Indian Journal of Agricultural Sciences **86** (12): 1581–5, December 2016/Article
https://doi.org/10.56093/ijas.v86i12.65452

Effect of sulphur on yield, nutrient uptake and economics of pearl millet (*Pennisetum glaucum*) and lentil (*Lens culinaris*) grown in sequence on an alluvial soil

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Received: 21 April 2016; Accepted: 18 June 2016

ABSTRACT

A field experiment was carried out in *kharif* and *rabi* seasons of 2010-11 and 2011-12 at Panwari village of Agra district (Uttar Pradesh) to study the response of pearl millet (*Pennisetum glaucum* (L) R. Br. emend Stuntz) and lentil (*Lens culinaris* Medikus) grown in sequence to sulphur (0, 15, 30, 45 and 60 kg/ha) application on alluvial soil. The experiment was laid out in randomized block design with four replications. Results revealed that increasing levels of sulphur up to 30 kg S/ha significantly increased the plant height (224.7 cm), ear head length (29.1 cm), ear head diameter (10.85 cm), test weight (11.00 g) and grain weight/ear (33.95 g) as compared to control. Application of 30 kg S/ha increased significantly the mean grain and stover yield of pearl millet by 23.0 and 18.7% over control, respectively. The uptake of nutrients by pearl millet crop increased significantly due to sulphur application over control. The highest protein content (10.8%) and yield (351.0 kg/ha) of pearl millet grain was obtained with 60 and 30 kg S/ha, respectively. Sulphur application in preceding pearl millet crop at 45 kg S/ha was found to be best for growth and yield attributes of lentil. The residual S at 45 kg S/ha significantly increased the grain and straw yield of lentil by 0.47 and 0.65 t/ha over control, respectively. Such beneficial effect of S was also found in increasing uptake of nutrients and protein content (24.0%) and yield (474.3 kg/ha) of lentil. Application of 45 kg S/ha recorded the highest net returns of ₹ 63 922/ha, which was closely followed by 30 kg S/ha. The maximum value of benefit: cost ratio (3.78) in crop sequence was recorded with application of 45 kg S/ha. Agronomic efficiency and apparent S recovery were recorded higher at 30 kg S/ha in pearl millet and 45 kg S/ha in lentil. Application of 60 kg S/ha significantly improved the status of available S in post-harvest soil over initial value of sulphur.

Key words: Economics, Nutrient uptake, Pearl millet-lentil crop sequence, Sulphur, Yield

Pearl millet [*Pennisetum glaucum* (L) R Br] and lentil (*Lens culinaris* Medikus) crops are very important for their contribution to human and animal nutrition, on components of indigenous cropping system, and as restorer of soil fertility. Pearl millet is the fourth most important cereal and widely grown in India because of its tolerance to drought, high temperature and low soil fertility. Lentil is an important legume crop mainly grown in residual soil moisture and prominent source of vegetable protein. Pearl millet-lentil cropping system is practiced with no application of chemical fertilizers. There is stagnation and deterioration in productivity of both the crops in a cropping sequence as well as on individual basis because sulphur deficiency is very common in alluvial soils of Agra (Singh 2015). Sulphur deficiency in crop plants has been recognized as a limiting factor not only for crop growth and grain yield but also for poor quality of products, because sulphur is a constituent of several essential compounds such as cysteine, methionine, cystine, coengymes thioredoxine and sulfolipids etc. In general, S requirement of legume crops is higher than those of cereal crops, but its application as a fertilizer or as a constituent of other fertilizers is generally overlooked resulting in widespread deficiency of this element. The response of pearl millet and lentil grown in sequence to S fertilization is guided by soil type, cropping systems followed and prevailing weather conditions. The nutrients applied in one crop are not fully utilized, which leads to their residual effect on succeeding crop. The experimental results at various places indicated that both pearl millet and lentil responded well to sulphur application (Singh *et al*. 2013, 2014). Thus, sulphur application benefits more than one crop and shows a significant residual effect on the succeeding crops. Since information on direct and residual effects of sulphur in pearl millet-lentil crop sequence in Agra region is meager. Therefore, a field experiment was conducted with the aim to

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study the direct and residual effects of sulphur on productivity, protein content and nutrient uptake in pearl millet-lentil crop sequence.

