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The relationship between exchangeable soil magnesium and response by sugar beet to magnesium sulphate

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SUMMARY

Fifty-three experiments made between 1959 and 1968 tested the response to magnesium sulphate by sugar beet on fields where magnesium deficiency symptoms were expected. Soil samples, taken before applying fertilizers, were analysed for exchangeable magnesium by four methods. Sodium, potassium and calcium in the soil extracts were also measured to determine whether they influenced response to magnesium.

Results of different methods of analysing soil for magnesium were related to each other and to the percentage yield-response to magnesium fertilizer. The concentration of other soil cations did not affect response to magnesium fertilizer, but giving other cations, especially sodium, as fertilizer decreased the concentration of magnesium in the crop. Nevertheless, even on fields deficient in magnesium, the largest yield was from plots given sodium and posassium fertilizer together with a dressing of magnesium.

Sugar beet grown on soils containing less than 20 p.p.m. Mg extracted with ammonium nitrate usually gave a profitable response to magnesium fertilizer. When soil magnesium was 20–35 p.p.m., yield of sugar beet on some fields was increased slightly. Plants in some experiments had poorly developed root systems and response to magnesium was then always larger than expected from soil analysis.

INTRODUCTION

There are recent reports (Arnold, 1967; Tinker, 1967) that the acreage of crops with magnesium deficiency symptoms is increasing in Great Britain. This is probably a consequence of intensified cash cropping which is depleting the reserve of available soil magnesium. Field experiments show that symptoms can be prevented and yield increased by magnesium fertilizers, so it is important to predict where magnesium fertilizer is justified.

Sugar beet has a relatively large requirement of magnesium and is one of the first agricultural crops commonly grown in Great Britain to show deficiency symptoms. Severe symptoms indicate lost yield (Tinker, 1967) and plant analysis is also a guide to crops that respond to treatment (Draycott & Durrant, 1969*a*). However, by the time symptoms appear, or the magnesium concentration in the plant is less than the critical amount (Ulrich, 1961), it is probably too late to prevent loss.

Many reports (Reith, 1963; Salmon, 1963; Williams *et al.* 1966; McConaghy & McAllister, 1967) describe methods of analysing soils for available magnesium but few series of experiments relate such analyses to the response of the crop to magnesium. We have used the yields and soil samples from fifty-three field experiments to study this relationship. Holmes (1962), Salmon (1963) and Charlesworth (1967) showed that the concentration of other soil cations influence availability of magnesium, so we investigated how sodium, potassium and calcium in the soil affect the relationship between magnesium and response to magnesium fertilizer.

Some experiments tested different amounts of magnesium sulphate and these have been used to see whether soil analyses can help estimate the quantity of magnesium fertilizer needed to give maximum yield.

EXPERIMENTAL

Field experiments

Between 1959 and 1968 fifty-three experiments tested magnesium fertilizers on commercial fields of sugar beet. Fieldmen of the British Sugar Corporation (who did much of the field work) were asked to make the experiments on fields where they expected the crop to show magnesium deficiency symptoms. Tinker (1967) described the experiments for the period 1957–63 and Draycott & Durrant (1968, 1969*a*, *b*) for the period 1964–8.

The magnesium treatment common to all experiments, namely 5 cwt/acre kieserite (90 lb/acre Mg), gave the percentage increase in sugar yield over plots without magnesium, Magnesium increased yield economically at twenty-four of the fifty-three sites. A basal dressing of about 1·0 cwt/acre N, 0·5 cwt/acre P_2O_5, 1·0 cwt/acre K_2O and 3 cwt/acre NaCl was given to all the plots.

A soil sample (0–9 in) was taken from each site during the winter preceding the experiment, before applying the fertilizers. The samples were air-dried, passed through a 2 mm round-hole sieve and stored at about 16 °C until analysed in 1969. All had pH > 6·8.

Methods of soil analysis

Exchangeable cations were extracted from the soils by four methods: (1) 10 g soil mixed with 10 g acid-washed sand in a glass column and leached with 100 ml N ammonium acetate at pH 7·0; (2) 10 g soil shaken with 100 ml N ammonium acetate at pH 7·0 for 1 h; (3) 5 g soil shaken with 25 ml N ammonium nitrate for ½ h; (4) 12·5 g soil intermittently shaken with 25 ml 0·01 M calcium chloride for 2 h.

