Rothamsted Experimental Station Report for 1972 Part 2


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J. Bolton (1973) *Effects of Potassium, Magnesium and Sodium Fertilisers and Lime on the Yield and Composition of Crops in a Ten-year Experiment at Rothamsted ;* Rothamsted Experimental Station Report For 1972 Part 2, pp 102 - 110 **- DOI: https://doi.org/10.23637/ERADOC-1-34690**

Effects of Potassium, Magnesium and Sodium Fertilisers and Lime on the Yield and Composition of Crops in a Ten-year Experiment at Rothamsted

J. BOLTON

Lawes and Gilbert included magnesium (plus sodium) treatments in all of the Rothamsted 'Classical' experiments, but yields of cereals, roots and grass were not significantly increased. Rothamsted soil has therefore been considered to contain enough magnesium for both arable crops and pasture. However, magnesium deficiency symptoms have been seen in some seasons, especially on the leaves of more susceptible crops such as potatoes and kale which were not grown before 1962 on the 'Classical' plots. The magnesium nutrition of crops is much influenced by potassium and large dressings of potassium fertilisers can increase magnesium deficiency, but there are insufficient treatments in these long-term experiments to measure the effects of magnesium at different levels of potassium fertilisation.

To study potassium–magnesium interactions on soils likely to contain enough magnesium for crops (at Rothamsted), or less than the optimum (at Woburn), two long-term experiments were started by P. W. Arnold in 1959 and 1960. At Woburn yields of many crops were increased by magnesium fertilisers (Bolton & Penny, 1968). This paper summarises the results of the Rothamsted experiment from 1959 to 1968.

The experiment

The site was in Sawyers Field where applications of lime and fertilisers have been restricted to those necessary for experiments. The soil is therefore more acid and contains less phosphate and potassium fertiliser residues than most other soils on Rothamsted Farm. Since liming was necessary to obtain reasonable yields, and crop responses to both potassium and magnesium fertilisers can be affected by liming, two levels of chalk were included in the experiment. There were eight replicates of a 3^2 factorial, K $\times$ Mg design; four replicate blocks were given more chalk than the other four. Table 1 gives the amounts of calcium carbonate, potassium and magnesium sulphates applied each year, and the sequence of crops grown. The initial 1959 liming raised the soil pH from 4·6 to 5·1 and 5·5 in the low and high lime plots respectively. Further liming before the clover was planted in 1962 raised the pH to 5·6 and 6·4 by 1964. In 1966 the design was modified to include sodium treatments in six of the eight replicates. This resulted in two interlinked 3^3 factorial K $\times$ Mg $\times$ Na designs at different soil pH and two blocks without sodium treatments. The sodium comparisons were between none, sodium chloride and sodium carbonate, not between different amounts of sodium. Basal nitrogen and phosphate fertilisers were given to all plots (Table 1). The 1968 crop of ryegrass was grown with basal N and P only, to evaluate residual effects of the K, Mg and Na fertilisers given in previous years.

Each plot was 19·8 $\times$ 4·3 m (0·0085 ha) and there were 1 m paths between the blocks.

Samples of harvested crops were dried overnight at 80°C, ground and 0·5 g subsamples dry-ashed at 450°C. Potassium, sodium and calcium in HCl extracts of the ash were measured by emission and magnesium by atomic absorption flame spectrophotometry.

The soil, derived from Clay-with-flints, is classified by the Soil Survey of England and Wales as Batcombe Series. It is a brownish silty clay loam with slightly impeded drainage

https://doi.org/10.23637/ERADOC-1-7

TABLE 1

Cropping sequence and rates of fertiliser and lime used

Year	Crop	Variety	K_0	K_1 as K_2SO_4	K_2	Mg_0	Mg_1 as $MgSO_4$	Mg_2	Na_0	Na as NaCl or Na_2CO_3	Ca_1 as $CaCO_3$	Ca_2 as $CaCO_3$	Basal dressing N*	Basal dressing P†
			kg/ha of element											
1959	Italian ryegrass	S22	0	106	213	0	32	64	—	—	489	1958	188	55
1960	Italian ryegrass	S22	0	106	213	0	32	64	—	—	—	—	213	0
1961	Italian ryegrass	S22	0	106	213	0	32	64	—	—	1861	3721	251	55
1962	Red clover	Dorset Marl	27	106	185	0	32	64	—	—	—	—	0	55
1963	Red clover	Dorset Marl	0	80	159	0	32	64	—	—	—	—	0	0
1964	Potatoes	King Edward	0	102	204	0	32	64	—	—	—	—	126	27
1965	Barley	Maris Badger	0	76	152	0	32	64	—	—	—	—	63	27
1966	Kale	Thousand headed	0	76	152	0	32	64	0	146	—	—	251	27
1967	Barley	Maris Badger	0	76	152	0	32	64	0	146	—	—	63	27
1968	Italian ryegrass	S22	0	0	0	0	0	0	0	0	—	—	565	27

