Beneficial Effects of Sulphur on Agricultural Crops and some Implications for Livestock Nutrition.

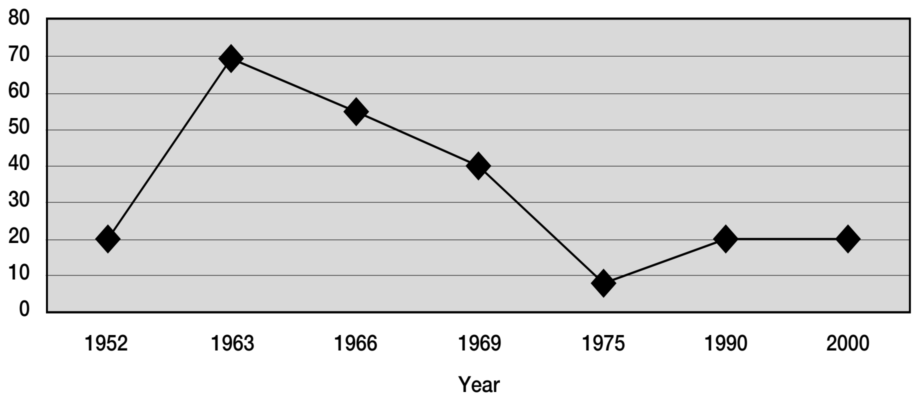
M D Murphy.
Teagasc, Johnstown Castle Research Centre, Wexford.

Introduction.

If "research' means to look at every problem more than once, then the story of the study of sulphur (S) nutrition in Ireland must be a textbook example. Until the late 1950's there was no evidence of a restriction of plant or animal growth due to a shortage of S. Gallagher (1969) working in 1959-1969 concluded on the basis of a small number of field trials that the S status of Irish soils was satisfactory. He did note, however, that S deposited in rainwater was lower in the midlands than near the coast, with a low value for S content of 10kg/ha/year at Birr. He also noted later that because of new high analysis nitrogen, phosphorus and potassium (NPK) fertilizers, S additions which had increased from 4.8 kg in 1952 to 14.6 kg/ha in 1963, had declined to 11.9 in 1966, and he predicted a further decline thereafter. This later proved to be correct and by 1980 the S additions in fertilizers had fallen to 3.3 kg/ha. Following the publication of research work on S at Johnstown Castle around that time, the consumption of S has now increased to around 20 kg/ha. On the other hand, the overall amount of fertilizer nitrogen increased from 12.8 kg to 56.8 kg/ha from 1966 to 1980.

In 1969 P.K.Hanley of Johnstown Castle returned to Ireland from a study trip to Iowa, USA. While there he had been impressed by the work of Bremner and co-workers on S and he decided to review its status in Irish Agricultural. One fact quickly became obvious. Sulphur in the Irish atmosphere was markedly lower than in the industrial nations of Europe. Figure 2 indicates the emissions of sulphur dioxide in various European countries in 1970, and the disparity between Ireland and most other countries is very evident. Concentrations of the element in the Irish atmosphere and rainfall were correspondingly lower. This country could not, therefore, be complacent and could not rely on information from the very strong agricultural facilities in Britain or Holland. Obviously a second look at S in Ireland was needed.

Figure 1: National annual consumption of S fertilizer (kt/year)



