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The effects of magnesium fertilizers on yield and chemical composition of sugar beet

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SUMMARY

Nineteen experiments were made between 1964 and 1967 on fields where previous sugar beet crops showed symptoms of magnesium deficiency. None, 2.5 or 5 cwt/acre kieserite or 20 cwt/acre dolomitic limestone were tested in a factorial design with none or 3 cwt/acre agricultural salt (crude sodium chloride), and 0.8 or 1.2 cwt/acre nitrogen as 'Nitro-Chalk'. Additional plots tested kainit (7 cwt/acre) and a large dressing of potash (2 cwt/acre) as muriate of potash.

Kieserite and dolomitic limestone increased sugar yield and the most effective dressing was 5 cwt/acre kieserite, which gave 3.1 cwt/acre more sugar than the crop without magnesium fertilizer. Agricultural salt and the larger dressing of nitrogen were profitable, and neither interacted with magnesium on average; the large dressing of potash also increased yield. The magnesium in the kainit increased yield slightly, but the dressing tested supplied too little to satisfy the crop's requirement of magnesium.

Each year in late summer the percentage of plants showing magnesium-deficiency symptoms was recorded, and a sample of twenty-four plants harvested from each of the magnesium treatments and analysed. All the magnesium fertilizers increased the concentration of magnesium in leaves, petioles and roots, and also decreased the number of plants showing deficiency symptoms.

The magnesium concentrations in plants grown without magnesium differed widely and were related both to the yield response to magnesium fertilizer and to the percentage of plants with deficiency symptoms. Both relationships showed a similar 'transition zone' from deficiency to adequate supply, for leaves this was 0.2–0.4 % Mg, for petioles 0.1–0.2 Mg and for roots 0.075–0.125 % Mg in the dry matter.

INTRODUCTION

Tinker (1967) showed that sugar beet grown on some soils responded economically to magnesium sulphate, but as he tested only one amount, could not decide the optimum dressing. Experiments started in 1964 by P. B. H. Tinker and completed by us investigated the optimum dressing of magnesium sulphate as kieserite, and tested dolomitic limestone and kainit as alternatives. The experiments were also designed to test whether magnesium fertilizer interacts with nitrogen or sodium fertilizers.

Hale, Watson & Hull (1946) showed that magnesium-deficiency symptoms were associated with a small magnesium concentration in the foliage, and Tinker (1967) found the number of sugar beet plants with magnesium-deficiency symptoms was related to the yield-response to magnesium. Thus, it seems that there is a limiting concentration of magnesium in sugar beet; with less than this, plants have deficiency symptoms

and respond to magnesium fertilizer. In California, Ulrich (1961) defined the 'critical concentrations' of some elements in sugar beet tissue; with less the crop will respond to that element. Ulrich did not give a critical concentration of magnesium and we used our experiments to see whether there is a critical concentration of magnesium for sugar beet in England.

EXPERIMENTAL

Nineteen field experiments between 1964 and 1967 tested the following fertilizer dressings (per acre), in complete factorial combination:

No magnesium	Mg ₀
2.5 cwt kieserite (45 lb Mg)	Mg ₁
5.0 cwt kieserite (90 lb Mg)	Mg ₂
1.0 ton dolomitic limestone (245 lb Mg)	Mg ₃
0.8 cwt N as 'Nitro-chalk'	N ₁
1.2 cwt N as 'Nitro-chalk'	N ₂
No agricultural salt	Na ₀
3 cwt agricultural salt	Na ₁
(crude sodium chloride)	

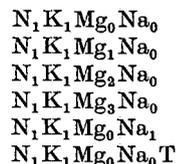
All the plots also received 0.5 cwt/acre P_2O_5 as triple superphosphate and 1.0 cwt/acre $K_2O(K_1)$ as muriate of potash.

In addition to the main factorial design, two plots ($N_1K_1Mg_0Na_0T$ and $N_2K_1Mg_0Na_0T$) received 7.0 cwt/acre kainit (T) and four plots ($N_2K_2Mg_0Na_0$, $N_2K_2Mg_0Na_1$, $N_2K_2Mg_2Na_0$ and $N_2K_2Mg_2Na_1$) had an extra 1.0 cwt/acre $K_2O(K_2)$ as muriate of potash. There were two replicates of all the treatments, which were in randomized blocks. The kainit dressing supplied 32 lb/acre Mg.

