



Effect of sulphur nutrition on productivity, nutrient uptake and economics of pearl millet (*Pennisetum glaucum*)-Indian mustard (*Brassica juncea*) cropping system

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ABSTRACT

A field experiment was conducted in two consecutive *kharif* and *rabi* seasons of 2010-11 and 2011-12 at Panwari village, Agra on a sulphur deficient soil to assess the direct effect of sulphur on productivity of pearl millet (*Pennisetum glaucum* (L.) R. Br. emend Stuntz) and residual effect on succeeding Indian mustard [*Brassica juncea* (L.) Czernj and Coss] and uptake of nutrients by the crops and soil fertility under pearl millet-mustard crop sequence. The experiment was laid out in randomized block design with five levels of sulphur (0, 15, 30, 45 and 60 kg/ha) and four replications. Results revealed that an application of 30 kg S/ha to pearl millet recorded significantly highest plant height (226.5 cm), ear head length (30.1 cm), ear head diameter (10.90 cm), 1000 grains weight (11.08 g) and grain weight/ear head (34.12 g). Sulphur fertilization in preceding pearl millet crop at 45 kg/ha was found to be best for growth and yield attributes of mustard. Pearl millet crop responded significantly up to 30 kg S/ha by producing 3.43 tonnes grain and 8.34 tonnes stover/ha. The residual effect in mustard crop was significant at 45 kg S/ha and grain and straw increments were to the extent of 28.2 and 24.9% over control, respectively. The content and yield of protein in both the crops increased significantly with sulphur up to 45 kg/ha, whereas the content and yield of oil in mustard seeds increased up to 60 kg S/ha. The uptake of S by both the crops increased significantly with increasing levels of sulphur. A phenomenal increase in N, P and K except of Zn was recorded in pearl millet and mustard crop due to increasing levels of sulphur up to 30 and 60 kg S/ha, respectively. The amount of available S was reduced in the control plot but at higher levels of S, sufficient amount of available S remained in the post harvest soil. The values of efficiency indices decreased with the increase in levels of sulphur. Net returns (₹ 54 961/ha) and benefit: cost ratio (3.82) were the highest with 45 kg S/ha in the pearl millet-mustard crop sequence.

Key words: Crop management, Nutrient uptake, Pearl millet- mustard crop sequence, Sulphur, Yield

Pearl millet [*Pennisetum glaucum* (L.) R. Br emend Stuntz] is an important rainfed crop and grown for both food and fodder. It is an imperative drought escaping cereal crop and grown in semi-arid and arid ecosystem of the world. Mustard [*Brassica Tuncea* (L.) Czernj and Coss] is the important oil seed crop mainly grown in residual soil moisture in Agra region and prominent source of vegetable oil. Adoption of pearl millet-mustard sequence over a long period without a provision for adequate replenishment of nutrients results in declining of soil fertility. There is a stagnation and deterioration in productivity of the crops in a cropping sequence because of sulphur deficiency. Oil seeds are energy rich crops so sulphur nutrition assumes greater importance in comparison to other nutrients. This necessitates rational application of sulphur as it has becoming limiting factor for obtaining higher yields of crops. The profitability of sulphur application could be higher if the residual benefits of initial application to subsequent crops are taken into account. The response of soil applied S could

be more correctly assessed on cropping system basis rather than on a single crop basis. Survey of Indian soils under AICRP Micronutrients has revealed that on an average, 41% of the Indian soils are deficient in S with widespread occurrence in the coarse textured soils. Sulphur deficiency is increasing with each passing year, which is restricting crop yields, quality of produce, nutrient use efficiency and economic returns (Tandon 2011). Thus, increasing S deficiency in soil as one of the major cause for declining yield seems to be true as a result of excess withdrawals than its replenishments. Sulphur, the fourth plant nutrient, plays an important role in growth and development of crops as it is a constituent of amino acids like methionine, cystiene and cystine needed for the synthesis of chlorophyll and improvement of oil production in oil seed crops (Marschner 1986). Sulphur is very important for oilseeds as the volatile di-acid poly-sulphide compounds help to increase the pungency of the vegetable oils. In general, S requirement of oil seeds crops is higher than those of cereal crops. In view of the limited information available on the sulphur nutrition in pearl millet-mustard crop sequence, a field

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experiment was conducted over two consecutive seasons to study the effect of S management on productivity, quality and nutrient uptake by pearl millet-mustard crop sequence.