Concentrations of magnesium in the extracts were measured by atomic absorption spectrophotometry, after dilution with strontium chloride to give 500 p.p.m. Sr in the solution. Calcium, sodium and potassium were also measured in the extracts.

RESULTS AND DISCUSSION

Response and method of soil analysis

Fig. 1 shows the relationship between percentage increase in yield from 90 lb/acre magnesium and the amount of magnesium extracted from the soils by each of the four methods. The lines of 'best fit' were drawn through the points by eye.

Although the amounts of magnesium extracted by the four methods differed, they were significantly correlated with each other at $P < 0·001$ as shown in Table 1.

The four methods extracted different amounts of

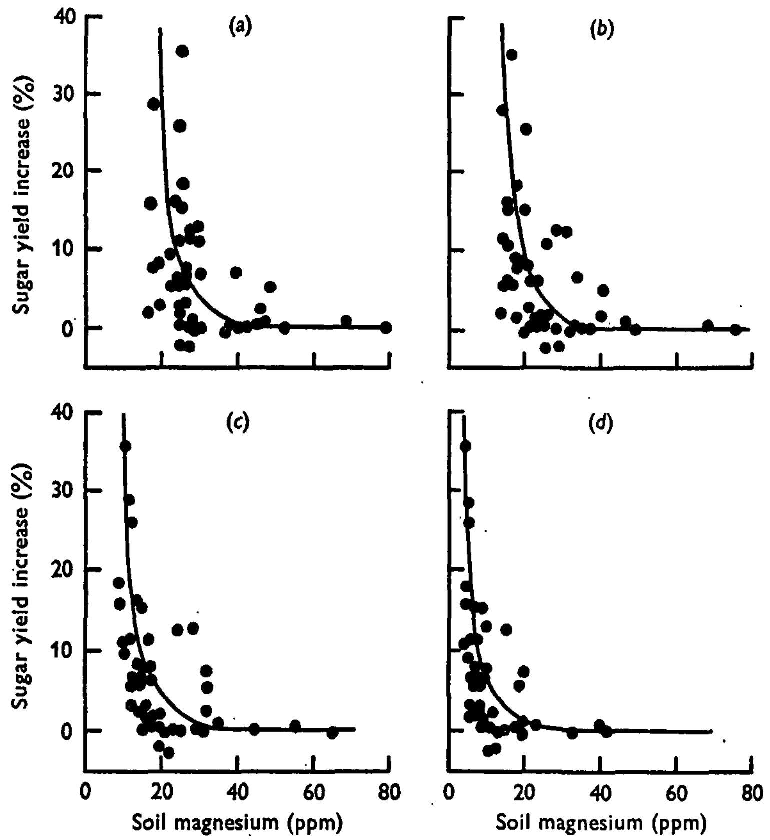

Fig. 1. Relationships between percentage increase in yield to magnesium and soil magnesium extracted by (*a*) leaching with ammonium acetate, (*b*) shaking with ammonium acetate, (*c*) shaking with ammonuim nitrate, (*d*) shaking with calcium chloride.

Table 1

Method	Correlation coefficient 1	2	3	4	Mean amount of Mg extracted (p.p.m.)
1	1·000	—	—	—	31·9
2	0·973	1·000	—	—	28·0
3	0·950	0·987	1·000	—	22·0
4	0·880	0·931	0·956	1·000	10·8

Table 2. *Between-site variance/site of responses to Mg fertilizer*

(cwt/acre)²

Total variance between sites	Experimental error variance	Remainder	Residue after fitting regression on log soil Mg Method 1	2	3	4
6·32 (47 D.F.)	4·30	2·02	0·84 (42 %)	0·30 (15 %)	0·07 (3 %)	0·13 (6 %)

magnesium because leaching removes more magnesium from the soil than an 'equilibrium' method (Hooper, 1967); also various soil:extractant ratios were used. However, the large correlation coefficients indicate that all four methods removed similar proportions of the exchangeable magnesium (Williams *et al.* 1966).