MATERIALS AND METHDOS

A field experiement was conducted during *kharif* and *rabi* seaons of 2010-11 and 2011-12 at farmer's field at Panwari (Agra), which is situated at 27º 14' N latitude and 77º 78' E longitude at an altitude of 168 meter above the mean sea level. Climate of the area is semi arid with an average annual rainfall of 650 mm most of which is received from June to September. The experiment soil was Entisol with sandy loam in texture. It had pH 7.9, organic carbon 3.1 g/kg, available N 152 kg/ha, available P 9.5 kg/ha, available K 106 kg/ha and S 15 kg/ha. The experiment was laid out in randomized block design with four replications. The treatments consisted of five levels of S (0, 15, 30, 45 and 60 kg/ha) applied through elemental sulphur. The direct effect of levels of S was studied with pearl millet (Hybrid Pioneer 86M86) and its residual effect was studied in the succeeding lentil crop (Var. T36). Elemental sulphur was applied one week before sowing of pearl millet. A basal dose of 100 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha to pearl millet and 20 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha to lentil was applied through urea, di-ammonium phosphate and muriate of potash, respectively. Half dose of N in pearl millet and full dose of P and K were applied at the time of sowing remaining N was top dressed after one month of sowing. After the harvest of pearl millet, lentil was grown as succeeding crop during rabi season in the same plot without application of sulphur. Crops were harvested at physiological maturity. Growth and yield attributes of both the crops were recorded at harvest. Grain and straw samples were digested in di-acid mixture of HNO_3: $HClO_4$ (10:4) and S content was determined turbid metrically (Chesnin and Yien 1951). Phosphorus, K and Zn in di-acid digest were determined by vanadomolybdate yellow colour method, flame photometer and atomic absorption spectrophotometer, respectively (Jackson 1973). Nitrogen content was estimated by modified Kjeldahl method and protein content was calculated by multiplying with a factor of 6.25. The uptake of nutrient was obtained as product of their concentration and yield.

Economics of the treatments was computed on the basis of prevailing market price of inputs and output. Post-harvest soil samples collected after two years of experiment were air dried, ground to pass through 2 mm sieve and analyzed for available S after extraction with 0.15% $CaCl_2$ solution by terbidi metric method. The data thus, obtained were analyzed statistically using analysis of variance technique for various parameters at 5% level of significance.

RESULTS AND DISCUSSION

Direct effect on pearl millet

Sulphur application resulted in increased plant height as well as yield attributes of pearl millet over control. The increase in these parameters was noted with increase in S dose from 0 to 30 kg S/ha. This may be attributed to supply of adequate quantity of sulphur to plants resulting in favourable increase in growth and development of plant which leads towards an increase in plant height and yield indices. Similar positive response of S on plant growth and yield attributes have also been reported by Kumar *et al.* (2014). The data (Table 1) reveals that the grain and stover yield of pearl millet increased significantly with increasing levels of sulphur up to 30 kg S/ha over control. But further increase in S levels showed an adverse effect, which might be due to antagonistic effect at higher level. The magnitude of response to 30 kg S/ha on grain and stover yield of pearl millet was computed 23.0 and 18.7% over control, respectively. The increase in yields on addition of sulphur might be attributed to low availability of sulphur in the soil. In addition, the higher yield with S application might be due to favourable effects of better plant nutrition on growth, which further got translated to yield attributes and finally on yield. Singh *et al.* (2014) reported higher grain and stover yield of pearl millet with sulphur application.

Application of sulphur to pearl millet crop significantly increased the protein content in grain from 10.1 to 10.8% with 60 kg S/ha. This may be attributed to role of sulphur in protein synthesis and nitrogen metabolism in the plants. Singh *et al.* (2014) also reported a significant increase in protein content in pearl millet grain. There was a consistent and significant increase in protein yield of pearl millet with increasing levels of sulphur and maximum value (351.0 kg/ha) was recorded at 30 kg S/ha. Protein yield in pearl millet grain ranged from 271.6 to 351.0 kg/ha. This increase in protein yield due to sulphur levels may be attributed to

Table 1 Effect of sulphur levels on growth, yield parameters, yield and quality of pearl millet (mean of 2 years)

