

INTERACTION EFFECT OF POTASSIUM AND SULFUR FERTILIZATION ON PRODUCTIVITY AND MINERAL NUTRITION OF SUNNHEMP

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□ *The interactive effect of potassium (K) and sulfur (S) fertilization on productivity and mineral nutrition of sunnhemp (*Crotalaria juncea* L.) was evaluated in a field experiment during 2008 and 2009 cropping seasons at Uttar Pradesh, India. Potassium and sulfur fertilizers increased fiber yield and nutrient uptake of sunnhemp. It was observed that an application of K and S at 40 kg ha⁻¹ each significantly increased the total dry matter, fiber yield, and nutrient uptake of sunnhemp. The crop yield response to the added S was greater than for K and the nutrient use efficiency was also higher at lower levels of fertilizer addition. The increased levels of K and S improved the number of nodules and crude protein content of sunnhemp leaves.*

Keywords: sunnhemp, fiber yield, potassium uptake, sulfur uptake, nutrient use efficiency

INTRODUCTION

Sunnhemp (*Crotalaria juncea* L.) is a tropical legume that has been used as a green manure for soil improvement in the tropics (Duke, 1981; Cook and White, 1996). Furthermore, sunnhemp fiber has great commercial importance in the textile industry. India is the largest producer of sunnhemp fiber followed by Bangladesh and Brazil (Dimsey, 1975). The fiber is mainly used as a source of raw materials in cottage industry for making various

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products. However, with the advent of the green revolution, synthetic fibers and improved varieties of other crops, the area under cultivation has dropped sharply (Pradhan et al., 1999). Adequate nutrient management is essential to sustain the productivity of sunnhemp with better nutrient uptake and biotic stress resistance capacity. Both sulfur (S) and potassium (K) play important role in the cultivation of sunnhemp for fiber production. Potassium is required in high concentrations for the synthesis of protein, which includes the binding of RNA to ribosome (Anjana et al., 2009). Lack of K inhibits photosynthesis and hence, the ability for dry matter accumulation (Marschner, 1995). Sulfur is the constituent of cystine, cysteine and methionine, among which cystine is an amino acid from which plant proteins are made. Sulfur deficiency retards chlorophyll synthesis that leads to chlorosis. Sulfur also promotes nodule formation, which improves biological nitrogen fixation and fulfills the nitrogen requirement of plant. Literature on K and S interaction on sunnhemp is limited. Thus, this experiment was conducted to study the effect of K and S interaction on productivity and mineral nutrition of sunnhemp.

MATERIALS AND METHODS

A field experiment was done with sunnhemp crop (variety K12 yellow) at Sunnhemp Research Station, Pratapgarh, Uttar Pradesh, India during 2008 and 2009 cropping seasons to determine the effect of K and S fertilizer on yield and mineral nutrition of sunnhemp. The rainfall during growing season normally ranged from 35 to 527 mm. The mean maximum temperature and minimum temperature during growing period varied from 30.0 to 41.5°C and 19.7 to 25.6°C, respectively. The soil of the experimental site (Inceptisol; Typic Ustocret) was sandy loam in texture (sand 56%, silt 24% and clay 20%) and was low in organic carbon (0.31%), available nitrogen (N) (235 kg ha⁻¹), available phosphorus (P) (10.2 kg ha⁻¹), available K (96 kg ha⁻¹), and available S (15 kg ha⁻¹). The experiment was laid out in split plot design with K in main plot and S in sub-plot. Four levels each of K (0, 20, 40 and 60 kg K ha⁻¹) and S (0, 20, 40 and 60 kg S ha⁻¹) were applied. There were three replicates of each treatment. The crop was sown in April with row to row spacing of 25 cm and plant to plant spacing of 5 cm. Uniform levels of nitrogen (20 kg N ha⁻¹) and P (40 kg P₂O₅ ha⁻¹) were applied in each plot before sowing. Farmyard manure at 7500 kg ha⁻¹ was applied three weeks before sowing to each plot. Soil samples were collected from the surface (0–15 cm depth), mixed, homogenized, sieved (2 mm) and analyzed for organic carbon (C), available N, P, K and S following standard procedures (Jackson, 1967). Plant samples were collected, weighed and then analyzed by the methods of Tandon (1993). 30 days after seedling emergence, nodule population data were collected by uprooting five plants from each replicated

wet plot and counting the number of nodules (Kutama et al., 2008). Crude protein content of leaves was estimated by [Lowry et al. \(1951\)](#) and crude protein content was calculated by multiplying the N content by a factor of 6.25. Agronomic efficiency, physiological efficiency and apparent recovery of nutrients were calculated as per Fageria et al. (1997).