Sites were chosen on commercial farms in areas where previous sugar beet crops showed symptoms of magnesium deficiency. Where several sites were offered, the one with the least exchangeable soil magnesium was chosen. Table 1 shows the soil analysis of plough-layer samples (0–9 in) from each site. Members of the Soil Survey of England and Wales established the soil series (Table 1) at each site. All the soils were sandy, had fairly small exchange capacities and all but three had a pH > 7.0. The Newport, Freckenham and Bridgenorth Series were commonly used (Tinker, 1967). The general procedure for harvesting the plots was similar to that described by Adams (1961), and the beet and soil analyses to those described by Tinker (1965, 1967).

During late summer, the percentage of plants in the harvest area (1/140 acre) with magnesium-deficiency symptoms was recorded. At about the same time twenty-four plants were taken at

random from the following six treatments (chosen as representing the magnesium fertilizers tested):



Leaves, petioles and roots were dried and analysed for potassium (by flame emission) and for sodium, calcium and magnesium (by atomic absorption).

RESULTS AND DISCUSSION

Yields

Table 2 shows the mean effects of dressings of magnesium, additional nitrogen and sodium, on yield and quality of sugar beet. Kieserite at $2\frac{1}{2}$ cwt/acre (Mg_1) increased root yield by 0.43 ton/acre, and an additional $2\frac{1}{2}$ cwt/acre kieserite (Mg_2) by a further 0.35 ton/acre. Dolomitic limestone (Mg_3) gave about the same increase as $2\frac{1}{2}$ cwt/acre kieserite. Kieserite slightly increased the yield of tops, probably by decreasing leaf necrosis. None of the magnesium treatments significantly affected sugar content or the purity of the juice. Kieserite increased the plant population significantly, but this effect is not understood.

The additional 0.4 cwt/acre nitrogen ($N_2 - N_1$) increased the yield of tops and roots; it decreased

Table 1. Soil analysis and soil series for magnesium fertilizer trials in 1964–67

Site	Year	Exchangeable cations (m-equiv/100 g)				pH	Soil series	Plant sampling date
		K	Na	Ca	Mg			
King's Lynn	1964	0.320	0.095	—	0.197	7.3	Newmarket/Methwold	21 August
Allscott	1964	0.268	0.054	—	0.156	7.0	Newport	2 September
Newark	1964						Unnamed	—
King's Lynn	1965	0.230	0.054	8.8	0.140	7.8	Freckenham/Moulton	20 August
Allscott	1965	0.527	0.055	8.2	0.140	6.5	Newport	9 September
Kidderminster	1965	0.409	0.052	10.9	0.400	7.6	Newport	9 September
Wissington	1965	0.357	0.053	18.5	0.230	8.0	Methwold/Newmarket	14 September
King's Lynn	1966	0.360	0.100	15.5	0.185	7.9	Freckenham	5 August
Allscott	1966	0.295	0.075	5.0	0.335	6.8	Bridgenorth	4 August
Kidderminster	1966	0.290	0.185	22.4	0.375	8.1	Newport	3 August
Ipswich	1966	0.340	0.065	7.5	0.200	7.4	Moulton	2 August
Bury St Edmunds	1966	0.380	0.105	11.2	0.315	7.6	Unknown	1 August
Newark	1966	0.325	0.120	3.55	0.200	6.2	Naburn	29 July
Allscott	1967	0.330	0.080	10.71	0.100	7.2	Newport	21 July
Kidderminster	1967	0.380	0.070	11.26	0.200	7.8	Bridgenorth	21 July
Ipswich	1967	0.285	0.070	9.28	0.210	7.9	Freckenham	24 July
Bury St Edmunds	1967	0.330	0.060	6.24	0.105	7.5	Croxton/Freckenham	25 July
Newark	1967	0.440	0.095	7.98	0.385	7.1	Unknown	31 July
Nottingham	1967	0.215	0.050	5.17	0.565	7.2	Bridgenorth	31 July

Table 2. Mean yields and responses to fertilizers in yield and beet purity for nineteen experiments in 1964-67

