Sulphur fertilizer for sugar beet

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Sulphur fertilizer for sugar beet: BBRO 03/04

Executive Summary

Objectives:

1. To determine the optimum dose of sulphur fertilizer in relation to the soil S content at sowing and the manuring history, and the effect of deficiency on beet yield and quality.
2. To determine the effect of time of S fertilizer application on beet yield and quality.
3. To establish a reliable diagnostic test for sulphur deficiency in the sugar beet crop.
4. To determine where and in what circumstances sulphur fertilizer will be needed for the sugar beet crop.
5. Report the experiment and survey results for a refereed journal and the agricultural media.

Findings:

1. A dose of 10 kg/ha S is sufficient to ensure that the crop does not suffer from a shortage of sulphur. However it seems that this should be applied where atmospheric deposition of S is small and where no S fertilizer or organic manure. has been applied recently.
2. The effects of S fertilizer were so small that an effect of timing could not be investigated.
3. The effects of S fertilizer were too small to allow a reliable diagnostic test to be developed.
4. Small amounts of S fertilizer will be needed in the current beet growing area wherever no organic manure or S containing fertilizer has been applied recently. About a quarter of the beet crop receives organic manure and much beet fertilizer is applied as a blend, which often contains S.
5. A paper describing the research (attached) has been submitted to a journal and an article will be written for British Sugar Beet Review.

Number of staff years and costs

2.4 staff years at a total cost of £143,796.

Further research

It is not envisaged that further research on this topic will be required in the next decade.

Responses of sugarbeet (*Beta vulgaris* L.) to sulphur fertilizer in England.

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SUMMARY

Six field experiments were carried out in eastern England between 2003 and 2005 to test the effect of S fertilizer on the yield of sugar beet. The experiments were made at sites where there had previously been a positive response to S in other crops or where no sulphur-containing materials had been applied for more than 20 years. No individual experiment produced a significant positive response to S application, but the treatments that received no S fertilizer produced the smallest yield in five of the six experiments. Analysis across years using REML showed that there was a positive and significant response in beet where positive responses had previously been recorded in other crops. Beet leaves collected from commercial crops that had no record of recent applications of S-containing fertilizers or manures showed that many had similar S concentrations to the unfertilized crops in the

experiments. Probably beet crops in these fields should receive S fertilizer, which can be applied conveniently as ammonium sulphate.

INTRODUCTION

The annual sulphur deposition rate in most areas used for beet production in the UK is now less than 8 kg/ha (www.uk-pollutantdeposition.ceh.ac.uk), and is expected to decrease further in the next decade. This compares to, for example, annual deposition of about 70 kg/ha at Woburn in eastern England during the mid 1970's (McGrath *et al.* 2002). Then, deposition was sufficient to supply the needs of most crops for S as a nutrient: this is no longer the case. Mineral sulphur, like mineral N, is leached from soil, so supplies for crop growth must either be added frequently or must be mineralized from soil organic matter reserves. Like nitrogen, sulphur is an essential ingredient in proteins, and what little evidence there is suggests that healthy beet crops should contain 25-35 kg/ha (Hoffmann *et al*. 2004). Deficient crops have pale green foliage (like those that are N deficient) and a yellow edge to the leaves (like Mg deficiency), so the symptoms are not easy to identify (Draycott & Christenson 2003). Deficiency in other crops causes reduced photosynthetic efficiency and an imbalance in the amino acid composition of the cells. In beet this is likely to (a) reduce yield (b) increase α amino N concentration of the roots. In the UK, sulphur deficiency is most likely to be found on sandy soils with low organic matter content, neutral or alkaline pH (McGrath & Zhao 1995) and on fields without a recent application of organic manure or sulphur-containing fertilizer. About 30% of the beet crop falls into this category. The research described in this paper was conducted to establish where, when and how much sulphur fertilizer should be applied to the UK sugarbeet crop to ensure maximum yield of high quality roots. Field experiments were carried out at locations either where very little sulphur-containing material had been applied to the soil for many years or where positive responses to S fertilizer had been recorded recently in experiments with winter wheat (Zhao *et al* 2002) and oilseed rape (McGrath & Zhao 1996). In addition, beet leaves were collected from a random sample of beet fields throughout England for S analysis.

