Durrant, M. J. and Draycott, A. P. 1971. Uptake of magnesium and other fertilizer elements by sugar beet grown on sandy soils. *The Journal of Agricultural Science.* 77 (1), pp. 61-68.

J. agric. Sci., Camb. (1971), **77**, 61–68
With 2 text-figures
Printed in Great Britain

Uptake of magnesium and other fertilizer elements by sugar beet grown on sandy soils

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(*Received* 8 *March* 1971)

SUMMARY

Ten experiments (1967–9) on sandy soil in East Anglia measured the effect of magnesium fertilizer on yield and cations in sugar beet. Magnesium fertilizer increased sugar yield by up to 0·80 t/ha and on the three most responsive fields it consistently increased top and root dry-matter yields throughout the growing period.

On average, without magnesium fertilizer, the concentration of magnesium in tops progressively decreased from 0·33 % at singling to 0·15 % at harvest, and in roots from 0·39 % to 0·09 %. The corresponding decreases with magnesium fertilizer were (tops) from 0·68 % to 0·20 % and (roots) from 0·48 % to 0·10 %. Yield was increased by magnesium fertilizers when tops contained less than 0·35 % Mg during May, 0·30 % during June, 0·22 % during July and 0·17 % during August. Deficiency symptoms were not visible until the concentration in tops averaged less than 0·2 % – the percentage of plants with symptoms increased rapidly at smaller concentrations. Magnesium fertilizer decreased the concentration of calcium in tops and roots but did not affect the concentration of potassium or sodium.

The maximum amount of magnesium, potassium, sodium and calcium in tops (August–September) was 11, 218, 75 and 62 kg/ha respectively; these decreased to 8, 168, 55 and 50 kg/ha at harvesting, showing that only about 75 % of the largest amount in tops was present at harvest. The amounts removed in roots at harvest were 9 kg/ha Mg, 75 kg/ha K, 11 kg/ha Na and 26 kg/ha Ca. A dressing of 100 kg/ha magnesium increased the amount of magnesium in the crop at harvest by only 4·5 kg/ha.

INTRODUCTION

To yield well, sugar-beet crops on some soils in Great Britain need to be supplied with magnesium (Harrod & Caldwell, 1967; Tinker, 1967; Bolton & Penny, 1968; Draycott & Durant, 1969, 1970*a*). Most fields where crops have shown many plants with deficiency symptoms are now given fertilizers containing magnesium. On such fields magnesium fertilizer gives a profitable return in increased yield. Past experiments have cast doubt on the value of giving magnesium where crops have only a few deficient plants (Tinker, 1967; Draycott & Durrant, 1969). These are the majority, because on average of the last ten years the acreage with 61–100 % plants affected was only 610 ha, 2750 ha had 21–60 % plants affected and over 16000 ha had 1–20 % plants with deficiency.

To measure the uptake of magnesium we chose ten fields by soil analysis (15–46 ppm exchangeable magnesium) as likely to give a range of response to magnesium fertilizer. At monthly intervals from seedling stage to harvest the plants and soil were analysed to discover when and under what conditions a shortage of magnesium affects yield. The concentration of other cations in the plant was also measured to see whether they were affected by magnesium and to compare the maximum amounts in the crop (usually in August or September) with the amount at harvest.

EXPERIMENTAL

Ten experiments, between 1967 and 1969, on sandy soil in East Anglia tested none and 100 kg/ha magnesium (as magnesium sulphate). Details of each field are given in Table 1. All plots received 125 kg/ha nitrogen (as 'Nitro-chalk'), 28 kg/ha phosphorus (as triple superphosphate), 100 kg/ha potassium (as muriate of potash) and 145 kg/ha sodium (as agricultural salt). General procedure was as described by Adams (1961). Plot size was 0·010 ha (12 rows). There were three replicates. Half of each plot was left for harvesting in the autumn (harvest area 0·0029 ha) and the other

Table 1. *Details of ten experiments on sandy soil* 1967–1969

Site	Soil series	Sowing date	Harvesting date	Soil analysis (ppm) Mg	K	Na	Ca	Plants with magnesium deficiency in August (%)	Response to $MgSO_4$: sugar (t/ha)
			1967						
Bury St Edmunds	Freckenham	28 March	31 October	24	70	12	1800	2	−0·04
Broom's Barn	Ashley variant	14 March	7 November	35	116	20	3000	1	−0·12
			1968						
Bury St Edmunds	Freckenham	4 April	11 November	22	175	11	1850	2	+0·16
Cantley	Freckenham	28 March	9 December	15	125	17	1350	5	+0·50
Ipswich	Soham	27 March	2 October	27	95	13	2850	80	+0·80*
King's Lynn	Worlington	21 March	1 October	35	175	18	3800	0	−0·03
			1969						
Bury St Edmunds	Worlington	24 April	14 October	29	63	13	4750	1	+0·21
Cantley	Freckenham	18 April	19 December	13	86	29	1450	25	+0·68*
King's Lynn	Beccles	1 May	9 October	46	78	50	3250	0	−0·20
Wissington	Isleham	1 April	22 October	25	86	41	3500	5	+0·23
Mean		4 April	31 October	27	107	22	2760	12	+0·23