	Root yield (ton/acre)	Sugar content (%)	Sugar yield (cwt/acre)	Tops* (ton/acre)	Plant population (1000/acre)	Purity (%)	Amino N (m-equiv/100 g)	Na (m-equiv/100 g)	K (m-equiv/100 g)
Mean	14.82	17.0	50.4	12.18	29.8	95.04	2.038	0.556	4.54
Mg ₁ -Mg ₀	0.43	0	1.5	0.36	1.0	0.05	-0.009	-0.005	-0.03
Mg ₂ -Mg ₁	0.35	0.1	1.6	0.04	0	-0.08	0.004	-0.038	-0.08
Mg ₃ -Mg ₀	0.41	0	1.6	0.03	0.6	-0.08	-0.003	-0.003	-0.05
S.E.	±0.136	±0.03	±0.48	±0.285	±0.21	±0.058	±0.0270	±0.042	±0.0204
N ₂ -N ₁	0.69	-0.3	1.6	1.87	0.3	-0.40	0.298	0.061	0.10
S.E.	±0.096	±0.02	±0.34	±0.201	±0.15	±0.041	±0.0191	±0.030	±0.0145
Na ₁ -Na ₀	0.71	0.1	2.8	0.44	0.5	-0.02	-0.045	0.263	0.18
S.E.	±0.096	±0.02	±0.34	±0.201	±0.15	±0.041	±0.0191	±0.030	±0.0145

* Yield of tops from twelve trials only

The standard errors were obtained from the Experiments x Treatments interaction.

Table 3. Mean sugar yields (cwt/acre) with various fertilizer combinations for nineteen experiments in 1964-67

	Na ₀	Na ₁	N ₁	N ₂	K ₁	K ₂
Mg ₀	47.7	50.1	48.1	49.7	49.7	51.7
Mg ₁	49.3	51.6	49.9	50.9	—	—
Mg ₂	50.8	53.1	50.7	53.2	53.2	54.5
Mg ₃	48.5	52.5	49.9	51.0	—	—
S.E.		±0.68		±0.68		±0.96
Kainit	—	—	51.3	53.5	—	—
S.E.		—		±0.96		—

The standard errors were obtained from the Experiments x Treatments interaction.

the sugar concentration but increased the sugar yield by 1.6 cwt/acre. Juice purity was decreased, largely because α -amino nitrogen in the roots increased.

Agricultural salt (Na₁) increased the yields of roots and of sugar significantly, and tops slightly. Although the salt increased the sodium in the roots, it had little average effect on the juice purity.

Table 3 shows the sugar yields for all the treatments in the factorial design and for the kainit (T) treatment, the yields for the additional potash treatments (K₂), and for comparable plots in the main design which had the small dressing of potash (K₁).

Interactions between magnesium and sodium and between magnesium and nitrogen were very small and none was significant. Kainit increased yield, but strict comparisons cannot be made with other magnesium fertilizers for it contained sodium and potassium. The plots given similar amounts of sodium and potassium, and the same amount of nitrogen (N₂K₂Mg₀Na₁), yielded 53.2 cwt/acre; the mean yield with kainit (N₂K₁Mg₀Na₀T) was 53.5 cwt/acre, indicating that magnesium in kainit

increased yield by about 0.3 cwt/acre. The additional potash increased yield by 2.0 cwt/acre and did not greatly affect the response to magnesium.

Effects on composition

Table 4 shows the effects of kieserite, dolomitic limestone, sodium and kainit on the chemical composition of the sugar beet sampled in late summer; the date of sampling is in Table 1. Magnesium fertilizers increased the magnesium concentration in the leaves, petioles and roots. The small dressing of kieserite (45 lb/acre Mg) increased the concentration in the leaves by 0.071% and the large dressing (90 lb/acre Mg) by a further 0.034% Mg. Although magnesium concentration in leaves was increased by approximately one-quarter, in petioles by one-fifth and in roots by one-tenth, the concentrations of sodium and potassium were not affected. However, the increase in magnesium concentration was accompanied by a decrease in calcium concentration indicating that the two elements are partially interchangeable.

Agricultural salt decreased the magnesium concentration, but kainit increased it slightly. Salt and

Table 4. Effect of magnesium, sodium and kainit on composition of dried beet leaves (L) petioles (P) and roots (R) in July-August. Means of nineteen experiments in 1964-67

Treatment	Potassium (%)			Sodium (%)			Magnesium (%)			Calcium (%)		
	L	P	R	L	P	R	L	P	R	L	P	R
Mg												
0	5.42	4.38	1.35	1.48	0.83	0.116	0.369	0.189	0.107	2.02	1.20	0.236
Response to:												
1	0.03	-0.04	0	-0.09	-0.13	-0.012	0.071	0.025	0.007	0.06	0.07	-0.001
2	-0.02	-0.12	-0.06	-0.03	-0.17	-0.005	0.105	0.038	0.009	0.13	-0.03	-0.010
3	0.01	-0.28	-0.04	0.10	-0.11	-0.005	0.042	0.011	0.003	0.06	0	0.004
0	-1.13	-0.27	+0.04	1.44	0.60	0.097	-0.017	0	-0.010	-0.22	-0.16	-0.009
0 (T)	-0.96	-0.15	0	1.43	0.60	0.080	0.021	-0.004	-0.004	-0.22	-0.17	-0.035

kainit doubled the sodium concentrations in leaves, petioles and roots with accompanying decreases in the concentrations of potassium and calcium.

