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Direct, residual and direct + residual effects of sulphur in garlic (*Allium sativum*) – maize (*Zea mays*) cropping sequence

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Abstract: *Significant positive effects of 30 kg/ha of sulphur as manifested on yield and yield parameters of garlic were further carried over to following maize crop. Garlic bulb and foliage yield (6.3 and 0.8 t/ha respectively) obtained at 30 kg/ha of sulphur dose was significantly higher over without sulphur (3.7 and 0.5 t/ha respectively) as revealed from two years' pooled data. Similarly number of leaves/plant, weight of cloves/5bulbs and weight/100 cloves at the said sulphur dose significantly increased over without sulphur from 10.5 to 11.9, 98.3 to 141.2 g and from 159 to 217 g in respective manner. Increase in grain yield of maize (residual effect) and in the economic yield of the whole cropping sequence (Bulb yield of garlic and grain yield of maize) i.e. direct plus residual effect at 30 kg/ha of sulphur dose over without sulphur was from 28.3 to 47.2 and from 71 to 116 q/ha in respective manner i.e. with significant differences. Sulphur use efficiencies (kg yield/kg sulphur) of these crops at 15, 30 and 45 kg/ha over no sulphur were 57, 43 and 32; 53, 63 and 6 and 160, 150 and 67, all in respective order. An optimum sulphur dose of 44.3 kg/ha produced increased bulb yield (over no S) worth Rs 34892 over fertilizer cost giving B:C ratio of 31.5 : 1. Utilization of sulphur added at 15, 30 and 45 kg/ha rates was 24.1, 19.3 and 15.7% by the garlic crop; and 29.6. 24.5 and 9.02% by the following maize crop, thus, adding up to 54.1, 43.8 and 24.9% by the cropping sequence, all in respective order.*

Key words: *Garlic, Maize, Sulphur, Sulphur uptake, Sulphur use efficiency, Sulphur utilization, Residual sulphur*
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Introduction

Garlic and onion respond well to sulphur application (Jaggi, 2005; Jaggi *et al*., 2006; Anonymous, 2004-05). Most of the Indian soils are deficient in available sulphur. Increasing agricultural production, use of high analysis sulphur free fertilizers, decreased use of organic manures, loss of sulphur through leaching and erosion render the soil poorer in sulphur. Recently, there is a shift in Himachal Pradesh from cultivation of low value to high value crops *i.e.* vegetables and condiments. This has been necessitated due to shrinking size of holdings, quick, consistent and attractive returns, suitable agro-climatic conditions and slopy lands. Additionally, garlic is blessed with better shelf-life affording to wait for favourable market because of which its cultivation is most preferred in garlic-maize sequence.

Fertilizer is a key component of the package of improved practices. The role of sulphur is vital for garlic production (Jaggi and Raina, 2005) and the same has remained totally ignored in Himachal Pradesh, though counted few reports may be available from other parts of India (Majumdar *et al*., 2003; Nagaich *et al*., 2003). It is with this purpose that investigation entitled above was undertaken.

Materials and Methods

Under the project, "Sulphur in Balanced Fertilization", sponsored by The Sulphur Institute (TSI), International Fertilizer Association (IFA) and Fertilizer Association of India (FAI), an experiment was conducted on farmer's field in district Kangra of Himachal Pradesh during Rabi 2003-2004 and Rabi 2004-2005 to study the direct effects of sulphur levels on garlic (*Allium sativum* var. GHC-1) and residual effect on maize (*Zea mays* var. early composite). Acid alfisol with loamy texture had the following characteristics: pH 5.6, organic carbon (OC) 0.83 percent and available nitrogen (N), phosphorus (P), potassium (K) and sulphur were: 334, 42, 83 and 21 kg/ha, respectively. Four sulphur levels (0, 15, 30 and 45 kg/ha) were applied through single super phosphate (SSP) in five replicates in a Randomized Block Design having a plot size of 6 x 5 m^2.

Nitrogen, P_2O_5 and K_2O were applied @125 (50 percent at sowing time), 76 and 60 kg/ha respectively through IFFCO (N; P2O5 ; K_2O 12:32:16) after duly adjusting the amount of P added through SSP in garlic crop. Additional N and K_2O were applied through urea and muriate of potash (MOP) respectively. Crop was sown before mid October in both the years. Remaining N was applied in two splits at 7 and 15 weeks' interval. Standard package of cultural practices (timely weeding and hoeing, irrigation when needed and close supervision on disease, insect and pest attack and their immediate remedy) were followed to raise the crop which was harvested in the second week of May in both the years. Fresh weights of garlic bulbs and foliage (mostly dry by harvesting time) were taken separately. Chopped bulb samples after drying in air were kept in oven at 65 ± 5°C to record the oven dry weight. Samples were then powdered for further chemical analysis. Data on plant heights and number of leaves were recorded on 20 plants selected at random in each plot to be averaged on per plant basis fifteen weeks after sowing. After harvesting garlic, maize was sown in early June as a Kharif crop to study residual effects of sulphur.