MATERIALS AND METHODS

A field experiment was conducted during *kharif* and *rabi* seasons of 2010-11 and 2011-12 at farmer's field at Panwari (Agra) which is situated at 27° 14' N latitude and 77° 78' longitude at an altitude of 168 m above the mean sea level. The experimental site is characterized by semi-arid climate with extreme temperature during summer (45 to 48° C) and very low temperature during winter (as low as 2° C). The average rainfall is about 650mm, most of which is received from June to September. The experimental soil was sandy lam in texture having 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 available 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 86 M 86) and its residual effect was studied in the succeeding mustard crop (Var. Rohini). Elemental sulphur was applied one week before sowing of pearl millet. A basal dose of 100 kg N, 60 kg P₂O₅ and 40 kg K₂O/ha to pearl millet and 100 kg N, 60 kg P₂O₅ and 40 kg K₂O/ha to mustard was applied through urea, di-ammonium phosphate and muriate of potash, respectively. Half dose of N and full dose of P and K were applied at the time of sowing of pearl millet and mustard. Remaining N was top dressed after one month of sowing. After the harvest of pearl millet, mustard was grown as succeeding crop during winter (*rabi*) season in the same plot without application of sulphur. Crops were harvested at maturity. Growth and yield attributes in both the crops were recorded at harvest. Grain/seed and straw/stover samples were digested in di-acid mixture of HNO₃: HClO₄ (10:4) and sulphur content was determined turbidimetrically (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. Oil content in the whole seed of mustard was determined by employing non-destructive method of oil estimation using nuclear magnetic resonance, spectroscopy Newport analyzer model MK 111 A. Sulphur use efficiency was calculated by subtracting the yield of control from yield at a given level of applied sulphur and divided by the applied level of sulphur. The uptake of nutrients was obtained as product of their concentrations 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 2mm sieve and analyzed for available S after extraction with 0.15% CaCl₂ solution (Chesnin and Yien 1951). The data thus obtained were analyzed statistically using analysis of variance technique for various parameters at 5% level of significance.

RESULTS AND DISCUSSION

Pearl millet

Yield and yield attributes: The effect of S fertilization on plant height, ear head length, ear head diameter and test weight of pearl millet was significant upto 30 kg S/ha over control. These growth and yield attributes tended to decrease with higher levels of sulphur over 30 kg S/ha. This increase may be attributed to the involvement of S in synthesis of S containing amino acids, various enzymatic processes and various oxidation-reduction reactions of plant resulting in greater meristematic activities and growth thereby improvement in plant growth and yield attributes (Chaudhary *et al.* 2013). The grain and stover yield of pearl millet increased significantly with increasing levels of S up to 30 kg S/ha (Table 1). The per cent increase in grain yield due to 15, 30, 45 and 60 kg S/ha were 9.5, 25.2, 19.7 and 16.4, respectively, over control. Whereas the stover yield increased by 6.9, 20.7, 16.8 and 10.8%. Further increase in S levels above 30 kg S/ha had an adverse effect on yield of pearl millet. The effect of S fertilization appears to be due to vigorous growth of plant as their presence in plant system suggest greater availability of metabolites and nutrients synchronized to demand for growth and development of reproductive structure. Such response of S on pearl millet was also found by Singh *et al.* (2014).