Sulphur (kg/ha)	Plant height (cm)	Ear head length (cm)	Ear head diameter (cm)	Test weight (g)	Grain weight/ ear (g)	Grain yield (t/ha)	% response	Stover yield (t/ha)	Protein content in grain (%)	Protein yield (kg/ha)
0	204.2	25.1	8.93	9.75	30.52	2.69		6.78	10.1	271.6
15	213.6	26.6	10.45	10.30	32.40	2.90	7.8	7.14	10.3	298.7
30	224.7	29.1	10.85	11.00	33.95	3.31	23.0	8.05	10.6	351.0
45	221.0	27.0	10.55	10.81	33.75	3.19	18.6	7.86	10.7	341.3
60	218.0	26.2	10.41	10.65	33.00	3.02	12.3	7.28	10.8	326.1
SEm ±	3.49	0.49	0.12	0.23	0.14	0.05		0.24	0.09	13.0
CD (P=0.05)	7.53	1.06	0.25	0.50	0.31	0.11		0.52	0.19	28.2

Table 2 Residual effect of sulphur on growth, yield parameters, yield and quality of lentil (mean of 2 years)

Sulphur (kg/ha)	Plant height (cm)	Branches/ plant	Grain/ pod	Pod/ plant	Test weight (g)	Grain yield (t/ha)	% response	Straw yield (t/ha)	Protein in seed (%)	Protein yield (kg/ha)
0	33.60	5.4	2.03	76.0	23.51	1.62		2.11	22.4	362.7
15	36.03	6.0	2.06	84.7	24.40	1.75	8.0	2.28	22.7	397.1
30	38.73	6.8	2.11	95.1	25.12	1.91	17.9	2.52	23.1	441.3
45	40.53	7.3	2.12	100.6	25.58	2.09	29.0	2.76	23.6	474.3
60	39.89	6.8	2.10	100.0	24.96	1.89	16.7	2.46	24.0	453.6
SEm ±	0.73	0.21	0.009	2.19	0.21	0.07		0.10	0.17	15.6
CD (P=0.05)	1.58	0.45	0.019	4.73	0.45	0.16		0.21	0.37	33.8

increased grain yield and protein content in grain of the crop (Singh *et al.* 2014).

The nutrient uptake by grain and stover of pearl millet was significantly affected by the sulphur application (Table 3). The highest uptake of nitrogen in grain (55.6 kg/ha) and stover (45.0 kg/ha) was associated with 30 kg S/ha. Since, N uptake is the product of N concentration and yield, so highest N uptake was observed with 30 kg S/ha followed by 45 kg S/ha. Sulphur is an essential constituent of enzymes involved in nitrogen metabolism, its application could lead to increase nitrogen assimilation. Addition of sulphur also resulted in increased P and K uptake by pearl millet crop over control. The P and K uptake by pearl millet grain and stover with 30 kg S/ha increased by 40.6 and 55.2% and 30.0 and 21.1% over control, respectively. (Table 3). Sulphur improves the growth of roots and shoots in sulphur deficient soil, so plant roots enhance the uptake rate of both the nutrients.

Kumar *et al*. (2012) reported that P and K uptake were stimulated in the presence of sulphur. Plant uptake of sulphur increased significantly along with the rise in level of sulphur, which varied from 5.6 to 8.1 kg/ha in grain and from 8.1 to 12.0 kg/ha in stover. If a plant nutrient is involved in improving the vegetative growth, it would certainly improve the uptake of all nutrients, which are required to maintain the growth. Among the different levels, direct application of 60 kg S/ha recorded significantly higher S uptake as compared to rest except 45 kg S/ha where they remained at par. This may be ascribed to better fertilization, resulting in better growth and higher grain and stover yields under these treatments that activated the greater absorption of nutrients from the soil and resulted in higher S uptake. The minimum S uptake was recorded under control which was significantly lower than all the treatments. Effect of S application on uptake of Zn by pearl millet grain and stover was found to be significant. The increase in Zn uptake by grain and stover due to sulphur application was from 64.5 to 76.8 g/ha and from 206.1 to 239.8 g ha, respectively with, the application of 30 kg S/ha.

