Responses to sulphate and elemental S in six provinces in China and the utility of mono-calcium phosphate extractable S in predicting soil S status

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Abstract

Reductions in atmospheric inputs of S in rainfall, and the world's reliance on non-, or low-S containing TSP, DAP, MAP and urea has resulted in a widening gap in the S input/output balance, and an increasing incidence of S deficiency in agriculture. A technology to incorporate elemental S, with or without sulphate S, into ammonium phosphate fertilizers has been developed and patented by Shell. The fertilizers produced by this process are generically called "Sulphur Enhanced Fertilizer" (SEF or Thiogro). A wide range of experimental N, P, S formulations have been made, with elemental S concentrations up to 15% or greater. Agronomic testing of several of these products has been undertaken in a wide range of crops in temperate and tropical environments in China, generating a weighted mean crop yield increase to Thiogro of 13%, compared to the zero S control, in S responsive sites.

Soil analyses from 82 of the 101 field trials were used to establish the utility of the mono-calcium phosphate extract to estimate the potential S response at each site. The accepted critical soil S test value for the MCP extract is 10 mg/kg. Predictability of an S response was low (47% correct) at low soil test values and acceptable (72%correct) on non-responsive sites. These data indicate that MCP extraction is not a good way to identify potentially S responsive sites.

Key Words

Sulphate, elemental S, mono-calcium phosphate extractable S, S status, China

Introduction

Sulphur is one of the essential elements required for the normal growth of plants and concentrations of S are lower than that of N and similar to P. Sulphur plays an important role as a constituent of many plant processes and because plant metabolism depends on S and a deficiency of this nutrient will cause basic metabolic impairment, which will not only reduce crop yield but can also affect the quality of produce. Deficiency symptoms of S in plants includes a yellowing of the younger leaves as a result of low chlorophyll production and a marked reduction in plant height and tiller number in cereals.

For many years, little attention was paid to sulphur as a plant nutrient mainly because it has been applied to soil in incidental inputs in rainfall and volcanic emissions, and as a component of nitrogen, phosphorus and potassium fertilizers. The awareness of sulphur deficiency is increasing, as is the development of S deficiency in previously S sufficient areas in many parts of the world.

As crop yields increase, and incidental inputs of atmospheric sulphur decrease deficiencies of S are becoming more widespread and severe. World consumption of ammonium phosphate fertilizers has increased dramatically and at the same time consumption of single superphosphate (SSP) and ammonium sulphate (AS), which provides S to crops, has decreased.

Sulphur cycling in soil is closely related to organic matter turnover. As such, S mineralisation and immobilization processes play a key role in determining the availability of S for plant growth. Sulphur can be added to the system in fertilizers, in irrigation water, through adsorption of S gases (e.g. SO_2), in additional organic matter, dry deposition, and in rainfall. Plants take up sulphur from the soil solution as sulphate, in much the same way as they do nitrate and phosphate. Like nitrate, sulphate is mobile in most soils and can be easily leached from the rooting zone.

Non-sulphate S sources, such as elemental S, must be converted to sulphate before the plant can access it. This oxidation process is primarily carried out by soil bacteria of the *Thiomonas* genus.

Elemental S is an almost ideal fertilizer as it contains 100% nutrients. The elemental S must be oxidized to sulphate before it is available to plants and since microorganisms carry out this process it is moisture and temperature dependant, as is the crop demand for S. The rate of oxidation is also dependent on the particle size of S. This means that there is great scope to manage the release rate of sulphate to the plant to maximize plant uptake and minimize losses by surface runoff and leaching.

Research carried out by Blair et al (1979) has shown that plants require S and P early in growth and that oxidation rates are enhanced by intimate mixing of P and elemental S (Lefroy et al 1997), which makes S inclusion into P containing fertilizers an attractive proposition.