MATERIALS AND METHODS

Field experiment procedures

The effect of sulphate fertilizer was tested at Broom's Barn Research Centre on a sandy loam soil (Barrow series, Hodge 1991) in 2003, 2004 and 2005. The experiments were made by splitting some of the plots on a long-term experiment testing the effects of fertilizers (Last *et al*. 1984). The plots that were split for applications of hydrated calcium sulphate (applied as gypsum) had not received any organic manure since 1965 and had not received any sulphur-containing fertilizers since 1986, when they were all given an application of hydrated magnesium sulphate (kieserite) to supply magnesium. Between 1986 and 2002 the plots received a spray of elemental sulphur (10 kg/ha) on to the foliage of beet plants as a fungicide every third year. All the plots had a history of receiving standard applications of N, P and K fertilizers every year. In each year, eight plots were split into four parts, and these were given 0, 10, 20 or 40 kg S/ha of gypsum ($CaSO_4.2H_2O$) in the seedbed in the two weeks before the beet seeds were sown (Table 1). At the same time the plots received their P and K fertilizer and 40kg N/ha as ammonium nitrate. The remaining 80 kg N /ha was applied when the seedlings reached the 2-4 leaf stage. All plots were sown with the variety Roberta in the first two years and with Aspect in the third: the seeds were spaced 17.5 cm apart. All crops received sprays of recommended plant protection products to keep them free from serious infestations of weeds, pests and diseases. The plots were five rows (2.5 m) wide and 8 m long; all samples were taken from the central 6m of the central three rows. All the experiments were sown in late March or April and the plant population was assessed in early June. The plots were harvested by machine on one day during autumn/early winter. After harvest, the roots were washed and weighed and then sampled; sub-samples were frozen for subsequent sugar and impurity concentration analyses (ICUMSA 2005). Representative samples of the roots were weighed, dried at 85℃ for 48 hours and reweighed to determine dry matter yield. These samples were then milled (< 0.5 mm) and stored in sealed glass vials for subsequent determinations of the concentrations of N and S (McGrath & Zhao 1996).

In the same years, the effect of sulphur fertilizer was tested on a loamy sand soil where significant positive yield responses to sulphur fertilizer had recently been measured in cereal crops. The experiments were at Woburn, Bedfordshire in 2003 and 2004 (Cottenham soil series) and at Docking, Norfolk in 2005 (Newmarket 1 soil series). These experiments tested five rates of gypsum supplying 0 – 40 kg S/ha in 10 kg/ha increments: the plots were arranged in five randomized blocks. The sugarbeet received 120 kg N/ha in two doses and received recommended doses (Anon, 2000) of P, K, Na and Mg fertilizers, as indicated by analyses of the topsoil during the previous autumn: none of these fertilizers contained S. The gypsum was applied by hand and incorporated into the seedbed in the week prior to drilling the sugarbeet (Table 1). The plots were all 2.5 or 3 m wide and 12 m long and observations were always confined to the central 9 m of the central 3 or 4 rows. These plots were harvested by hand, the plants were counted and the produce was transported to Broom's Barn Research Centre for yield and quality assessments.

Plant and Soil Samples

The soil in each experiment was sampled in February or March, before any S fertilizer was applied, by taking five soil cores from each zero fertilizer plot in the 0 - 30 and 30 – 60 cm depths. The five cores were bulked and mixed. This was repeated immediately after the final harvest, when the plots that had received 40 kg S/ha were also sampled. The soils were dried and milled to <2 mm and were then analysed to determine their sulphate concentration (McGrath & Zhao 1996). The plants were sampled to determine dry matter yield and S concentration at approximately the time of canopy closure. These samples were always taken during the last half of June, when 1.5 m^2 was harvested by hand, topped at the level of the lowest leaf scar, cleaned, sub-sampled and dried at 85℃ for 48 hours and then wei ghed. The foliage of the beet was sampled to determine dry matter yield and S concentration immediately before final harvest. The top was sliced off 20 plants chosen at random from each plot. The tops were weighed, chopped into small pieces, mixed and sub-sampled, weighed and dried at 85°C for 48 hours to determine dry matter yield.

Survey of leaves from commercial beet crops

In early September, 2005, ten recently produced but fully expanded beet leaves were collected from each of 170 beet fields. These beet fields were chosen according to a protocol that ensured each hectare of the crop in England had an equal chance of being included (Turner 1992), except that fields treated at any time in the previous 12 months with farmyard manure, ammonium sulphate, magnesium sulphate or elemental S were excluded. The district and the texture of the surface soil were recorded and the leaves were sent to Broom's Barn Research Centre where they were dried and ground before being analysed to determine their S concentration.