Table 1 Effect of sulphur level 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	205.0	25.5	9.05	9.82	30.70	2.74		6.91	10.0	273.8
15	215.0	27.0	10.60	10.39	32.51	3.00	9.5	7.39	10.2	306.1
30	226.5	30.1	10.90	11.08	34.12	3.43	25.2	8.34	10.5	360.5
45	224.7	28.8	10.75	10.96	33.96	3.28	19.7	8.07	10.6	348.0
60	221.0	27.5	10.10	10.82	33.11	3.19	16.4	7.66	10.6	337.7
SEm ±	2.70	0.51	0.22	0.09	0.61	0.07		0.17	0.08	11.14
CD (P=0.05)	5.85	1.11	0.47	0.19	1.32	0.15		0.37	0.17	24.17

Quality: The protein content in pearl millet grain increased from 10.0 to 10.6% with 45 kg S/ha. The protein content of 6% was higher under 45 or 60 kg S/ha than control. This increase in protein content with S addition may be attributed to its involvement in nitrogen metabolism (Singh *et al.* 2014). The protein yield increased significantly with each increment of sulphur dose. The highest protein yield was obtained with 30 kg S/ha which was significantly higher than the control and lower levels of sulphur. This was mainly owing to higher grain yield and protein percentage in pearl millet grain. Protein yield is the function of protein content and seed yield. Since, variation in protein content has genetic and biochemical limitations, the protein yield thus followed almost trend similar to grain yield. Singh *et al.* (2014) also reported such results in pearl millet.

Uptake of nutrients: Nitrogen uptake by pearl millet grain and stover increased significantly with increasing levels of sulphur and the highest N uptake was observed with 30 kg S/ha, i.e. 57.2 and 45.8 kg/ha and lowest in the control, i.e. 43.5 and 35.2 kg/ha (Table 2). 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 in nitrogen assimilation. These results are in accordance with the findings of Singh *et al.* (2014). Phosphorus uptake increased significantly with S levels due to increase in yield. Sulphur improves the growth of roots and shoots in sulphur deficient soil, so plant roots enhance the uptake rate of phosphorus. The uptake of K by pearl millet grain and stover increased significantly with increasing levels of S up to 30 kg/ha. The magnitude of increase in K uptake with 30 kg S/ha was 32 and 23% in grain and stover, respectively over control. Sulphur uptake by pearl millet grain and straw increased significantly with increasing levels of S up to 30 kg S/ha (Table 2). However, the highest S uptake was recorded with 60 kg S/ha and lowest in the control. The increase in S uptake by grain and stover with 30 kg S/ha was 49 and 47.7% over control, respectively. The higher S removed due to its application could be attributed to the priming effect caused by higher crop growth and consequently higher sulphur removal due to balanced fertilization. There was a significant increase in Zn uptake by pearl millet grain and stover up to 30 kg S/ha over control. Thereafter, a

reduction in Zn uptake was recorded with 45 and 60 kg S/ha over 30 kg S/ha. This reduction in zinc uptake owing to higher levels of sulphur may be due to antagonistic relation between sulphur and zinc.

Mustard

Yield and yield attributes: Significant differences were observed among sulphur levels for growth and yield attributes (Table 2). Application of 45 kg S/ha to preceding pearl millet crop recorded significantly taller plants, higher branches/plant, siliquae/plant, seeds/silique and test weight than the control. These characters increased with S application due to increase in cell multiplication, cell elongation and cell expansion through out the entire growth period. Similar results on variation in growth and yield attributes due to sulphur levels were reported by Singh *et al.* (2013). The mustard seed yield increased from 1.70 tonnes/ha (control) to 2.20 tonnes/ha and stover yield from 7.02 to 9.00 tonnes /ha with residual effect of 60 kg S/ha. The increases in seed and stover yield due to application of 60 kg S/ha were 29.4 and 28.2% over control, respectively. However, sulphur levels (60 and 45 kg/ha) were statistically at par. The yield is the cumulative sum of all the yield attributing components which have higher values at higher sulphur levels. These together led to significantly higher yield with increasing levels of sulphur. Residual effect of S on mustard crop was also supported by Singh *et al.* (2013) and Singh *et al.* (20015).