Residual effect on lentil

Residual effect of applied levels of S to pearl millet was evident on succeeding lentil crop (Table 2). Impact of residual S was more pronounced at higher level of S than at lower levels. Residual effect of sulphur showed significant effect on growth and yield attributes of lentil. Among the S levels, residual effect of 45 kg S/ha was significant on plant height, branches/plant, grains/pod, pods/plant and test weight. The favourable effect of residual sulphur on growth and yield attributes may be due to its role in many physiological processes and celluar function within plants. It is quite obvious that the experimental soil was deficient in S, so residual effect was found favourable on the growth of lentil (Kumar *et al.* 2014). Averaged over two years, application of 45 kg S/ha increased the grain and straw yield of lentil by 29.0 and 38.8% over control, respectively. The marked improvement in productivity of lentil with residual S could be ascribed to the enhancement of available S content of the soil as sulphur applied to pearl millet was not fully utilized by the crop leading to residual effect. Further, this might have improved nutritional environment to rhizosphere and consequently in plant growth. Thus, it indicated that the higher level of S application was necessary to obtain higher crop yields of succeeding lentil in pearl millet- lentil crop

Table 3 Effect of sulphur levels on uptake of N, P, K, S (kg/ha) and Zn (g/ha) by pearl millet grain and stover (mean of 2 years)

Sulphur	Nitrogen		Phosphorus		Potassium		Sulphur		Zinc	
(kg/ha)	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
0	43.6	35.2	5.9	6.7	15.0	136.2	5.6	8.1	64.5	206.1
15	47.5	38.5	7.0	8.5	16.8	144.0	6.4	10.0	70.1	218.4
30	55.6	45.0	8.3	10.4	19.5	165.0	7.6	12.0	76.8	239.8
45	53.9	44.6	7.9	10.0	19.0	161.1	7.9	12.5	70.8	231.1
60	51.6	42.2	7.5	9.8	18.2	150.0	8.1	12.0	65.5	200.2
SEm ±	1.20	1.17	0.48	0.56	0.73	3.43	0.26	0.40	1.46	4.15
CD (P=0.05)	2.60	2.53	1.04	1.21	1.58	7.44	0.56	0.86	3.16	9.00

Table 4 Effect of sulphur levels on uptake of N, P, K, S (kg/ha) and Zn (g/ha) by lentil grain and stover (mean of 2 years)

Sulphur	Nitrogen		Phosphorus		Potassium		Sulphur		Zinc	
(kg/ha)	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
0	59.2	23.4	4.0	3.2	12.8	43.9	3.7	3.2	39.7	59.3
15	64.4	25.5	4.5	3.6	14.0	47.6	4.4	3.6	41.5	62.2
30	70.6	28.9	5.3	4.5	15.5	53.1	5.1	4.5	44.1	66.8
45	74.0	30.7	6.3	5.2	17.1	58.5	6.0	5.5	46.6	71.2
60	70.8	28.2	5.8	4.9	15.7	52.4	5.8	5.2	40.8	61.7
SEm ±	2.07	1.20	0.28	0.25	0.87	2.11	0.19	0.17	1.07	1.58
CD (P=0.05)	4.55	2.64	0.60	0.55	1.88	4.56	0.41	0.38	2.31	3.41

sequence. Similar were the findings of Singh *et al.* (2013) in rice- lentil crop sequence.

Residual effect of sulphur upto 60 kg S/ha significantly improved the protein content in lentil grain from 22.4 to 24.0% (Table 2). Similar increase in protein content in lentil grain was reported by Upadhyay (2013). The successive increase in sulphur levels applied in pearl millet crop significantly increased the protein yield over lower levels of S. The influence of sulphur management on protein yield is the function of content as well as grain yield. Since, variation in protein content has genetic and bio chemical limitations, the protein yield is more influenced by grain yield and thus followed almost trend similar to grain yield. Application of sulphur significantly increased the N uptake from 59.2 to 74.0 kg/ha in grain and 23.4 to 30.7 kg/ha in straw with rise in S levels from 0 to 45 kg/ha. Phosphorus uptake ranged from 4.0 to 6.3 kg/ha in grain and 3.2 to 5.2 kg /ha in straw, while K uptake ranged from 12.8 to 17.1 kg /ha in grain and 43.9 to 58.5 kg/ha in straw. At all the levels of S, most of the P and K were utilized by grain and straw, respectively. This could be due to the balanced nutritional environment inside the plant and higher photosynthetic efficiency which may favour better growth and crop yield and ultimately higher uptake of these nutrients. Similar results were reported by Upadhyay (2013) in lentil. The S uptake by lentil grain and straw varied remarkably with the residual S levels. Among the different levels, the S uptake increased progressively with the increase in residual S levels from 15 to 45 kg S/ha (Table 4). The significant residual effect of sulphur on zinc uptake by grain and straw of succeeding lentil crop was observed up to 45 kg S/ha (Ali *et al.* 2013). Application of 60 kg S/ha resulted in significant decrease in zinc uptake over 45 kg/ha. This reduction in Zn uptake owing to application of sulphur may be due to the antagonistic relation between Zn and sulphur.

