



Sulphur management in pigeonpea (*Cajanus cajan*) – wheat (*Triticum aestivum*) cropping system

D.R. PALSANIYA¹ AND I.P.S. AHLAWAT

Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

A field experiment was conducted at New Delhi during 2003 and 2005 on sandy loam soil with 14.35 kg/ha available S to evaluate the relative efficiency of sulphur (S) sources and rates in pigeon pea [*Cajanus cajan* (L.) Millsp.]–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] cropping system. The study revealed that application of 30 kg S/ha being at par with 60 kg/ha produced 24.9 and 0.62 more pods/plant and seeds /pod respectively than control (no S). This increase in yield attributes finally led to 0.47 t/ha higher pigeon pea yield over no S application (1.15 t/ha). S applied to pigeon pea at 60 kg/ha left behind 1.19 kg/ha more S in soil than 30 kg/ha, which resulted in higher grain yield of succeeding wheat by 0.58 tonne/ha. Among the S sources, cosavet being on par with gypsum gave 14.8% (0.23 t/ha) more grain yield of pigeon pea over elemental S (1.55 t/ha). Both these sources also proved superior in their residual effect on succeeding wheat when compared with elemental S. Wheat responded to direct application of 30 kg S/ha only. Cosavet was the best source from productivity point of view. However, application of 30 kg S/ha to pigeon pea as gypsum and to wheat as elemental S was promising in terms of S efficiency and economics.

Key words: Cosavet, Elemental sulphur, Gypsum, Pigeonpea, Sulphur, Wheat

Pigeon pea is the most important rainy season pulse crop in India. The scope for its cultivation in a yearly crop rotation was conceived long back in 1947. Since then several pigeon pea based cropping systems have emerged in different parts of the country. In irrigated Indo-Gangetic plains, the predominant cropping system of rice-wheat is now facing the problem of stagnant or declining factor productivity. The development of short duration pigeon pea cultivars of wider adaptability and also wheat cultivars suitable for late sown conditions has given impetus to this pulse-cereal system, without much hampering food grain production of the country (Ahlawat *et al.*, 2005). Sulphur is the fourth major plant nutrient after N, P and K playing an important role in growth and development of plants being a constituent of 3 amino acids *viz.*, methionine, cysteine and cystine. Sulphur is also needed for the synthesis of other metabolites like co-enzyme A, biotin, thiamin (Vitamin B₁) and glutathione, besides its role in the synthesis of chlorophyll and improves nodulation in legumes. Due to continuous use of high grade S free fertilizers and intensive cropping, its deficiency has been re-

ported as hidden hunger in many crops, especially pulses. According to an estimate, 68 m ha of cropped land is suffering from S deficiency in India (*The Financial Express*, 2006), needing 2.3 million tonnes of S fertilizers. However, only 0.7 million tonne of sulphur is used in the country. The benefit of system based S management is that it enables the distribution of this nutrient among the component crops as per their requirement and also aims at taking residual effect into account while making recommendations to the farmers. The S-recommendation for individual crops of pigeon pea and wheat are already available. But these recommendations do not take into account the utilization of S by the preceding crops and the S applied to them in sequence indicating a gap in information available on S management in cropping systems. In view of this, a field experiment was conducted to find out the effect of sulphur and its sources in pigeon pea-wheat cropping system.

MATERIALS AND METHODS

A field experiment was carried out at the research farm of Indian Agricultural Research Institute, New Delhi during rainy and winter seasons of 2003 and 2004. The soil was sandy loam with pH (1:2.5 soil: water) nearly neutral pH 8.0, low organic carbon (0.37 and 0.39%), total N (868.3 kg/ha) and medium in available S (14.3 and 14.4

Corresponding author: (E mail: drpalsaniya@gmail.com)