Agronomic Efficiency (kg grain/kg nutrient)

$$= \frac{[\text{Grain yield from treated plot (kg ha}^{-1}\text{)}] - [\text{Grain yield from control plot (kg ha}^{-1}\text{)}]}{\text{Amount of nutrient added (kg ha}^{-1}\text{)}} \times 100$$

Physiological Efficiency (kg grain/kg nutrient uptake)

$$= \frac{[\text{Grain yield of treated plot (kg ha}^{-1}\text{)}] - [\text{Grain yield of control plot (kg ha}^{-1}\text{)}]}{[\text{Nutrient uptake of treated plot (kg ha}^{-1}\text{)}] - [\text{Nutrient uptake of control plot (kg ha}^{-1}\text{)}]} \times 100$$

Apparent Recovery (%)

$$= \frac{[\text{Nutrient uptake of treated plot (kg ha}^{-1}\text{)}] - [\text{Nutrient uptake of control plot (kg ha}^{-1}\text{)}]}{\text{Amount of nutrient added (kg ha}^{-1}\text{)}} \times 100$$

Data on all observations were subjected to analysis of variance (ANOVA) and least significant difference (LSD) was calculated using SPSS10 software (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Crop Yield and Response

The pooled data of the two year study showed that K and S fertilizer significantly ($P \leq 0.05$) increased the dry matter and fiber yield of sunnhemp (Table 1). The increasing levels of K and S to 40 kg ha⁻¹ significantly increased the total dry matter and fiber yield of the crop. Further additions to 60 kg ha⁻¹ gave no significant increase in yield of dry matter or fiber. Highest dry matter yield (8590 kg ha⁻¹) was reached at K₆₀S₆₀ level, whereas maximum fiber yield (788 kg ha⁻¹) of sunnhemp was recorded at K₆₀S₄₀ level. The results indicated that the application of K and S at 40 kg ha⁻¹ significantly increased the total dry matter yield by 5.7 and 11.2% over the lower application amount (20 kg ha⁻¹). The application of K at 40 kg ha⁻¹

TABLE 1 Effects of potassium and sulfur on dry matter yield (kg ha^{-1}) and fiber yield (kg ha^{-1}) of Sunnhemp. Crop data were averaged across the two years (2008 and 2009)

S level (kg ha ⁻¹)	Potassium level (kg ha ⁻¹)				Mean
	K ₀	K ₂₀	K ₄₀	K ₆₀	
Total dry matter yield (kg ha ⁻¹)					
S ₀	5800	6640	7110	7120	6670
S ₂₀	6400	7570	7800	7900	7420
S ₄₀	7950	7960	8500	8580	8250
S ₆₀	8240	8010	8520	8590	8340
Mean	7100	7550	7980	8050	
LSD (P = 0.05) K = 0.14 S = 0.14 K × S = 0.26					
Total fiber yield (kg ha ⁻¹)					
S ₀	530	631	614	609	596
S ₂₀	574	684	725	733	679
S ₄₀	665	699	783	788	733
S ₆₀	659	671	742	768	710
Mean	607	671	716	725	
LSD (P = 0.05) K = 0.37 S = 0.37 K × S = 0.74					

increased the fiber yield by 17.9% over the control (K₀) and higher application of K (at 60 kg ha^{-1}) did not show any significant increase in fiber yield. An application of 40 kg S ha^{-1} resulted in 22.9% increase in fiber yield over the S₀ treatment. The results indicate that the sunnhemp response was greater for S rather for K additions. From the K*S interaction, it was observed that better fiber yield (788 kg ha^{-1}) was obtained for the K₆₀S₄₀ treatment. From the crop response study, the agronomic efficiency of sunnhemp was higher (3.2 and 4.2 $\text{kg fiber yield ha}^{-1}$ for applied K and S respectively) at K₂₀ and S₂₀ application (Table 2). Further additions of K and S reduced the

TABLE 2 Effect of potassium and sulfur on agronomic efficiency, physiological efficiency and apparent recovery of nutrients