Chemical and statistical analyses

The concentration of available S in the soil samples was measured by inductively-coupled plasma emission spectrometer (ICP-AES) after extraction with 0.016_M KH_2PO_4. The concentration of total S in the crop tissues was measured by ICP-AES after grinding to pass through a 0.5 mm mesh sieve followed by digestion with $HNO_3/HClO_4$.

The data were analysed using ANOVA and REML procedures within the GENSTAT suit of programmes (Lane & Payne 1996).

RESULTS

The soils at the start of each experiment contained 3-5 mg/kg of available S in the plough layer and 2.5-5.5 mg/kg in the layer from 30-60 cm deep (Table 2). There was no consistent difference in concentration between the surface and subsoil layers. The lack of differentiation in these concentrations between the top soil and the subsoil is similar to the findings of McGrath & Zhao (1996), whose experiments were on the Woburn farm, close to some of the experiments in this study. The concentrations in the soils in this study were similar to the amounts reported for the low-S site used by Thomas *et al*. (2003). The amounts of available S in the soils were between 30 and 60 kg/ha.

In 2003, the growth of these rain-fed beet crops was strongly influenced by dry weather during August and September, which stressed the plants. This had a large impact on growth on the sandy soil at Woburn, where the yield of sugar only averaged 5.96 t/ha (Table 3). In 2004, frequent rain during March and April caused delayed sowing on the medium textured soil at Broom's Barn Research Centre (Table 1). This, together with an early harvest, was responsible for the small yield there in that year. Frequent rainfall in March and early April again delayed the sowing at Broom's Barn Research Centre in 2005, and this had an adverse impact on yield (Table 3). The smallest and largest yields in these experiments are similar to the average yields for the lowest and highest quartiles of the UK beet crop (Lang 2007).

None of the six experiments, in isolation, produced a significant response to the application of sulphur in terms of sugar yield. However, in five of the six experiments the yield of the control treatment without an application of sulphur was the smallest (Table 3). When analysed over years using REML, there was a significant positive response to the fertilizer treatments in those experiments that were on the loamy sand soils at Woburn and Docking (Table 3), where responses had already been recorded in wheat or oilseed rape. Overall, the average yield response provided by sulphur applications was 0.45 t/ha of sugar, an increase of 5.2%.

Sulphur concentration in dry matter and uptake by the crops was measured at harvest in October. The S concentrations in the beet tops (leaves plus crowns) ranged from about 1.8 to 5.4 mg/g, much of the variation being associated with site and season (Table 4). In most cases there was a positive response to fertilizer application which, on average, raised the concentration at Broom's Barn Research Centre from 2.22 to 2.52 mg/g and at Woburn/Docking from 2.40 to 3.08 mg/g. Concentrations in tops were also measured in late June, approximately at the time of canopy closure. There was usually, but not always, a small decline in the concentration between then and final harvest (Table 4). This contrasts with the results of Thomas *et al* (2003), who observed an increase in the concentration in the foliage between June and early October on all treatments in one of their experiments.

In the roots at final harvest, the concentrations were between 0.3 and 0.4 mg/g. All of these values are similar to those of Zhao & Bravo (as tabulated by Draycott & Christenson 2003) and are much less than the values obtained by Sexton (1996).

The amounts of S present in the tops varied widely, from 7 to 22 kg/ha and averaged 11.4 kg/ha. However, sometimes there was not a positive response to the fertilizer. This was probably because variable amounts of the crops' foliage dies and falls off the plants by the time of harvest (October onwards). Uptake in the roots ranged between 2.7 and 6.8 kg/ha (average 4.0 kg/ha) and there was always a small gain in uptake from applying fertilizer. In crops without sulphur fertilizer, whole-plant uptake ranged from 10 to 18 kg/ha and averaged 14.2 kg/ha: the variations were related to the average concentration of available S in the uppermost 60 cm of soil at the time of sowing (Fig. 1). Sulphur fertilizer application tended to increase S uptake measured at harvest, but the tendency was never big enough to be significant (Table 5), and the change in uptake from the addition of 40 kg/ha of S fertilizer was only 2.6 kg/ha on average. These uptake quantities are broadly in agreement with values published by Syers *et al*. (1987), Bravo *et al*. (1989) and Jourdan *et al*. (1992), but are rather less than the values reported by Hoffmann *et al*. (2004), especially for the amounts in the roots. All of these values are much less than the quantities reported for crops grown in eastern England by Armstrong (1985), despite all the yields being similar in size.