Efficiency indices

Apparent S recovery and agronomic efficiency of added levels of S by pearl millet and lentil are presented in table 5. The S use efficiency with added S (15-60 kg S/ha) in pearl millet varied from 5.5 to 20.7 kg grain/kg S. The direct application of 30 kg S/ha recorded the highest S use efficiency and apparent S recovery in pearl millet. In lentil, apparent S recovery and S use efficiency were noted higher with the residual S. The highest apparent S recovery was noted at 45 kg S/ha. It seems that greater recovery of added S was recorded at lower levels of S. The highest S use efficiency (10.4 kg produce /kg applied) was recorded with 45 kg S/ha which was higher than that recorded with 60 kg S/ha. It might be due to lower S used and comparatively lower seed yield recorded under 60 kg S/ha than under 45 kg S/ha. Higher recovery of S at lower level of applied S was reported by Kumar *et al.* (2014) in rice- pea crop sequence.

Economics

Economics of pearl millet-lentil crop sequence was significantly influenced by different levels of sulphur (Table 5). Among the levels of sulphur, application of 45 kg S/ha fetched the maximum net return (₹ 63 922 /ha) and benefit cost ratio (3.78) of pearl millet-lentil crop sequence which were significantly higher than the control. Averaged

Table 5 Effect of sulphur levels on efficiency indices and economics of pearl millet-lentil crop sequence (mean of 2 years)

Sulphur	Pearl millet		Lentil		Pearl millet-Lentil		Available S
(kg/ha)	Apparent S recovery (%)	S use efficiency (kg grain/kg S applied)	Apparent S recovery (%)	S use efficiency (kg grain/kg S applied)	Net return (₹/ha)	B:C ratio	(kg/ha)
0					43 599	2.91	13.5
15	5.3	14.0	4.6	8.7	51 303	3.29	17.0
30	6.7	20.7	4.7	9.7	61 333	3.76	20.6
45	5.1	11.1	5.1	10.4	63 922	3.78	25.4
60	4.1	5.5	3.5	4.5	60 102	3.41	28.0
SEm ±							0.74
CD (P=0.05)							1.60

over 2 years, 45 kg S/ha gave 46.6% higher net returns over control. This might be owing to greater yield increment with S application over control. Increasing levels of S beyond 45 kg S/ha reduced the net returns and benefit: cost ratio in pearl millet- lentil crop sequence due to increased cost of inputs and reduced yields of pearl millet and lentil crops.

Available sulphur

The application of sulphur in pearl millet crop improved the available S status of the soil after the harvest of crops in pearl millet-lentil sequence (Table 5). The available S content in post-harvest soil ranged from 13.5 to 28.0 kg/ha with 60 kg S/ha application. Available S (0.15% $CaCl_2$ solution extractable) remained much higher than the original level at higher levels of S. This is due to the fact that the uptake of S by pearl millet and lentil crops was much lower compared to the amount of sulphur applied. The status of available S in control was 13.5 kg/ha as against the initial value of 15 kg/ha indicating depletion of native sulphur by the crops.

From the present studies, it can be concluded that a significant beneficial effect on pearl millet and lentil grown in sequence could be achieved by the application of sulphur. Application of 30 kg S/ha recorded substantial increase in yield, nutrient uptake and quality of pearl millet. Residual effect of 45 kg S/ha may also benefit lentil crop grown in sequence in S deficient soil. Thus, application of 45 kg S/ha appears to be the best dose for obtaining the higher yield in pearl millet-lentil cropping sequence under agro-climatic conditions of Agra region, Uttar Pradesh.

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