* Significant at $P = 0{\cdot}05$.

part of the plot was used to provide plant and soil samples (0–25 cm) at approximately 4-week intervals, from singling to harvest. Each month the plants in 7·3 m of row (about 4 m²) were taken from each plot giving a total harvest area of 12 m² (about 90 plants) per treatment per sampling per experiment).

The percentage of plants with magnesium deficiency was recorded and dry matter of tops (leaf, petiole and crown) and roots measured. A subsample was ashed at 450 °C and the cations extracted with dilute hydrochloric acid. This solution was analysed for potassium by flame emission and for sodium, calcium and magnesium by atomic absorption. The soil samples were air-dried and ground to less than 2 mm. Exchangeable soil cations were extracted by shaking 2 g soil with 40 ml normal ammonium nitrate solution and determined as above.

RESULTS

Response to magnesium fertilizer at harvest

Magnesium fertilizer increased yield by up to 0·80 t/ha sugar (Table 1), but only on two fields were the responses statistically significant at $P = 0{\cdot}05$. Four responses were small but positive (between 0·21 and 0·50 t/ha sugar) and on four fields magnesium fertilizer did not increase yield. These results resemble those reported by Tinker (1967) and by Draycott & Durrant (1969, 1970*a*). The use of magnesium fertilizer is clearly justified on two fields and not required on four. However, the decision is more difficult on the other four, which are typical of the majority of crops with 1–20 % plants showing magnesium-deficiency symptoms (Draycott & Durrant, 1970*b*). On these, treatment may give small responses but these could be profitable because only about 0·25 t/ha sugar is needed to repay the cost of the fertilizer.

In nine of the experiments the available magnesium in soil taken before the experiment was related to response to magnesium fertilizer, but one crop (Ipswich, 1968) gave a large response even though soil magnesium was 27 ppm. Probably the soil contained enough magnesium for a crop with a good root system but most of the plants had fangy roots which failed to exploit the soil thoroughly. Crops with magnesium-deficiency symptoms commonly have restricted root systems (Harrod & Caldwell, 1967).

Magnesium concentration and uptake

Table 2 gives the relationship between time of sampling and magnesium concentration in tops and roots of plants grown with and without magnesium fertilizer. The concentration of magnesium in the dry matter of tops decreased throughout the growing period, slowly during May and June, rapidly during July and August and slowly later. The concentration in roots decreased rapidly at first but little during the latter part of the season. Without magnesium fertilizer the concentration of magnesium decreased by 0·17 % in tops and 0·30 % in roots; the corresponding decreases with magnesium fertilizer were 0·48 % (tops) and 0·38 % (roots). Initially, magnesium fertilizer doubled the concentration of magnesium in tops and caused a large increase in the roots but the effect progressively decreased as the crops grew. Its effects were smallest at harvest.

Table 3 shows the magnesium uptake by the crop. Without magnesium fertilizers, tops contained a maximum of about 11 kg/ha magnesium and 14·5 kg/ha with magnesium fertilizer; at harvest the amounts were 8 and 10 kg/ha respectively. Giving 100 kg/ha magnesium increased the total uptake at harvest by only 4·5 kg/ha and amount in the roots from 9 to 11 kg/ha – thus much of the applied magnesium is not used by the crop but remains in the soil or is lost in the drainage water. One hundred kg/ha magnesium seems excessive, but was necessary to give maximum yield where soil magnesium was less than 20 ppm (Draycott & Durrant, 1970*a*).