However, residual crop of maize could not be taken during the second year due to some unavoidable reasons. Crop was raised following standard package of cultural practices *i.e.* timely weeding and hoeing and close supervision on disease, insect and pest attack and their immediate remedy. Grain and straw yields of maize crop were recorded separately. Sulphur content (%) in garlic bulbs and foliage, and in maize grains and straw samples were determined to calculate sulphur uptake. At the end of study, soil samples from all plots were taken and analysed for residual available sulphur status. Per cent utilization of added sulphur by garlic (Rabi 2003-04), maize (Kharif 2004), the cropping sequence and by the three crops were calculated using the formula:

$$\text{\% utilization of added S} = \frac{\text{(S uptake (kg/ha) in treated plots)} - \text{(S uptake (kg/ha) in control plots)}}{\text{Amount (kg/ha) of S added}} \times 100$$

The soil's available sulphur was extracted by 0.15% $CaCl_2$ solution (Wiliiam's and Steinberg, 1959). The sulphur content in soil as well as in plant was determined using the turbidimetric method of Chesnin and Yien (1951). Standard procedures (Jackson, 1973) were followed for the determination of pH, O.C., available N, P and K.

Results and Discussion

Direct effects of sulphur : Although sulphur application upto 45 kg/ha consistently increased fresh and also the stable yield of garlic bulbs; however, significant increase remained restricted upto 30 kg/ha (Table 1). Foliage yield also increased consistently with increasing sulphur levels upto 45 kg/ha. Whereas, increase in foliage yield at sulphur application rates of 15 and 30 kg/ha was significant over no sulphur; that at 45 kg sulphur/ha was significant over 15 kg/ha of sulphur (Table 1). It is further revealed from the same table that the pattern of increase/improvement in all yield parameters of garlic was, by and large, similar. The number of leaves/plant, normal and oven dry weight of cloves/5 bulbs; and normal and oven dry weight/100 cloves -all these parameters were found consistently improving in response to each increment of added sulphur upto 45 kg/ha. Yet significant improvement was noticed at sulphur dose of either 15 or 30 kg/ha over no sulphur. Sulphur addition beyond these levels, although, showed increase/improvement in these yield parameters; but not to a significant extent (Table 1).

Residual effects of sulphur: Sulphur applied to previous *i.e.* garlic crop significantly and positively affected the grain yield of succeeding maize crop; showing, therefrom, significant residual effect (Table 2). Grain yield in plots carrying residual of 30 kg/ha sulphur was recorded significantly higher over all other sulphur levels including control which were statistically similar. No residual effects of sulphur were reflected on the straw yield of maize (Table 2).

Direct plus residual effects of sulphur: Direct plus residual effects were studied on the yield of whole crop sequence *i.e.* garlic (Rabi 2003-04) and maize (Kharif 2004) for one year only. In crop sequence economic yields of both crops *i.e.* bulb yield of garlic and grain yield of maize were added up. Similarly foliage yield of garlic and straw yield of maize were also added up separately. The economic yield of the sequence increased significantly in progressive manner upto sulphur application rate of 30 kg/ha over without sulphur (Table 2). Sulphur addition beyond 30 kg/ha brought down the economic yield of the crop sequence at par with sulphur levels of 0 and 15 kg/ha. No effect of sulphur levels was seen on foliage and straw yields of the cropping sequence.

Sulphur use efficiency: Sulphur use efficiency (kg economic yield/kg sulphur) was worked out on 2 year's garlic data (direct effect), one year's maize data (residual effect) and on one year's garlic and maize (direct + residual) combined data in response to 3 sulphur levels (15, 30 and 45 kg/ha) over no sulphur. The sulphur use efficiency so worked out was 57, 43 and 32; 53, 63 and 6; and 160, 150 and 67 all in respective order (Table 1, 2).

Optimum yield equation interprets that sulphur dose of 44.3 kg/ha produced 6.7 tons bulb yield *i.e.* 3.0 t/ha additional, earning a net return (over fertilizer cost) of Rs 34, 892. The benefit: cost ratio so obtained is 31.5: 1.

