Effect of sources of sulphur on yield and disease incidence in crops in Jiangxi Province, China

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Abstract
The Jiangxi Academy of Agricultural Sciences (JAAS) has conducted five experiments to compare elemental S and sulphate S containing fertilizers. The elemental S containing fertilizer used was a sulphur enhanced di-ammonium phosphate (SEF12) and the sulphate S was supplied from single superphosphate (SSP). A di-ammonium phosphate (DAP) control was used. In a cabbage experiment conducted in 2003 there was a significant response to S and a lower incidence of soft rot where SEF12 was applied (18-19% reduction compared to DAP, c.f. 5% with SSP) and leaf disease (20-31% reduction, c.f. 19% with SSP) where elemental S was applied. In two rice experiments there was a greater response to SEF12 compared to SSP and this was associated with a lower incidence of disease and insects (rice leaf roller and brown plant hopper) where SEF12 was applied. Incidences of rice leaf blight and rice blast were also observed on the DAP and SSP treatments. Two plot trials with rapeseed were established in 2006 in which the fertilizers were applied either at rates to deliver the same rate of P as applied in DAP at Maying Shishan or with the same rate of S as applied in SSP at Maying Sequ. At the Maying Shishan site there was a significant response to S in SSP and SEF12 when applied at the same P application rate. At the Maying Sequ site SEF12 out yielded SSP when applied at the same S rate. These trials are the first to report soil applied elemental S having an effect on protecting crops against insects and disease and indicate that the mechanism involved requires further investigation in both upland and flooded crops.

Key Words
Elemental S, sulphate, cabbage, rice, rapeseed.

Introduction
Sulphur is one of the essential elements required for the normal growth of plants and concentrations of S in plants are lower than that of N and similar to P. Sulphur plays an important role as a constituent of many plant processes as plant metabolism depends on S and a deficiency of this nutrient will cause basic metabolic impairment, which will not only reduce crop yield but also the quality of produce. 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. In a recent report The Sulphur Institute (TSI) stated "The intensification of agricultural production per unit area, coupled with an expanding use of high-analysis, sulphur-free fertilizers or low-sulphur fertilizers, such as urea and ammoniated phosphates, is causing sulphur deficiencies to spread rapidly throughout China. The problem could be exacerbated further as sulphur dioxide emissions are increasingly controlled. If this problem is neglected, the inevitable consequences will be decreased yields and reduced efficiency of other inputs, which will, in turn, result in higher production costs. According to TSI, it is estimated that the current annual deficit for sulphur fertilizers in China is about 2.0 million tons, and will increase to 2.6 million tons annually by 2015 unless corrective measures are taken."

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 autotrophic bacteria in the *Thiomonas* genus, which use reduced S sources as their energy source. The question arises as to whether these organisms, or other S oxidizers, are present in soils that have not been fertilized with elemental S. This is important if elemental S containing fertilizers are introduced into nutrient management packages. Elemental S is an almost ideal fertilizer as it contains 100% nutrients. Since micro-organisms carry out the oxidation process it is moisture and temperature dependent, 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. Shell Canada invented a process in 2001 to include elemental S into DAP and MAP and a patent for this was filed in 2003. This group of fertilizers, collectively known as Thiogro, is being introduced into agriculture in several countries, including China. 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.

Methods

Cabbage trial Xiajiang County, 2003

This trial was conducted on a sandy loam soil of pH 4.8 with a high extractable S concentration of 23.2 μg/g. The fertilizers applied were di-ammonium phosphate (DAP), S enhanced DAP, Thiogro (SEF12) and single superphosphate (SSP). The SEF12 used had an analysis (16.2% N, 43.0% P_2O_5, 0% K_2O, 14.9% S) which contained 0.6% SO_4-S.

Rice trials 2006

Two trials were established in 2006 on sandy loam paddy soils in Jiangxi Province. S was applied at 15 kg/ha in the SEF12 (17.2:38.9:0:12S, 3.6% SO_4-S) and SSP treatments and nutrients, other than S, were balanced between treatments. A DAP treatment, which supplied 2.5 kg S/ha, was also included. Each trial occupied a total area of 1200 m^2 and was divided into four sections and different fertilizers applied to each section. At maturity areas of 53 m^2 and 60 m^2 were sampled from within each fertilizer treatment at the Nanfeng and Nichuan sites, respectively, and yields determined. Although the quarters were not randomized the four samples have been statistically analysed as quadruplicates. Scoring of the treatments was undertaken at the tillering, rapid growth and heading growth stages by three to five technicians. Scoring or insect damage was undertaken on a 0-10 scale with the most affected plot given a score of 10 and the least affected a score of 1 and the other plots scored relative to these two plots. At heading, 20 plants/plot were harvested and the degree of leaf damage estimated as a % of the leaf area. The major insects were rice leaf roller and brown plant hopper.

Rapeseed trials 2006

Two randomized small plot trials were established in 2006 in which DAP, SSP and SEF12 (17.2:38.9:0:12S) were compared. The fertilizers were applied at rates to deliver the same rate of P as applied in DAP (75 kg P_2O_5/ha) at Maying Sishan and at the same rate of S as applied in SSP (30 kg S/ha) at Maying Sequ (
Table **6**).
At both sites a DAP treatment was included.

