



**PROJECT REPORT No. OS2**

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EFFECTS OF SULPHUR ON  
SEED GLUCOSINOLATE  
CONTENT AND SEED YIELD**

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GLUCOSINOLATE CONTENT AND SEED YIELD**

by

**P. J. A. WITHERS** ADAS, Kenton Bar, Newcastle-upon-Tyne, NE1 2YA.

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**Title** Winter Oilseed Rape: Effects of Sulphur on Seed Glucosinolate Content and Seed Yield (HGCA Ref. No. OS35/2/90A).

**Author** Paul J A Withers, ADAS, Kenton Bar, Newcastle-upon-Tyne NE1 2YA.

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**ABSTRACT**

To determine the effect of sulphur (S) fertilisers on seed yield and glucosinolate (GLS) content of double low varieties of winter oilseed rape, ammonium sulphate (10, 20, 30, 50 and 80 kg S/ha), gypsum (20 and 50 kg S/ha) and foliar elemental sulphur (20 kg S/ha) were applied in spring to 4 crops on shallow chalk soils and one crop on a sandy soil in areas where the rate of annual deposition of sulphur was less than 20 kg/ha.

Application of S significantly increased yield at the site on sandy soil which was in North Northumberland and which showed severe S deficiency symptoms from stem extension onwards. There was also a significant yield response to increasing rates of ammonium sulphate at a shallow chalk site in Dorset which did not show symptoms of S deficiency. There was no significant advantage from putting on more than 10 and 50 kg S/ha respectively at these sites. At these rates of applied S respective yield responses of 15 and 12% were best predicted by the concentrations of total S in young fully expanded leaves at flowering which were at or below 0.36%.

Increasing rates of ammonium sulphate gave small significant increases in seed GLS at 3 of the sites on chalk soils but at the site on sandy soil seed GLS was trebled at rates of 50 and 80 kg S/ha applied. Application of S decreased oil content at sites on chalk soils by an average 0.3% but at the site on sandy soil the reduction was over 1% and significant. When compared at a single rate of 20 kg/ha, the effectiveness of the different forms of S applied in raising plant S status was in the order ammonium sulphate > gypsum > foliar elemental sulphur although differences did not significantly affect yield response.

The pattern of yield and GLS response in North Northumberland has been found in previous experiments and confirms that sandy soils in this locality are very susceptible to S deficiency. Shallow chalk soils in Dorset have also previously shown yield response to applied S. The results reported here suggest that further research is required to more accurately quantify the supply of S from the soil.

#### **OBJECTIVE**

To study the effect of spring-applied sulphur on seed glucosinolate content and yield of oilseed rape grown on potentially sulphur-deficient soils in areas of low atmospheric deposition.

#### **INTRODUCTION**

Oilseed rape remains an important break crop in U.K. arable farming but concerns over the anti-nutritional effects of rapeseed meal in livestock diets has necessitated a switch to varieties which are low in glucosinolates (GLS). The introduction of double low varieties against a background of declining atmospheric sulphur (S) inputs has led to an increased incidence of S deficiency in oilseed rape in recent years (Chalmers et al., 1992) and substantial yield increases

from application of S fertilisers have been recorded (Withers, 1989; Booth et al., 1991). Glucosinolates are an important sink for S taken up by the plant and crop S supply is thought to be the second most important factor affecting seed GLS content after variety (Schnug, 1989).

The potential conflict between the need to adequately control sulphur deficiency yet keep glucosinolate content low in double low varieties of winter oilseed rape was investigated at a number of potentially sulphur deficient sites in England and Wales from 1989-91. This report covers the final year of those investigations.

#### **MATERIALS AND METHOD**

Increasing rates of ammonium sulphate (10, 20, 30, 50 and 80 kg S/ha), agricultural gypsum (20 and 50 kg S/ha) and foliar elemental sulphur (20 kg/ha) were applied to field plots at 5 sites in 1991. Site details are given in Table 1. Sulphur treatments and 2 control (nil sulphur) treatments were incorporated into a randomised block design with 4 replicates.

Ammonium sulphate and gypsum fertilisers were applied at the start of crop growth in early spring. Extra nitrogen (as ammonium nitrate) was applied to plots not receiving the maximum rate of ammonium sulphate such that all plots received an initial nitrogen application of 70 kg/ha. A further 130 kg/ha N was applied by stem extension stage. Foliar elemental S (Thiovit) was applied at the start of stem extension in line with product recommendations except at ADAS Bridgets where it was applied at the same time as the solid S treatments. Crop management was consistent with current commercial practice.

Available sulphate in the topsoil (0-15 cms) was determined before treatment application using a potassium dihydrogen phosphate extract

(modified from Scott, 1980). Samples of young fully expanded leaves were taken at green bud and early flowering stages and nitrogen (N), total sulphur (S) and sulphate-sulphur (SO<sub>4</sub>S) content determined according to standard ADAS analytical procedures (Anon., 1986). Grain yields were determined and expressed at 91% dry matter. Seed GLS were measured by X-ray diffraction after drying at 85 C for 70 minutes (Schnug and Haneklaus, 1988).