Being sulphur loving crop, sulphur response in garlic is natural and expected. Majumdar *et al.* (2003), Wani and Chatto (2005), Losak and Wisniowska-kielian (2006) and Nagaich *et al.*

Table - 1: Sulphur levels affecting garlic yield (t/ha) and yield attributes (data pooled over 2 years)

S levels (kg/ha)	Bulb yield (fresh)	Bulb yield (stable)	Foliage yield (dry weight)	Number of leaves/plant	Number of cloves/ 5 bulbs	Weight* of cloves (g)/ 5 bulbs	Oven dry weight(g) of cloves/ 5 bulbs	Weight (g) /100 cloves	Oven dry weight (g) /100 cloves
0	4.4	3.7	0.5	10.5	62.1	98.3	30.4	159	48
15	6.1	5.4 (57)**	0.7	11.0	68.3	129.0	40.9	190	60
30	7.1	6.3 (43)	0.8	11.9	65.0	141.2	44.4	217	69
45	7.7	6.6 (32)	0.9	12.0	64.7	149.0	47.3	225	73
CD (p=0.05)	0.96	0.91	0.19	0.9	NS	27.3	9.0	37.8	13

* Weight at stable moisture content

** Fig. in parenthesis indicate S use efficiency (kg bulb yield/kg S)

Table - 2: Residual effects of sulphur on maize (kharif 2004) yield (q/ha); and direct* + residual effects on the total yield of sequence (Rabi 2003-04 and Kharif 2004)

S levels (kg/ha)	Residual effects (Maize crop) Yield		Direct + residual effects (Garlic-maize sequence) Yield*	
	Grain	Straw	Economic yield	Foliage of garlic + straw of maize
0	28.3	48.1	71	64
15	36.2 (53)**	59.1	95 (160)***	68
30	47.2 (63)	67.1	116 (150)	76
45	30.6 (06)	54.4	101 (67)	64
CD (p=0.05)	9.5	NS	20.2	NS

* Stable yield of garlic has been used

** Fig. in parenthesis indicate S use efficiency (kg bulb yield/kg S)

*** Fig. in parenthesis indicate S use efficiency (kg economic yield/kg S)

Table - 3: Total sulphur uptake* (kg/ha) and utilization (%) of added S by garlic, maize and garlic-maize cropping sequence

S levels (kg/ha)	Garlic (Rabi 2003-04)		Maize (Kharif 2004)		Garlic-maize cropping sequence		Garlic (Rabi 2004-05)	S uptake 3 crops	S utilization by 3 crops
	S uptake	S utilization	S uptake	S utilization	S uptake	S utilization	S uptake		
0	3.02		9.44		12.46		4.55	17.01	
15	6.64	24.1	13.88	29.6	20.58	54.1	8.02	28.60	38.6
30	8.82	19.3	16.78	24.5	25.60	43.8	11.33	36.93	33.2
45	10.08	15.7	13.60	9.02	23.68	24.9	13.63	37.31	22.6
CD (p=0.05)	1.60		4.33		4.69		3.64	7.17	

* S uptake by whole crop (grain + straw)

Table 4 - : Sulphur balance sheet

S levels (kg/ha)	Soil available S (kg/ha)	S (kg/ha) added in 2 crops of garlic	Total available S (kg/ha)	S (kg/ha) uptake by 3 crops	Observed residual S (kg/ha)	Calculated residual S (kg/ha)	Observed-calculated residual S (kg/ha)
0	20.7	0	20.7	17.0	8.0	3.7	4.3 (20.8)*
15	20.7	30	50.7	28.6	11.6	22.1	-10.5 (-20.7)
30	20.7	60	80.7	36.9	14.0	43.8	-29.8 (-54.3)
45	20.7	90	110.7	37.3	16.5	73.4	-56.9 (-66.3)
CD (p=0.05)					2.7		

* Fig. in parenthesis indicate unaccountable S as % of total available S

(2003) have also reported increased bulb and foliage yields and other yield attributes (number of cloves/bulb, yield/plant and per cent dry weight of bulb) in garlic following sulphur application ranging from 20 to 60 kg/ha over without sulphur. Majumdar *et al.* (2003) observed highest sulphur use efficiency in garlic at its dose of 20 kg/ha. Jaggi (2005) reported value: cost ratio (VCR) in onion, a sister crop of garlic, as high as 32:1 at sulphur application rate of 30 kg/ha over without sulphur.

Total sulphur uptake and utilization of added sulphur: Total sulphur uptake (hereafter referred to as sulphur uptake) was calculated for individual crops of garlic and maize; and then for the whole sequence (Table 3). From sulphur uptake, per cent utilization of added sulphur was derived using the formula given in Materials and Methods section.