¹Present address: ¹Scientist, National Research Centre for Agroforestry, Jhansi, Uttar Pradesh 284 003

kg/ha) at 0-30 cm soil depth during 2003 and 2004. In pigeonpea, 7 treatments comprising combinations of 3 levels (0, 30 and 60 kg/ha) and 3 sources of S (cosavet, gypsum and elemental sulphur) were tested in randomized block design as main plots with 3 replications. During *rabi* season, treatments applied to preceding pigeon pea were further divided into 3 sub-plots (0, 30 and 60 kg S/ha supplied through elemental S) in wheat crop in a split design. Pigeon pea 'Pusa 992' was sown on 25 June (2003) and 27 June (2004) in rows 50 cm apart and harvested on 15 December in 2003 and 25 November in 2004. In pigeon pea, a plant population of population of 83.3×10^3 plants was maintained. Wheat 'Pusa gold' was sown in rows 22.5 cm apart using a seed rate of 125 kg/ha on 24 December in 2003 and 4 December in 2004 and harvested on 15 April in 2004 and 12 April in 2005. Pigeon pea received recommended dose of N and P (20 and 26.4 kg/ha) at sowing through urea and di-ammonium phosphate. Wheat received 60 kg N/ha (50% of recommended dose) along with 26.4 kg P/ha at sowing and the remaining 50% N at crown root initiation stage. Sulphur was applied as per treatment 2 weeks before sowing and incorporated in the soil. The cosavet, gypsum and elemental sulphur contained 80%, 18.6%, 85% sulphur, respectively. S concentration in soil and plant was analyzed as per standard turbidometric method (Chesin and Yien, 1950). Various S use efficiencies *viz.* agronomic S use efficiency, ASUE (kg grain/kg applied), physiological S use efficiency, PSUE (kg grain/kg uptake), apparent S recovery, ASR (%), and S harvest index and SHI (%) using standard procedures. The S efficiency ratio, SER (kg dry matter/kg S uptake), and physiological efficiency index of sulphur, PEIS (kg

grain/kg S uptake) were arrived as below.

$$\text{SER} = \frac{Y_d}{S_h}$$

$$\text{PEIS} = \frac{Y_g}{S_h}$$

where, Y_d =Dry matter yield (kg/ha); S_h =S accumulated at harvest (kg/ha) and Y_g =Grain yield (kg/ha)

RESULTS AND DISCUSSION

Effect of S on pigeonpea

Sources and levels of sulphur have marked influence on growth {(plant height, branching and leaf area index (LAI)}; yield attributes (pods/plant and seeds/pod) and yield of pigeon pea (Table 1). Application of 30 kg S/ha increased the number of pods/plant and seeds/pod of pigeon pea by 24.9 and 0.52 respectively that combined together have improved its yields by 0.44 tonnes/ha (38.3%) over control (1.15 t/ha). However, a further increase in S dose (60 kg/ha) could not bring in any perceptible increase in pods/plant and seeds/pod (2.3 and 0.27) and thus failed to improve pigeon pea yield markedly (0.09 t/ha). Sulphur fertilization exerted no significant increase in 1,000-grain weight of pigeon pea. Sulphur application to pigeon pea (rest of the treatments *i.e.* mean of 30 and 60 kg S/ha) recorded 41.7% higher pigeon pea grain yield over no sulphur. Sulphur is associated with the smaller component (Fe-S clusters) of nitrogenase enzyme involved in N-fixation by nodule bacteria and also by free living bacteria. Further, S forms a part of ferredoxin, which acts as electron carrier connected with supply of energy for the N-

Table 1. Effect of S on growth, yield attributes and yield (t/ha) of pigeonpea (mean of 2 seasons)