Nutrient level	Agronomic efficiency ($\Delta\text{kg yield kg}^{-1}$ fertilizer added)	Physiological efficiency of potassium ($\Delta\text{kg yield } \Delta\text{kg}^{-1}$ K uptake)	Physiological efficiency of sulfur ($\Delta\text{kg yield } \Delta\text{kg}^{-1}$ S uptake)	Apparent potassium recovery (%)	Apparent sulfur recovery (%)
K (kg ha^{-1})					
0	—	—	—	—	—
20	3.2	9.3	21.6	34.5	14.9
40	2.7	12.7	22.2	21.5	12.3
60	2.0	12.2	22.2	16.0	8.8
S (kg ha^{-1})					
0	—	—	—	—	—
20	4.2	10.0	23.1	41.6	18.0
40	3.4	10.3	26.9	33.3	12.8
60	1.9	8.5	20.7	22.2	9.2

agronomic efficiency, which indicated greater competition among plants for nutrients in short supply.

Nutrient Removal

Nitrogen (N) uptake by sunnhemp increased as K levels increased to 40 kg ha⁻¹. Similarly the application of S at 40 kg ha⁻¹ significantly ($P \leq 0.05$) increased the N uptake by sunnhemp by 8.4% as compared to the control (S₀) (Table 3). The higher N uptake might be attributed to the increased N requirement for the higher dry matter yield as amounts of fertilizer S increased for the increased synthesis of different enzymes and amino acids. Lower N accumulation and yield reduction was observed for legumes grown in pots when S was limiting (Scherer and Lange, 1996). With S deficiency, amino acids and other N forms accumulated due to a lack of being

TABLE 3 Effect of potassium and sulfur on N, K, S, and P uptake (kg ha⁻¹) of sunnhemp crop (averaged across two years of field work)

S level (kg ha ⁻¹)	Potassium levels (kg ha ⁻¹)				Mean
	K ₀	K ₂₀	K ₄₀	K ₆₀	
Nitrogen uptake (kg ha ⁻¹)					
S ₀	92	111	115	121	109.75
S ₂₀	115	126	128	135	126.00
S ₄₀	129	132	147	156	141.00
S ₆₀	138	140	148	153	144.75
Mean	118.50	127.25	134.50	141.25	
LSD (P = 0.05) K = 7.08 S = 7.08 K × S = 14.17					
Potassium uptake (kg ha ⁻¹)					
S ₀	51.37	55.37	57.42	57.62	55.45
S ₂₀	53.5	65.29	67.72	68.59	63.78
S ₄₀	61.98	70.13	70.85	72.16	68.78
S ₆₀	64.83	68.5	70.03	71.81	68.79
Mean	57.92	64.82	66.51	67.55	
LSD (P = 0.05) K = 1.79 S = 1.79 K × S = 3.58					
Sulfur uptake (kg ha ⁻¹)					
S ₀	10.74	12.97	13.7	13.56	12.74
S ₂₀	12.49	16.31	17.34	19.25	16.35
S ₄₀	13.81	16.77	20.57	20.27	17.86
S ₆₀	14.98	17.87	20.03	20.11	18.25
Mean	13.01	15.98	17.91	18.30	
LSD (P = 0.05) K = 0.55 S = 0.55 K × S = 1.09					
Phosphorus uptake (kg ha ⁻¹)					
S ₀	20.7	30.6	31.8	33.3	29.10
S ₂₀	30.2	32.5	33.2	35.3	32.80
S ₄₀	30.4	36.6	38.9	39.0	36.23
S ₆₀	30.8	37.8	39.1	38.8	36.63
Mean	28.03	34.38	35.75	36.60	
LSD (P = 0.05) K = 1.01 S = 1.01 K × S = 2.03					

synthesized into proteins may have a feed-back repression on N fixation (Janssen and Vitosh, 1974) and N uptake by the crop. From the interaction effect, the $K_{60}S_{40}$ treatment had the maximum N removal (156 kg ha^{-1}) by sunnhemp (Table 3) which might be the consequence as the highest dry matter yield was obtained in this treatment.

Increasing the K application significantly increased the K uptake by the crop over control. Application of 60 kg K ha^{-1} had the highest K uptake (67.55 kg ha^{-1}) which was statistically the same as that obtained by 40 kg K ha^{-1} . However, K_{40} treatment could not improve K uptake by sunnhemp over K_{20} . The results showed S application to 40 kg ha^{-1} significantly increased the K uptake by the crop. Combined application of K and S improved K uptake by sunnhemp and maximum K uptake (72.16 kg ha^{-1}) was at $K_{60}S_{40}$, which was 40% higher than the control (K_0S_0) (Table 3).

