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Research paper

Phosphorus and Sulphur uptake and utilization efficiency in response to Lentil (*Lens culinaris* Medikus) productivity in central highlands of Ethiopia

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Recently, one of the causes of the current stagnating yield levels of lentil is the deficiency or imbalance of essential plant nutrients. To provide insight on this phenomenon, a field experiment was conducted to evaluate the effect of phosphorus and Sulphur fertilization on lentil productivity and determine the P and S uptake and utilization efficiency of lentil. The experiment consisted of four levels of P (0,10,20 and 30 kg P ha^{-1}) and three levels of S (0, 20 and 40 kg S ha^{-1}) in RCBD with factorial arrangement of treatment combinations and replicated three times. The results revealed that interaction of P and S at 20/20 kg ha^{-1} application enhanced grain yield, P uptake in grain and haulm and S uptake in haulm over the other interaction as well as the main effect. Similarly, grain S uptake, P and S recovery efficiency and harvest index of lentil were significantly enhanced among the combined of P and S fertilization. Individual agronomic efficiency of P and S were also improved at the lower rate of P and S, but it decreased with increasing P and S levels, respectively. Even if, the partial budget analysis suggested that separate P and S application were cost-effective as compared to combined application, the present finding signified that fertilizer use efficiency, nutrient uptake and grain yield of lentil improved by the joint application of phosphorus and Sulphur. Therefore, further trials are required to formulate comprehensive suggestions concerning accurate ratio of the P and S on lentil production.

Keywords: Agronomic Efficiency; Nutrient Harvest index; Nutrient uptake; Phosphorus; Recovery efficiency; Sulphur

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INTRODUCTION

Lentil is among the major grain legume crops in Ethiopia that constituted the major food crops for the majority of the country's population. It is one of the heavily consumed legumes crops in Ethiopia and is a popular ingredient of every day diet in most of households. Besides being rich in protein, the ability of crop to use atmospheric nitrogen through biological nitrogen fixation (BNF) is economically appealing and environmentally friendly. It also served as a source of income at household level and a contributor for the country's foreign currency earnings (Eyob and Baye, 2019).

Despite the immense economic and ecologic merits, the productivity of lentil in Ethiopia is far below the potential due to a number of biotic and abiotic constraints, attributed, at least partly, to a combination of several biophysical and socioeconomic constraints in smallholder farms and inadequate technological interventions, which ultimately resulted in one of the least productive agriculture (Abraham, 2015). Production of lentil in Ethiopia over the last two decades showed an increasing trend regardless of the static nature of area under cultivation. Yet, the current production trends are insufficient to meet food demands in Ethiopia. This indicates that the increased grain production resulted from an increase in the production areas not productivity of the crop per unit area. In addition to this, farmers grow their lentil without commercial fertilizers under suboptimal management practices. To solve these problems, it will be imperative to apply balanced amounts of the most limiting nutrients to obtain the highest yield while minimizing nutrient losses, that is, when fertilization is fine-tuned to local soil chemical conditions and crop requirements.

Phosphorus (P) fertilization to legumes is more important than that of nitrogen, due to improving nodulation, yield contributing components and grain quality in various legumes (Singh *et al*., 2014). However, P is available in the soil after application for a very limited period and the crops are perform well at optimal rates of P with high P use efficiency. Further, the yield potential of grain legumes also is best utilized in the presence of optimum fertilization of Sulphur (S). In terms of nutritional requirement, S plays a major role in determining yield, quality and resistance of lentil toward various stress factors (Kiran *et al*., 2019). So far, the growth of the grain legumes production is projected to require increased use of chemical fertilizers, but since the current environmental impact of agriculture and fertilizer use has reached its planetary boundaries (Steffen *et al.,* 2015), the nutrient use efficiency of fertilizers should be increased dramatically.

Despite plentiful information, as mentioned above, on the beneficial effect of different inputs on the productivity of crops, reports on cumulative effects of P and S fertilizer on the performance of lentil in Ethiopia is limited in general and with respect to central highland in particular. Therefore, this field experiment was undertaken to assess the response of lentil to phosphorus and Sulphur fertilization and determine the P and S uptake and utilization efficiency of lentil in the central highlands of Ethiopia.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at Denkaka, East Showa Zone of Oromia Regional State of Ethiopia in 2016/17 cropping season. Denkaka is located 60 km East of Addis Ababa and its geographical extent ranges from 08 ^{0}45' to 08 ^{0}46'N and 38 ^{0}46' to 39 ^{0} 01' E with an altitude 1850 m above sea level. The data of climatic parameters such as rainfall, maximum and minimum temperature were recorded at meteorological observatory; main agriculture research station, Debre Zeit during cropping period of the experimental year and mean of past 10 years (2007-2016) are presented in (Figure 1). The area received an annual rainfall of 824.6 mm during the cropping season (January-December) which was higher than the mean annual rainfall (788.5mm) of the ten years. Mean maximum and minimum temperatures recorded at the station during the season were 25.3 and 13.5°C, respectively. The area received high amount of rainfall from May to September months of the cropping season in which the highest amount (262.3 mm) was obtained in July followed by August (200.2 mm) and nil.