Deficiency symptoms

Magnesium-deficiency symptoms usually appear in July or August. Typical leaves have large chlorotic areas and later develop marginal necrosis. Table 5 shows the average effect of fertilizers on the percentage of plants with magnesium-deficiency symptoms. All the magnesium fertilizers decreased symptoms, as did nitrogen; kieserite was the most effective. On average, sodium and potassium increased symptoms. There was a negative interaction between sodium and magnesium and between nitrogen and magnesium; the effect of sodium and nitrogen was greatest without magnesium fertilizer. No treatment completely eliminated symptoms at any site, but none of the plants on plots with 5 cwt/acre kieserite had severe symptoms.

Yield, composition and deficiency symptoms

Figure 1 shows the relationship between percentage yield response to magnesium (average of Mg₁, Mg₂ and Mg₃) and the magnesium concentrations in leaves, petioles and roots for each of the eighteen sites sampled. The percentage yield response to magnesium was large when magnesium concentration was small (Ulrich (1961) called this the 'deficient zone'). When the magnesium concentration was large, response was small (Ulrich's 'adequate zone').

Figure 1a shows that when the leaf magnesium was < 0.2% response was generally large, but small when the concentration was > 0.4%. The transition zone from deficiency to an adequate supply of magnesium was, therefore, between 0.2 and 0.4% for sugar-beet leaves. Figures 1b and c show corresponding results for petiole and root magnesium of 0.1-0.2% and 0.075-0.125% Mg respectively.

Two experiments (one at Allscott and one at Newark, both in 1966) gave results quite different from the rest. Beet at both sites responded to magnesium fertilizer, but the magnesium concentrations in leaves, petioles and roots were large. At Allscott the beet were severely deficient in nitrogen, which may account for the unusual magnesium concentration. At Newark the experiment had to be resown and therefore the plants were much younger than the rest: Draycott & Durrant (1968) showed that magnesium concentration in sugar beet plants decreases with age.

Figure 2 shows the relationship between the percentage of plants with symptoms and the concentration of magnesium in sugar beet from the six treatments sampled in each of the eighteen experiments. When more than 20% of plants had

Table 5. Average effect of various fertilizer combinations on the percentage of plants with magnesium-deficiency symptoms in eighteen experiments, 1964-67

	Na ₀	Na ₁	N ₁	N ₂	K ₁	K ₂
	Percentage of plants with symptoms					
Mg ₀	12.5	16.8	17.3	12.3	12.3	12.8
Mg ₁	5.0	6.4	6.0	5.3	—	—
Mg ₂	3.0	3.6	4.2	2.4	2.4	6.7
Mg ₃	6.8	8.5	9.4	6.2	—	—
Kainit	—	—	10.8	7.2	—	—

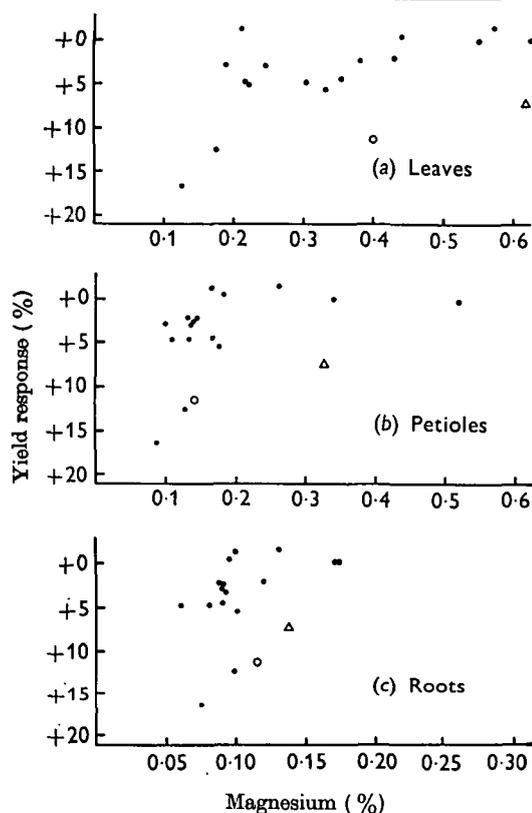


Fig. 1. Percentage yield response to magnesium fertilizers and magnesium concentration in the dry matter of plants grown without magnesium fertilizer in 18 experiments, 1964-67. (O Resown crop, Δ crop showing severe nitrogen deficiency.)

symptoms, the leaves usually had < 0.2% Mg, there was < 1.25% Mg in petioles and < 0.075% Mg in roots. When the leaves had > 0.5% Mg, petioles > 0.2% Mg and roots > 0.125% Mg, then the plants were free from deficiency symptoms.

