increasing levels of P was decrease the ARE of P at given S level. With keeping P at 11 kg ha^{-1}, ARE of P was significantly increased with increasing levels of S. Apparent recovery efficiency of P highly enhanced with the application of S because of the synergistic effect in between P and S at low levels of P.

Data on phosphorus utilization efficiency (PUE) of wheat are given in Figure 7. The results revealed that lower PUE was seen at higher P and S rates. The maximum PUE of 28.1 % was observed at 11 kg P ha^{-1} combined with 15 kg ha^{-1} S and it decreased at higher P and S rates.

3.3.2. *Sulfur use efficiency*

Different indices of Sulfur Use Efficiency of the conducted experiment are given in Figure 8. Sulfur Agronomic Efficiency (AE) was considerably affected by S levels at all P levels (Table 6). Increasing levels of S was decrease the S agronomic efficiency at given P level. As application levels of P increase up to 22 kg ha^{-1}, significantly increased the agronomic Use Efficiency of S with keeping S at 15 kg ha^{-1}. The maximum agronomic efficiency of S (96.7 kg kg^{-1})) was obtained in the plots receiving 22 kg P ha^{-1} in combination with 15 kg S ha^{-1} followed by 95.3 (kg kg^{-1}) in the plots receiving 44 kg P ha^{-1} in combination with 30 kg S ha^{-1}. While minimum (28.4 (kg kg^{-1}) was noted in the plots receiving only 30 kg S ha^{-1}. Application of P and S at a rate of 22 P kg ha^{-1} with 15 S kg ha^{-1} and 44 P kg with 30 S kg ha^{-1} has statistically similar results. AE of S declined significantly when the level of S was raised from 15 to 30 kg S ha^{-1}.

Apparent recovery efficiency (ARE) of S provides the quantity of nutrient uptake per unit of nutrient applied. The highest recovery efficiency (89.0%) of S was noted due to combined application of P and S at 44 kg P ha^{-1} with 15 kg S ha^{-1}. However, the lowest recovery efficiency (20.9 %) was noted due to application of S at 30 kg ha^{-1} with 0 kg P ha^{-1}.

Sulfur utilization efficiency (SUE) of wheat significantly affected by combined application of P and S (Table 6). Data regarding to SUE of wheat presented on Graph 8. The result revealed that increasing levels of P, increased SUE at a given level of S. But with increasing application rate of S from 15 to 30 kg ha^{-1} SUE become declined. Maximum SUE (28.0 %) was noted in the plots receiving 44 kg P ha^{-1} in combination with 15 kg S ha^{-1} followed by 27.7 % in the plots receiving 22 kg P ha^{-1} in

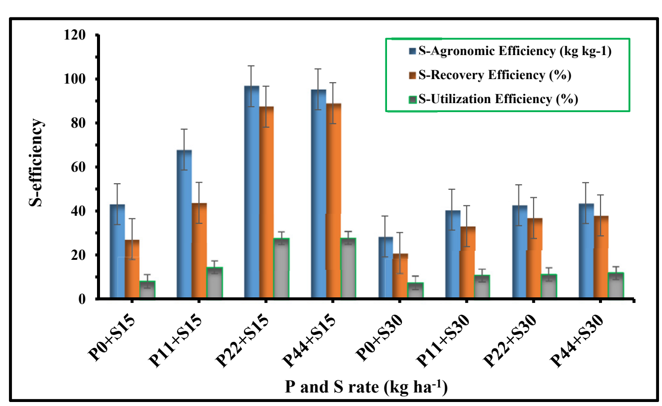

Figure 8. Effects of P and S, on Sulfur efficiency indices of wheat.

combination with 15 kg S ha^{-1} while minimum (7.4 %) was noted in the plots receiving 30 kg S ha^{-1} without P.

3.4. Effects of P and S on grain protein content (GPC) of wheat

Protein content due to various single P, S and their interaction showed highly significant ($P < 0.01$) difference (Table 6). The protein content affected by single P, S and their interaction as presented in Table 2. Application of S at 15 and 30 kg ha^{-1} increased the grain protein content of wheat by 4.3 and 7.4% over control respectively. This indicates that application of different S levels increased grain protein content of wheat over control. Similarly, grain protein content was varied with P levels. The highest protein content (9.6%) obtained from treatment that received P at 44 kg ha^{-1}. The second highest protein content (9.5%) was recorded at 22 kg P ha^{-1} but statistically similar with 44 kg P ha^{-1}. This implies that application of P beyond 22 kg ha^{-1} not significantly increased grain protein content. In contrast the lowest protein grain content obtained in control.