Studies of S metabolism have led some researchers to examine the effect of S fertilizer on the amino N concentration in the beet at harvest time. Amino N is an important impurity in beet juice and it reduces the proportion of sugar that can be recovered in a purified form. In these experiments S fertilizer always reduced the concentration of amino N when expressed on a 'per unit sugar' basis, but the average value without S fertilizer was 926 mg/kg sugar compared with 825 mg/kg where 40 kg S/ha was applied: this reduction was always less than 10% and was never significant. This is similar to the observations of Hoffmann *et al*. (2004) but contrary to the findings of Thomas *et al*. (2003), who found a marked reduction in amino N concentration where S fertilizer was added to a low-S soil.

The malate/sulphate in leaf tissue has been suggested as a stable indicator of sulphur deficiency in cereals and oilseed rape (Blake-Kalff *et al*. 2001). This ratio was measured in the leaf tissue of the beet plants from the June samples in the experiments in 2003. This is approximately the latest time when it would be practical to apply a remedial dose of fertilizer to a beet crop. At both sites the fertilizer that was given in the seedbed reduced the ratio significantly, from 2.9 to 0.8 (± 0.29) and from 1.8 to 0.9 (± 0.25). However, the yield results in the experiments gave little indication of a shortage of sulphur supply, so it was not possible to correlate the ratio with deficiency.

The S concentration in leaf samples taken from commercial beet fields that had received no recent additions of S except from atmospheric deposition ranged from 1.59 to 6.33 mg/g, with a mean value of 3.08 mg/g (Fig. 2).

About half of the samples had concentrations less than the critical value of 3.0 mg/g determined by Hoffmann *et al*. (2004), but their value was determined on the lamina and not the whole leaf, and on younger plants. Young leaf blades that do not show marked deficiency symptoms probably contain larger concentrations of S than whole, fully-expanded leaves. Approximately one third of the samples had concentrations similar to those in the unfertilized plots in the experiments, and 3% had S concentrations in the leaves that were smaller than the values measured at final harvest in the unfertilized experimental plots. The differences between the S concentrations determined in the survey were not associated with soil texture but were associated with the area of the country where the samples were collected. On average, the concentrations were least in the northern part of the beet growing area and most in the south (Table 6). This conflicts with the results of Sexton (1996), who surveyed beet fields in 1995 and found the largest concentrations in the leaves of beet plants collected in Yorkshire, Nottinghamshire and Lincolnshire.

DISCUSSION

A large proportion of beet fields in England receive some sulphate in the fertilizer because approximately 30% of them are treated with animal manure in the autumn before sowing in the spring, and most are treated with blended fertilizer to supply P, K, Na and Mg: these blends are partly composed of ground rocks, many of which contain some sulphate. However, all of the experiments in this study were grown on sites that had either a history of being responsive to S fertilizer in other crops (wheat or oilseed rape) or where S additions were known to be very small for the previous two decades. Despite this, none of the individual experiments produced a significant yield response to S fertilizer application. However, averaging over years did produce a significant response in the loamy sand experiments and the treatment given no S fertilizer produced the smallest yield in five of the six experiments. In the light of this, it is probably worthwhile to apply some S fertilizer to beet fields that have not received any sulphur-containing fertilizers or manures recently. This can be done simply by using ammonium sulphate for the first application of nitrogen fertilizer. Typically, this would apply 35 – 40 kg S/ha at an additional cost of £10 - 20/ha, depending upon the relative prices of ammonium sulphate and the alternative N fertilizer. The average yield response to S fertilizer in these experiments is worth approximately £70/ha.

Addition of sulphur-containing fertilizers would almost certainly be worthwhile on those 3% of fields in the survey with S concentrations smaller than the unfertilized plots in the experiments. Unfortunately this study did not provide a method to predict where these fields are, nor did it provide clues to a satisfactory and rapid diagnostic that could be used on beet plants.