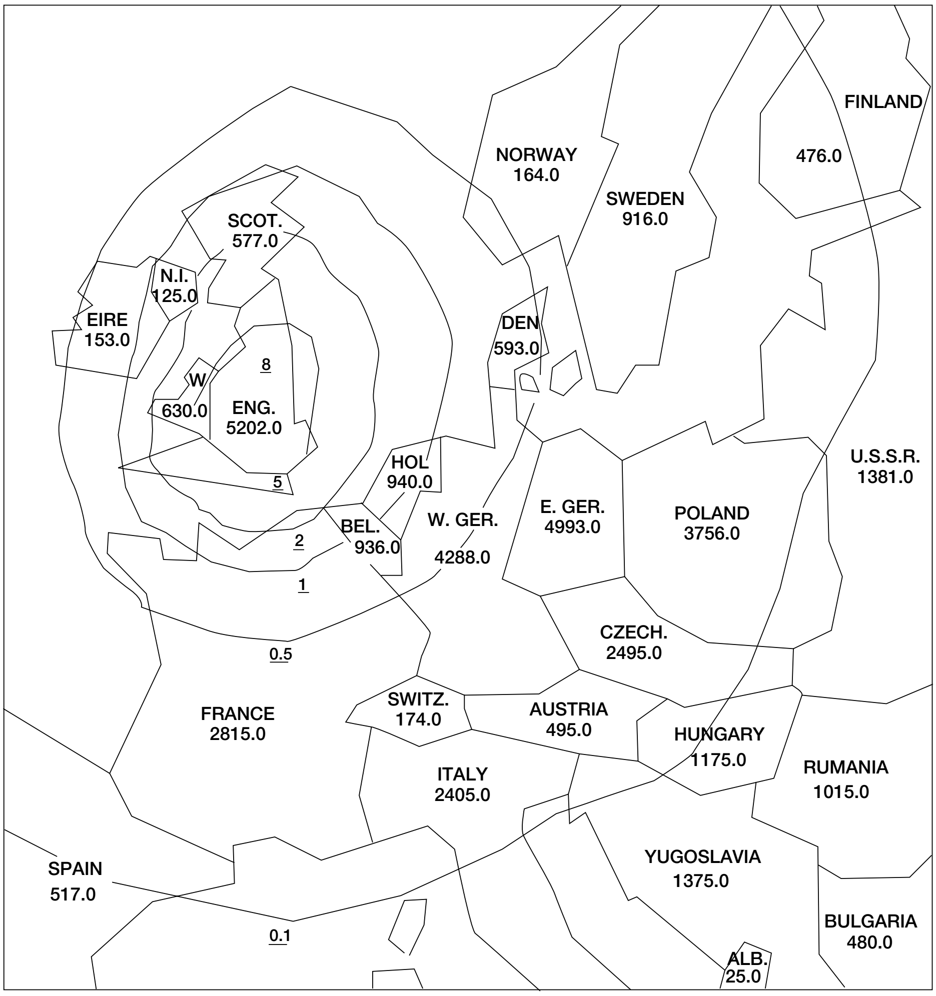
A series of pot culture experiments under greenhouse conditions with grasses and clovers were carried out on 24 soils from different areas of the country in 1970 and 1971. Under these intensive conditions S deficiencies developed fairly rapidly with leaf symptoms and weight reductions becoming obvious after about two cuts of herbage. The sandy, light textured soils were most deficient. Therefore in 1973, after careful study, a statistical significant response to S of 15.4% was obtained on a ryegrass sward on a sandy soil at Screen, Co. Wexford. This was the first recorded response to S under field conditions in Ireland, and although the site was sandy, it was decided to launch a national programme to determine the extent of the problem. (Hanley el al,1974.)

Grassland research.

Since grassland is by far our most important crop, accounting for 75% of the total utilisable land of 5.7 million hectares the bulk of the research has been devoted to this crop. Between 1974 and 1984 field trials were carried out on predominantly ryegrass swards, at 140 locations throughout the country. (Murphy and Boggan, 1988).

Findings from these trials are summarised below:

Figure 2: SO_2 deposition rates over Europe



Increased Herbage Yields

S deficiency occurs in soils when removals by crops and leaching exceed the inputs from fertilizers. Some soils may in formers years have built up a reservoir of sulphur in their organic matter and materialisation of this may postpone the onset of deficiency. However it must be remembered that two crops of silage remove about 30 kg/ha of sulphur and also it is estimated that between 20 and

50 kg/ha are removed by leaching. Applications of S, mainly, as gypsum increased herbage yields in 70 of the 140 grassland sites. Table 1. Responses were smallest in spring and increased as the season progressed, and by autumn were doubled by S application at some of the responsive site. Extrapolation of the results from the 140 sites suggests that 1.5 million hectares are deficient in S and an extra 1.5 million tonnes of herbage dry matter with a value of ¤100 M could be obtained annually by S fertilization on these areas. The shaded areas in Figure 3 are where most of the responses to S occurred.