Quality characteristics: Seed protein and oil contents are important parameters which govern the quality of mustard. The protein content and yield in seed were significantly influenced by the residual effect of sulphur and the maximum values were recorded with 60 kg S/ha. It may be because sulphur is the key constituent of essential amino acids like methionine, cysteine and cystine, which are the precursors for protein synthesis. Ram *et al.* (2014) also reported similar results. The levels of residual S had significant influence on oil content and yield in seeds of mustard. Oil content and yield in the seeds significantly increased from 38.1 to 40.9% and 648 to 900 kg/ha respectively with increase in residual S levels from 0 to 60 kg S/ha (Table 3). This increase might be due to the additional supply of sulphur which ultimately resulted in more synthesis of oil (triacyl glycerol) as biosynthesis of

Table 2 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 (kg/ha)	Nitrogen		Phosphorus		Potassium		Sulphur		Zinc	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
0	43.5	35.2	6.3	7.6	15.0	138.2	5.5	9.0	64.1	207.3
15	49.0	39.1	7.2	8.8	17.1	149.3	6.6	10.3	70.5	223.1
30	57.2	45.8	8.3	10.8	19.8	170.0	8.2	13.3	77.2	246.8
45	55.4	45.1	8.2	10.4	19.6	165.4	8.8	13.7	70.8	234.7
60	54.2	43.6	7.9	8.2	19.4	157.7	8.9	13.7	67.6	217.5
SEm \pm	1.18	1.15	0.48	0.55	0.74	3.41	0.27	0.36	1.47	4.17
CD (P=0.05)	2.56	2.49	1.04	1.19	1.63	7.39	0.58	0.78	3.23	9.17

Table 3 Residual effect of sulphur on growth, yield parameters, yield and quality of mustard (mean of 2 years)

Sulphur (kg/ha)	Plant height (cm)	Branches/plant	Siliquae/plant	Seeds/siliqua	Test weight (g)	Seed yield (t/ha)	% response	Stover yield (t/ha)	Protein in seed (t/ha)	Protein in seed (%)	Oil in seed (%)	Oil yield (kg/ha)
0	170.1	5.7	200.0	10.3	4.4	1.70		7.02	20.6	350.0	38.1	648.0
15	176.0	6.8	241.9	11.6	4.6	1.84	8.2	7.28	20.8	382.4	38.5	708.2
30	181.5	7.6	257.6	12.7	5.1	2.08	22.3	7.83	21.2	440.1	39.2	814.8
45	185.0	8.5	270.0	14.0	5.3	2.18	28.2	8.77	21.4	466.2	40.6	885.0
60	184.2	8.2	268.7	13.9	5.2	2.20	29.4	9.00	21.5	473.0	40.9	900.0
SEm ±	1.61	0.01	7.51	0.43	0.01	0.05		0.11	0.01	13.17	0.11	17.0
CD (P=0.05)	3.49	0.02	16.29	0.93	0.02	0.11		0.24	0.02	28.57	0.24	36.8

oil involves S-containing compounds such as acetyl Co A and this might be produced higher amount of oil in mustard seeds. The results of present investigation find report from Jyoti Kumari *et al.* (2012) and Singh *et al.* (2015) who observed significant increase in oil and protein content of mustard seed up to 60 kg S/ha.

Uptake of nutrients: The uptake of nutrient (N, P and K) by mustard seed and stover was significantly affected by the residual effect of sulphur application in pearl millet. A marked increase in uptake of N, P and K was recorded up to 60 kg S/ha (Table 4). However, both the levels of residual sulphur (45 and 60 kg/ha) were statistically at par with respect to uptake of N, P and K by the crop. On an average, the uptake of N, P and K by seed and stover increased with 45 kg S/ha applied in preceding crop by 31.9 and 29.4, 36.4 and 38.6 and 34.3 and 24.6%, respectively over the control. This showed that enhancement in S levels not only increased the yields but also increased the nutrient concentrations and ultimately their uptake by mustard crop. Singh *et al.* (2013) reported an increase in uptake of N, P and K by mustard with increasing levels of sulphur. The data (Table 4) revealed that there was a significant residual effect of the levels of S to give higher S uptake by mustard seed and stover and 60 kg S/ha proved significantly superior to control and other levels of sulphur. This may be attributed to increase in S content and yields of the crop with S application. Our results confirm the findings of Singh *et al.* (2015). The uptake of Zn by mustard seed and stover increased with the application of 45 kg S/ha in preceding pearl millet crop over the control, followed by a reduction in

Zn uptake at higher residual level of S (Noman *et al.* 2015).