## RESULTS

### Seed Yield and Quality

Seed yield was significantly increased by S application at Yeavinger and at Charminster but there was no yield response at other sites (Fig. 1). Yield response to increasing rates of ammonium sulphate could not be satisfactorily explained by fitted functions but examination of treatment means indicates a significant effect from 10 kg S/ha at Yeavinger and from 50 kg S/ha at Charminster. Seed oil content was reduced with increasing rate of S applied at all sites although this was only significant at Yeavinger (Fig. 2), where application of 80 kg S/ha reduced oil content by 1.5%. However this was not sufficient to nullify the beneficial effect of S on oil yield which increased by 14% at this site. The average reduction in seed oil content at the remaining sites on shallow chalk soils was only 0.33% when meaned across all S treatments and 0.63% at 80 kg S/ha applied.

Sulphur treatments significantly increased seed GLS concentrations at all sites except Lewes where crop S content with nil applied S (7.1 g/kg) was relatively high compared to other sites (range of 2.8 to 4.0 g/kg). Increases in seed GLS were comparatively small (+4-6 umoles/g) at sites on shallow chalk soils where S deficiency symptoms did not develop despite a yield response at Charminster. However at Yeavinger, which was the only site to develop crop symptoms of S deficiency, seed

GLS contents were trebled by application of 50 and 80 kg S/ha (Fig. 3). Seed GLS contents with nil applied S were consistently lower in 1991 compared to previous years.

Application of S gave large significant increases in plant S status at all sites except Bridgets. Increases in total S, SO<sub>4</sub>-S and N:S ratio in leaf tissue at flowering with increasing rates of ammonium sulphate were satisfactorily fitted by a quadratic function (Figs. 4, 5 and 6). At Yeavinger a linear fit was just as good as a quadratic fit but the latter was kept for consistency. The mean rate of increase in leaf S concentration at Yeavinger (0.15 g/kg per kg S applied) was 3 times larger than the mean rate of increase at sites on chalk soils (0.05 g/kg per kg S applied). Within sites on chalk soils the largest rate of increase was obtained at Charminster.

#### Form of Sulphur

Ammonium sulphate (AS), agricultural gypsum (G) and foliar elemental S (FES) were not significantly different in terms of their effect on seed yield, oil content or oil yield although small differences did occur. At Yeavinger, seed yield was less where G was applied and seed oil content was reduced less where FES was applied. Increases in seed GLS at the highly responsive Yeavinger site were in the order AS > G > FES but there were no consistently significant trends at other sites where increases in GLS from 20 and 50 kg/ha applied S were much smaller.

Differences between the forms of S applied were however more consistent in their effects on leaf S, SO<sub>4</sub>-S and N:S ratio at flowering (Table 2). Increases in total S and SO<sub>4</sub>-S and decreases in leaf N:S ratio were always larger from AS than from G or FES, although only at Yeavinger and Lewes were the effects significant at the 5% level. FES was not significantly less effective than G at any site

although increases in leaf S content were always slightly lower. When compared at the 50 kg S/ha rate, G was slightly less effective than AS at increasing leaf S content although differences were not significant.

#### **Prediction of Response**

Although deficiency symptoms were observed only at sites on sandy soils in North Northumberland, a yield response was obtained on both sandy and shallow chalk soils. Based on a recent atmospheric deposition map, all sites were located in areas receiving less than 20 kg/ha from the atmosphere. Yield response to applied S could not be explained by differences in pH, organic matter content or available soil sulphate (Table 1).

The results of leaf analysis are shown in Table 3. Sites which gave a significant yield response to applied S showed the lowest concentration of total S in the leaf at the flowering stage. There was no consistent relationship between leaf S contents at green bud stage and at the flowering stage. A knowledge of leaf S<sub>04</sub>-S content or N:S ratio did not improve prediction of yield response although was useful in confirming deficiency symptoms. Analysis of deficient leaves at Yeavinger during stem extension showed values of total S, S<sub>04</sub>-S and N:S ratio of 0.35%, 0.06% and 20 respectively.

#### **DISCUSSION**

The data reported here represent the third and final year of a series of experiments initiated in 1989 by the Ministry of Agriculture, Fisheries and Food (MAFF) to investigate the effect of S fertilisers on the yield and quality of double low varieties of winter oilseed rape. At that time there was growing concern that fertiliser S applied to prevent or correct yield loss due to S deficiency would increase



seed GLS concentrations to a level which would exceed the proposed subsidy payment threshold of 20 umoles/gram (whole seed). Since then the system of subsidy payment has changed to one based on the area of oilseed rape grown rather than on seed GLS content at harvest but the impact of S on GLS is still relevant for those growers wishing to grow home-saved seed. The GLS content of rapemeal remains important to feed compounders wishing to include it in livestock rations.

The results of experiments in 1991 confirmed the results obtained in 1989 (Withers, 1989) showing large increases in seed GLS content were obtained only at sites on sandy soils in North Northumberland where crop symptoms of severe S deficiency were noted from stem extension onwards. Other experiments on sandy loam soils in Northern Britain using potassium sulphate fertiliser have also shown up to 3 times higher seed GLS contents from applied S where symptoms have developed but in the absence of a yield response (Evans et al., 1991).