Table 1. Means yields of dry matter and responses to S at 70 responsive grassland sites.

Cutting Date	yield t/ha		% Response	Significance
	S -	S+		
April	2.70	2.84	5.2	**
June	3.57	4.01	12.3	**
July	2.57	3.09	20.2	**
September	2.06	2.59	25.2	**
Total	10.9	12.53	15.0	**

Improved Quality of Herbage.

The herbage growing on the no S treatments at responsive sites showed visible signs of S deficiency i.e. the leaves were spindly and stunted and pale green or yellow in colour. S has been shown to markedly affect the chlorophyll content of many crops and the yellowing of S deficient plants is due to inadequate synthesis of this plant constituent.

Various parameters of quality within the plant were significantly improved by S application. Chlorophyll, vitamin A and protein-nitrogen were increased and the potentially harmful nitrite and nitrate nitrogen fractions were reduced. S application reduced the nitrogen to sulphur ratio (N/S), in herbage to below 15:1, which is considered desirable for the grazing animal (Table 2).

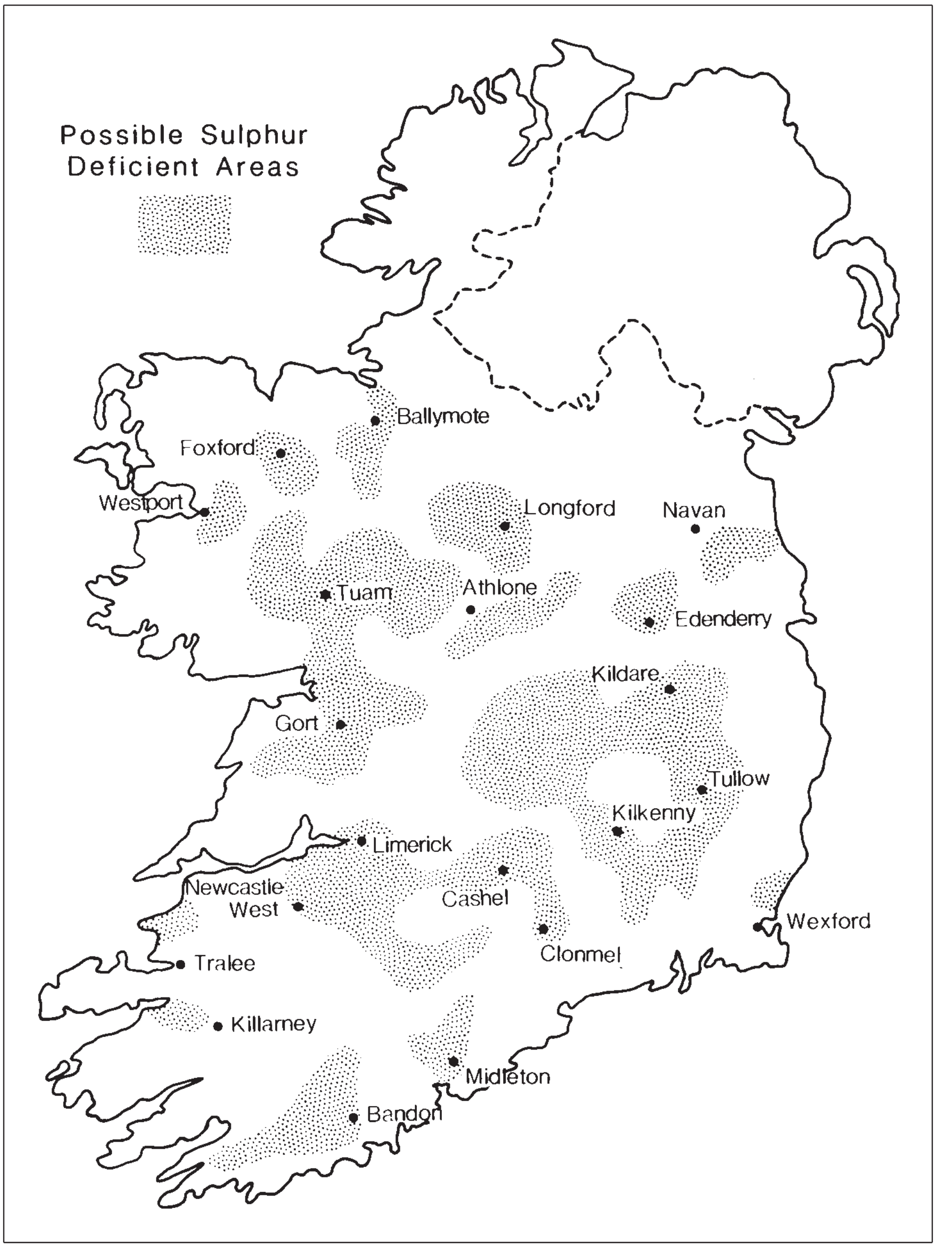
Table 2. The effect of S fertilizer on the quality of late season herbage