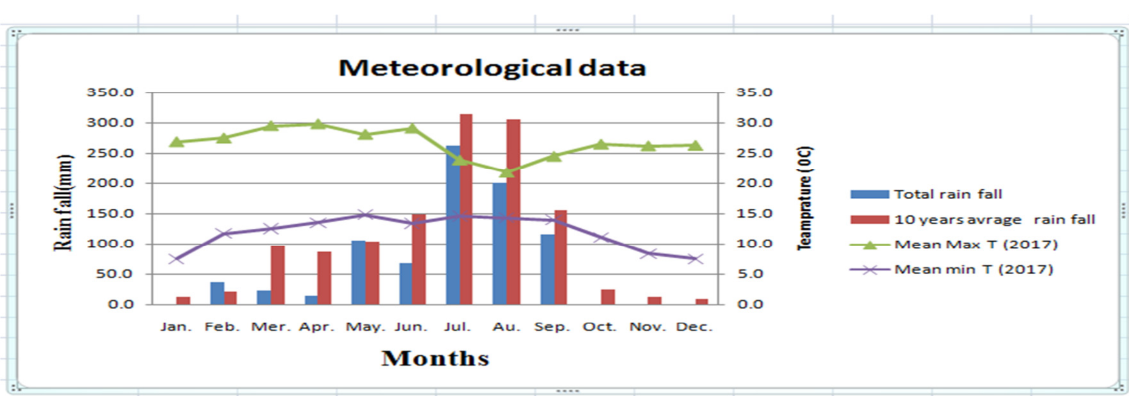

Figure 1: Climate parameters of the research site during the period of experimentation.

Experimental material and soil characteristics

Grains of *Alemaya* lentil cultivar was obtained from highland pulse plant breeding and genetics program of Debre Zeit Agricultural Research Center, Ethiopia. Source of P and S were triple super phosphate (Ca $(H_2PO_4)_2$; 46% P_2O_5 or 20 % P) and potassium sulphate (K_2SO_4; 51% K_2O &18% S), respectively. Potassium chloride fertilizer was also added to adjust the amount of potassium in plots. The soil (0–20 cm surface layer) was collected from research area of Denkaka and a composite soil sample of the collected soil was air-dried and grinded to pass through a 2 mm sieve. A uniform portion of the sieved soil was subjected to analytical analysis for various physicochemical soil characteristics (Table 1).

Table 1: Selected physico-chemical characteristics of soil used in the experimental site.

Soil characteristics	Unit	Value	Methodology/reference
Soil Physical properties			
Sand	%	24	Rowell, 1994
Silt	%	32	Rowell, 1994
Clay	%	44	Rowell, 1994
Textural class	---	Clay	Rowell, 1994
Soil Chemical properties			
pH (1:2.5)	----	6.770	Murphy ,1968
Organic matter	%	1.396	Murphy ,1968
Total Nitrogen	%	0.084	Murphy ,1968
Available phosphorus	mg. kg^{-1}	6.183	Olsen ,1954
Available Sulphur	mg. kg^{-1}	5.399	Hariram & Dwivedi, 1994
Cation exchange capacity	cmol (+) kg^{-1}	35.940	Hazelton &Murphy, 2007

Treatment setup and experimental design

The experiment was laid out in randomized complete block design with factorial arrangement of treatment combinations and replicated three times. Each replication consisted of six treatment combinations and the total numbers of plots were eighteen. Four levels of P (0, 10, 20 and 30 kg ha^{-1}) and three levels of S (0, 20 and 40 kg ha^{-1}) treatment combinations were applied to the plots. The size of each experimental plot was 4.2 m^2 (1.4 m × 3 m) accommodating seven rows of plants spaced at 20 cm between rows. A spacing of 50 cm between the plots and 1m between blocks were kept. The outer most rows of both sides were considered as boarder. Second row at both side of each plot was used as sampling row for nodulation study. The other rows were kept for final sampling. Hence, three rows of 2.80 m length (leaving 0.20 m at both sides of plot) were regarded as net plot (0.60 m x 2.80 m = 1.68 m2). All other field managements were carried out following the recommended agronomic practices for lentil.

Plant tissue sampling and analysis

At harvesting time, five randomly selected plants were harvested from three central rows and partitioned into grain and haulm. Each sample was separately oven dried at 70°C for 24 hrs and ground to pass 1 mm sieve and saved for tissue analysis of grain and haulm. Sulphur concentrations in grain and haulm sub-samples were determined by turbidimetric method using a spectrophotometer by di-acid (HNO3 and HClO4) in the ratio of 9:4 for sample digestion (FAO, 2008). The reading of S was made at 470 nm using spectrophotometer. Phosphorus concentrations in grain and haulm sub-samples were also determined using Spectrophotometric vanadium phosphomolybdate method by tri-acid (HNO3, H2SO4 and HClO4) in the ratio of 9:4:1 for sample digestion (FAO, 2008). The P in the solution was determined calorimetrically using ammonium meta vanadate and ammonium molybdate for color development. The reading of P was made at 464 nm using spectrophotometer. Grain and haulm concentrations of P and S were used to compute the P and S uptake which was calculated by multiplying grain and haulm yields on hectare basis with the respective P and S content in percentage for each plot. Total P and S uptake were calculated as the sum of grain P uptake and haulm P uptake (Hussain *et al.,* 2011). Based on the laboratory results of plant tissue analysis; agronomic and recovery efficiency were computed according to the formula described by Albrizio *et al.* (2010) and nutrient harvest index was also computed according to the formula described by (Fageria and Santos, 2002).