However, these results are contrary to those obtained in Scotland where a severely deficient crop on a sandy soil gave a significant yield response to foliar elemental S but increases in seed GLS were only small (Booth et al., 1991). It is probably relevant that only foliar elemental S was applied in Scotland since at Yeavinger, FES gave as good a yield response as ammonium sulphate (AS) yet was less than 50% as effective in raising leaf S or seed GLS concentration: e.g. the increases in seed GLS from FES and AS applied at the rate of 20 kg S/ha were 4.8 and 10.4 umoles/gram respectively. It has been shown that only a very small proportion of FES is actually directly absorbed through the leaf (McGrath and Johnston, 1986) and on reaching the soil FES must first be oxidised by Thiobacillus organisms to sulphate before being taken up by the roots. Foliar elemental sulphur can therefore be expected to be a less efficient fertiliser in terms of raising crop S status than soluble sulphate forms especially if soil populations of Thiobacillus are small, although this may not

necessarily result in reduced yield response. Full fungicide programmes to counter-act any yield benefit derived from the known fungicidal properties of foliar elemental sulphur were not included in the experiments reported here.

It is difficult to come to a satisfactory conclusion over the amount of S required for maximum yield. At Yeavinger, and at a similar site in 1989, there was no significant yield response above 10-20 kg S/ha although yields were very low in successive dry summers. Rainfall between application of S and harvest was only 30-40% of the total rainfall over the growing season at these sites (Appendix 1) and uptake of S will almost certainly have been restricted for long periods despite large increases in the leaf S content with each increment of S applied. At Charminster, there was a response up to 50 kg/ha although the data were too scattered to adequately describe the yield response by fitted function. Significant within site variation was a noteworthy feature of these experiments and of a similar series on cereals, despite careful site selection. This is perhaps not surprising considering the heterogeneous nature of soil and atmospheric S supply but does indicate that a randomised block design may not be the most appropriate for investigating crop response to S inputs.

There has been a consistent trend for S application to reduce oil content over the 3 year experimental period. Previous work has shown that oil content can be increased as well as decreased by applied S (Withers, 1989; Chalmers et al., 1992). The effects of applied S on oil content and oil composition remain poorly understood.

The response of yield and seed GLS content to applied S is known to be influenced by crop nitrogen (N) supply (Booth et al., 1991; Milford and Evans, 1991). The N application at these trials was kept constant at 200 kg/ha and represented current commercial practice at the time.

As the U.K. price for oilseed is now dictated by the world market, N inputs to oilseed rape are likely to reduce and the N:S interaction may become of less significance.

The results presented here indicate that leaf analysis rather than soil analysis is a better predictor of S deficiency and yield response. Although plant S concentrations are useful indicators of crop S status at one point in time, they are not a definitive guide to future deficiency risk. This is suggested by the lack of any consistent relationship between leaf S contents at green bud and flowering stages. The results of plant analysis at flowering appear to be a reasonable indicator of response but probably come too late to treat the crop although this aspect was not investigated here. Comparison of seed GLS content and to a lesser extent leaf S contents between years indicates there can be considerable seasonal variation in plant S supply on similar soils, in the same locality and within one variety.

Measurement of available soil sulphate in the topsoil (15 cms) has been shown in these experiments to have little predictive value yet seasonal variation in soil S supply clearly has a major influence on the frequency with which S deficiency occurs (Syers et al., 1987; Chalmers et al., 1992). Too little is known about the availability of S reserves in the subsoil and how the soil S supply interacts with the crop in different seasons. The results from these experiments tend to confirm the need to develop prediction systems which are based on modelling the S cycle in the soil-plant system rather than relying on single measurable site parameters which are useful only in hindsight. At present, a knowledge of soil type and location together with retrospective leaf analysis offers the only means of assessing deficiency risk and the need for fertiliser S.

This report will be further published as part of a paper to be submitted to the Journal of Science, Food and Agriculture detailing all 3 years results.

#### ACKNOWLEDGEMENTS

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Fig 1. The effect of increasing rates of ammonium sulphate on seed yield (t/ha @ 91% dry matter) at Yeavinger (—●—), Charminster (—○—), Lewes (—■—), High Mowthorpe (—□—) and Bridgets (—▼—) in 1991.