The data on grain protein content influenced by P and S interaction are presented in Table 2. The combined application of 22 kg P ha^{-1} with 15 kg S ha^{-1} produced maximum grain protein content (9.8%). This treatment has a grain protein content increment of 20.4% over control treatment. The minimum grain protein content (7.8%) was recorded in control plot. This implies that combined application of P with S improves grain protein content of bread wheat than individual application of P and S, this showed synergistic effect of P and S on each other as both the nutrients mutually helps in their absorption and utilization to give better grain protein content of wheat.

3.5. Partial budget analysis

Partial budget analysis allows assessing the impact of a change in the production system on a farmer's net income without knowing all his costs of production. The data related to partial budget analysis is given in Table 7. The maximum net benefit (45351.7 ET Birr) was obtained from combined application of P and S at the rate of 22 kg P and 15 kg S ha^{-1} and followed by rate of 44 kg P and 15 kg S ha^{-1} (44128.3 ET Birr.). Minimum net benefit (25697.4 ET Birr.) was recorded in control (treatment that did not receive any S and P fertilizers).

Depend on dominancy analysis, treatments of S and P at 15 kg S without P, 44 kg P without S, 30 kg S without P, 30 kg S with 22 kg P, 15 kg S with 44 kg P, 30 kg S with 44 kg P, 30 kg S with 11 kg P ha^{-1} and control were dominated by the rest four treatments and they were also excluded from further economic analysis. The data regarding the marginal rate of return (MRR) revealed that maximum MRR (5490%) was obtained when P and S was applied at the combined rate of 15 kg S and 22 kg P ha^{-1} followed by rate of 11 kg P ha^{-1} without S (2502%). Minimum MRR was (175%) recorded in treatment where application of P at 22 kg ha^{-1} without S. Data from Table 7 clearly revealed that the non-dominated treatments associated with MRR are greater than 100%. This implies that the four non-dominated treatments are economically feasible alternative to the other dominated treatments. The marginal rate of return, 5490 % means the producer obtained an additional income of 54.9 Ethiopian birr per a unite cost they have invested. Generally, treatment combination of S and P at 15 kg S and 22 kg P ha^{-1}gave better MRR value relative to the other four non-dominated treatments and profitability can be optimized by using this treatment.

4. Discussions

Nutrient interaction in crop is probably one of the most important factors affecting yields of annual crops (Fageria, 2014). Soil nutrients interaction affects their availability to crops as on overabundance one may result in deficiency of another nutrients (Karimizarchi et al., 2014). Application of P fertilizers results in increased of anion adsorption sites by phosphate which releases sulfate ions into the soil solution and phosphate ion is more strongly bound than sulfate (Tiwari and Gupta, 2006). Different combination of P and S revealed significant influence on grain and straw yield of wheat. In the present study the synergism and antagonism relationship between P and S fertilizer levels on wheat yield was observed. Synergism relationship was observed where treatment receiving up to 22 kg P with 15 kg S ha^{-1}. Interacted application of P and S at 22 P and 15 S kg ha^{-1} increased grain and straw yield of wheat by 40.1 and 53.4 % respectively over control. The beneficial synergism relationship reported by Randhawa and Arora (2000) and Phogat et al. (2018) where P and S interaction significantly improved grain and straw yield of wheat. It was also observed from another studies that significantly the maximum grain yield was produced when wheat crop was fertilized with 90 kg P2O5 ha^{-1} with 40 kg S ha^{-1} (Bairwa et al., 2018). The authors (Hussain and Leitch, 2005) who stated that grain yield improved with phosphorus use and those plots receiving 90 kg P ha^{-1} gave maximum grain yield as compared to lower dose. Furthermore, the authors (Khan et al., 2006) reported that 43% raise in grain yield with the addition of 90 kg P and 60 kg ha^{-1} S. In addition, combined application of P and S at 50 kg P_2O_5 and 20 kg S ha^{-1} improve yield of wheat over control (Sandeep et al., 2017). Similarly, the interaction of P and S levels increased their beneficial synergistic effect and applying of the individual S level with P level produced increases in the grain yield of wheat (Ibrahim et al., 2012). The variation of P and S levels may affect yields in different field trials in the diver's location of the soils. Antagonism

Table 7. Partial budget Analysis for Phosphorus and Sulfur fertilizers Studied area.