Irrespective of S levels, increase of K levels significantly increased the S uptake by sunnhemp and application of 40 kg K ha^{-1} increased the uptake by 37.6% as compared to the no K control. Further increase in K level (60 kg ha^{-1}) did not significantly increase the S uptake by the crop. Application of S increased the S uptake by sunnhemp. The increasing S removal at higher levels of S additions could be attributed to higher dry matter yield of sunnhemp and consequently the increased demand for S for synthesis of the S-containing amino acids. The K*S interaction revealed that S uptake (20.57 kg ha^{-1}) was a maximum at the $K_{40}S_{40}$ treatment (Table 3). Similarly, phosphorus (P) uptake and maximum P uptake (39.0 kg ha^{-1}) was measured at $K_{60}S_{40}$. A significant synergistic effect of K and S application was also observed for the P uptake by sunnhemp. Increasing levels of K and S significantly increased the P removal by the crop. Ghosh et al. (2000) also reported synergistic interaction effect of S and K in soybean for low levels of P.

Sulfur recovery decreased with each addition of S and K while the physiological efficiency increased as levels of K and S increased (Table 2). However, the effect was noticed up to 40 kg ha^{-1} level in both the nutrients. Higher S use efficiency was recorded in S_{40} (26.9) and K_{40} (22.2) treatments, which indicated better utilization of applied nutrient for fiber production. The use efficiency (12.7 and 10.3) and apparent recovery (34.5 and 41.6) of K followed the similar trend and maximum use efficiency of K was observed in K_{40} and S_{40} treatments, respectively (Table 2).

Nodule Population and Crude Protein Content

Application of K fertilizer increased nodule formation (increased number of nodules) of sunnhemp crop (Table 4). A significant increase in nodule number was measured with an increase in K fertilizer to 60 kg K ha^{-1} . Potassium plays a significant role for the growth and yield of legumes by increasing the number and improving the efficiency of root nodules (Premaratne and

TABLE 4 Effect of potassium and sulfur on nodule count and crude protein content (%) of sunnhemp crop (averaged across two years of field work)

S level (kg ha ⁻¹)	Potassium levels (kg ha ⁻¹)				
	K ₀	K ₂₀	K ₄₀	K ₆₀	Mean
	Nodule count				
S ₀	24.2	29.8	28.6	30.0	28.1
S ₂₀	23.6	34.3	33.8	34.4	31.5
S ₄₀	26.5	35.6	37.2	38.4	34.4
S ₆₀	29.6	37.1	43.2	42.9	38.2
Mean	26.0	34.2	35.66	36.40	
LSD(P = 0.05) K = 0.72 S = 0.72 K × S = 1.44					
	Crude protein content of leaf (%)				
S ₀	9.58	9.3	9.47	9.7	9.51
S ₂₀	9.19	9.66	10.38	10.43	9.92
S ₄₀	9.73	10.42	11.05	10.97	10.54
S ₆₀	10.13	9.92	11.38	11.41	10.71
Mean	9.66	9.83	10.57	10.63	
LSD(P = 0.05) K = 0.37 S = 0.37 K × S = 0.75					

Oertli, 1994). This phenomenon might be supported by the fact that dry matter yield and total N accumulation in legumes are very responsive to K fertilizer (Grewal and Williams, 2002). Higher additions of S significantly increased nodule formation with 40% more nodules measured at 60 kg S ha⁻¹ as compared to the control (Table 4). Possible reasons might be attributed to S involvement in formation of nitrogenase enzymes for N fixation in legumes (Vidyalakshmi et al., 2009). Khandkar et al. (1985) also reported S fertilizer increased nodule numbers in blackgram. Similarly, Scherer and Lange (1996) measured increased nodule formation in legume plants with the application of S. The application of K and S, the K₄₀S₆₀ treatments gave the maximum number of nodules.

Application of S at 40 kg ha⁻¹ increased the crude protein content of sunnhemp leaf by about 12.6% over the control (S₀) (Table 4). This may be due to S role as a constituent of S containing amino acids (methionine, cystine and cysteine) and as a constituent of Fe-S proteins (ferredoxins) (Goswami, 1988). It was observed that the protein synthesis and photosynthesis in leaf was significantly decreased by S deficiency (Sexton et al., 1997). The application of K at 40 and 60 kg ha⁻¹ significantly increased the protein content of leaf as compared to the control. These results agree with Misra (2003), who also observed that application of S and K increased the protein content of mustard significantly to 60 and 90 kg nutrients ha⁻¹ levels, respectively. The increase in protein content with K fertilizer application may be attributed to the increase in biomass that enhanced the synthesis of effective ribosome, amino acyl-tRNA's, peptide bond synthesis during protein synthesis (Anjana et al., 2009).