	N and S fractions No S	S applied 25 kg/ha S	Significance
Total N g/kg	39.1	32.0	**
Total S g/kg	2.0	2.6	**
N/S ratio	19.7	12.3	**
% of total N as protein N	55.5	73.4	**
% of total N as amino N	41.2	25.6	**
% of total N as nitrate N	2.6	2.0	**

Predicting S deficiency.

To date it has not been possible to correlate field responses to S with either

Figure 3.



Possible Sulphur Deficient Areas
Ballymote
Foxford
Westport
Longford
Navan
Tuam
Athlone
Edenderry
Kildare
Gort
Tullow
Kilkenny
Limerick
Newcastle West
Cashel
Wexford
Clonmel
Tralee
Killarney
Midleton
Bandon

soil or plant analytical measurements. This is not surprising, in view of the fluctuations that occur in soil and plant values of S during the growing season. Work at Johnstown Castle has shown that soils with more than 50% sand and less than 3% organic carbon, are generally deficient, as demonstrated by the dot-graph in Figure 4. A rapid method for measuring these factors is been developed and this together with a measurement of available soil S and information on atmospheric and fertilizer inputs and crop removals may form the basis of a model for predicting S deficiency.

Figure 4. The relationship between response of herbage to sulphur and sand/organic carbon content at 120 grassland sites

	> 50% Sand and <3% Carbon	< 50% Sand and <3% Carbon
Response	★★★★★★★★★★ ★★★★★★★★★★ ★★★★★★★★★★ ★★★★★★★★★★ ★★★★★★★★★★ ★★	★★★★★★
Non-Response	★★★★★★★★★★ ★	★★★★★★★★★★ ★★★★★★★★★★ ★★★★★★★★★★ ★★★★★★★★★★ ★★★★★★★★★★ ★

S fertilizer recommendations

For grassland the S recommendation is for 25 kg/ha for each cut of silage and 25 kg/ha during the season in a rotational grazing situation. The advent of N + S type fertilizers means that, for grazing, the S can be applied in small incremental amounts with the N fertilizer throughout the season. For cereals 20 kg/ha are recommended. The S is normally in the sulphate form in fertilizers but it has been shown that elemental S from the oil refinery at Whitegate, Co. Cork is equally efficient.

The effects of S at different rates of N fertilizer.

The effects of adding incremental amounts of N fertilizer with and without S to a grassland sward for four cuts of herbage are shown in Table 3. Significant responses to S ranged up to 207% and increased with each level of N application. In general responses to S increased as the season progressed and at the 3rd.and 4th.cuts it was responsible for more than doubling herbage yields at high rates of N application.

Table 3. The effect of S fertilizer on herbage yield at various rates of N fertilizer.