On all fields relatively rich in magnesium, yield was not increased by magnesium fertilizer. From the lines of 'best fit' in Fig. 1 this region of 'adequate supply' was > 50 p.p.m. by Methods 1 and 2, > 35 p.p.m. by Method 3 and > 20 p.p.m. by Method 4. In almost every experiment where the magnesium fertilizer increased yield by more than 5 % (an economic response), the magnesium extracted from the soils was < 30 p.p.m. by Method 1, < 25 p.p.m. by Method 2, < 20 p.p.m. by Method 3 and 10 p.p.m. by Method 4. The increase in yield from magnesium fertilizer varied greatly with soils in this category, and no method of soil analysis was able to predict it quantitatively.

At harvest, plants in some experiments had poorly developed, fangy root systems, with many fibrous roots near the soil surface. Recent evidence suggests that this condition was probably caused by one of the ectoparasitic nematodes reported on similar soils (Dunning & Cooke, 1967). Response to magnesium was probably larger on these fields than expected from the soil analysis, indicating that the root system was less efficient than healthy ones in exploiting soil magnesium.

With soil analyses showing Mg between adequate supply and deficiency, sugar beet on only a few fields responded to the magnesium dressing and usually had poor root systems. Field response to magnesium fertilizer is clearly determined not only by available soil magnesium but by factors not fully explained, one of which is the health of the root system (Harrod & Caldwell, 1967). This important aspect of response by poorly rooted sugar beet to magnesium is being investigated in new experiments.

Sugar yields in forty-eight of the experiments were included in an analysis of variance in which the mean response to magnesium was compared with the variation between responses and the partitioned variance is shown in Table 2. The mean response to magnesium fertilizer was significant at $P < 0{\cdot}001$ but the variation between responses from site to site was significant only at $P < 0{\cdot}05$. The reliability of each of the methods for forecasting responsive fields was compared by making regressions of sugar yield and logarithms of the concentrations of exchangeable magnesium, also shown in Table 2. The experimental error variance formed two-thirds of the total variation in response between sites, leaving one-third to be accounted for by soil analysis. Of this, Method 1 accounted for over half whereas the other three methods accounted for almost all of it (Table 2). However, these percentages are not accurately determined because they are much influenced by the few very responsive sites.

Effect of soil potassium, sodium and calcium

There have been several reports (Salmon, 1962; Holmes, 1962; Arnold, 1967) that large concentrations of other cations in the soil decrease availability of magnesium. Batey (1967) suggested using the ratio K/Mg as a guide to the requirement for

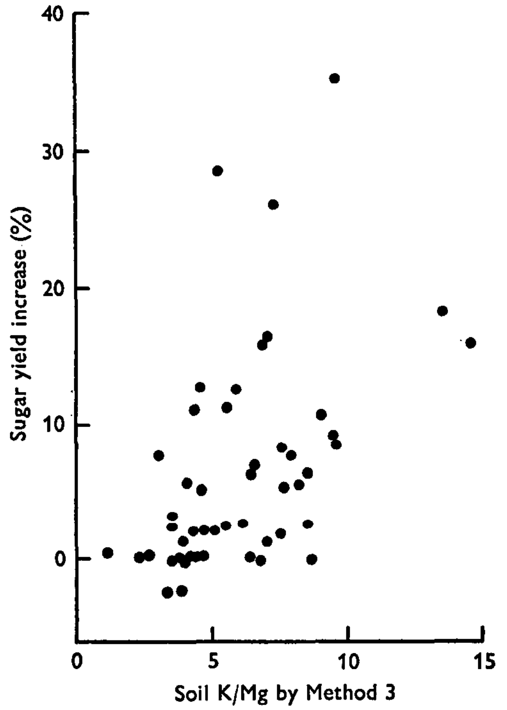

Fig. 2. Relationship between percentage increase in yield from magnesium fertilizer and soil K/Mg ratio.

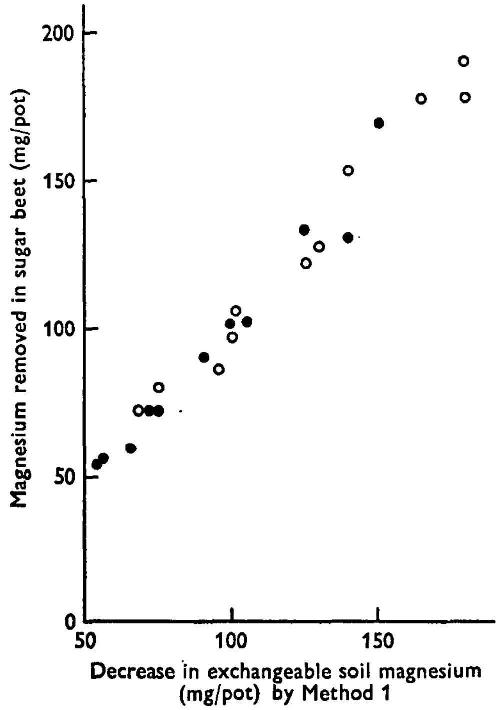

Fig. 3. Magnesium removed from soils by sugar beet in the glasshouse and decrease in exchangeable soil magnesium. Magnesium removed by two crops (●) and by five crops (○).