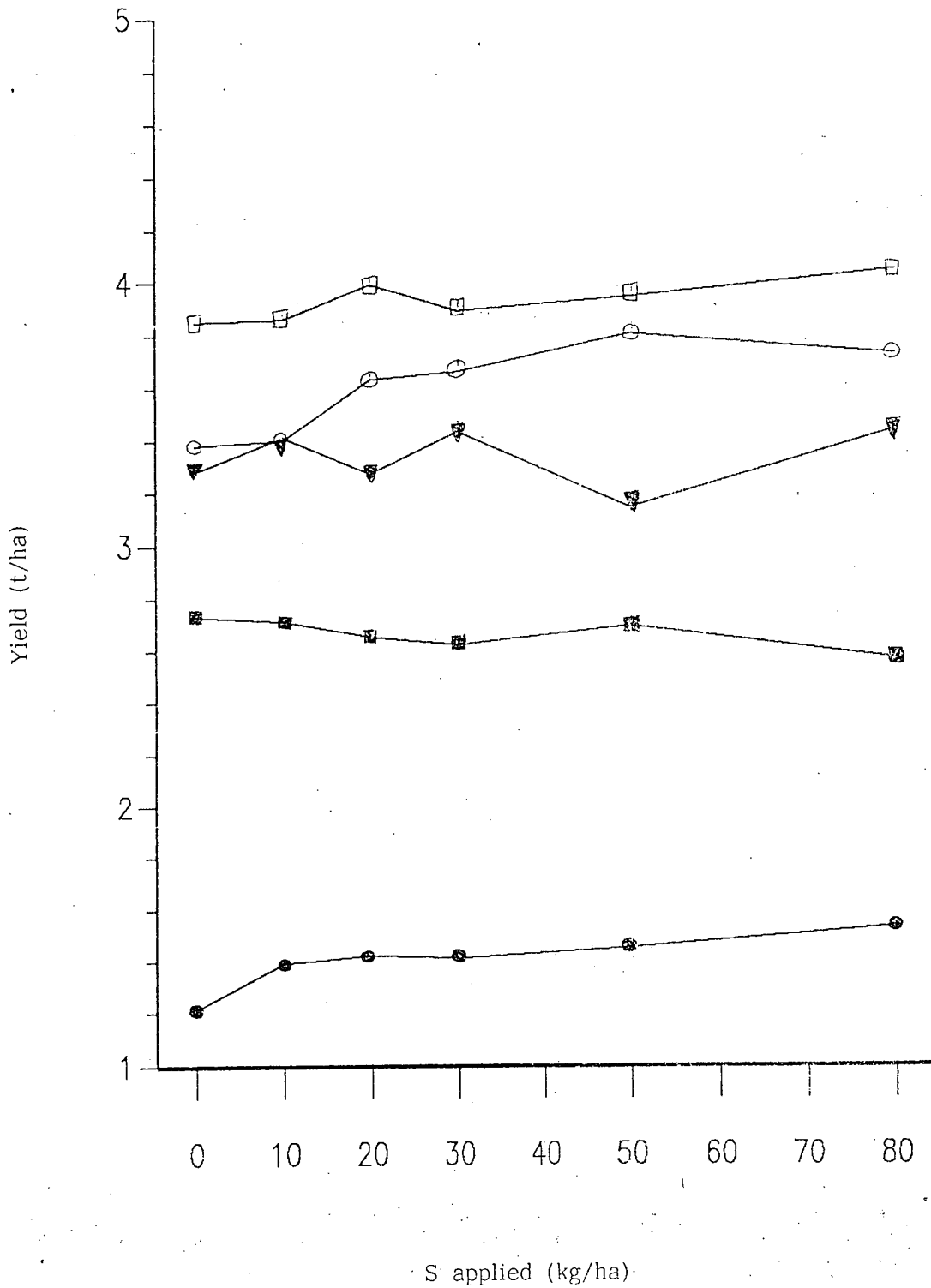


Fig 2. The effect of increasing rates of ammonium sulphate on oil content (% @ 91% dry matter) at Yeavinger (—●—), Charminster (—○—), Lewes (—■—), High Mowthorpe (—□—) and Bridgets (—▼—) in 1991.

