The effect of different rates and forms of sulfur on seed yield and micronutrient uptake by chickpea

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ABSTRACT

Field experiments were conducted at two different locations (Barani Agricultural Research Institute Chakwal and farm field Talagang, district Chakwal) for two crop-growing seasons in northern rainfed Punjab, Pakistan to assess the yield and micronutrient uptake of chickpea (*Cicer arietinum*). The treatments were four combinations of two levels of sulfur (15 and 30 kg/ha) from two sources (gypsum and ammonium sulfate) and a no-sulfur control. Application of sulfur resulted in a significant increase in seed yield up to 17% over control. Ammonium sulfate was a more efficient source of sulfur as compared to gypsum at both the locations. Sulfur application resulted in a significant increase in micronutrient uptake by plant; however effect of sulfur application on soil pH at the end of experiment was not significant. Availability of soil zinc and copper increased with sulfur application at the end of two year experiment. Tissue copper and iron and soil available copper and iron correlated negatively with soil pH. Sulfur should be applied to chickpea grown under rainfed conditions in order to increase seed yield, to improve nutritional composition of product and to enhance efficiency of other fertilizers.

Keywords: *Cicer arietinum*; soil reaction; gypsum; ammonium sulfate; soil fertility

Chickpea is an important pulse crop grown on more than one million hectare area in Pakistan (Annonymous 2011). However, per hectare production is only 0.5 t/ha which is only one third of that achieved in developed countries of the world such as China (2.4 t/ha), USA (1.7 t/ha) and Canada (1.9 t/ha) (FAO 2009). This low yield is due to a number of agronomic, environmental and genetic factors and inadequate fertilizer application is the key among them.

Surveys were conducted from time to time to asses the sulfur (S) status of soil and they showed that the soils of rainfed area are deficient in sulfur (Khalid et al. 2011). Soils have become deficient in S due to cultivation of high yielding varieties, use of high grade S free fertilizers and lack of industrial activity (Scherer 2009).

Sulfur fertilizers are known to enhance crop yield and uptake of macronutrients especially nitrogen (Islam et al. 2012a). Application of S fertilizers to alkaline soils has been reported to reduce the pH of soil (Taalab et al. 2008). However, information regarding effects of S fertilizers on micronutrients especially zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) availability and uptake by crop plants is very scarce. Therefore present field survey was conducted to study the effect of S fertilizer from two sources on seed yield and micronutrient uptake by chickpea crop and soil pH and micronutrient status after crop harvest.

MATERIAL AND METHODS

Field experiments were conducted using chickpea cultivar Balkassar 2000 at the Barani Agriculture Research Institute (BARI), Chakwal and farmer field Talagang, district Chakwal during crop growing seasons of 2006–07 and 2007–08. The details of physical and chemical properties of soil at the start of experiment are presented in Table 1. The trials were laid out in randomized complete block design with split plot arrangement (1.5 × 3.5 m plot at BARI Chakwal and 1.8 × 4 m at farm field Talagang) keeping S sources in main plots and S levels in subplots. There were five treatments comprising of 4 combinations of two S sources (gypsum and ammonium sulfate) and two S levels (15 and 30 kg/ha) and a no-S control. Starter dose of nitrogen (26 kg/ha) was

Table 1. Location, rainfall and physical and chemical properties of soils of experimental sites

Parameter	Unit	Chakwal	Talagang
Elevation	m	511	624
Latitude	N	32.5°	32.5°
Longitude	E	72.4°	72.2°
Mean annual rainfall (1979–2009)	mm	630	450
Cropping season (October to March) rainfall during	mm		
(i) 2006–07		385	362
(ii) 2007–08		90	30
Sand	%	69	80.8
Silt	%	21	6.7
Clay	%	10	12.5
Texture	–	sandy loam	loamy sand
pH	–	7.6	7.7
ECe	mS/m	32	26
Total organic carbon	g/kg	3.7	1.8
$CaCO_3$	%	5.2	2.9
Total N	%	0.02	0.01
NO_3-N (AB-DTPA extractable)	ppm	11.2	5.6
Phosphorus (AB-DTPA extractable)	ppm	3	1.4
Sulfate-sulfur ($CaCl_2$ extractable)	ppm	6.4	7.5
Zinc (AB-DTPA extractable)	ppm	0.75	1.30
Copper (AB-DTPA extractable)	ppm	1.21	0.92
Iron (AB-DTPA extractable)	ppm	7.82	5.63
Manganese (AB-DTPA extractable)	ppm	2.98	2.10