Phosphorus recovery efficiency (PRE) (%)
PRE= [(Total P uptake Treatment – Total P uptake Control)/P applied] × 100
Sulphur recovery efficiency (SRE) (%)
SRE = [(Total S uptake Treatment – Total S uptake Control)/S applied] × 100
Agronomic P efficiency (APE) (kg kg^{-1} P applied)
APE= (Yield Treatment – Yield Control)/P applied
Agronomic S efficiency (ASE) (kg kg^{-1} S applied)
ASE= (Yield Treatment – Yield Control)/S applied
Phosphorus harvest index (PHI) (%)
PHI= (Grain P uptake/Total P uptake) × 100
Sulphur harvest index (SHI) (%)
SHI= (Grain S uptake/Total S uptake) × 100

Statistical data analysis

Statistical analysis of the data collected from the field and laboratory were analyzed by SAS +version 9.0 statistical software using mixed model procedure after checking the compliance of the data with the assumptions of the statistical test (SAS, 2012). Comparisons among treatment means with significant difference for measured and scored characters were done using least significance difference (LSD) at 5% probability level.

Partial budget analysis

Yield from experimental plots was adjusted downward by 15%, i.e. 10% for management difference and 5% for plot size differences, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment. Accordingly, the mean grain yields for P and S treatment combinations were subjected to a discrete partial budget analysis using the procedures outlined by CIMMYT (1988). To estimate economic parameters, the variable cost of P fertilizer (ETB 18.55 kg^{-1}) and potassium Sulphate (ETB 26.9kg^{-1}) were recorded at time of planting. Price of current lentil grain (ETB 21 kg^{-1}) and price of haulm (birr 2.45 kg^{-1}) data were taken from Office of Trade and Transportation marketing case team of Debre Zeit district.

RESULTS AND DISCUSSION

Grain and haulm yield

Interaction effect of phosphorus and Sulphur levels was found significant for grain and haulm yield of lentil during the period of experimentation. As a result, the highest grain yield (2.29 t ha^{-1}) was obtained from the combined application of 20/20 kg P/S ha^{-1} which was statistically par at 40 kg S ha^{-1}without P fertilization. Whereas the lowest grain yield (1.89 t ha^{-1}) was recorded from the control treatment (Figure 2A). The interaction of both nutrients also given greater grain yield than the main effect of two nutrients as well as the control treatment. This might be due to the fact that addition of P along with S enhanced markedly the uptake of grain P and S as indicated in figure 3A, thereby acting and increasing mutually the grain yield ha^{-1}. Every increase in S rate resulted in increasing grain yield without P fertilization, while application of P at10, 20 and 30 kg ha^{-1}, grain yield increased with S fertilizer rates up to 20 kg S ha^{-1}, but further increasing of S fertilizer rate did not consistently increased. This might be due to the positive effect of P and S on each other at lower levels of P and S in soil as both the nutrients mutually help in their absorption and utilization probably due to balanced nutrition. The declined trend of grain yield at higher rate of S with increasing P application also indicated that the antagonistic effect of S and P might be due to the likely competition between the two anions i.e. sulphate and phosphate at the same absorption sites on root surface (Paliwal *et al*., 2009). The present result is in agreement with the findings of Shubhangi *et al*. (2014).

Further, the maximum mean haulm yield of lentil (6.7t ha^{-1}) was recorded at 20/40 kg P/S ha^{-1} which was statistically at par with the combined 30/20 kg P/S ha^{-1} in soil due to synergistic effect of P and S on each other. It may be due to utilization of high quantities of nutrients through their well-developed root system and nodules which might have resulted in better growth and yield at medium. Whereas the minimum haulm yield (4.5t ha^{-1}) was recorded from the control treatment (Figure 2B). These results confirm the earlier findings of Niraj and Prakash (2015) in black gram and Teotia *et al.* (2000) in moong bean have shown that nature of P and S interaction depends on their rates of application.