CONCLUSIONS

Magnesium fertilizers increased yields of sugar beet profitably on soils where previous crops had

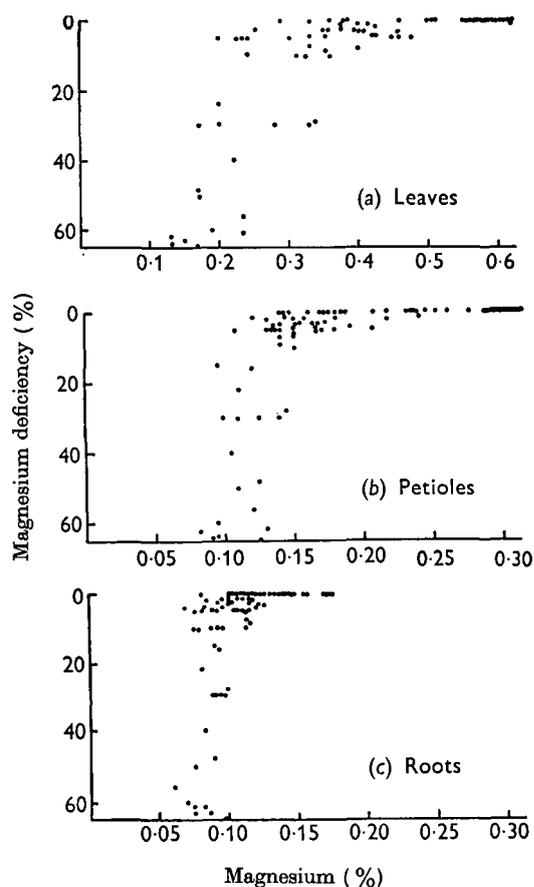


Fig. 2. Percentage of plants showing magnesium deficiency symptoms and their concentrations of magnesium from six treatments sampled (see text) in 18 experiments, 1964-67.

deficiency symptoms. About 3 cwt/acre sugar (worth £6) was obtained from a dressing of 5 cwt/acre of kieserite (costing about £3), similar to the increases reported by other workers (Tinker, 1967; Harrod & Caldwell, 1967). At one site (Allscott, 1964) a following barley crop (in 1966) responded well to the magnesium which had been applied 2 years previously, grain being increased by 3.7 cwt/

acre. Benefits for other crops in the rotation help to justify the cost of magnesium fertilizers.

Although the dolomitic limestone supplied 245 lb/acre Mg, in only three out of nineteen experiments did beet in plots so treated out-yield beet grown with kieserite (the large dressing supplied 90 lb/acre Mg). Chemical analyses and counts of plants with deficiency symptoms suggested this was because magnesium in the limestone was less 'available' than that in kieserite. Dolomitic limestone supplies magnesium cheaply (about 4d. per lb Mg compared with 8d. per lb Mg in kieserite), and its long-term value is being tested in further experiments.

On average of all the experiments, 5 cwt/acre kieserite was more profitable, giving significantly more sugar than 2½ cwt/acre. The kainit (which supplied 32 lb/acre Mg) had less effect on symptoms, yields and magnesium concentrations than 45 lb/acre Mg in kieserite, but weight for weight magnesium in kainit and in kieserite decreased symptoms and increased magnesium concentrations to the same extent. The 7 cwt/acre of kainit contained too little magnesium to give maximum yield.

Although more magnesium was applied by the treatments than sugar beet takes up (Jacob, 1958), the deficiency symptoms were not entirely eliminated in any experiment, perhaps because the magnesium was not well mixed with the soil, or was spread unevenly.

The relationships between yield response to magnesium and magnesium concentration, and between yields response to magnesium and the percentage of plants showing deficiency symptoms, were similar. A 'critical concentration' for magnesium could not be defined from the results, but there was a fairly well-defined transition zone from deficiency to adequate supply. This was 0.2–0.4 % for leaves, 0.1–0.2 % for petioles and 0.075–0.125 % for roots, whether the criterion was yield response or percentage of plants with symptoms.

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