Much of the developmental work on Thiogro has been undertaken at the International Fertilizer Development Center (IFDC) where the process has been used with pre-neutralizers (PN) and pipe cross reactors (PCR) and combined PN/PCR units with S concentration ranging up to 20%. A significant feature of the process is that the elemental S is distributed throughout the fertilizer granule. The process allows for the production of a wide range of Thiogro formulations which vary in the ratios of N, P and S and in the proportions of sulphate and elemental S they contain.
Given the increasing demand for high analysis DAP and MAP fertilizers, which contain little or no S, a new group of Sulphur Enhanced Fertilizers (SEF or Thiogro) has been developed by Shell Canada Energy and their agronomic effectiveness is the subject of this paper.

Methods

Plots, varying in size depending on the crop, were established at 101 sites in six Provinces in China (Table 1) between 2003 and 2007. Either 3 or 4 replicates of each treatment were used. There were a range of treatments used but at each site there was a minus S control, MAP + gypsum or DAP + gypsum (to simulate SSP) and one or more Thiogro treatments, The formulations of the Thiogro ranged in S concentration from 11 to 18% with elemental S the predominant form of S in each product. S was applied at recommended rates for the various crops generally being 20 and/or 40 kg S/ha for grain crops and 30 and/or 60 kg S/ha for cash crops. Nitrogen and all other nutrients were balanced between treatments so that S was the only variable. Soil samples were taken from most sites prior to the application of the treatments and these extracted with mono-calcium phosphate (500 ppm P) to estimate their S status.

Crops were harvested at maturity and dry weights of commodity crops or fresh weights of vegetable crops were determined (see Table 2 for the crops used).

Results

Of the 123 experiments conducted in China 89 were responsive to S with a weighted mean yield increase to Thiogro of 14%, compared to the zero S control (Table 1). The control treatment consisted of a mixture of MAP + gypsum or DAP + gypsum used to simulate an addition of SSP and comparisons shown below are with this treatment.

Table 1. Summary of crop responses to Thiogro in six Provinces in China.

Province	Control	Thiogro	S responsive site		% response to Thiogro	Thiogro v SSP		
	Yield relative to SSP=100		Yes	No		Equal	Superior	Inferior
Jiangsu	92	111	19	0	18	5	14	0
Fujian	91	102	15	8	9	12	1	2
Jiangxi	93	107	16	6	18	9	7	0
Guangxi	92	102	17	5	10	17	0	0
Heilongjiang	93	105	12	13	13	8	1	3
Yunnan	91	107	10	2	17	8	2	0
TOTAL OR AVERAGE	**92**	**106**	**89**	**34**	**14**	**59**	**25**	**5**

Thiogro produced yield responses equal to SSP at 59 sites, responses superior to SSP at 25 sites and responses inferior to SSP at 5 sites (Table 1).
The proportion of S responsive sites was similar in Fujian, Jiangxi, Guangxi and Yunnan (average 78%). By contrast all 19 sites were S responsive in Jiangsu and only 48% in Heilongjiang, One possible explanation for these differences may be the cropping history and crop yields in these Provinces. In Jiangsu crop yields of the two crops per year are high and in Heilongjiang the soils are more fertile (higher SOM) and only a single crop is grown each year.

When the data is examined in relation to individual crop responses there is no pattern of individual crops being more or less responsive to S (Table 2).

Table 2. Individual crop responses to S in China.