applied in the form of urea in all treatments except those receiving nitrogen from ammonium sulfate. Phosphorus (18 kg P/ha) was applied in the form of triple super-phosphate. All the treatments were replicated three times. Chickpea crop was sown during the second week of October maintaining row to row distance of 30 cm. There were approximately 25 to 30 plants in the area of one square meter. All the fertilizers were applied as basal dose. Crop was grown under rainfed conditions and no supplemental irrigation was applied. There was no incidence of pest or disease attack so no chemical was sprayed. Rainfall data for both the locations were recorded. Harvesting was done in the first week of May each year. Crop from an area of one square meter in the middle of each plot was harvested separately. The plant samples were dried and data were recorded for seed and dry matter yield. Representative samples of 100 g for both straw and seed separately, were collected from bulk sample, oven dried and ground. Micronutrients (Zn, Cu, Fe and Mn) were determined by atomic absorption spectrometer (model GBC-932 plus, Dandenong, Victoria, Australia) from the filtrate obtained after dry ashing (Chapman and Pratt 1961). After harvesting of crop, soil samples were taken from each treatment and were analyzed for pH by preparing soil saturated paste with addition of deionized water (Thomas 1996). Soil samples were also analyzed for available micronutrient status (Ryan et al. 2001).

The results of the yields and chemical analysis of plant and soil were statistically analyzed by MSTATC software (East Lanring, USA) with ANOVA. Treatment means were compared by *LSD* test. Simple linear correlation analysis was also performed to study relationship among different soil and plant characteristics.

RESULTS AND DISCUSSION

Seed yield and micronutrient uptake were higher during the first year as compared to the second year (Table 2). This was due to favorable climatic conditions during first year especially timely rainfall throughout growing season. Although there was

Table 2. Seed yield and micronutrient uptake by chickpea as function of year and location

Cop growing season/location	Seed yield (t/ha)	Zn uptake	Cu uptake	Fe uptake	Mn uptake
		(g/ha)			
2006–07					
Chakwal	1.28[b]	46	22	128	65[b]
Talagang	1.98[a]	55	27	116	86[a]
Mean	1.63[a]	50[a]	24[a]	122[a]	75[a]
2007–08					
Chakwal	0.82[d]	32	18	88	45[d]
Talagang	1.05[c]	36	20	84	56[c]
Mean	0.93[b]	34[b]	19[b]	86[b]	50[b]
***LSD* value and significance level**					
Year	**	**	**	**	**
Location	**	**	**	**	**
Year × location	0.06**	ns	ns	ns	3.7**

Means followed by similar letters are not significantly different at 5% level of probability. **$P < 0.01$; ns – non significant difference

abundant moisture supply at the time of sowing during second year, germination and crop growth was better at the start but there was incidence of frost at flowering stage accompanied by prolonged drought which adversely affected crop growth and yield. Total rainfall during second year from October 2007 to March 2008 was 90 mm and 30 mm at Chakwal and Talagang, respectively, which was 77 and 92 percent less than first year (385 and 362 mm). Khalid et al. (2009) also observed that growth and yield of crop was better during cropping season of higher rainfall due to abundant supply of moisture when crop was grown under rainfed conditions.