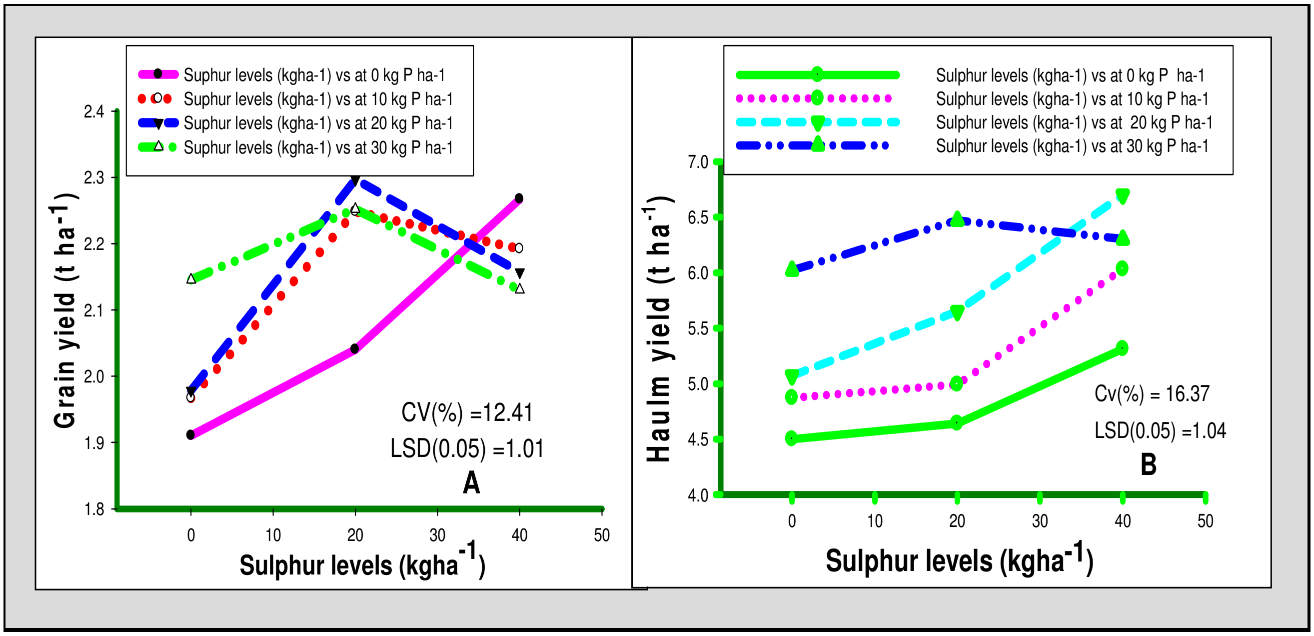

Figure 2 : Effects of interactions between S and P fertilizer rates on grain yield (A) and haulm yield (B) of lentil

Phosphorus and Sulphur grain and haulm uptake

The application of phosphors and Sulphur fertilizer on grain P uptake (GPU) and haulm P uptake (HPU) of lentil is illustrated in Figure 3A. The maximum SPU was observed in 20/20 kg P/S ha^{-1}, while the minimum was recorded in the control treatment which is statistically different from the other treatments. The result also showed that, with increasing S rates up to 20 kg ha^{-1}across P rates except nil application SPU enhanced, but beyond the rate of 20 kg S ha^{-1}SPU was linearly declined. The declined trend of SPU at higher rate of S and P application also indicated that the antagonistic effect of S and P might be due to the likely competition between the two anions i.e. sulphate and phosphate at the same absorption sites on root surface (Paliwal *et al*., 2009). The highest HPU was obtained at the rate of 20/20 kg P/S ha^{-1} which is statistically par with 30/20kg P/S ha^{-1} and 30 kg P ha^{-1} without S application, while the lowest value of HPU was recorded at the control treatment (Figure 3B). Application of 20/20 kg P/S ha^{-1} significantly improve haulm P uptake by 63.4% over the control. This showed that, there is a positive effect of P and S on each other at lower levels of 20 kg P ha^{-1} soil and 20 kg S ha^{-1} soil as both the nutrients mutually help in their absorption and utilization probably due to balanced nutrition. The similar trends of Niraj and Prakash (2015) was reported in black gram.

Sulphur uptake in grain and haulm of lentil was influenced significantly under various P and S levels. Significantly, the highest S uptake in grain (4.8 kg ha^{-1}) was obtained at rate of 10/40 kg P/S ha^{-1}, while the lowest (0.9 kg ha^{-1}) was obtained from 30 kg P ha^{-1}without S fertilization (Figure 3C). Application of 10/40 kg P/S ha^{-1} increased S uptake in grain by 79.7% compared to the control. Application of S at 20 and 40 kg ha^{-1}, grain S uptake significantly increased with P fertilizer rates increase up to 20 and 10 kg P ha^{-1}respectively, but further increasing of P fertilizer rate, grain S uptake turns to declined. This might be due to the competition of sulphate and phosphate ions on the root absorption sites or for the same uptake pathway within the root stem and leaf cell. Similar trends of S uptake were observed by Singh *et al.* (2014) in mung bean and Yadav (2011) in cluster bean. The maximum haulm S uptake in plant (23 kg ha^{-1}) was recorded at 20/20 kg P/S ha^{-1} which was statistically similar at 30/20 kg P/S ha^{-1}, while the minimum haulm S uptake (9 kg ha^{-1}) was recorded at the control treatment (Figure 3D). This might be argued that increased S and P availability resulted in better root and shoot growth and ultimately increased dry matter production due to the positive effect of P and S application on root growth and crop morphology. This result was in conformity with those of others (Bagayoko *et al*., 2000 and Tang *et al*., 2001).