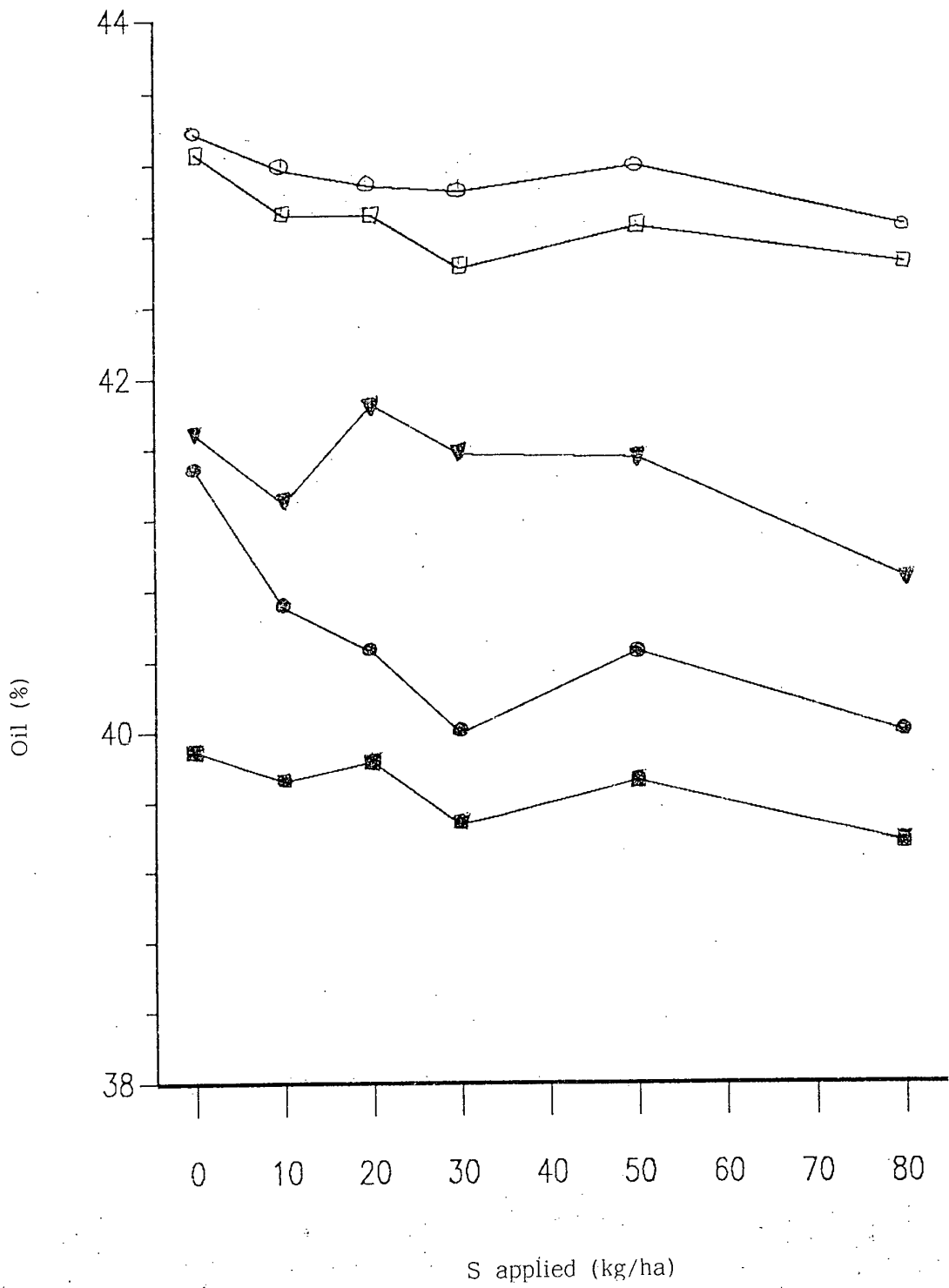


Fig 3. The effect of increasing rates of ammonium sulphate on seed glucosinolate content ( $\mu$  moles/gram whole seed @ 91% dry matter) at Yeavinger ( $\bullet$ ), Charminster ( $\circ$ ), Lewes ( $\blacksquare$ ), High Mowthorpe ( $\square$ ) and Bridgets ( $\blacktriangledown$ ) in 1991.