Treatment	Plant height (cm)	Branches/plant	Leaf area index	Pods/plant	Seeds/pod	Grain yield	Biological yield	Harvest index
<i>Control vs rest</i>								
Control	129.0	15.2	1.83	144.5	3.17	1.15	5.29	21.25
Rest	149.7	20.2	2.29	170.9	3.92	1.63	7.19	22.76
SEd±	7.9	1.1	0.11	9.5	0.27	0.07	0.30	1.00
CD (P=0.05)	13.6	2.3	0.24	20.9	0.46	0.15	0.66	NS
<i>S level (kg/ha)</i>								
30	148.5	19.9	2.22	169.4	3.79	1.59	7.01	22.71
60	150.9	21.1	2.35	171.7	4.06	1.68	7.37	22.81
SEm±	3.8	0.5	0.06	5.1	0.12	0.06	0.15	0.81
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
<i>S source</i>								
Elemental S	148.6	19.1	2.24	160.9	3.97	1.53	6.73	22.76
Gypsum	149.8	19.8	2.29	165.5	3.92	1.62	7.07	22.92
Cosavet	150.6	22.5	2.34	184.9	4.07	1.76	7.78	22.60
SEm±	4.9	0.7	0.08	6.2	0.14	0.06	0.20	0.61
CD (P=0.05)	NS	2.1	NS	19.1	NS	0.15	0.63	NS

fixation process (Lakkineni and Abrol, 1994) might have favoured better N fixation, thus growth, yield attributes and yield formation finally. A similar effect of sulphur fertilization (30 kg/ha) on plant height, branches/plant and yield together led to 32.5% higher biological yield over control. Further increase in S dose to 60 kg/ha has increased the biological yield by 0.36 t/ha, however, this increase was not statistically significant. The harvest index was not influenced by S fertilization.

Among the sources of sulphur, cosavet proved promising for pigeonpea growth, yield attributes and yield formation than the other two sources *i.e.* elemental sulphur and gypsum (Table 1). Cosavet enhanced the number of pods/plant and seeds/pod of pigeon pea by 24.0 and 0.10 which together brought in 14.8% improvement in pigeon pea yield over the elemental sulphur. The performance of gypsum as a source of S to pigeon pea remained in between elemental sulphur and cosavet and thus recorded at par yield with these two sources. The impact of sources of sulphur on plant height, LAI, seeds/pod and 1,000-seed weight was not significant. Better growth and yield with cosavet may be attributed to the smaller particle size, resulting in greater surface area which might have hastened its solubility as well as the oxidation of S to SO_4^{2-} , the available form of S to plants. Thus, the better S nutrition of crop could have contributed to better root and shoot growth and nodulation and ultimately higher yield. Barman

(2004) also reported similar findings.

S-uptake in pigeon pea increased significantly with each successive increase in S up to 60 kg/ha (Table 3). The increase in S uptake with S fertilization might be ascribed to the increase in biological yield and S concentration in plant parts. First increment of 30 kg S/ha improved the uptake of S by 7.22 kg/ha over control, while further increase of 30 kg S/ha enhanced S-uptake by 3.13 kg only over 30 kg S/ha. Agronomic and physiological sulphur use efficiency (ASUE, PSUE), S-efficiency ratio (SER) and apparent S-recovery (ASR), S-harvest index (SHI) were highest with 30 kg S/ha (Table 5). All these parameters registered lower values with higher dose (60 kg S/ha). However, physiological efficiency index of S (PEIS) and SER were maximum with no sulphur and the least with 60 kg S/ha. The declining rate of yield increase with 60 kg S/ha when compared with 30 kg S/ha was responsible for lower ASUE at higher rates of S application. Further, decline in PSUE at 60 kg S/ha might be ascribed to greater increase in S-uptake than increase in yield. In general, S-content in soil after crop harvest increased by 2.56 kg/ha even in control. However, successive increases in S levels up to 60 kg/ha further improved the available S content in soil. The increase in soil S might be ascribed to the fact that the additions exceeded the crop uptake by 5.92 and 32.79 kg/ha in 30 and 60 kg S application respectively. Application of 30 kg S/ha fetched Rs 384/ha more net re-

Table 2. Direct and residual effect of S on growth, yield attributes and yields (t/ha) of wheat (mean of 2 seasons)