Sulphur uptake by garlic (Rabi 2003-04) increased progressively with each level of added sulphur, however, significant increase remained restricted upto 30 kg sulphur/ha. On the contrary, utilization of sulphur added at the rate of 15, 30 and 45 kg/ha decreased from 24% to 19.3 and then to 15.7% in respective manner (Table 3). In maize (Kharif 2004), sulphur uptake increased progressively from 9.44 kg/ha in control plots to 16.78 kg/ha in plots carrying over residual of 30 kg/ha of sulphur dose. Further level of residual sulphur (45 kg/ha) decreased sulphur uptake to an amount (13.60 kg/ha) statistically at par with those of 15 (13.88 kg/ha) and 30 (16.78 kg/ha) kg/ha of residual sulphur, but not over control (9.44 kg/ha). Highest sulphur uptake (16.78 kg/ha) recorded from plots carrying 30 kg/ha residual sulphur was significantly different only over control (Table 3). Similarly, sulphur uptake by garlic (Rabi 2003-04) – maize (Kharif 2004) cropping sequence was also observed increasing progressively in a significant amount with each increment of sulphur upto 30 kg/ha (Table 3). Sulphur applied to garlic beyond 30 kg/ha, decreased its uptake by garlic-maize cropping sequence to an amount at par with 15 (20.58 kg/ha) and 30 kg/ha (25.60 kg/ha). The maize (Kharif 2004) crop utilized 29.6, 24.5 and 9.02% of the sulphur applied to garlic (Rabi 2003-04) at the rate of 15, 30 and 45 kg/ha respectively. And the total utilization by the cropping sequence (direct + residual) was 54.1, 43.8 and 24.9% of the sulphur applied in above order (Table 3). Table 3 indicates progressive increase in sulphur uptake by garlic (Rabi 2004-05) in response to each increment of sulphur. The sulphur uptake at 30 and 45 kg/ha dose was significantly higher over 0 and 15 kg/ha levels in respective manner (Table 3). The total sulphur uptake by three crops (2 crops of garlic and 1 crop of maize) increased progressively in a significant manner with each dose of sulphur, although this increase remained restricted upto 30 kg sulphur/ha. The utilization of total added sulphur (0, 30, 60 and 90 kg/ha) by two crops of garlic and one crop of maize (direct + residual + direct effect) was 38.6, 33.2 and 22.6% in respective manner (Table 3).

A review of the data on observed residual available sulphur (hereafter called as residual sulphur) contained in table 4 indicate that at the end of three crops a balance of 8.0 kgs of available sulphur was found (observed) against the calculated value of 3.7 kg/ha in control plots *i.e.* an increase of 4.3 kg/ha. In plots receiving sulphur at the rate of 30, 60 and 90 kg/ha (in the two years), though the observed residual sulphur increased consistently (significantly higher over control treatment) upto the highest level of added sulphur; yet the amounts fell far short (10.5, 29.8 and 56.9 kg/ha respectively) of calculated residual sulphur (Table 4). Such an unaccountable amount of sulphur apparently found lost was 20.7, 54.3 and 66.3% of the total pool (native + added) of sulphur available in the respective plots (Table 4). A gain in the status of observed residual sulphur in control plots and the loss from the sulphur treated plots was due to mineralization of native organic sulphur in the absence of applied sulphur and immobilization of applied sulphur into organic sulphur; strongly controlled by the demand for and supply of sulphur (Aulakh *et al.,* 2002). Our results further demonstrate the role of soil microbial biomass as sink and/or source of sulphur to maintain an equilibrium between the demand for and supply of sulphur. The other losses were possibly through uptake by weeds, leaching, erosion and through run-off. It is, therefore, suggested that to increase the efficiency of applied sulphur and save it against various types of losses; the same should be applied in 2 or 3 splits and plots be kept free of weeds during the crop growth and also during the vacant interval between two crops.

This study reveals significant positive direct, residual and direct+ residual effects of sulphur upto its dose of 30 kg/ha in garlic (*Allium sativum*) – maize (*Zea mays*) cropping sequence as reflected by yield, sulphur uptake and other yield parameters. To get optimum yield and earning, sulphur may be applied 44.3 kg/ha in garlic crop. Even after so much of sulphur removals and losses during the period of 3 crops, there is noticeable build up of available sulphur in response to its addition at different rates. Raising second crop to utilize residual sulphur, applying sulphur in 2 or 3 splits; and keeping the fields free of weeds are some of the measures suggested to increase sulphur use efficiency.

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