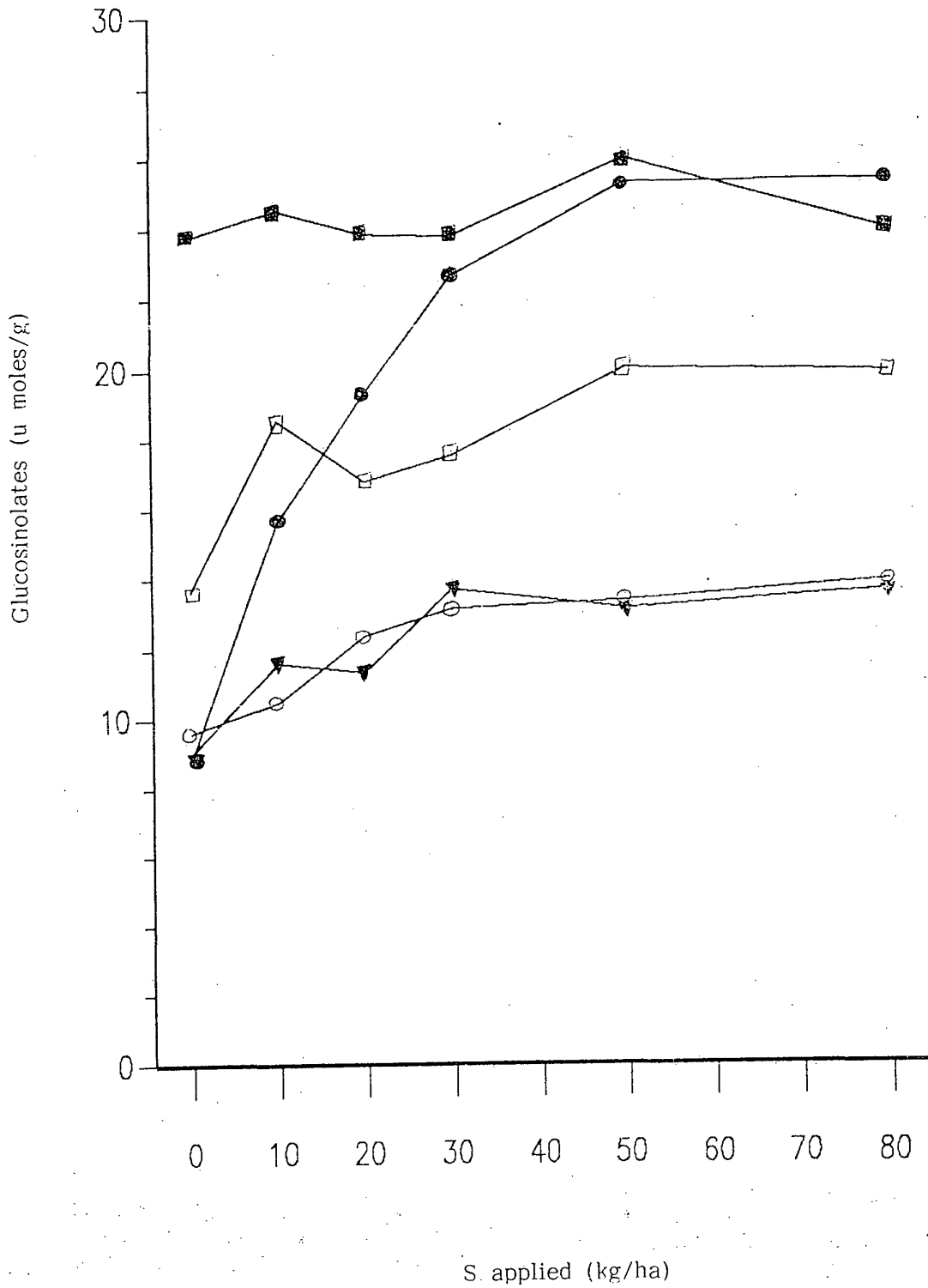




Fig 4. The effect of increasing rates of ammonium sulphate on total sulphur (S) concentration (g/kg in the dry matter) of leaf tissue at flowering as fitted by quadratic function at Yeavinger (—●—), Charminster (—○—), Lewes (—■—), and High Mowthorpe (—□—) in 1991.

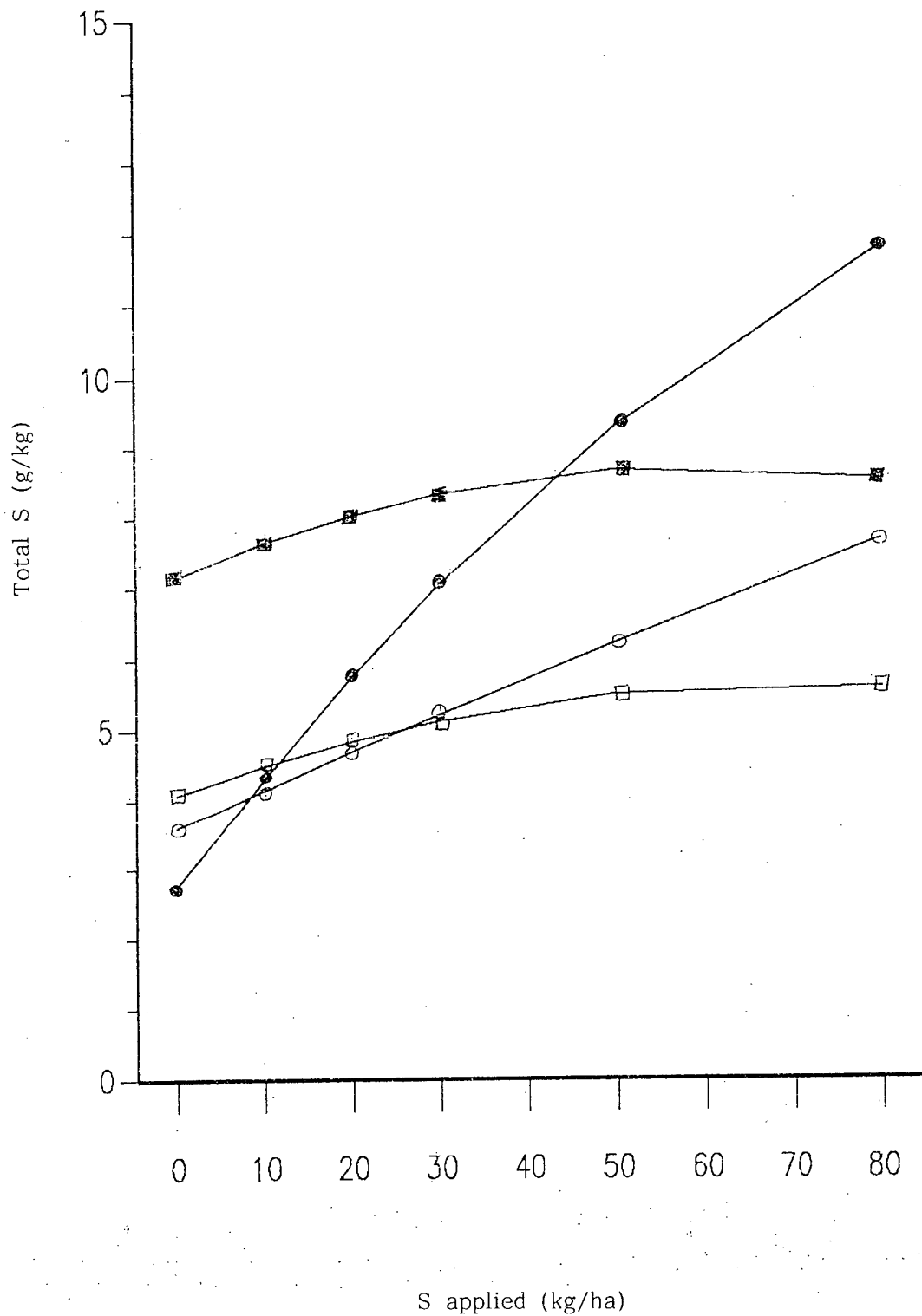


Fig 5. The effect of increasing rates of ammonium sulphate on sulphate-sulphur ( $SO_4S$ ) concentration (g/kg in the dry matter) of leaf tissue at flowering as fitted by quadratic function at Yeavinger (—●—), Charminster (—○—), Lewes (—■—) and High Mowthorpe (—□—) in 1991.