Treatment	Adj. GY	Adj. STY	GBGY	GBSTY	TVC	TGB	NB	MRR
S_0P_0	2076.7	2385.6	21805.6	5558.5	1666.6	27364.0	25697.4	D
S_0P_{11}	2941.5	3554.9	30885.9	8282.8	2120.2	39168.7	37048.5	25.0
S_0P_{22}	3016.0	3754.7	31667.7	8748.5	2573.7	40416.1	37842.4	1.8
$S_{15}P_0$	2722.9	3666.7	28590.3	8543.5	2706.4	37133.8	34427.5	D
$S_{15}P_{11}$	3094.8	4233.5	32495.0	9864.1	3148.0	42359.1	39211.1	10.8
S_0P_{44}	3082.3	4129.7	32363.8	9622.3	3484.7	41986.1	38501.4	D
$S_{15}P_{22}$	3526.8	5120.0	37031.6	11929.5	3609.4	48961.2	45351.7	54.9
$S_{30}P_0$	2927.4	3831.6	30737.7	8927.7	3748.6	39665.4	35916.7	D
$S_{30}P_{11}$	3295.7	4576.9	34604.9	10664.2	4190.3	45269.1	41078.8	D
$S_{15}P_{44}$	3505.6	5081.6	36808.5	11840.2	4520.4	48648.7	44128.3	D
$S_{30}P_{22}$	3356.0	4894.2	35237.7	11403.5	4651.7	46641.2	41989.5	D
$S_{30}P_{44}$	3384.4	4860.6	35535.8	11325.1	5558.9	46860.9	41302.0	D

Adj.GY = Adjusted grain yield (kg ha^{-1}), Adj. STY = Adjusted Straw yield (kg ha^{-1}) TGB = Total growth benefit, TVC = Total variable cost, NB = Net benefit, MC = marginal cost, MB = marginal benefit, MRR = marginal rate of return, P0 = 0 kg ha^{-1}P, P11 = kg ha^{-1}11P, P22 = 22 kg ha^{-1}P, P44 = 44 kg ha^{-1} phosphorus, S0 = 0 kg S ha^{-1}, S15 = 15 kg S ha^{-1}, S30 = 30 kg S ha^{-1}.

relationship was also observed in the present study at higher rates of P and S fertilizer. Findings from this study shows that application of P and S on vertisols beyond 22 kg P with 15 kg S ha^{-1} result in reduction of wheat yield. Interactive application of P and S at higher rate (44P + 30 S kg ha^{-1}) showed reduction in grain and straw yield of wheat. Similarly, Islam (2006) who reported that application of P and S at higher rate (35.2 kg P and 40 kg S ha^{-1}) showed reduction in wheat yields.

Interaction among plant nutrients can yield antagonistic or synergistic outcomes that influence nutrient uptake and use efficiencies (Rietra et al., 2017). Results from the present study revealed that, interaction of P with S significantly increased the uptake of N in grain and Straw. Combined application of 22 kg P with 15 S kg ha^{-1} gave the highest N uptake by grain over lower rates and control. Previous study has showed that the application of P and S improved the N uptake (Singh et al., 1999). While, the uptake of N showed a decreasing at higher rates of P and S (44P and 30 S kg ha^{-1}). This implies that, beyond 22 kg P and 15 kg S ha^{-1} failed to increase in total N uptake and it was declined which might be due to inhibition effect of higher doses of S on N uptake (Dwivedi and Bapat, 1998).

In the present study, the P uptake in grain and straw significantly improved with combined application of P and S fertilizer. The uptake of P lower at higher P and S application and vice versa. Application of P and S cause significant increase in total P uptake up to 22 kg P and 15 kg S ha^{-1}. The interaction of both P and S produced significant steady increases in P uptakes by both straw and grains (Ezzat, 2016; Teotia et al., 2000). In the current finding, the uptake of P showed a decreasing trend at higher rates of P and S (44P and 30 S kg ha^{-1}). This probably due to competition between these two anions for adsorption sites on soil colloids at higher levels of S application (Bapat et al., 1986). The interaction between P and S on wheat yield has also reported by Randhawa and Arora (2000) who revealed that highly significant positive interaction was obtained between P and S in terms of total P uptake at lower rates of S application and higher rates of S resulted in a decreased total P uptake. The synergistic effect of P and S on each other as both the nutrients mutually helps in their absorption and utilization probably due to balanced nutrition (Mamta et al., 2017). Similarly, Mandai et al. (2002) reported that P and S interaction is synergistic at low to medium level of P and antagonistic only at higher levels. Significantly, positive interaction was obtained between P and S in terms of P uptake at lower rates of application and at higher combinations reduced P uptake (Islam et al., 2006; Randhawa and Arora, 2000; Deo and Khaldelwal, 2009).