The concentrations of S measured in the leaves of beet plants from the survey of commercial fields ranged from 1.5 to 6.3 mg/g. The concentrations in the leaves measured by Sexton (1996) in 1995 were generally larger, averaging about 9 mg/g of the dry weight. This suggests that there are large annual variations in the concentrations, that the concentrations decreased rapidly during the intervening 10 years, or that there were errors in the analyses. The concentrations reported from 1995 are more akin to those found in the S-rich crop oilseed rape (McGrath & Zhao 1996) than in other beet studies (Thomas *et al*. 2003; Hoffmann *et al*. 2004).

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Table 1. Dates of fertilizer application, sowing and harvesting and the sugar beet varieties used in the experiments.

S application	Sowing	Variety	Harvest
	Broom's Barn Research Centre		
3/3/03	19/3/03	Roberta	4/12/03
23/4/04	26/4/04	Roberta	25/10/04
12/4/05	19/4/05	Aspect	8/11/05
	Woburn		
21/3/03	21/3/03	Roberta	8/10/03
30/3/04	30/3/04	Roberta	21/9/04
	Docking		
21/4/05	28/3/05	Dominika	20/10/05

Table 2. Plant available sulphur (mg S/kg soil) prior to sowing in plots that did not have an application of S fertilizer.

Site	Depth (cm)	2003	2004	2005
Broom's Barn	0-30	5.17 ± 0.481	3.51 ± 0.344	3.85 ± 0.141
D.F. 7	30-60	3.80 ± 0.358	2.67 ± 0.286	4.00 ± 0.212
Woburn/Docking	0-30	3.41 ± 0.186	4.84 ± 0.384	4.60 ± 0.861
D.F. 4	30-60	3.96 ± 1.166	4.46 ± 0.365	5.55 ± 0.902

Table 3. The effect of sulphur fertilizer application on the sugar yield (t/ha) of sugarbeet crops.

Location	Year	Sulphur application (kg S/ha)					
		0	10	20		40	S.E. (21 D.F.)
Broom's Barn	2003	9.77	10.61	10.50		10.03	0.458
Broom's Barn	2004	6.16	6.64	6.76		6.92	0.573
Broom's Barn	2005	8.40	8.33	7.99		8.30	0.498
Mean		8.14	8.55	8.42		8.39	0.261 (58.0 D.F.)
		0	10	20	30	40	S.E. (16 D.F.)
Woburn	2003	5.31	6.20	5.61	6.74	5.94	0.268
Woburn	2004	9.77	10.65	9.79	9.90	10.09	0.701
Docking	2005	12.60	13.11	13.26	12.90	13.29	0.359
Mean		9.14	9.90	9.53	10.04	9.76	0.211 (40.4 D.F.)

The standard errors of the treatment means over years were calculated using REML variance components analysis.

Table 4. Sulphur concentration (mg/g) in sugar beet tops in summer (late June) and at final harvest (Sept./Oct.).

		S fertilizer application (kg/ha)		
		0	40	S.E. (21 D.F.)
Broom's Barn Research Centre				
2003	June	2.17	2.35	0.058
	October	2.68	2.43	0.101
2004	June	2.38	2.90	0.184
	October	1.79	2.64	0.373
2005	June	2.72	3.01	0.043
	October	2.19	2.57	0.157
Woburn/Docking				S.E. (16 D.F.)
2003	June	2.25	3.81	0.215
	October	2.20	3.46	0.226
2004	June	3.56	3.93	0.247
	October	3.16	5.44	0.554
2005	June	2.69	2.78	0.059
	October	1.85	1.79	0.113

Table 5. The effect of sulphur fertilizer application on the sulphur uptake (kg/ha) of sugarbeet crops at harvest.

Location	Year	Sulphur application (kg S/ha)						
		0	10	20	30	40	S.E.	D.F.
Broom's Barn	2003	15.7	15.8	16.8		15.5	0.96	21
Broom's Barn	2004	10.6	11.2	13.2		12.7	2.62	21
Broom's Barn	2005	13.8	-	-		15.1	0.96	7
Mean		13.6	-	-		14.4	0.98	2
Woburn	2003	10.3	12.4	13.8	16.4	13.8	1.87	16
Woburn	2004	17.0	19.0	20.7	22.8	26.7	2.66	16
Docking	2005	17.9	17.8	18.0	18.4	17.8	1.09	16
Mean		15.1	16.4	17.5	19.2	19.5	1.15	12

Table 6. Mean and standard deviation of S concentrations in samples of leaf dry matter collected from commercial beet fields in September, 2005.