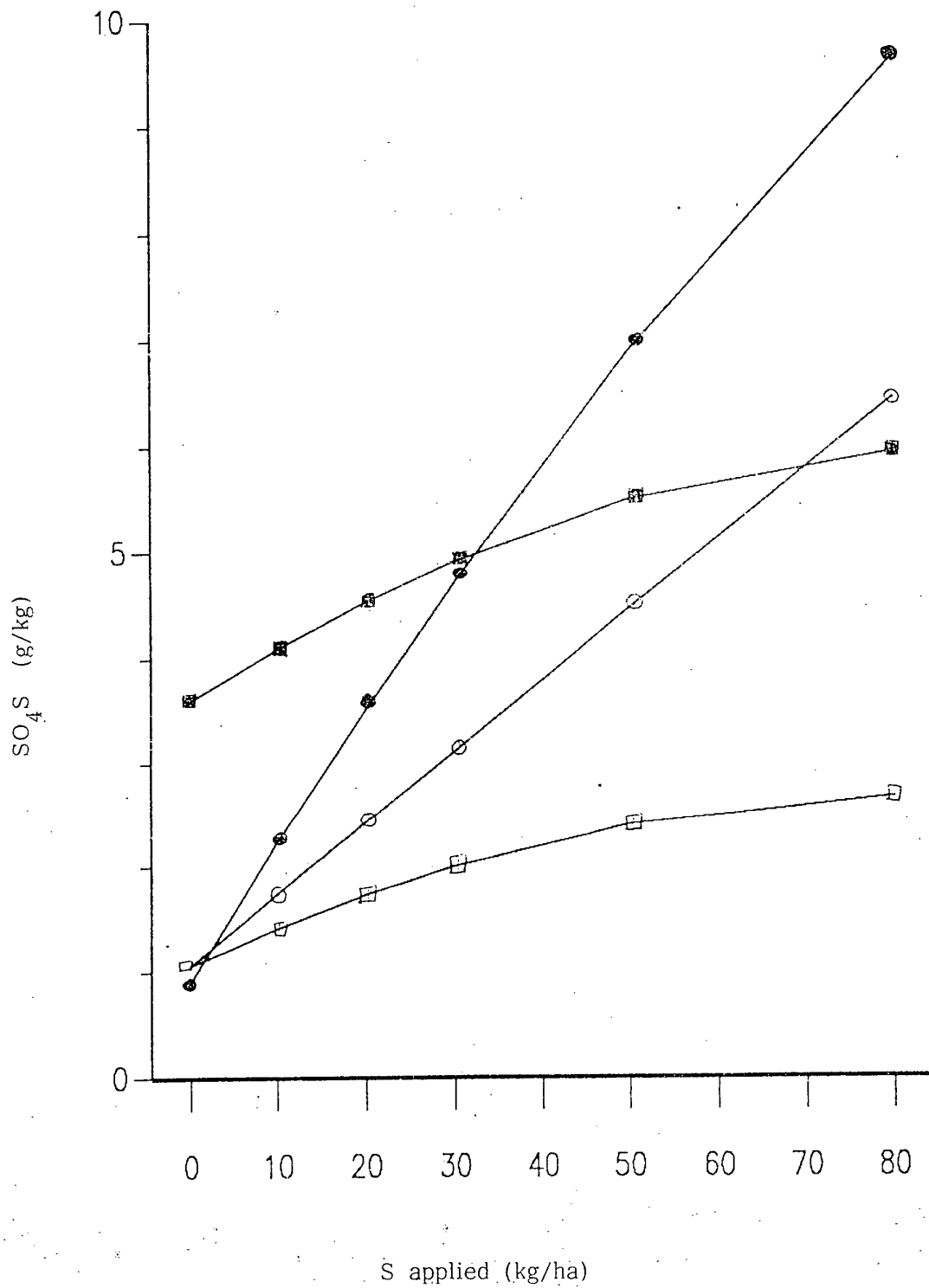
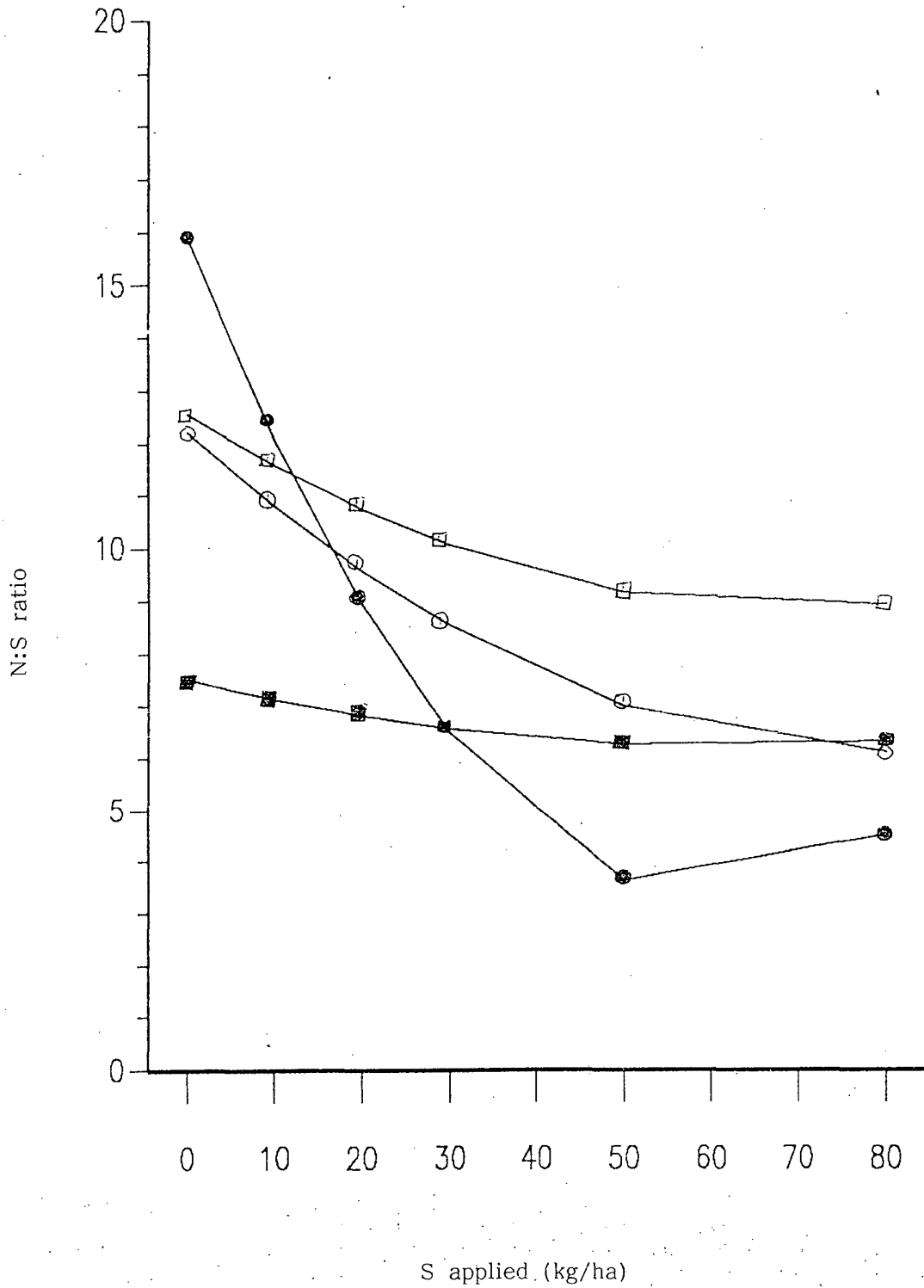