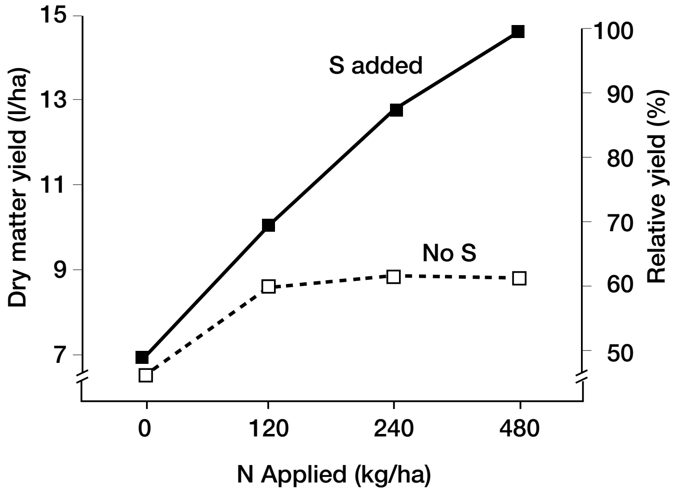
Nutrient kg/ha		Dry matter yield t/ha				
N	S	Cut 1	Cut 2	Cut 3	Cut 4	Cuts 1to 4
30	0	3.71	2.58	0.88	1.50	8.67
30	7	4.23	2.78	1.13	1.81	9.95
Significance	**	**	**			
60	0	4.19	2.68	0.79	1.36	8.67
60	14	4.46	3.43	1.68	2.28	12.15
Significance	**	**	**	**		
120	0	4.23	2.68	0.66	1.20	8.77
120	28	5.32	3.97	2.03	3.26	14.58
Significance	**	**	**	**	**	

The total annual yield of herbage and the percentage of maximum yield for each level of N and S are shown in Figure 5. When the highest rate of N (480kg/ha) was applied with no S, it was only possible to achieve 60% of the maximum yield obtained when both N and S were applied. The addition of S to the high N treatment resulted in the production of an extra 5.8 t/ha of dry matter on this S deficient soil Responses to S however were not confined to the high N treatment, and yields were significantly increased at lower N levels, particularly at the third and fourth cuts This has important commercial and environmental implications for S deficient soils it is possible by applying S fertilizer to in increase production when using high levels of N fertilizer or to maintain production levels with reduced N application.

Response to S under grazing.

Data from the 150 cutting trials carried out in the country showed the 30% of them were deficient in S and yields could be increased by up to 40% with applied S. However the findings from the cutting trials could not in principle be extrapolated to the grazing situation, where frequent defoliation of the herbage and the return of dung and urine could alter the pattern of response. Therefore between 1981 and 1985 a grazing experiment with Friesian steers was carried out at Screen, Co. Wexford to determine if the beneficial effect of S in increasing herbage yields would occur under grazing and be reflected in

Figure 5: Effect of applied N and S to dry matter yield



improved animal performance. (Murphy et al, 2002) Results showed that when S was applied to pasture the stock carrying capacity was increased, especially in late season, during the four years of the experiment.

Interaction of S with trace elements

Ireland has extensive areas of soils where animal performance is affected by copper (Cu) deficiency. This may be caused directly by a low Cu content on a small number of soils or more frequently on soils where their high molybdenum (Mo) content can induce Cu deficiency .in herbage. Suttle (1978) and others have shown that on such soils, S may be a contributing cause of Cu deficiency in cattle Because of the many chemical and physical similarities between the two elements and the fact that selenium (Se) is present in the soil on minute quantities (<10mg/kg) it is reasonable to assume that applications of S to the soil could reduce the uptake of Se by plants. Findings from the grazing experiment at Screen showed that large applications of S reduced the uptake of Selenium and Molybdenum in herbage but had no effect on uptake of copper. Table 4.The effects of S fertilization on the concentration of Cu and Se in the blood of grazing animals from the Screen experimenters are shown in Table 5

Table 4 The effect of S fertilization on the uptake of Mo and Cu in herbage under grazing. (mg/kg)

Element	Treatment	April	September
Mo	S -	1.09	2.61
	S +	0.74	1.01
	Significance	**	**
Cu	S -	6.2	8.9
	S +	5.8	7.6
Significance	NS	NS	

Table 5 Effect of S fertilizer on the Cu and GPx (Se) status in blood of grazing steers over three years.