Available Nutrient Status of Post-Harvest Soil (kg ha⁻¹)

The higher available N status of post harvest soil was observed only at the treatment of 40 and 60 kg S ha⁻¹ (Table 5), but no significant effect was found at the levels of 20 and 40 kg S ha⁻¹. Incorporation of S at 60 kg ha⁻¹ increased available N status of soil by 8.72% over control. The increased nodule population in sunnhemp roots at higher levels of S (Table 4) may have increased the fixation of atmospheric N and significant amount of organic N may be mineralized after decomposition of the plant residues i.e. root and nodules in soil (Ambrosano et al., 2009). No significant effect on available N content was measured for the K application.

The results revealed that increasing amounts of K and S significantly increased the available P content in the soil (Table 5). Highest soil available P (160 kg ha⁻¹) was measured at K₆₀S₆₀. The increase of the soil available P might be due to increased acidity due to the activity of S oxidizing

TABLE 5 Effect of potassium and sulfur on available nutrient status of post-harvest soil

S level (kg ha ⁻¹)	Potassium levels (kg ha ⁻¹)				Mean
	K ₀	K ₂₀	K ₄₀	K ₆₀	
Available nitrogen (kg ha ⁻¹)					
S ₀	235	237	238	242	238
S ₂₀	242	244	246	247	244
S ₄₀	249	247	252	251	249
S ₆₀	257	249	271	258	258
Mean	245.8	244.3	251.8	249.5	
LSD (P = 0.05) K = 10.45 S = 10.45 K × S = 20.87					
Available phosphorus (kg ha ⁻¹)					
S ₀	10.2	10.3	11.2	12.5	11.05
S ₂₀	10.5	12.1	12.2	13.7	12.13
S ₄₀	12.6	14.5	15.1	15.9	14.53
S ₆₀	13.8	14.6	15.8	16.0	15.05
Mean	11.8	12.9	13.6	14.5	
LSD (P = 0.05) K = 0.43 S = 0.43 K × S = 0.85					
Available sulfur (kg ha ⁻¹)					
S ₀	15.0	16.3	16.2	16.4	15.98
S ₂₀	18.5	19.5	20.0	20.8	19.70
S ₄₀	21.1	21.3	22.8	24.2	22.35
S ₆₀	22.0	22.8	22.9	25.4	23.28
Mean	19.2	20.0	20.5	21.7	
LSD (P = 0.05) K = 0.61 S = 0.61 K × S = 1.21					
Available potassium (kg ha ⁻¹)					
S ₀	96	102	112	118	107
S ₂₀	105	109	121	128	115
S ₄₀	109	110	125	130	118
S ₆₀	109	113	130	138	122
Mean	104.8	108.5	122.0	128.5	
LSD (P = 0.05) K = 10.22 S = 10.22 K × S = 20.44					

bacteria through production of Sulfuric acid from elemental S (Vidyalakshmi and Paranthaman, 2009) or mineralization of P from organic forms (Jaggi et al., 2005). Magorzata and Lucyna (2009) also reported an increase in soil available P at different levels of elemental S.

The application of elemental S also increased the soil available S content as compared to control (Table 5). Application of 60 kg S ha⁻¹ recorded maximum availability of S (23.28 kg ha⁻¹) in post-harvest soil that was 31.3% higher than the control. This might be attributed to the lower S utilization efficiency at higher S applications. Moreover, as sunnhemp leaves contains 0.25% Sulfur, excessive leaf fall might have increased the S content of the soil. Application of K also influenced the available S content in soil. Higher available S (21.7 kg ha⁻¹) was measured at 60 kg K ha⁻¹. Lower amounts of K (20 and 40 kg ha⁻¹) had similar values of soil available S.

The available K content in soil increased significantly with S application to the 40 kg S ha⁻¹ level (Table 5). Higher nutrient uptake at 60 kg K ha⁻¹ might be the possible reason for lower soil available K content.

From the present study it may be concluded that there is a synergistic interaction effect between K and S. Also an application of 40 kg each of K and S per hectare may be recommended for obtaining optimum yield of sunnhemp for this soil type or soils with similar levels of soil available K and S in the soil. Better nodule formation with K and S fertilizer increased N availability that further increased productivity of sunnhemp.

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