Fig 6. The effect of increasing rates of ammonium sulphate on the nitrogen to sulphur (N:S) concentration ratio of leaf tissue at flowering as fitted by quadratic function at Yeavinger (—●—), Charminster (—○—), Lewes (—■—) and High Mowthorpe (—□—) in 1991.



**Table 1            Site Details**

Year	Site Location	Soil Series	Soil Analysis (0-15 cm)			Variety
			pH	OM %	SO4-S mg/l	
1991	Yeavinger, Northumberland	Alun	6.2	3.2	3.3	Cobra
1991	Charminster, Dorset	Upton	7.9	7.9	4.1	Capricorn
1991	Lewes, West Sussex	Upton	6.9	6.5	5.4	Lictor
1991	High Mowthorpe, N Yorks*	Andover	7.8	3.4	4.0	Libravo
1991	Bridgets, Hants*	Andover	8.1	4.0	3.0	Lictor

\* ADAS R & D Centres

Table 2

The mean effect of ammonium sulphate (AS), agricultural gypsum (G) and foliar elemental sulphur (FES) on leaf sulphur contents at flowering

	S applied (kg/ha)				
	20			50	
	AS	G	FES	AS	G
Total S (g/kg)	6.09	4.98	4.77	7.12	6.93
SO <sub>4</sub> -S (g/kg)	3.22	2.39	2.15	4.75	4.39
N:S ratio	8.35	10.08	10.67	7.20	7.39

**Table 3** Leaf analysis parameters measured at green bud and flowering stages as potential indicators of yield response

Site	Green Bud			Flowering			Yield Response
	S	S04S	N:S	S	S04S	N:S	
Yeavinging	0.49	0.14	10.7	0.28	0.10	16.5	Yes
Charminster	0.76	0.25	6.4	0.36	0.10	11.9	Yes
Lewes	n.d.	n.d.	n.d.	0.71	0.36	7.5	No
High Mowthorpe	0.36	0.10	14.2	0.40	0.10	12.6	No
Bridgets	0.53	0.10	n.d.	0.40	0.11	13.3	No

n.d. = not determined

Appendix 1. Monthly rainfall (mm) between sowing, treatment application and harvest

Site	Sowing Date	Sulphur (a) Application Date	Harvest Date	Rainfall (mm)							
				Sowing to Treatment	Treatment Date to end of March	April	May	June	July	Start of August to Harvest Date	Sowing to Harvest
Yeavinging	28 August	15 March	13 August	435	34	23	22	34	71	11	632
Charninster	27 August	28 February	12 August	465	139	67	8	147	64	7	896
Lewes	2 August	20 February	7 August	496	83	60	22	150	146	0	977
High Nowthorpe	5 September	22 March	13 August	455	6	34	12	70	31	3	606
Bridgets	3 September	26 February	2 August	385	84	51	6	111	91	0	727

(a) Ammonium sulphate and agricultural gypsum treatments which were soil applied

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