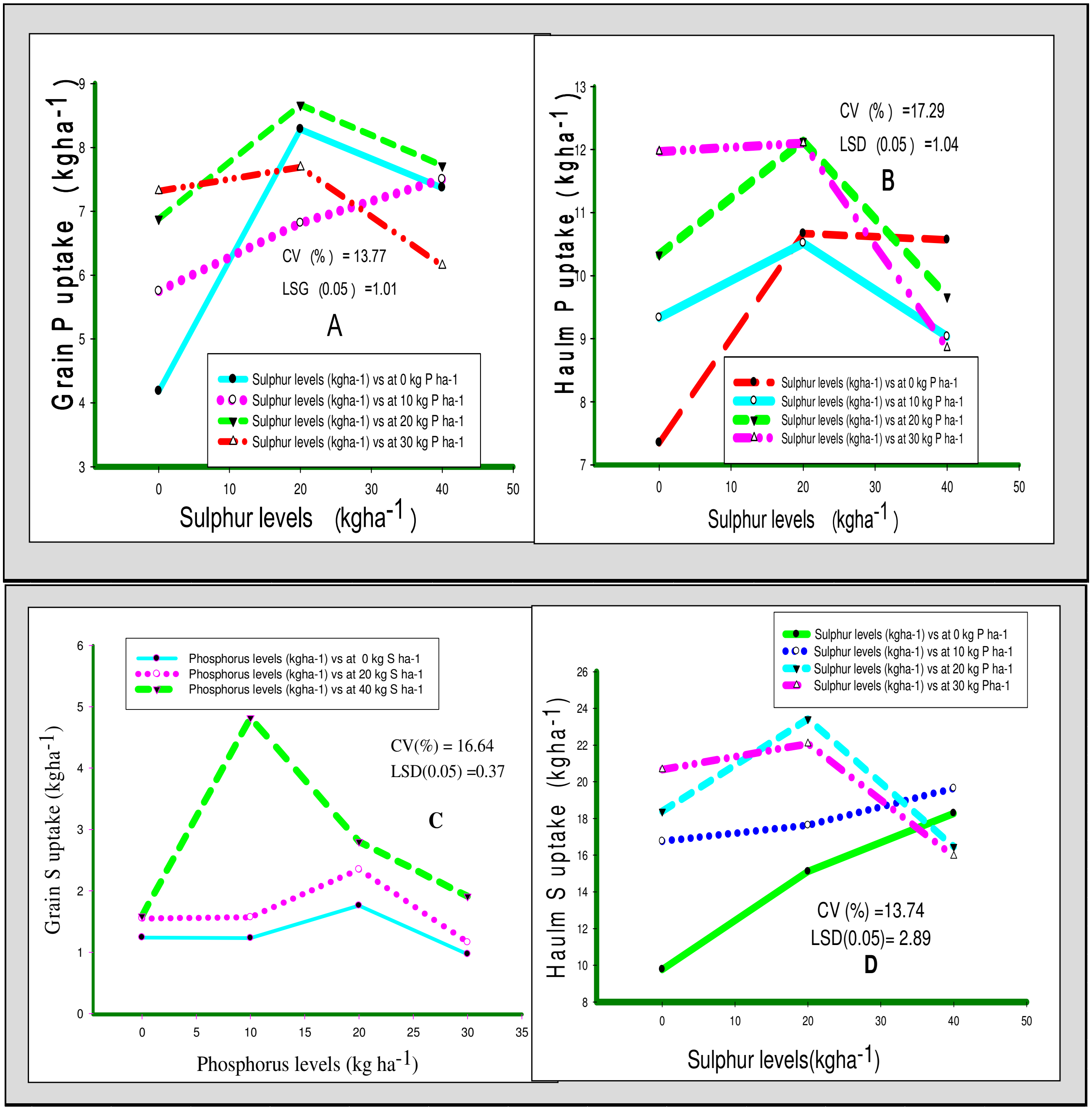

Figure 3: Effects of interactions between S and P fertilizer rates on grain P uptake (A), haulm P uptake (B), grain S uptake (C) and haulm S uptake (D) of lentil.

Phosphorus and Sulphur agronomic use efficiency

Phosphorus and Sulphur agronomic use efficiency (AE) by lentil was significantly declined with increasing levels of P and S. The highest agronomic efficiency of P (PAE)and S (SAE) were obtained at 10 and 20 kg ha^{-1} application of P and S, respectively (Table 2). This might be due to small amounts of applied fertilizer optimized nutrient use efficiency. However, the least P and S agronomic use efficiency value were noted at 30 and 40 kg P and S ha^{-1} in all treatments. This implies that the response of PAE and SAE to additional P and S fertilizer application above 10 and 20 kg P and S

ha^{-1} were not noticeable and the lowest level of P and S relatively responded better to P and S AE than higher rate. The decline in PAE with higher level of P might be due to fixation of P in the soil and attributed to operation of law of diminishing marginal production. The SAE also decreases with increase in S level might be due to decrease in rate of increase in grain yield with successive increase in input. This indicated that greater competition among plants and better utilization for nutrients in short supply. The decreasing trend in phosphorus AE with increasing P rates were also reported by Gidago *et al*. (2011) found a declining trend of PAE from 69.8 to 9.3 kg kg^{-1} at the rates of P ranging from 10 to 60 kg P ha^{-1} on haricot bean. Similarly, Tesfaye (2015) reported a decreasing trend of PAE from 8.79 to 2.85 kg kg^{-1} at the rates of P ranging from 10 to 30 kg P ha^{-1} on soybean. Agronomic efficiency declined significantly when the level of S was raised from 15 to 45 kg S ha^{-1} (Yashbir *et al*., 2014). In line with this, Shiveshwar *et al*. (2014) reported that AE of applied sulfur in wheat-soybean cropping sequence decreased with an increase in sulfur level from 15 to 45 $kgha^{-1}$. Sarabdeep *et al*. (2014) also reported increase in S levels from 15 to 60 kg ha^{-1} recorded a decrease in AE from 9.60 to 5.08 kg grain kg^{-1}.