magnesium dressings, especially in horticultural soils which are often rich in potassium.

The K/Mg ratio in these soils was poorly related ($r = 0{\cdot}614$) to percentage yield response to magnesium (Fig. 2). Sodium values were relatively small and no relationship was found between Na/Mg and response to magnesium. Calcium was always the dominant cation in these soils with pH > 6·8, and Harrod & Caldwell (1967) suggested that calcium: magnesium antagonism is usually unimportant in practice, otherwise there would be widespread magnesium deficiency on many chalk soils.

When the logarithm of the exchangeable soil potassium, sodium and calcium were included separately and together in a partial regression analysis between response to magnesium and the logarithm of exchangeable soil magnesium (all by Method 3), the percentage of the variation from site to site accounted for by soil magnesium analysis methods was not increased. This also indicates that other soil cations had little influence on the relationship between exchangeable magnesium and response to magnesium fertilizer.

Relationship between plant and soil magnesium

(*a*) *In the glasshouse*

Five crops of sugar beet were grown in the glasshouse in pots containing 4·5 kg of soil taken from the eleven experimental sites in 1967. Four plants in each pot were harvested when they each had six pairs of true leaves. Enough nitrogen, phosphate, potash and borax were given before each crop to give vigorous growth. Yield and magnesium concentrations in the dry matter were determined after each harvest and exchangeable soil magnesium before and after each crop, using ammonium acetate leaching.

Differences between initial and final exchangeable soil magnesium were linearly related to the magnesium removed in the plants, as found by Salmon & Arnold (1963) and Bolton (1967). Fig. 3 shows the relationships between the difference between exchangeable magnesium before and after the first two crops and before and after all five crops. The gradients of the two lines did not differ significantly from each other or from 1·00, showing that magnesium was not released from non-exchangeable forms and that exchangeable soil magnesium determined in this way was a measure of the amount available to plants.

(*b*) *In the field*

Eighteen of the experiments were sampled during late summer, when deficiency symptoms are usually most severe. Plants were taken from plots with and without a dressing of agricultural salt. Fig. 4 shows that the magnesium in the dry matter of the sugar beet leaves, petioles and roots was related to the magnesium in the soil extracts.

Leaf magnesium was influenced most by soil magnesium and the results show both a similar deficient region (< 20 p.p.m. Mg in soil) to that shown in Fig. 1 and a region of adequate supply (> 35 p.p.m. Mg in soil). Thus the values of magnesium in the soil extracts seem a measure of the soil magnesium available to the crop (Bolton & Penny, 1968).