Treatment	Plant height (cm)	Leaf area index	Spikes/m row	Grains/spike	Grain yield	Biological yield	Harvest index
<i>S to pigeonpea</i>							
Control	69.4	2.68	89.5	31.4	3.16	7.64	41.23
Rest	75.7	2.98	123.7	34.5	4.26	10.17	41.74
SEd±	2.3	0.07	4.0	1.2	0.15	0.27	1.63
CD (P=0.05)	5.0	0.16	9.0	2.9	0.34	0.65	NS
<i>S level (kg/ha)</i>							
30	74.8	2.96	120.0	34.2	4.14	9.93	41.63
60	76.6	2.99	127.5	34.9	4.37	10.41	41.85
SEm±	1.1	0.03	2.2	0.7	0.08	0.16	0.84
CD (P=0.05)	NS	NS	6.6	NS	NS	NS	NS
<i>S source</i>							
Elemental S	75.5	2.97	115.0	34.3	3.95	9.49	41.61
Gypsum	74.8	2.97	127.0	34.5	4.36	10.41	41.77
Cosavet	76.6	2.99	130.0	34.8	4.47	10.61	41.84
SEm±	1.3	0.05	2.6	0.8	0.09	0.19	1.02
CD (P=0.05)	NS	NS	7.9	NS	0.32	0.57	NS
<i>S to wheat(kg/ha)</i>							
0	73.1	2.79	109.2	33.0	3.77	9.05	41.59
30	76.8	3.06	128.8	34.0	4.41	10.54	41.70
60	77.1	3.10	133.8	35.5	4.58	10.92	41.93
SEm±	1.1	0.04	2.1	0.7	0.07	0.18	0.85
CD (P=0.05)	3.2	0.13	6.0	2.2	0.26	0.51	NS

turns than 60 kg S/ha (Rs 15,308/ha), Table 3. The lower net returns with 60 kg S/ha could be attributed to marginal increase in yield coupled with more additional cost. Similar findings were also reported by Shivran (1998).

Cosavet recorded markedly higher S-uptake over both gypsum and elemental sulphur. Further, gypsum also recorded significantly higher S-uptake over elemental sulphur. The status of available soil S improved with the application of S irrespective of its source. However, gypsum and cosavet left behind more S in the soil than elemental S after harvest of crop. The increase in available S content in soil after crop harvest might be attributed to the fact that only a small fraction of the applied S was utilized by the crop (Lal, 1992; Singh, 1997 and Shivran, 1998). Over the seasons, elemental sulphur recorded the highest SER followed by cosavet and gypsum. Among the sources of S, gypsum recorded the highest PEIS (66.3 kg grain/kg S uptake) followed by elemental sulphur (65.6 kg grain/kg S uptake) and the least by cosavet (62.6 kg grain/kg S uptake).

Among the sources of sulphur, gypsum fetched the highest net return (Rs 17,890/ha) followed by elemental sulphur (Rs 16,123/ha) and cosavet (Rs 13,193/ha). The higher net return with gypsum could be attributed to its lower cost as compared to other sources. Cosavet

though recorded the highest yield, but fetched the lowest net return because of its higher cost. The response to S in pigeonpea was quadratic in nature. The economic optimum dose of S was 47.4, 49.8 and 28 kg/ha in 2003 and 49.1, 46.9 and 28.6 kg/ha in 2004 for elemental sulphur, gypsum and cosavet respectively with corresponding yield of 1.63, 1.73 and 1.74 t/ha in 2003 and 1.53, 1.60 and 1.64 t/ha in 2004. Each kg of S gave a response of 9.5, 10.9 and 20.1 kg grain in 2003 and 9.3, 11.3 and 19.8 kg grain in 2004 for elemental sulphur, gypsum and cosavet, respectively.