Table 2: Phosphorus and Sulphur agronomic efficiencies of lentil as affected by P and S application.

Treatments	PAE ($kgkg^{-1}$)	Treatments	SAE ($kgkg^{-1}$)
Phosphorus levels ($kgha^{-1}$)		Sulphur levels ($kgha^{-1}$)	
0	---	0	---
10	60.34a	20	30.76^{a}
20	29.97^{b}	40	17.44^{b}
30	21.62^{c}		
S. Em ±	2.89	S. Em ±	1.92

S.Em=standard error of mean; PAE= Phosphorus agronomic efficiencies and SAE= Sulphur agronomic efficiency

Phosphorus and Sulphur recovery use efficiency

Phosphorus recovery efficiency (PRE) and Sulphur recovery efficiency (SRE) provides the quantity of nutrient uptake per unit of nutrient applied. PRE and SRE were influenced considerably by varying rates of P and S application. The maximum PRE (85%) and SRE (82%) were obtained by combined application of S and P at the rate of 10/20 kg P/S ha^{-1}, while the minimum value (21and 25%) was recorded at the combined application of 30/40 kg P/S ha^{-1}(Figure 4 A & B). In the present study, PRE and SRE increased with combined application of P and S as compared to individual application, but the mean value of PRE and SRE decreased as P levels increased at each rate of 40 and 20 kg S ha^{-1}. This might be due to antagonistic effect of P and S in soil. This result in line with the conclusions of Tariq *et al*. (2017) who reported that PRE was elevated due to pooled application of P and S as over the individual ones in chickpea and highest at lower level of P and S in contrast to superior levels. He also reported a decreasing trend of SRE from 5.9 to 4.0 % at the rates of 50/20 ranging from 100/40 kg P_2O_5/S ha^{-1} on chickpea. In general, the value of PRE and SRE were greater than the previous research finding, this may be most of PRE and SRE governed by a number of factors such as initial P and S status of soil, rate of P and S application and type of crop.

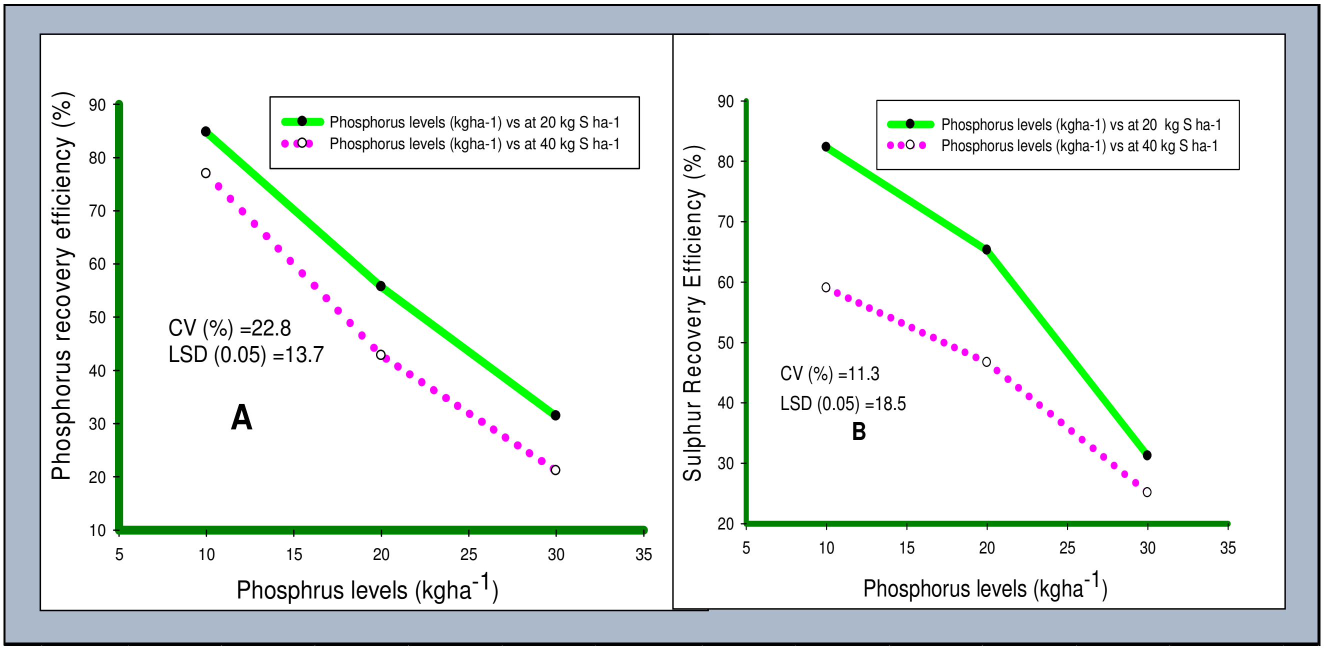

Figure 4 : Effects of interactions between S and P fertilizer rates on P recovery efficiency (A) and S recovery efficiency (B) of lentil.