The data on the application of P and S levels revealed a significant effect on S uptake in grain and straw of wheat (Table 6). Interaction of different P and S levels increased the uptake of S and more S accumulation noted on in straw than grain (Figure 6). In the current finding, total S uptake improved with application of P and S at 44 kg P and 15 kg S ha^{-1}; but it was statistically similar with S uptake obtained by application of 22 kg P with 15 kg S ha-1. Similarly, previous study by Dash et al. (2015) reported that, accumulation of S, in straw was higher than grain. In addition, other finding reported by Venkatesh et al. (2002) who found that P application with respective S increased the S uptake by which seemed to have induced better root development as well as increased activity of S-oxidizing bacteria. The increasing does of P and S to the higher does (44 kg P and 30 kg S ha^{-1}) did not differ statistically with that of 22 kg P and 15 kg S ha^{-1} and but showed decreasing trend numerically at higher rates of P and S. Similarly, in other finding reported by Randhawa and Arora (2000) showed that the uptake of P or S increased at lower levels of counter ion but decreased at higher rates. Results are in conformity with those of Rahim et al. (2010) and Sandana and Pinochet (2014) who found that at higher P application rates decreased P or S utilization efficiency. In addition, Yashbir et al. (2014) who found that the maximum agronomic efficiency noticed on lower rate (15 kg ha^{-1}) of sulfur and vis versa and crop recovery efficiency declined as the level of S application was increased from 15 to 45 kg S ha^{-1}; it declined from 41.3% at 15 kg ha^{-1} to 29.8% at 45 kg S ha^{-1}. In the present experiment agronomic efficiency of S declined significantly when the level of S was raised from 15 to 30 kg S ha^{-1}.

Data regarding on grain protein content of wheat as affected by various P and S levels are shown in Table 2. Application of P with S improve grain protein content of bread wheat. Jarvan et al. (2008) who reported that increase in protein content of wheat due to maximum supply of S. In current experiment, combined application of P and S improve grain protein content of bread wheat than individual application of P and S, this showed synergistic effect of P and S on each other as both the nutrients mutually helps in their absorption and utilization to give better grain protein content of wheat. The combined application of 22 kg P ha^{-1} with 15 kg S ha^{-1} produced maximum grain protein content and has an advantage of 20.4% over control treatment. While, in other study reported by Ibrahim et al. (2012) interaction of P and S showed no significant effect on grain protein content of wheat.

5. Conclusions

Nutrient mining due to sub optimal fertilizer use in one hand and unbalanced fertilizer uses on other have favored the emergence of multi nutrient deficiency in Ethiopian soils. For the last five decades, Ethiopian agriculture depended solely on imported fertilizer products, only urea and di-ammonium phosphate (DAP), sources of N and P. However, recently it is perceived that the production of such high protein cereals like wheat can be limited by the deficiency of S and other nutrients. Sulfur is a nutrient most overlooked in Ethiopian agriculture and major prone areas of S deficiency are the central highlands. The results of this experiment revealed that application of P and S fertilizer has significantly increased yield, nutrient uptake and nutrient use efficiencies of wheat compared to unfertilized control plot, indicating insufficient soil P and S content for optimum production of wheat. Combined application of P and S produced significantly higher yield of wheat than that obtained with single application of S or P indicating synergistic interaction between these nutrients. But this was true for treatments involving combined applications low level of S and increasing levels of P or vice versa. Otherwise, there was decreasing trend of yield gains with treatments involving at higher levels of both nutrients. In all cases, optimum grain yield of wheat was obtained with treatment involving at 22 P + 15 S kg ha^{-1}. The maximum grain N, P and S uptakes were obtained due to P and S application at rate of 22 P and 15 S kg ha^{-1}. Phosphorus and Sulphur use efficiency indices were also improved significantly by combined application of P and S. While, partial budget analysis result revealed that, combination of 22P and 15S kg ha^{-1} produced the highest MMR (54.9 %) and thus, this treatment is found to be economically feasible treatment for bread wheat production in study area of the district. Based on the results obtained, therefore, P and S fertilization is necessary in the study district and 22 kg P combined with 15 kg S ha^{-1} produced the highest yield of wheat and thus, this treatment is found to be recommended for bread wheat production in Vertisols of the district. We recommend further experiments on different combination of P with S in different agro-ecologies and soil types are required for confirmation of results and the residual effect of P and S on the following crop is needed to study the long-term effect of P and S.