Table 3. Seed yield and zinc uptake by chickpea as affected by sources and levels of sulfur (data are pooled across years)

Treatments	Seed yield (t/ha)			Zinc uptake (g/ha)		
	Chakwal	Talagang	mean	Chakwal	Talagang	mean
Control	0.97	1.39	1.18	34	43[c]	38[d]
Gypsum (kg S/ha)						
15	1.03	1.44	1.24	40	43[c]	42[c]
30	1.08	1.53	1.31	40	45[bc]	43[bc]
Mean	1.03[b]	1.45[b]	1.24[b]	38	43	41[b]
Ammonium sulfate (kg S/ha)						
15	1.09	1.60	1.34	41	48[b]	44[b]
30	1.14	1.74	1.44	45	52[a]	48[a]
Mean	1.07[a]	1.59[a]	1.33[a]	40	48	44[a]
***LSD* value and significance level**						
S sources (S)	*	*	**	ns	ns	*
S levels (L)	0.03**	0.09**	0.05**	1.8**	2.3**	1.4**
S × L	ns	ns	ns	ns	3.2*	2.0*
CV (%)	6.6	6.7	6.0	5.4	5.8	5.6

Means followed by similar letters are not significantly different at 5% level of probability. *$P < 0.05$; **$P < 0.01$; ns – non significant difference

Table 4. Copper and iron uptake of chickpea as affected by sources and levels of sulfur (data are pooled across years)

Treatments	Copper uptake (g/ha)			Iron uptake (g/ha)		
	Chakwal	Talagang	mean	Chakwal	Talagang	mean
Control	17[c]	21[c]	19[d]	88[c]	91	90[c]
Gypsum (kg S/ha)						
15	21[b]	21[c]	21[c]	108[b]	99	104[b]
30	18[c]	23[bc]	20[cd]	95[bc]	111	103[b]
Mean	18[b]	22	20[b]	96[b]	101	99[b]
Ammonium sulfate (kg S/ha)						
15	21[b]	25[b]	23[b]	109[b]	98	103[b]
30	26[a]	30[a]	28[a]	159[a]	109	134[a]
Mean	21[a]	25	23[a]	119[a]	99	109[a]
***LSD* value and significance level**						
S sources (S)	*	*	**	**	ns	**
S levels (L)	1.6**	1.6**	1.1**	10**	6.7**	5.8**
S × L	2.3**	2.3**	1.6**	14**	ns	8.2**
CV (%)	9.6	8.1	8.8	10.8	7.8	9.5

Means followed by similar letters are not significantly different at 5% level of probability. *$P < 0.05$; **$P < 0.01$; ns – non significant difference

Two locations differed significantly in respect of seed yield and micronutrient uptake (Table 2). Comparatively higher seed yield and micronutrient uptake (with the exception of iron) was recorded at Talagang as compared to Chakwal. This was due to difference in climatic conditions as well as soils of two locations. Intensity of frost was less at Talagang as compared to Chakwal especially during the second crop growing season. Another reason might be that well drained soils are suitable for the production of chickpea (Khalil and Jan 2002). Soil at Talagang was well drained being loamy sand compared to sandy loam soil of Chakwal (Table 1).

Seed yield. Sulfur application resulted in an increase in seed yield at both the locations (Table 3) which is in line with the finding of Hussain et al. (2011) who observed a significant increase in seed yield of soybean under similar soil and climatic conditions. Ammonium sulfate was a better S source than gypsum regarding its effect on seed yield. These results coincide with the previous studies conducted under similar environmental and soil conditions (Islam et al. 2012b). Contrary to these findings Khalid et al. (2009) observed that different S sources such as gypsum, AS and single super-phosphate were similar to each other in respect of seed yield of *Brassica napus*; however, three S sources differed in respect of S uptake by plants.

Micronutrient uptake. Sulfur application increased tissue Zn uptake at both locations (Table 3). The solubility of Zn increases as soil pH decreases (Yoo and James 2003). Therefore the increase in tissue Zn uptake might be due to acidifying effect of S which resulted in increased availability of Zn in soil (Cui and Wang 2005). Two S sources differed only when data were pooled over locations and years (Table 3). Results regarding the effect of different S sources on Zn uptake in tissue are not reported previously. One of the reasons for increase in plant tissue Zn is pH reduction and in some studies gypsum and AS are found to have similar effect on soil pH (Ryant and Skládanka 2009).