Table 2. *The effect of magnesium fertilizer on magnesium concentration in dry matter* (%)*: mean of ten experiments*, 1967–1969

	Magnesium concentration in dry matter (%)					
	Tops			Roots		
Month of sampling	Without Mg	Response to Mg	S.E.	Without Mg	Response to Mg	S.E.
May	0·33	+0·35	±0·072	0·39	+0·09	±0·040
June	0·30	+0·29	±0·080	0·16	+0·05	±0·025
July	0·24	+0·14	±0·052	0·11	+0·02	±0·012
August	0·19	+0·07	±0·027	0·10	+0·02	±0·006
September	0·19	+0·05	±0·024	0·10	+0·01	±0·004
October	0·15	+0·05	±0·016	0·09	+0·01	±0·005

Table 3. *The effect of magnesium fertilizer on magnesium uptake (kg/ha): mean of ten experiments*, 1967–1969

	Magnesium uptake (kg/ha)					
	Tops			Roots		
Month of sampling	Without Mg	Response to Mg	S.E.	Without Mg	Response to Mg	S.E.
May	0·06	+0·08	±0·02	0·008	+0·001	±0·002
June	1·69	+1·70	±0·94	0·13	+0·04	±0·051
July	8·31	+6·37	±2·56	2·32	+0·64	±0·572
August	10·61	+3·90	±1·84	5·18	+1·23	±0·605
September	11·17	+3·63	±1·77	8·27	+1·95	±1·099
October	7·82	+2·42	±1·19	9·01	+2·11	±0·897

Fig. 1 gives the mean effect of magnesium fertilizer on yield, magnesium concentration and uptake in tops and roots for the three crops where magnesium affected yield most (Cantley and Ipswich, 1968, and Cantley 1969). Magnesium consistently increased top and root yields throughout the whole growing period and delayed leaf senescence (Fig. 1*a*, *b*). Hence corrective treatment in August, after symptoms show, would not give the maximum yield increase. This may explain the small responses reported by Tinker (1967) from spraying deficient beet with Epsom salts. Magnesium fertilizer increased the magnesium concentration in tops from 0·31 % to 0·75 % and from 0·37 % to 0·45 % in roots, at singling (Fig. 1*c*). Although these differences later became smaller, the tops from plots with magnesium fertilizer contained 0·10 % more magnesium in August and these plants showed no deficiency. Fig. 1 (*d*) shows that magnesium fertilizer doubled magnesium uptake in tops from June to Sdptember. Maximum uptake in tops (July–September) was 17 kg/ha, with magnesium fertilizer and 8·5 kg/ha without magnesium fertilizer; maximum uptake in roots (at harvest) was 11 and 9 kg/ha respectively.

Fig. 2 shows the relationship between yield response at harvest to magnesium fertilizer and magnesium concentration in tops and roots in May, June, July and August. An increase of at least 0·25 t/ha sugar is needed to pay for the magnesium fertilizer, so the application was not justified unless the magnesium concentration (%) was less than the following:

	May	June	July	Aug.
Tops	0·35	0·30	0·22	0·17
Roots	—	0·15	0·11	0·09

It is unlikely that deficiency detected in this way could be effectively corrected for the current crop, but such concentrations are useful for diagnosis of nutritional problems.

Only one crop, Ipswich 1968, had a substantial proportion (80 %) of deficient plants in August on plots without magnesium fertilizer. Table 4 shows the relationship between month of sampling, percentage of plants with deficiency and magnesium concentration of plants with and without magnesium fertilizer. Although magnesium fertilizer increased the dry-matter yield throughout the growing period, deficiency symptoms were not visible until the magnesium concentration in tops averaged less than 0·20 %. When the concentration decreased further, the number of plants with symptoms increased rapidly. With 0·11 % magnesium in tops, 95 % of the plants showed symptoms.

Table 5 shows the quantity of exchangeable magnesium in the plough layer. Most of the 100 kg/ha magnesium applied as fertilizer was in the exchangeable fraction. The difference between soil magnesium at singling and at harvest was as follows:

	Mg (kg/ha)
Without magnesium fertilizer	17
With magnesium fertilizer	27

At harvest, the total amount of magnesium in the crop was 17 kg/ha magnesium (without magnesium fertilizer) and 21 kg/ha magnesium (with magnesium fertilizer). This suggests a small proportion of the applied magnesium was below 25 cm by harvest. Salmon & Arnold (1963), Bolton (1967) and Draycott & Durrant (1970*a*) reported a linear relationship between magnesium uptake and exchangeable magnesium removed from the soil by plants grown in glasshouses but in our experiments the differences in exchangeable soil magnesium were too small to substantiate this relationship.