	S mg/g		
County	Mean	S.D.	n
S Yorks & Humberside	2.61	0.661	51
Notts & Lincs	2.68	0.903	42
S Lincs, Cambs, W. Norfolk	3.15	0.533	34
E Norfolk, Suffolk & Essex	4.00	1.101	43
Grand Mean/Total	3.08	1.005	170

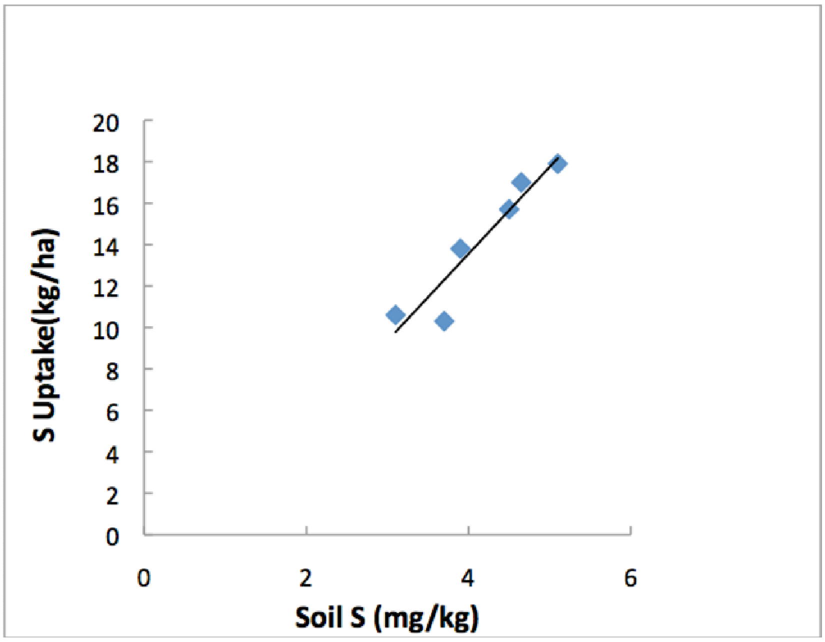

FIG.1 Relationship between S uptake by the crops without S fertilizer and the concentration of available S present in the uppermost 60cm of soil at the time of sowing.

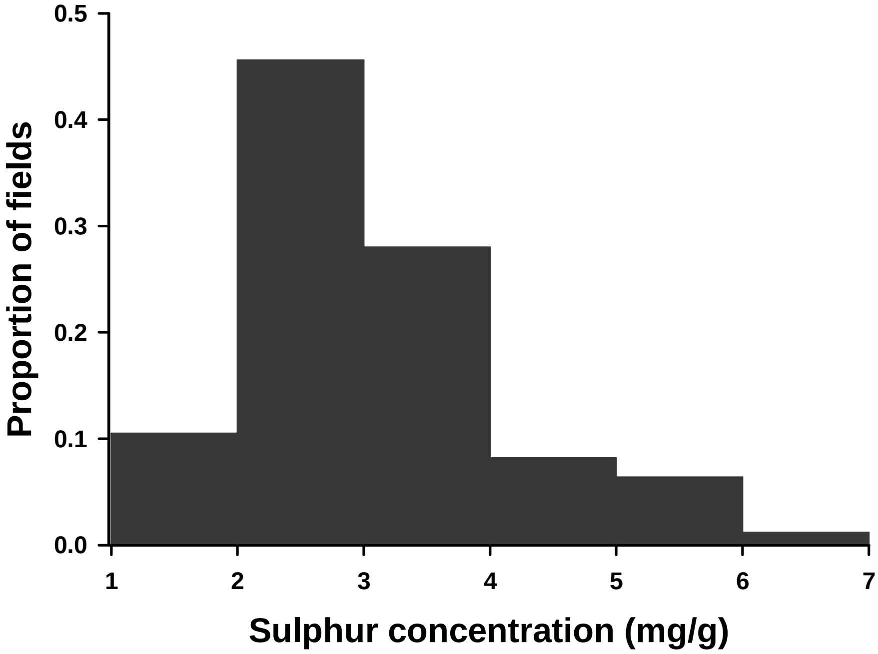

Fig. 2. Proportion of fields classified by Sulphur concentration in the leaves in September, 2005.