Declarations

Author contribution statement

Shawl Assefa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Wassie Haile; Wondwosen Tena: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

Abu, Tefera, 2012. Ethiopian grain and feed annual report, USDA Forgign Agricultural Services GAIN Report, Global Agricultural information Network, GAIN Report Number. ET1201.
Adamu, Mola., 2018. Response of wheat to NP fertilizer rates, precursor crops and types of *vertisols* in central highlands of Ethiopia. J. Agric. Sci. 10 (4), 1–14.
Akande, M.O., Makinde, E.A., Oluwatoyinbo, F.I., Adetunji, M.T., 2010. Effects of phosphate rock application on dry matter yield and phosphorus recovery of maize and cowpea grown in sequence. Afr. J. Environ. Sci. Technol. 4 (5), 293–303.
Assefa, M., 2016. Sulphur Status of Soils and Wheat Plants in Three Representative Areas of the central highlands of Ethiopia. PhD. Dissertation. University of agriculture, Morogoro, Tanzania, p. 162.
Bairwa, D.D., Modhvadia, J.M., Bhadu, V., 2018. Response of wheat (*Triticum aestivum L .*) to phosphorus and sulphur fertilization. Int. J. Pure Appl. Biosci. 6 (6), 354–357.
Bapat, P.N., SinhaS, B., Shinde, D.A., 1986. Effect of Sulphur and phosphorus on yield and nutrient content. J. Indian Soc. Soil Sci. 34, 82–86.
Benjamin, Wolf, 1982. A comprehensive system of leaf analyses and its use for diagnosing crop nutrient status. Commun. Soil Sci. Plant Anal. 13 (12), 1035–1059.
Bereket, Hailesilassie, Dawit, Habte., Haileselassie, Mehretab, Gebremeskel, Gebremedhin, 2014. Effects of mineral nitrogen and phosphorus fertilizers on yield and nutrient utilization of bread wheat (Tritcum aestivum) on the sandy soils of Hawzen District, Northern Ethiopia. Agric. For. Fish. 3 (3), 189–198.
Birhan, A., Sofiya, K., Temesgen, D., Kassu, T., Mihreteab, H., 2016. Soil fertility management studies on wheat in Ethiopia: a review. Ethiopian J. Nat. Res. 16, 1–23.
Bouyoucos, G., 1962. Hydrometer method improved for making particle size analysis of soils. Agron. J. 54, 464–465.
Bremner, G.M., Mulvarey, C.S., 1982. Nitrogen Total. Prentice Hall, Inc., pp. 95–624
Chapman, H.D., 1965. Cation exchange capacity by ammonium saturation. In: Black, C.A., Ensminger, L.E., Clark, F.E. (Eds.), Method of Soil Analysis. ASA, Madison, pp. 891–901.
CIMMYT (International Maize and Wheat Improvement Center), 1998. From agronomic data to farmer recommendations: An economic workbook. CIMMYT, Mexico.
Cottenie, A., 1980. Soil and Plant Testing as a Basis of Fertilizer Recommendations. FAO soil bulletin 38/2. Food and Agriculture Organization of the United Nations, Rome.
CSA (Central Statistical Agency), 2019. Agricultural Sample Survey 2018/2019 Agricultural Sample Survey. Volume I: Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season), 584. Statistical Bulletin, Addis Ababa.
Dash, A.K., Singh, H.K., Mahakud, T., Pradhan, K.C., Jena, D., 2015. Interaction effect of nitrogen, phosphorus, potassium with sulphur, boron and zinc on yield and nutrient uptake by rice under rice – rice cropping system in *inceptisol* of coastal Odisha. Int. Res. J. Agric. Sci. Soil Sci. 5 (1), 14–21.
DBARC (Debre Birhan Agricultural Research Center), 2007. Ministry of Agriculture and Rural Development. Crop development department Crop variety Register. Issue No. 10.
Deo, C., Khaldelwal, R.B., 2009. Effect of P and S nutrition on yield and quality of chickpea (Cicerarietinum L.). J. Indian Soc. Soil Sci. 57, 352–356.
Dwivedi, A.K., Bapat, P.N., 1998. Sulphur-phosphorus interaction on the synthesis of nitrogenous fractions and oil in soybean. J. Indian Soc. Soil Sci. 46 (2), 254–257.
EIAR (Ethiopian Institute of Agricultural Research), 2007. Crop Production Technologies and Their Application. Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa.
Ezzat, M., 2016. Impact of phosphorus and sulphur application on yield, phosphorus and micronutrients uptake by wheat plants. Assiut J. Agric. Sci. 47 (4), 201–214.
FAOSTAT (Food and Agricultural Organization of the United Nations Statistics), 2015. Food Balance Sheets. FAOSTAT, Rome.
Fageria, N.K., Oliveira, J.P., 2014. Nitrogen, phosphorus and potassium interactions in upland rice. J. Plant Nutr. 37 (10), 1586–1600.
FAO (Food and Agriculture Organization), 2006. Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome.
FAO, 2017. FAOSTAT. FAO, Rome. Available at: http://faostat.fao.org (accessed 15 JanuarySeptember 2017).
Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research. Wiley, New York.
Hedge, D., Murthy, I., 2005. Management of secondary nutrients. Indian J. Fert. 9, 90–100.
Hussain, Z., Leitch, M.H., 2005. The effect of applied sulfur on the growth, grain yield and control of powdery mildew in spring wheat. Ann. Appl. Biol. 147 (1), 49–56.