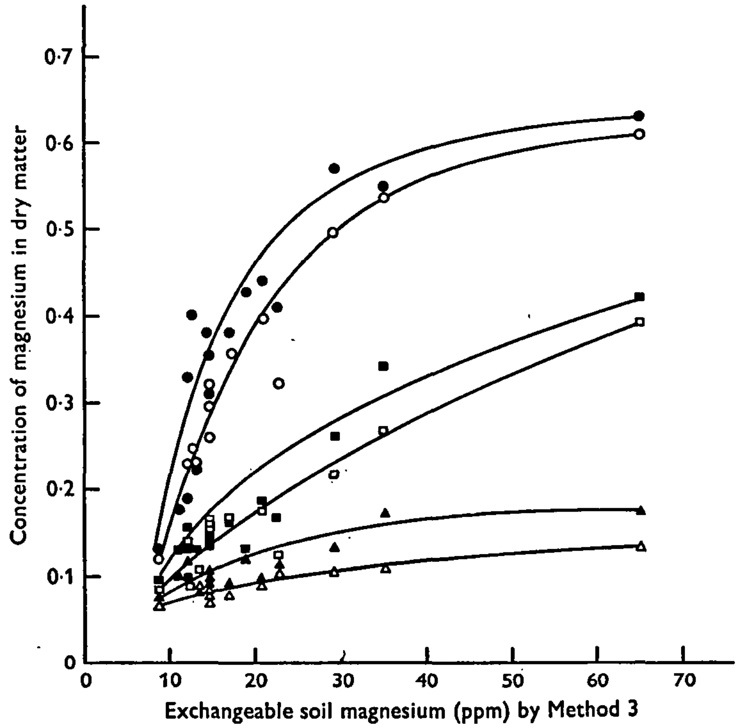

Fig. 4. Concentration of magnesium in sugar beet and exchangeable soil magnesium. Plots without sodium fertilizer: ●, leaves; ■, petioles; ▲, roots. Plots with sodium fertilizer: ○, leaves; □, petioles; △, roots.

Table 3. *Effects of sodium, potassium and magnesium on sugar yield on fields with < 20 p.p.m. exchangeable magnesium* (*Method* 3)

	Mean of eleven fields: Without agricultural salt	Mean of eleven fields: With 5 cwt/acre agricultural salt	Mean of ten fields: Without potash	Mean of ten fields: With 1·7 cwt/acre muriate of potash
	Sugar (cwt/acre)			
Without kieserite	48·3	50·9	49·2	52·4
With 5 cwt/acre kieserite	51·3	55·2	53·0	56·2
S.E.	±0·89		±0·94	

Table 4. *Effect of kieserite on percentage of plants with magnesium deficiency symptoms and on yield of sugar for soils in three groups based on exchangeable magnesium* (*Method* 3)

	Percentage of plants with deficiency symptoms			Sugar yield (cwt/acre)		
Soil group...	1	2	3	1	2	3
Exchangeable magnesium (p.p.m.) Mean	12·3	19·8	48·4	12·3	19·8	48·4
Exchangeable magnesium (p.p.m.) Range	8·5–14·6	14·6–24·0	29·0–100·0	8·5–14·6	14·6–24·0	29·0–100·0
Without kieserite	28·0	7·0	0	47·0	55·1	57·2
With 2·5 cwt/acre kieserite	13·3	1·0	0	+4·1	+1·1	+0·5
With 5 cwt/acre kieserite	5·0	0·5	0	+5·3	+1·5	−0·2
Number of fields	8	8	7	8	8	7

Effect of sodium and potassium fertilizers on yield

Fig. 4 also shows that agricultural salt consistently decreased the magnesium concentration in all the plant parts (Jacob, 1958; Hale, Watson & Hull, 1946), which probably accounts for observations that sodium fertilizers increase the severity of magnesium deficiency symptoms. Potassium fertilizers also decrease the concentration of magnesium in sugar beet (Hale, Watson & Hull, 1946). The question therefore arises whether sodium or potassium fertilizers should be withheld from soils poor in magnesium, or whether extra magnesium fertilizer is necessary when sodium and/or potassium fertilizers are used. Table 3, which gives yields of sugar obtained with and without sodium and potassium fertilizer on soils within which Method 3 gave < 20 p.p.m. magnesium, shows that for maximum yield sodium and potassium fertilizers must be used together with magnesium. There was no significant interaction either between magnesium and sodium or between magnesium and potassium.

Amounts of magnesium fertilizer to correct deficiency

The results given show that shortage of magnesium limits yield and that soil analysis can detect responsive fields. The question that next arises is the amount of magnesium fertilizer needed to correct deficiencies and this was answered by twenty-three experiments comparing 0, 45 and 90 lb/acre Mg as magnesium sulphate.

Table 4 shows the effect of the magnesium on the percentage of plants with deficiency symptoms. The fields were divided into three equal groups of soil analysis (Method 3). Few plants had symptoms where soils in Group 2 were given 45 lb/acre Mg, whereas in Group 1 even 90 lb/acre Mg did not completely eliminate symptoms. Table 4 also shows effects of the magnesium dressings on yield; 90 lb/acre Mg gave a larger response than 45 lb/acre in Group 1, but not in Group 2 where the response was small. Assuming a 9 in layer of soil to weigh 3×10^6 lb/acre, 90 lb/acre Mg is equivalent to 30 p.p.m. and should suffice to increase all soils to at least 40 p.p.m. (Method 1) in the surface 9 in. This would be enough for all crops with a healthy root system.

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