Effect of S on wheat

Residual effect: Application of S to the preceding pigeon pea significantly increased the growth attributes (plant height, tillers/m row and LAI), yield attributes (spikes/m row and grains/spike) and yield of succeeding wheat over no sulphur (Table 2). The yield increment in wheat due to residual effect of S applied to preceding pigeon pea was 34.8% over unfertilized pigeon pea. Application of 60 kg S/ha to pigeon pea failed to bring significant increase in growth and yield attributes and yield in succeeding wheat over 30 kg S/ha applied to pigeon pea. However, the successive increase in S fertilization up to 60 kg/ha to pigeon pea significantly improved available S

Table 3. Total S-uptake, available soil S and economics in pigeonpea-wheat cropping system (mean of 2 seasons)

Treatment	Total S-uptake (kg/ha)			Available soil S (kg/ha)		Net returns (Rs/ha)		
	Pigeonpea	Wheat	Pigeon pea-wheat	After pigeonpea	After wheat	Pigeon pea	Wheat	Pigeon pea-wheat
<i>S to pigeon pea</i>								
Control	16.86	13.45	30.30	13.73	13.97	10,723	20,221	30,944
Rest	25.64	20.62	46.25	16.46	15.31	15,735	29,973	45,903
SEd±	1.06	0.68	1.44	0.51	0.33			
CD (P=0.05)	2.29	1.47	3.75	1.09	0.69			
<i>S level (kg/ha)</i>								
30	24.08	20.05	44.12	15.87	14.86	15,692	29,072	45,235
60	27.21	21.19	48.39	17.06	15.75	15,308	30,873	46,570
SEm±	0.58	0.37	0.78	0.28	0.19			
CD (P=0.05)	1.73	1.07	2.79	0.83	0.52			
<i>S source</i>								
Elemental S	23.32	18.20	41.51	15.63	14.50	16,123	27,163	43,286
Gypsum	25.53	21.43	46.95	16.79	15.63	17,890	31,171	49,063
Cosavet	28.08	22.22	50.29	16.97	15.80	13,193	31,582	45,359
SEm±	0.69	0.46	0.99	0.34	0.22			
CD (P=0.05)	2.11	1.37	3.47	1.01	0.84			
<i>S to wheat (kg/ha)</i>								
0		17.34	42.98		14.84		26,233	41,968
30		21.52	47.18		15.13		31,736	47,472
60		23.00	48.63		15.96		31,950	48,268
SEm±		0.45	0.46		0.21			
CD (P=0.05)		1.26	1.28		0.57			

content in soil after the harvest of wheat (Table 3). Similarly, application of 60 kg S/ha to pigeon pea caused significant increase in total S uptake in succeeding wheat over 30 kg S/ha. The marked improvement in productivity of wheat with residual S could be ascribed to enhancement of SO_4^{2-} S content of the soil as S applied to pigeon pea was not fully utilized by the crop leading to residual effect. This might have modified soil environment along with the improvement in physical parameters of the soil conducive for the growth and development of wheat crop. Similar behaviors of S in soil were also reported by Lal (1992), Singh (1997) and Shivran (1998). Application of 60 kg S/ha fetched the highest net return (Rs 30,873/ha) followed by 30 kg S/ha (Rs 29,072/ha), Table 3. Further, ASUE, ASR, SER and PEIS in succeeding wheat were higher when the preceding pigeon pea received 30 kg S/ha when compared with 60 kg S/ha (Table 5). However, 60 kg S/ha to pigeon pea recorded the highest PSUE in wheat. Lower values of these indices could be due to lower dry matter production and grain yield and comparatively lower S uptake by the crop.

Among the sources of S, cosavet and gypsum, being on par, recorded significantly more spikes/m row over the elemental S. Similarly, both these sources markedly improved the total S-uptake in succeeding wheat and also recorded significantly higher soil available S than elemental sulphur (Table 3). Cosavet fetched higher net return (Rs 31,582/ha) over gypsum (Rs 31,171/ha) and elemental sulphur (Rs 27,163/ha). The highest PEIS and SER was observed when pigeon pea was applied S through elemental sulphur followed by gypsum and cosavet (Table 5).