Treatment	No.of animals	April	September
		GPx i.u./g Hb	
S –	69	54.4	90.5
S +	71	57.5	17.5
Significance		NS	**
		Blood Cu (ug/ml)	
S -	0.76	0.56	
S +	0.79	0.49	
Significance		NS	**

Table 6 The effect of urea + S and CAN + S on yield components of barley.

Fertilizer	Nutrient applied Kg/ha		Components of yield			
	N	S	Yield t/ha	Ears no/m^2	Grain no/ear	Grain wt. g/1000
Urea	150	0	5.11	696	25.4	50.3
Urea + S	150	15	5.25	898	22.8	50.9
Significance	NS	**	**	NS		
CAN	150	0	6.27	736	25.8	52.9
CAN + S	150	15	6.12	859	22.0	51.3
Significance	NS	**	**	NS		

The low value of GPx (17.5 i.u./g Hb) which occurred in the cattle grazing the S+

Treated are considered unsatisfactory and although they the steers showed no ill effects, it has been shown that low Se levels in blood can lead to infertility problems and abortion or stillbirth in calves. (Murphy and Quirke, 1997)

The possible negative effects of S fertilization on the Cu status of the animal may be partially offset by the effect of S in significantly reducing Mo concentrations in the herbage. (Suttle, 1978) However, at Screen levels of herbage Mo were low and unlikely to affect the Cu status of the animal. It seems that on this coarse textured soil, the lowering of the Cu status was brought about by the influence of S fertilization on Cu availability (Brogan et al 1973).

Considerably more research in needed before a proper understanding of the complex interactions between the major element S, and the trace elements Cu, Mo and Se and their effect on animal metabolism is reached. However if S deficiency is affecting the yield and quality of herbage S fertilizer should be applied at the recommended rates and Cu and Se supplied to animals by injection, oral supplementation or other means.

Cereals

Cereals have a lower requirement for S than forage crops and only a few yield responses of cereals to S have been recorded. However, it is noted that S fertilizer alters the growth pattern of cereals. In both wheat and barley experiments, S fertilizer significantly increased the number of ears per m^2 and reduced the number of grains/ear. It would be expected that increasing the ears per m^2 would result in higher yields but this was largely offset by a reduction in grain/ear. Table 6 Further research on the effects of S on the quality of cereals and other crops are needed

Suggestions for future work.

The following bullet points suggest the author's view on the direction that future research should take.

- Examine the interaction of S with trace elements Se, Cu and Mo in grazing heifers on a loam soil.
- Develop a rapid test based on sand content, organic carbon and available S.
- Consider S as a major element and depending on soil analysis and type of crop, fertilizer compounds such as NSK, PSK, SK or NPKS could be applied.

- Falling emissions of S in Europe means that sulphur deficiency is becoming widespread. We should keep in contact with German and other researchers.

REFERENCES

Brogan, J.C., Fleming, G.A. and Byrne, 1973. Molybdenum and copper in Irish pasture soils. Irish Journal of Agricultural Research, 12: 71-82.

Gallagher, P.A. 1969. The effect of sulphur in fertilizers, rainwater and soils on crop nutrition. Proceedings Royal Dublin Society Series B 2: 191-204.

Hanley, P.K., Murphy, M.D. and O'Donnell, T, 1974. Beneficial effects of sulphur on permanent pastures. Irish Journal of Agricultural Research, 13: 122-126.

Murphy, M.D. AND Boggan, J.M. 1988. Sulphur deficiency in herbage in Ireland 1. Causes and extent. Irish Journal of Agricultural Research 27: 83-90.

Murphy, M.D., Coulter, B.S., Noonan, D.J. and Connolly J. 2002. The effect of sulphur fertilization on grass growth and animal performance. Irish Journal of Agricultural and Food Research, 41: No. 1, 1-15.

Murphy, M.D. and Quirke, W.A. 1997. The effect of sulphur/nitrogen/selenium interactions on herbage yield and quality. Irish Journal of Agricultural and Food Research 36: 31-38.

Suttle, N.F. 1978. Effects of sulphur and molybdenum on the absorption of copper from forage crops by ruminants. Proceedings of Symposium "Sulphur in Forages" An Foras Taluntais, Johnstown Castle, Wexford. pp 197-211.