Iqtidar, H., Khan, M., Khan, E., 2006. Bread wheat varieties as influenced by different nitrogen levels. J. Zhejiang Univ. Sci. B. 7 (1), 70–78.
Ibrahim, M., Ullah, H., Ahmad, B., 2012. Effect of incremental dose of phosphorous and sulphur upon yield and protein content of wheat. Biol. Divers. Conserv. 5 (3), 76–81.
Islam, M.N., Hoque, S., Islam, A., 2006. Effect of P× S interactions on nutrient concentration and yield of wheat, rice and mung bean. J. Indian Soc. Soil Sci. 54 (1), 86–91.
Jarvan, M., Edesi, L., Adamson, A., Lukme, L., Akk, A., 2008. The effect of Sulphur fertilization on yield, quality of protein and baking properties of winter wheat. Agron. Res. 6/2, 459–469.
Jones, B.J.J., 2001. Laboratory Guides for Conducting Soil Tests and Plant Analysis. CRC Press, London, p. 363.
Karimizarchi, M., Aminuddin, H., Khanif, M.Y., Radziah, O., 2014. Elemental sulphur application effects on nutrient availability and sweet maize (Zea mays L.) response in a high pH soil of Malaysia. Malaysian J. Soil Sci. 18, 75–86.
Khan, M.J., Khan, M.H., Khattak, R.A., 2006. Response of maize to different levels of sulfur. Soil Sci. Plant Anal. 37, 41–51.
Landon, J.R., 1991. Booker Tropical Soil Manual: a Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York, p. 474. OR John Wiley & Sons Inc., New York.
Mamta, P., Rai, A.P., Sunil, K., 2017. Interaction effect of phosphorus and Sulphur application on nutrient uptake, yield and yield attributing parameters of black gram [*Vigna mungo* (L.) Hepper]. Arcc, J. www.legumeresearch.in.
Mandai, K., Ghosh, P., Wanjari, R., Hati, K., Bandyopadhyay, K., Misra, A., 2002. Practical implication of nutrient x nutrient interaction to boost oilseeds productivity in India. Fertil. News 47, 13–26.
Minale, Liben., Alemayehu, A., Tilahun, T., Abreham, M., 2006. Effect of Nitrogen and phosphorus fertilizers on the yield of bread wheat (Triticum aestivum) in major wheat growing areas of northwestern Ethiopia. In: Proceedings of the 1st Annual Regional Conference on Completed Crop Research Activities. Amhara Regional Agricultural Research Institute, Bahir Dar, Ethiopia, pp. 84–90.
NSL (National Soil Laboratory), 1994. Manual for plant analysis and interpretation. Food and Agriculture Organization of the United Nations, Addis Ababa.
Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A., 1954. Estimation of available phosphorus in soils by extraction with sodium carbonate. USDA Circular 939, 1–19.
Phogat, M., Rai, A.P., Kumar, S., 2018. Interaction effect of phosphosrus and sulphur application on nutrient uptake , yield and yield attributing parameters of black gram [Vigna mungo (L .) Hepper]. Legume Res.-An Int. J. 212–220.
Rahim, A., Ranjha, A.M., Rahamtullah, Waraich, E.A., 2010. Effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency. Soil Environ. 29 (1), 15–22.
Rakshit, A., Singh, H.B., Sen, A., 2015. Nutrient Use Efficiency: from Basics to Advances, 417. Springer, New Delhi.
Randhawa, P.S., Arora, C.L., 2000. Phosphorus-sulfur interaction effects on dry matter yield and nutrient uptake by wheat. J. Indian Soc. Soil Sci. 48, 536–544.
Rietra, R.P.J.J., Heinen, M., Dimkpa, C.O., Bindraban, P.S., Rietra, R.P.J.J., Heinen, M., Dimkpa, C.O., Prem, S., 2017. Communications in soil science and plant analysis effects of nutrient antagonism and synergism on yield and fertilizer use efficiency effects of nutrient antagonism and synergism on yield and. Commun. Soil Sci. Plant Anal. 48 (16), 1895–1920.
Sandaña, P., Pinochet, D., 2014. Grain yield and phosphorus use efficiency of wheat and pea in a high yielding environment. J. Soil Sci. Plant Nutr. 14 (4), 973–986.
Sandeep, K.Y., Ghanshyam, S., Rajeev, K., Pradeep, K., Brij, M., 2017. Effect of phosphorus, sulphur and zinc on growth, yield and yield attributes of wheat *Triticum aestivum*). Int.J. Curr. Microbiol. App. Sci. 6 (8), 2581–2584.
SAS Institute Inc, 2011. Companion for Windows. Cary, NC: SAS Institute Inc., Cary, NC, USA.
Sharma, N., Singh, R., Kumar, K., 2012. Dry matter accumulation and nutrient uptake by Wheat (Triticum aestivum L.) under Poplar (Populus deltoides) based agroforestry system. Agronomy, 359673.
Singh, P., Garg, A., Raman, M., Agrawal, D., 1999. Effect of replacing barley grain with wheat bran on intake and utilization of nutrients in adult sheep. Small Rumin. Res. 31 (3), 215–219.
Sinha, R., Sakal, R., Kumar, S., 1995. Sulphur and phosphorus nutrition of winter maize in calcareous soil. J. Indian Soc. Soil Sci. 43, 413–418.
Tadesse, W., Bishaw, Z., Assefa, S., 2018. Wheat production and breeding in Sub-Saharan Africa climate change, 11 (5), 696–715.
Tandon, H.L.S., 1991. Sulphur Research and Agricultural Production in India, third ed. The Sulphur Institute, Washington DC, USA, p. 200.
Tekalign, M., Haque, I., 1991. Phosphorus status of some Ethiopian soils. III: evaluation of soil test methods for available phosphorus. Trop. Agric. 68, 51–56.