Efficiency indices

Apparent S recovery and sulphur use efficiency (SUE) of added levels of S by pearl millet and mustard are presented in Table 5. The SUE with added S (15-30 kg S/ha) in pearl millet varied from 17.3 to 23.0 kg grain/kg S and in mustard from 9.3 to 12.7 kg seed/kg S. The direct application of 30 kg S/ha recorded the highest agronomic efficiency and apparent S recovery in pearl millet. Similar results were observed by Kumar *et al.* (2014) in rice. In mustard, apparent S recovery was noted at 45 kg S/ha. Recovery efficiency of S in pearl millet and mustard was the highest with application of 30 and 45 kg S/ha, respectively. It seems that greater recovery of added S was recorded at its lower levels. Higher recovery of S at lower level of applied S was also reported by Jena *et al.* (2006).

Economics

The application of 45 kg S/ha to pearl millet proved economically beneficial with highest net returns (₹ 54 961.0/ha) and fetched an additional net return of ₹ 14 525.0 /ha over control. This could be ascribed to the fact that substantial fraction of S applied in pearl millet was utilized by succeeding mustard which consequently reflected in net returns accrued from mustard. This treatment (45 kg S/ha) also produced significantly higher benefit: cost ratio (3.82) over other levels of sulphur. These observations are in agreement with the findings of Ram *et al.* (2014), who also reported higher net returns and benefit: cost ratio with sulphur application.

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

Sulphur (kg/ha)	Nitrogen		Phosphorus		Potassium		Sulphur		Zinc	
	Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover
0	56.4	55.1	9.6	25.6	12.8	108.1	10.4	29.8	71.6	184.5
15	60.7	57.9	10.5	27.3	13.9	112.9	11.4	32.0	75.2	187.6
30	68.1	64.1	11.7	30.6	15.8	122.9	13.3	38.0	79.8	184.6
45	74.4	71.3	13.1	35.5	17.2	134.7	15.3	43.1	82.3	195.4
60	75.8	73.6	36.8	38.8	18.1	140.0	16.5	47.3	83.1	195.9
SEm ±	1.04	1.14	0.33	0.71	0.43	4.31	0.46	0.99	1.26	1.23
CD (P=0.05)	2.26	2.48	0.72	1.55	0.93	9.35	1.01	2.15	2.73	2.68

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

Sulphur (kg/ha)	Pearl millet		Mustard		Pearl millet-mustard		Available S (kg /ha)
	S apparent recovery (%)	SUE (kg grain/kg S)	S apparent recovery (%)	SUE (kg seed/kg S)	Net returns (₹/ha)	B:C ratio	
0					40436.0	3.13	13.0
15	160	17.3	21.3	9.3	44196.0	3.30	16.6
30	23.3	23.0	37.0	12.7	49609.6	3.57	19.5
45	17.8	12.0	40.0	10.7	54961.0	3.82	26.4
60	13.5	7.5	39.3	8.3	54179.9	3.61	29.0
SEm ±							0.71
CD (P=0.05)							1.54

Available sulphur

The available sulphur (0.15% CaCl₂ solution extractable) after harvest of the crops is presented in Table 5. It increased with increasing levels of S after harvest of the crops. Available S varied from 13.0 in control to 29.0 kg/ha in 60 kg S/ha treatment. Significant build-up of available S in soil was observed due to application of S compared to control. The S content in control plot decreased after taking the crops over initial value, indicating an exhaustion of S by the crops. Available S remained much higher (14.0 kg/ha) than the original level at higher levels of S, i.e. 60 kg S/ha (Noman *et al.* 2015).

From the study, it could be inferred that use of 45 kg S/ha is beneficial in terms of obtaining high crop productivity and soil available S status under pearl millet-mustard sequence. Quality characteristics of pearl millet and mustard were also improved significantly and favourably by use of sulphur. Thus, application of 45 kg S/ha appears to be the best dose for obtaining higher productivity and profitability in pearl millet-mustard cropping sequence under agro-climatic conditions of Agra region.

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