Results

Cabbage trial Xiajiang County, 2003

There was a significant response to S in SEF12 with all granule sizes and the 2.0-0.5 mm and <0.5 mm granule sizes produced higher yields than SSP (
Table **3**). Although replicate data is not available to test the statistical significance there was a lower incidence of soft rot where SEF12 was applied (18-19% reduction) and leaf disease (20-31% reduction where S was applied following a freezing event on February 7, 2003.
There is no published data on the effect of soil applied elemental S on the incidence of disease when it is applied at agricultural rates such as the 30 kg S/ha as applied here. A lower incidence of crown rot has been observed in alfalfa grown in the NW of NSW, Australia when S was applied (Blair GJ, pers. comm.).
Another interesting feature of this trial is the differential N and S utilization rates in the different treatments (
Table **4**). Apparent N and S utilization is the N and S content of the cabbage expressed as a % of the N or S applied in fertilizer. Apparent utilization of both N and S was highest in the SEF treatments and NUE and SUE was also higher in these treatments.

Rice trials 2006

There was no grain yield response to the sulphate applied in single superphosphate (SSP) at either site; however, there was a significant response to SEF12 at both sites (Table 5). SEF12 was superior to SSP at both sites. These differences between treatments were evident in the vigour scorings from the tillering stage. The yield differences appear to be due to the differential effect of insect and disease damage in the treatments. Scoring data indicates that the differences between treatments was evident at tillering and continued throughout the growth of the crop. Whilst there is much data on the effect of foliar applied elemental S on fungal pathogens, there is no evidence in the literature that soil applied elemental S and sulphate can have differential effects on insects and disease.

Table 3. Yield of cabbage grown at Xiajiang, Jiangxi, 2003.

Fertiliser	Yield[A] (t/ha)	Relative yield	Soft rot disease (%)	% reduction in soft rot	Leaf disease (%)	% reduction in leaf disease
DAP	24.67 c	100	61.2		54.8	
SEF12	28.94 a	117	43.2	18	35.1	20
SSP	28.27 b	114	56.6	5	35.6	19

[A] Yields followed by the same letter are not significantly different from each other.

Table 4. N and S utilization rates (calculated as N and S content of cabbage as a % of the nutrient applied in fertiliser) and Nitrogen and sulfur use efficiency expressed as kg yield/kg nutrient applied in fertilizer.

Fertiliser	Apparent utilization (%)	Apparent S utilization (%)	Nitrogen Use Efficiency (NUE) (kg grain/kg N applied)	Sulfur Use Efficiency SUE) (kg grain/kg S applied)
DAP	46.9		7.7	
SEF	62.1	57.7	9.5	63.7
SSP	57.8	56.0	9.8	65.0

Table 5. Yield of rice grain (kg/ha) and degree of disease and insect damage in trials conducted in Jiangxi Province, 2006.

	Nanfeng County, Shantian Town				Nichuan County		
Treatment	DM Yield (kg/ha)	RAE	Disease and insect score at heading (10=most severe)	Rice leaf roller damage (%)	DM Yield (kg/ha)	RAE	Disease and insect score at heading (10=most severe)
DAP	7868 b	100	10	29.4	6560 b	100	10
SEF12	8686 a	110	1	3.6	7453 a	114	1
SSP	7886 b	100	7	23.1	6790 b	104	8

Rapeseed trials 2006

At the Maying Shishan site there was a significant response to S in SSP and SEF12 (
Table **6**) with no significant difference between them despite an additional 41 kg S/ha being applied in the SSP treatment compared to the SEF12 treatment. At the Maying Sequ site (
Table **6**) SEF12 out yielded SSP when applied at the same S rate It is unlikely that the higher yield was due to the additional P applied in the SEF12 as there was no significant difference in yield between the SSP and DAP treatments, with each receiving 98 kg P_2O_5/ha.

Table 6. Nutrient application rates made in each treatment and yield of rapeseed (kg/ha), Jiangxi Province 2006/7.

Fertilizer	Nutrients applied (kg/ha) N	P_2O_5	S	Fertilizer rate (kg/ha)	DM yield[A] (kg/ha)	Nutrients applied (kg/ha) N	P_2O_5	S	Fertilizer rate (kg /ha)	DM yield[A] (kg/ha)
	(----------------Maying Sishan	---------------------	)			(--------------------Maying Sequ	----------------------	)		
DAP	150	75	0	163	2345 c	150	98	0	212	2476 bc
SEF12	150	75	23	192	2453 ab	150	98	30	250	2686 a
SSP	150	75	64	536	2607 a	150	35	30	250	2358 c

[A] Yields followed by the same letter are not significantly different at 5% probability according to Duncan's multiple range test.

Conclusion

Differential response to soil applied sulphate and elemental S have been recorded in cabbage and flooded rice with less soft rot disease in cabbage and less disease and insect damage in rice when elemental S was applied. No mechanism for this can be found in the literature. Elemental S was superior to sulphate-S in one of two trials on rapeseed. These trials suggest that elemental S containing fertilizers require further investigation in both upland and flooded crops.

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