Direct effect: Direct application of S to wheat markedly increased the growth, yield attributes and yield. Application of 30 and 60 kg S/ha to wheat, being on par, significantly increased the growth attributes (plant height, tillers/m row and LAI), yield attributes (spikes/m row and grains/spike) and grain yield over control (Table 2). Application of 30 and 60 kg S/ha increased the grain yield of wheat by 17 and 21.5%, respectively over no sulphur. The total S-uptake increased with successive doses of S up to 60 kg/ha. Higher level of 60 kg S/ha left the soil rich in available soil S after wheat crop. This might be attributed to more addition of S from fertilizer source than its removal by the crop. Similar trend was also observed by Dewal and Pareek (2004). Further, 60 kg S/ha recorded higher net return (Rs 31,950/ha) over 30 kg S/ha (Rs 31,736/ha) and no S (Rs 26,233/ha). This might be due to greater yield increment with 60 kg S/ha over the lower levels of 30 kg S/ha. Similar trend was also noticed in pigeon pea-wheat sequence (Table 3). The response of wheat to direct application of S might be due to continued and balanced supply of nutrients with their active involve-

ment in shoot and root growth which consequently translated into higher yield. Higher rates of S application recorded lower values of S use indices viz., ASUE, PSUE, AR of S, SER and PEIS (Table 5). This could be attributed to lower S-uptake when compared with dry matter production and grain yield. The economic optimum dose of S was 48.0 and 47.3 kg/ha, yielding 4.42 and 4.97 t grains /ha in 2003-04 and 2004-05, respectively. Each kg of S gave a response of 16.8 kg grain in 2003-04 and 22.9 kg grain and 2004-05.

Interaction effect between residual and direct S in wheat: The residual effect of 60 kg S/ha applied to pigeon pea on grain yield of succeeding wheat was marked over 30 kg S, where wheat did not receive direct application of S. On an average, wheat without S gave 16.6 % of higher grain yield when grown after pigeon pea receiving 60 kg S/ha when compared with 30 kg S/ha. The residual effects could not be noticed when S fertilization of wheat was made. This is evident from the fact that the differences in wheat yields between residual effect of 30 and 60 kg S/ha applied to pigeonpea were only 0.10 t/ha, that almost disappeared when wheat received 60 kg S/ha. Further, pigeon pea and wheat fertilized with 30 kg S/ha each gave yields on par with pigeon pea with 60 kg S/ha and wheat receiving no S (Table 4). The total S uptake also had similar behaviour. Shivran *et al.* (2000) also noticed similar behaviour of S in pigeonpea-wheat cropping system.

Pigeonpea-wheat system

The pigeon pea-wheat sequence recorded the highest system productivity in pigeon pea equivalent yield (4.08 t/ha).

Table 4. Interaction effect between S applied to pigeonpea and wheat on grain yield and S uptake of wheat, and pigeon pea equivalent yield of system on mean basis

S to pigeon pea (kg/ha)	Sulphur to wheat (kg/ha)		
	0	30	60
<i>Grain yield of wheat (t/ha)</i>			
30	3.46	4.34	4.56
60	4.04	4.44	4.57
SE m±		0.09	
CD (P=0.05)		0.27	
<i>S-uptake (kg/ha)</i>			
30	15.85	21.35	22.89
60	18.78	21.65	23.08
SE m±		0.51	
CD (P=0.05)		1.48	
<i>Pigeonpea equivalent yield (t/ha) of system</i>			
30	3.45	3.88	3.99
60	3.81	4.02	4.08
S Em±		0.09	
CD (P=0.05)		0.27	

Mean price (Rs/t): pigeonpea grain 14,875; stalk: 675; wheat grain, 7,750; wheat straw, 1,625.

Table 5. S-use efficiencies as influenced by S fertilization in pigeonpea-wheat cropping system (mean of 2 seasons)