Potassium, sodium and calcium

On average, magnesium fertilizer did not affect the concentration of potassium or sodium in dry

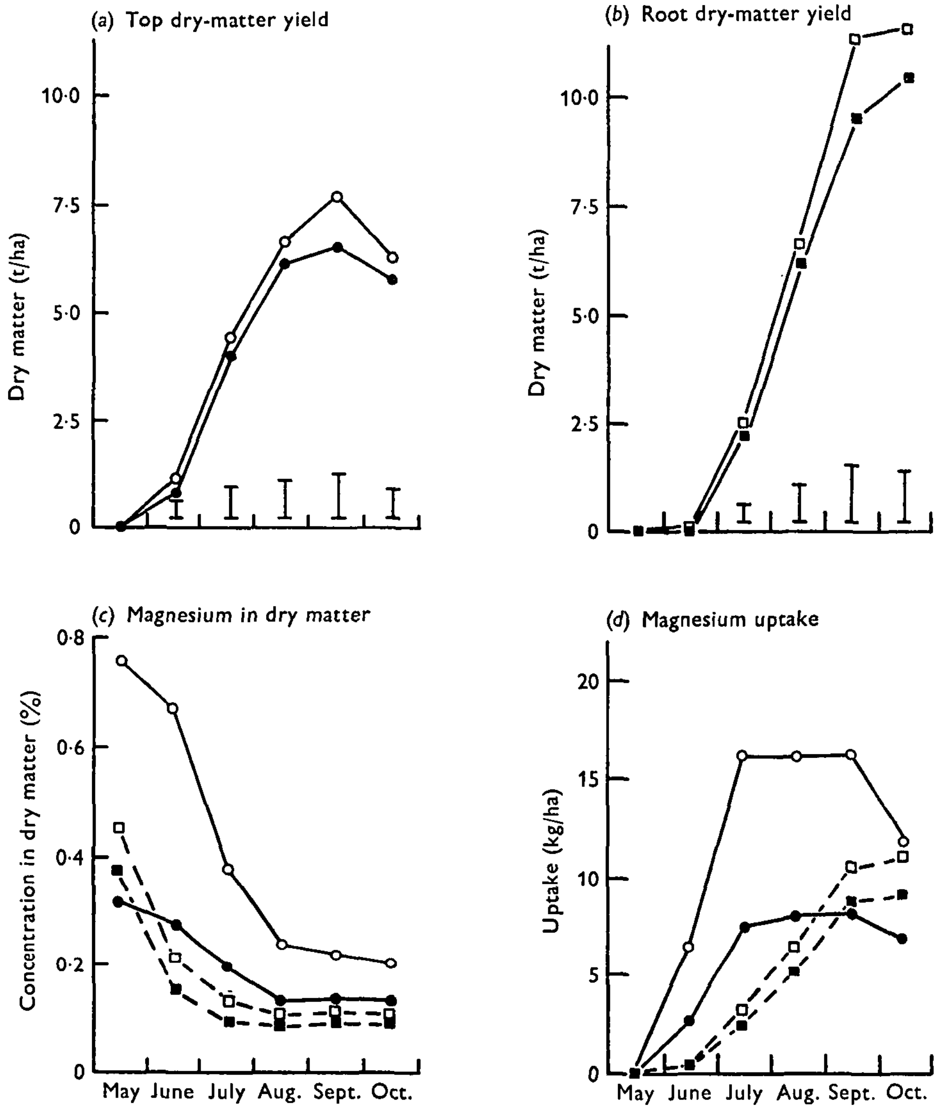

Fig. 1. The effect of magnesium fertilizer on yield, magnesium concentration and magnesium uptake by sugar beet, Cantley and Ipswich 1968, Cantley 1969. ●, Tops, ■, roots, without Mg fertilizer. ○, Tops, □, roots, with Mg fertilizer.

Table 4. *Magnesium concentration in sugar-beet tops and the percentage of plants with magnesium-deficiency symptoms, Ipswich* 1968

	Without magnesium fertilizer		With 90 lb/acre Mg	
Month of sampling	Mg concentration (%)	Plants with symptoms (%)	Mg concentration (%)	Plants with symptoms (%)
May	0·30	0	0·78	0
June	0·25	0	0·73	0
July	0·16	25	0·38	0
August	0·12	80	0·20	0
September	0·11	95	0·20	2