Sulfur application resulted in a significant increase in Cu uptake at both locations (Table 4) which is in line with previous findings and is mainly due to acidification effect produced as a result of S application (Ghosh et al. 2000, Rahman et al. 2011). There was significant but weak negative correlation of soil pH at the end of two year experiment with Cu uptake by plant ($r = -0.33$, $P < 0.01$) and available Cu in soil ($r = -0.31$, $P < 0.01$) which clearly indicates the role of soil pH reduction in enhancing Cu availability and uptake by plant.

Sulfur application resulted in an increase in Fe uptake (Table 4), as was also recorded by Malewar and Ismail (1997). It is apparent from correlation analysis that tissue Fe ($r = -0.40$, $P < 0.01$) and

Table 5. Manganese uptake by chickpea and soil micronutrient status after crop harvest as affected by sources and levels of sulfur (data are pooled across years)

Treatments	Manganese uptake (g/ha)			soil pH	Soil available micronutrients (ppm)			
	Chakwal	Talagang	mean		Zn	Cu	Fe	Mn
Control	45^{d}	65^{d}	55^{d}	7.63	1.01	0.71	5.13	1.93
Gypsum (kg S/ha)								
15	52^{c}	75^{b}	63^{c}	7.53	1.30	0.87	5.17	1.80
30	55^{c}	79^{a}	67^{b}	7.42	1.48	0.81	5.22	2.22
Mean	50^{b}	75^{a}	62	7.53	1.25	0.80	5.14	1.96
Ammonium sulfate (kg S/ha)								
15	61^{b}	69^{c}	65^{bc}	7.55	1.29	0.86	5.33	2.01
30	70^{a}	73^{b}	72^{a}	7.39	1.45	0.90	6.85	2.26
Mean	60^{a}	67^{b}	64	7.52	1.26	0.82	5.81	2.09
***LSD* value and significance level**								
S sources (S)	**	*	NS	NS	NS	NS	NS	NS
S levels (L)	2.3**	2.7**	1.7**	NS	0.33*	0.11*	NS	NS
S × L	3.3**	3.9*	2.5**	NS	NS	NS	NS	NS
CV (%)	5.0	4.5	4.7	6	19	11	11	21

Means followed by similar letters are not significantly different at 5% level of probability. *$P < 0.05$; **$P < 0.01$; NS – non significant difference

soil available Fe ($r = -0.24$, $P < 0.05$) at the end of experiment correlated negatively with soil pH which is clear indication that fluctuation in Fe availability and uptake is a result of change in pH. The S source by S level interaction was significant when data was pooled over years and locations (Table 4). Iron uptake was higher in AS treatments as compared to gypsum treated plots. This difference might be due to difference in solubility of two S sources.

There was a significant increase in Mn uptake due to S application (Table 5) which coincide with the findings of Rahman et al. (2011) who observed an increase in Mn uptake by corn plant with the application elemental S as a result of soil acidification although temporarily.

Soil chemical properties. Neither S source nor S levels had any significant effect on soil pH at both locations at the end of the two year experiment (Table 5). These results are in line with the findings of Velarda et al. (2005) who observed a small (0.3 units), non-significant reduction in soil pH with application of 125 kg S/ha. Soaud et al. (2011) observed a significant reduction in pH of calcareous soils due to S application during first eight weeks of incubation and after soil pH started to increase over time. Contrary to our findings, Skwierawska et al. (2008) recorded a significant reduction in soil pH from 5.3 to 4.36 with application of 120 kg S/ha at the end of a three year experiment. However, a difference in results might be due to fact that S application rate was lower in our study. Different S levels were similar regarding Zn and Cu availability in soil at Chakwal but were different at Talagang (Table 5). There was a slight increase in soil Zn and Cu availability due to S application at Talagang. Different treatments were similar in respect of available Fe and Mn concentration which might be due to two reasons. First, lower rate (30 kg/ha) of S was applied as compared to previous studies. Second, there was no reduction in soil pH at the end of experiment as a result of S application.

Sulfur application resulted in a significant increase in seed yield and micronutrient uptake. It may also result in increased availability of micronutrient from soil as a result of temporary reduction in soil pH. Therefore sulfur should be applied to chickpea grown under rainfed conditions in order to improve yield and micronutrient composition of the product.

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