Teotia, U.S., Mehta, V.S., Srivastava, P.C., 2000. Phosphorus-Sulphur interaction in moongbean (*Vigan radiate L.* Wilczek): I. Yield, phosphorus and Sulphur contents. Legume Res. 23, 106–109.

Tilahun, Tadesse., Minale, Liben., Assefa, Alemayehu, Mariye, Abreham, 2006. Maize fertilizer response at the major maize growing areas of northwest Ethiopia. In: Proceedings of the 1st Annual Regional Conference on Completed Crop Research Activities,14 to 17 August 2006. Amhara Regional Agricultural Research Institute Bahir Dar, Ethiopia.

Tiwari, K.N., Gupta, B.R., 2006. Sulphur for sustainable high yield agriculture in Uttar Pradesh. Indian J. Fertilizer 1, 37–52.

Venkatesh, M.S., Majumdar, B., Kumar, Kailash, Patiram, 2002. Effect of Sulphur, phosphorus and molybdenum on yield and nutrient uptake by black gram. Indian J. Hill Farmg 15 (2), 61–67.

Walkley, A., Black, I., 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29–37.

Yashbir, Singh Shivay, Prasad, Rajendra, Pal, Madan, 2014. Effect of levels and sources of sulfur on yield, sulfur and nitrogen concentration and uptake and S-use efficiency in basmati rice. Commun. Soil Sci. Plant Anal. 45 (18), 2468–2479.