Phosphorus and Sulphur harvest index

The effect of different levels of P and S application on phosphorus harvest index (PHI) and Sulphur harvest index (SHI) of lentil is presented in figure 5A&B, respectively. The data clearly indicated that the maximum PHI (49%) of lentil was recorded at 10/20 kg P/S ha^{-1} which was statistically at par with combined application of 20/20 and 30/20 kg P/S ha^{-1}, while the minimum PHI (32.7%) was obtained at the control plot. This combined treatment enhanced PHI by 60% over the control. The higher PHI indicates increased partitioning of P to the grain and amount of P remobilized from storage tissues to grain yield and this high PHI also directly associated with the grain uptake of P as indicated in figure 3A. The PHI is an excellent parameter, which explains the ability of a genotype/cultivar to accumulate higher grain P than straw. Increased P translocation and subsequent accumulation in grain is important to achieve high grain yield and without dropping grain P concentration (Yaseen and Malhi, 2009). Regarding the combined application of P and S on SHI, result showed that the highest SHI (32%) of lentil was recorded at 10/40 kg P/S ha^{-1}, while the lowest (4.2%) was obtained from the control treatment (Figure 5B). This combined treatment also enhanced PHI by 88% over the control. As evident from the current result, PHI was 60.5% higher than SHI in grain of lentil. The difference in partitioning of P and S may be a function of a sink limitation on S use by the developing grain. This may be S remobilization from stems, which accumulated sulfate during growth and were a potential pool for S remobilization (Sexto *et al.*, 1998). In addition to this, highly significant correlation between grain P uptake and grain yield (r = 0.98) justified this argument (Table 3).

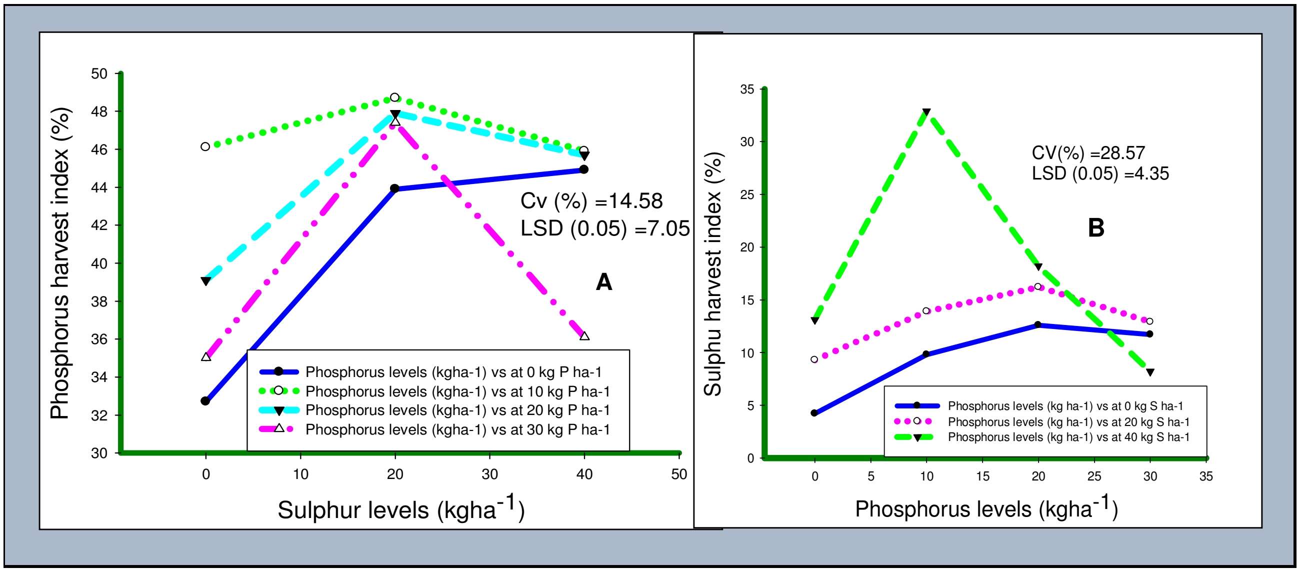

Figure 5: Effects of interactions between S and P fertilizer rates on P harvest index (A), S harvest index (B) of lentil**.**

Generally, correlation analysis showed that seed yield had positive and highly significant association with grain and haulm P and S uptake as well as use efficiencies except Sulphur recovery efficiency (Table 3). The positive interrelationship between seed yield and the uptake parameters indicates that those attributes exhibited positive influence on physiological process to mobilize and translocate photosynthetic to the organs of economic value, which, in turn, might have increased the seed yield. On the other hand, Non-significant association of seed yield with Sulphur recovery efficiency. This indicates that the increase in those parameters resulted in positive effect but with minimum contribution to seed yield of the crop.