Crop	No of Sites	Average -S Yield	Average Thiogro Yield	% response to Thiogro^A
		(kg/ha)		
Rice	21	6535	7408	13.4
Peanut	20	3147	3588	14.0
Corn	13	6435	7302	13.5
Soybean	11	2284	2717	19.0
Rapeseed	4	2100	2344	11.6
Cassava	3	32196	35736	11.0
Sugarcane	3	85805	97146	13.2
Cabbage	2	16720	20068	20.0
Lettuce	2	47230	50004	5.9
Potato	2	21211	24147	13.8
Sweet Potato	2	17618	19978	13.4
Coffee	1	23758	31863	34.1
Tobacco	1	2735	2961	8.2
Hot pepper	1	1638	1785	9.0
Tea	1	9758	11670	19.6
Upland rice	1	2530	2970	17.4
Watermelon	1	23107	29510	27.7

Relationship between soil test and S response

Soil analyses are available from 82 of the 101 field trials conducted in the THiogro trials in China. In all trials the mono-calcium phosphate extract was used and the relationship between this concentration of S in this extract and crop response, expressed as % of maximum yield ((Yield in SSP treatment-Check yield)/Check yield)*100) has been plotted. No relationships were found either when the data was plotted on an overall basis (Figure 1)or within a Province.

The accepted critical soil S test value is 10 mg/kg. When the data is examined using this value the results shown in Table 3Figure 1 indicates poor predictability (47% correct) at low soil test values and acceptable predictability (72%) of non-responsive sites.
These data indicate that MCP extraction is not a good way to identify potentially S responsive sites.

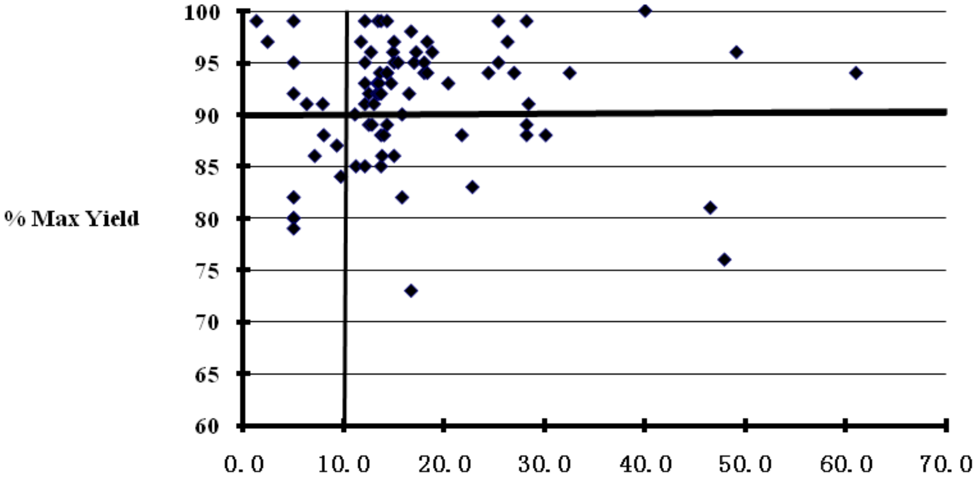

Figure 1. Relationship between monocalcium phosphate extractable S (MCP-S) and % of maximum yield

Table 3. Probability of correct prediction of S response based on MCP soil test.

Soil test (ppm)	% yield <90% of maximum	% yield <90% of maximum	Probability of a correct prediction
	Number of sites		
<10	8	7	of a response 47%
>10	19	49	of adequate S 72%

Conclusion

Significant areas in six agriculturally important Provinces in China are responsive to S and fertilizers containing either sulphate or elemental S, or combinations of both forms. Fertilizers such as the predominately elemental S containing Thiogro used in these studies have a potential freight advantage over single superphosphate because of their higher nutrient density (higher concentration of P and S, in addition to a small quantity of S) and the elemental S they contain is less likely to be lost by leaching.

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References

Blair GJ, Momuat EO and Mamaril CP (1979). Sulfur nutrition of Rice. II. Effect of source and rate of S on growth and yield under flooded conditions. *Agronomy Journal* **71**, 477-480.

Lefroy RDB, Sholeh and Blair GJ. (1997).Influence of sulfur and phosphorus placement, and sulfur particle size, on elemental sulfur oxidation and the growth response of maize (Zea mays). *Australian Journal of Agricultural Research* **48**, 485-495.