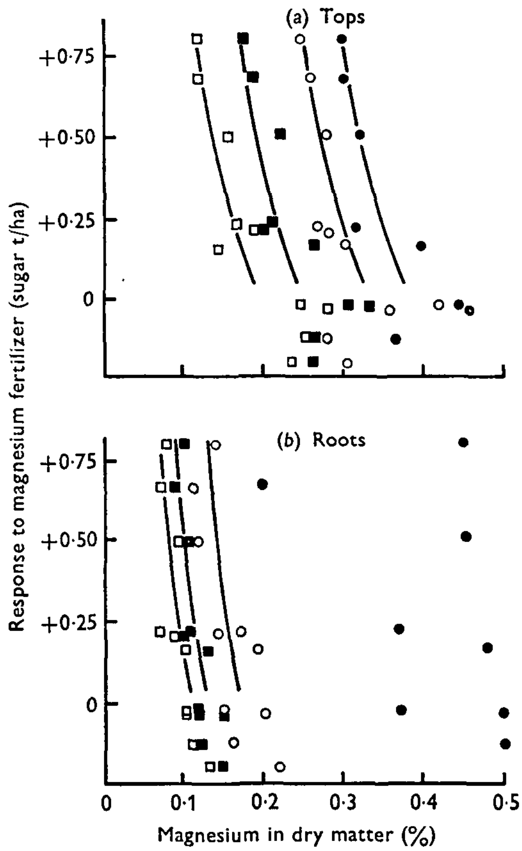

Fig. 2. The relationship between yield response to magnesium fertilizer and magnesium concentration in dried sugar-beet tops and roots. ●, May; ○, June; ■, July; □, August.

Table 5. *The relationship between month of sampling and the amount of exchangeable magnesium in the plough layer (0–25 cm): mean of ten experiments,* 1967–1969

	Exchangeable Mg	
Month of sampling	Without magnesium fertilizer (kg/ha)	With magnesium fertilizer (kg/ha)
May	91	188
June	94	185
July	77	175
August	73	148
September	74	155
October	74	161

matter, but as shown in Table 6, it consistently lessened the concentration of calcium throughout the growing period by about one-twelfth (tops) and one-fifth (roots). The total uptake (tops + roots) of potassium, sodium and calcium increased until top yield was greatest (August or September), when on average the crop contained 285 kg/ha K, 84 kg/ha Na and 83 kg/ha Ca. During autumn, the loss of nutrients (a consequence of leaves dying) exceeded nutrient uptake by the roots.

Table 7 illustrates the differences between the maximum amount of cations in the crop and the amount at harvest. On average for tops, approximately 75% of the maximum was in the crop at harvest. Increases in the amount in the roots offset decreases in the tops, so about 85% of the maximum total amount was present at harvest. Table 8 compares nutrients applied in the fertilizers and crop uptake. Without magnesium fertilizer 9 kg/ha Mg was removed in the roots at harvest, but with 100 kg/ha magnesium applied about 90 kg/ha remained after harvest to add to the soil reserves. On balance, of the 100 kg/ha K applied, 28 kg/ha was not removed in the roots, but as the crop contained 285 kg/ha in August, 185 kg/ha must have come from the soil. Sodium applied was always

Table 6. *The effect of magnesium fertilizer on the concentration of calcium in sugar beet tops and roots: mean of ten experiments*, 1967–69

	Calcium concentration in dry matter (%)			
	Tops		Roots	
Month of sampling	Without Mg	Response to Mg	Without Mg	Response to Mg
May	2·56	−0·24	1·13	−0·24
June	2·29	−0·23	0·35	−0·05
July	1·26	−0·14	0·25	−0·03
August	1·16	−0·14	0·29	−0·07
September	1·15	−0·19	0·30	−0·08
October	1·01	−0·12	0·40	−0·15

Table 7. *The relationship between maximum nutrient uptake and uptake at harvest: plots received basal NPKNa but no Mg fertilizer* (*mean of ten experiments*, 1967–1969)

	Amounts of elements in crop							
	Tops only				Tops and roots			
	Mg	K	Na	Ca	Mg	K	Na	Ca
Maximum uptake (kg/ha)	11	218	75	62	19	285	84	83
Uptake at harvest (kg/ha)	8	168	55	50	17	241	66	76
Proportion of maximum uptake measured at harvest (%)	70	77	73	82	88	84	79	92

Table 8. *The relationship between nutrients applied in fertilizers and crop uptake: all plots received basal NPKNa* (*mean of ten experiments*, 1967–1969)

	Mg_0	Mg_+	K	Na	Ca
Nutrients applied (kg/ha)	0	100	100	145	0
Nutrients applied − maximum total nutrient uptake	−19	+76	−185	+62	−83
Nutrients applied − total nutrient uptake at harvest	−17	+80	−140	+80	−76
Nutrients applied − nutrients removed in roots at harvest	−9	+90	+28	+135	−26

more than sufficient for crop requirement. Although 135 kg/ha was added to the soil at harvest, much of this is lost within 2 years (Draycott, Marsh & Tinker, 1970), so will not be available for the next sugar-beet crop.

We thank the field staff of the British Sugar Corporation, especially L. Fuller (Cantley), T. Haines and R. Isaacson (King's Lynn), for helping with the experiments and Mrs E. M. Wright for technical assistance.

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