Table 3: Pearson correlation (r) matrix among grain yield and P and S uptake and use efficiency of lentil.

	GPU	HPU	PAE	PRE	PHI	GSU	HSU	SAE	SRE	SHI	HM	YLD
GPU	100											
HPU	0.88^{**}	100										
PAE	0.76^{**}	0.64^{*}	100									
PRE	0.73^{**}	0.80^{**}	0.83^{**}	100								
PHI	0.97^{***}	0.79^{**}	0.74^{*}	0.64^{*}	100							
GSU	0.76^{**}	0.63^{*}	0.66^{*}	0.57^{*}	0.78^{**}	100						
HSU	0.90^{***}	0.80^{**}	0.66^{*}	0.63^{*}	0.88^{***}	0.68^{*}	100					
SAE	0.77^{*}	0.65^{*}	0.56^{*}	0.54^{*}	0.75^{**}	0.60^{*}	0.56*	100				
SRE	0.11^{ns}	0.03^{ns}	0.03^{ns}	0.02^{ns}	0.08^{ns}	0.18^{ns}	0.35^{ns}	0.05^{ns}	100			
SHI	0.76^{**}	0.71^{**}	0.65^{*}	0.62^{**}	0.77^{**}	0.85^{**}	0.59^{*}	0.63^{**}	-0.12^{ns}	100		
HM	0.93^{***}	0.96^{***}	0.69^{*}	0.77^{**}	0.89^{***}	0.72^{**}	0.90^{**}	0.64^{**}	0.07^{ns}	0.79^{**}	100	
YLD	0.98^{***}	0.91^{**}	0.76^{**}	0.73^{**}	0.96^{***}	0.76^{***}	0.89^{**}	0.75^{**}	0.04^{ns}	0.74^{**}	0.96^{***}	100

PAE: agronomic P efficiency; SAE: agronomic S efficiency; GPU: grain P uptake; GSU: grain S uptake; GLD: grain yield; PHI: P harvest index; SHI: S harvest index; PRE: P recovery efficiency; SRE: S recovery efficiency ; HPU: haulm P uptake; HSU: haulm S uptake; HM: haulm yield; *significant at P ≤ 0.05; **significant at P ≤ 0.01; ns = nonsignificant at P ≥ 0.05.

Partial budget analysis

According to the results of partial budget analysis, the highest net benefit was obtained from the application of 20 kg S ha^{-1} without phosphorus (ETB 51628 ha^{-1}), followed by 30 and 10 kg P ha^{-1} without Sulphur, respectively (Table 4). According to dominance analysis, as indicated on Table 4 most of the treatments were dominated by the highest net benefit treatments hence, eliminated for further economic analysis. To identify treatments with maximum return to the farmers' investment, marginal analysis was performed on non-dominated treatments. For a treatment to be considered as a worthwhile option to farmers, the marginal rates of return (MRR) need to be at least between 50% and 100% (CIMMYT, 1988).Thus, to draw farmer' recommendations from marginal analysis in this study, 100% return to the investment is a reasonable minimum acceptable rate of return since farmers' in the study area usually not apply combined P and S for lentil production. Accordingly, application 10 kg P ha^{-1} without Sulphur (1336% MRR) and 30 kg P ha^{-1} without S (568% MRR) were superior rewarding treatment and they were recorded above the minimum acceptable rate of return.

CONCLUSION

From the foregoing experimental findings, fertilization of phosphorus and Sulphur had crucial role in mitigating soil fertility depletion, thereby improve production and productivity of lentil. The results indicated that S and P fertilization enhanced all variables studied, consequently the improvements were more pronounced for the combined application of S and P than their separate application except P and S agronomic use efficiency. Among the interaction of P and S levels, application of 20/20 kg P/S ha^{-1} exhibited the highest grain yield, grain and haulm P uptake as well as haulm S uptake over other levels. Application of 10/40 kg P/S ha^{-1} also given the maximum grain S uptake and Sulphur harvest index. Phosphorus and Sulphur recovery efficiency and PHI can be increased by the combined application of 10/20 kg P/S ha^{-1} and decreased as P levels increased at each rate of 40 and 20 kg S ha^{-1}for PRE and SRE of lentil. Agronomic efficiency of P and S were higher at 10 and 20 kgha^{-1} and found significantly decreased with increase in level of P and S, respectively.

Mainly, most of the correlation analysis showed that seed yield had positive and highly significant association with grain and haulm P and S uptake as well as use efficiencies. This showed that P and S application ensured higher crop yields and also maintained soil productivity for sustainable crop production. Partial budget analysis also described that separate application of P and S fertilization was cost-effective as compared to combined application based on acceptable and maximum MRR values. Therefore, it can be concluded that S and P ought to be incorporated in nutrient management programmed in order to acquire utmost yield of lentil. This will result in augmented fertilizer use efficiency and uptake of this valuable and expensive input. Though, further trialing is required to formulate comprehensive suggestions concerning accurate ratio of the P and S.

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