Treatment	Pigeonpea						Wheat						
	ASUE	PSUE	ASR	SER	PEIS	SHI	ASUE	PSUE	ASR	SER	PEIS	SHI	
<i>S to pigeonpea</i>													
Control				314.35	66.82	25.73					569.09	233.31	37.08
Rest	12.35	58.83	20.67	280.77	63.75	27.25	28.74	155.12	17.45	494.14	205.70	36.38	
<i>S level(kg/ha)to pigeonpea</i>													
30	15.51	64.39	24.07	291.46	66.09	27.44	32.87	151.67	21.98	496.27	205.82	36.19	
60	9.18	53.27	17.26	271.35	61.66	27.16	24.61	158.56	12.91	492.12	205.58	36.46	
<i>S source</i>													
Elemental sulphur				288.84	65.63	27.69				522.49	216.07	36.29	
Gypsum				276.93	66.33	27.07				486.50	202.64	36.25	
Cosavet				277.70	62.59	27.13				478.61	200.29	36.63	
<i>S level (kg/ha) to wheat</i>													
0										523.00	216.66	36.34	
30							21.45	154.03	13.93	490.82	204.46	36.35	
60							13.58	144.12	9.44	475.71	198.69	36.62	

ASUE: Agronomic S use efficiency (kg grain/kg applied), PSUE: Physiological S use efficiency (kg grain/kg uptake), ASR: Apparent S recovery (%), SER:S efficiency ratio (kg dry matter/kg S uptake),PEIS: Physiological efficiency index of S (kg grain/kg S uptake), SHI: S harvest index (%)

ha) with 60 kg S/ha application to each crop. However, it was on par with 30 or 60 kg S/ha application to pigeon pea and or 30 or 60 kg S/ha to wheat. System productivity significantly increased with increase in S-fertilization of pigeonpea from 30 to 60 kg/ha where wheat was not fertilized (Table 4). Total S-uptake and net returns were significantly higher where pigeon pea was supplied with 60 kg S/ha when compared with 30 kg S/ha. Further, cosavet being on par with gypsum recorded 10.58 kg/ha higher total S-uptake in pigeon pea-wheat system than elemental sulphur. However, the net returns were highest with gypsum being Rs 3,704 and Rs 5,777/ha higher than cosavet and elemental sulphur respectively. Application of 60 kg S/ha in wheat recorded the highest net returns in the cropping system (Table 3).

Thus it is concluded that application of 30 kg S/ha to both pigeon pea and subsequent wheat is necessary to realize higher productivity and profitability of this cropping system. Among the sources of sulphur, gypsum and cosavet are better options as compared to elemental sulphur.

REFERENCES

- Ahlawat, I.P.S., Gangaiah, B. and Singh, I.P. 2005. Pigeon pea research in India-an overview. *Indian Journal of Agricultural Sciences* **75**(6): 309–320.
- Barman, M. 2004. Studies on relative efficiency of S sources in rice. M.Sc. Thesis, IARI, New Delhi.
- Chesin, L. and Yien, C.H. 1950. Turbidimetric determination of available sulphate. *Soil Science Society of America Proceedings* **15**: 134–136.
- Dewal, G.S. and Pareek, R.G. 2004. Effect of phosphorus, sulphur and zinc on growth, yield and nutrient uptake of wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **49**(3): 160–162.
- Lakkineni, K.C. and Abrol, Y.P. 1994. Sulphur requirement of crop plants: physiological analysis. *Fertilizer News* **39**(3): 11–18.
- Lal, K. 1992. 'Studies on direct effect of different levels of P and S on soybean and their residual effects on the succeeding wheat crop'. Ph.D. Thesis, Division of Agronomy, IARI, New Delhi.
- Shivran, P.L. 1998. Studies on phosphorus and sulphur fertilization in pigeonpea and their residual effect on succeeding wheat. Ph.D. Thesis, IARI, New Delhi, India.
- Shivran, P.L., Ahlawat, I.P.S. and Shivran, D.R. 2000. Effect of phosphorus and sulphur on pigeon pea and succeeding wheat in pigeonpea-wheat cropping system. *Indian Journal of Agronomy* **45**: 25–30.
- Singh, D. 1997. Response of summer peanut (*Arachis hypogaea* L.) and succeeding maize (*Zea mays* L.) to sulphur and phosphorus fertilization. Ph.D. Thesis, RAU, Bikaner, Rajasthan.
- The Financial Express. 2006. Grave sulphur deficiency in Indian soils. October 5, 2006.