* As ammonium sulphate 1959–64; 'Nitro-Chalk' 1965–68
† As triple superphosphate

TABLE 3

Yields of dry matter for the main fertiliser treatments averaged over all plots

Year	Crop		K_0	K_1	K_2	Mg_0	Mg_1	Mg_2	Na_0	NaCl	Na_2CO_3	S.E.	Ca_1	Ca_2	S.E
			t/ha												
1959	Ryegrass		No harvest												
1960	Ryegrass	(3 cuts)	8·15	8·49	8·73	8·41	8·47	8·47	—	—	—	±0·073	8·42	8·47	±0·059
1961	Ryegrass	(2 cuts)	2·22	3·09	3·14	2·81	2·86	2·77	—	—	—	±0·065	2·88	2·76	±0·080
1962	Clover		No harvest												
1963	Clover	(3 cuts)	6·08	8·03	8·73	7·53	7·76	7·56	—	—	—	±0·115	7·75	7·48	±0·130
1964	Potatoes		1·51	5·06	6·08	4·14	4·22	4·07	—	—	—	±0·055	4·28	4·01	±0·062
1965	Barley	grain	4·07	4·50	4·41	4·26	4·32	4·40	—	—	—	±0·043	4·43	4·23	±0·059
		straw	3·92	4·52	4·62	4·34	4·37	4·35	—	—	—	±0·069	4·27	4·44	±0·091
1966	Kale		9·26	10·24	9·67	9·77	9·67	9·74	9·62	9·74	9·84	±0·191	9·32	10·14	±0·156
1967	Barley	grain	2·01	3·34	3·52	2·63	2·96	3·29	3·09	3·06	2·71	±0·125	2·41	3·50	±0·200
		straw	1·21	1·87	2·05	1·61	1·70	1·80	1·82	1·74	1·55	±0·108	1·31	2·09	±0·150
1968	Ryegrass	(4 cuts)	14·9	16·7	16·8	16·1	16·2	16·2	15·9	16·3	16·2	±0·12	16·1	16·3	±0·20

https://doi.org/10.23637/ERADOC-1-7

in the subsoil. Some analyses of topsoil from a discard area near the experiment are shown in Table 2.

TABLE 2

Analyses of the soil (Batcombe Series) 0–23 cm

Mechanical composition

% Coarse sand	% Fine sand	% Silt	% Clay	pH (water)
14	40	23	21	4·65

Exchangeable cations K	Mg (mg/100 g)	Ca	Total cations % K	% Mg	% Ca
4·7	3·4	134	1·1	0·3	0·4

Soil core samples were taken 23 cm deep with at least ten cores from each plot in 1961, 1964, 1967 and 1968. The soils were air-dried, sieved (< 2 mm) and 5 g subsamples leached with 75 ml of N-ammonium acetate adjusted to pH 7·0. Cations in the leachates (made up to 100 ml) were measured by flame spectrophotometry, with standards made up in ammonium acetate and suitable buffers added (Salt, 1967). pH was measured in 1 : 2·5 w/v soil : water suspensions.

Results

1. Crop yields. The ryegrass in 1959 and the clover in 1962 were so slow to establish that only samples were cut and no yields were measured. Yields of dry matter (t/ha) for the other years from the main fertiliser treatments (averaged over all plots) are shown in Table 3. Interactions between the fertilisers were generally unimportant and are not given.

Potassium fertiliser increased the yields of all crops but the magnitude of the response varied. In 1960 ryegrass yields were increased by 0·4–0·6 t/ha (4–7%) and the following year by 0·9 t/ha (40%) when only two cuts were taken. In 1968 when ryegrass was again grown to measure the effects of fertiliser residues, yields were very large (average 16·2 t/ha of dry matter) even on the untreated plots and potassium increased yields by about 1·8 t/ha (12%). These responses, as in the Woburn experiment, were smaller than for the other crops. Kale yields were increased less (4–11%) than barley (10–60%) and clover (30–40%). The most responsive crop was potatoes which yielded little in plots not given potassium fertilisers. Growth of the potatoes was satisfactory during a wet June but in drier weather in July and August severe potassium deficiency symptoms appeared on the leaves. By mid-August the tops on K_0 plots were dead and deficiency symptoms were present in the K_1 plots and some K_2 plots. The order in which the crops responded in yield was potatoes > clover = barley > kale = ryegrass—a similar order as at Woburn (Bolton & Penny, 1968).

Only barley responded to the magnesium fertilisers. Grain yields were increased about 3% in 1965 and by a surprisingly large 25% in 1967. In the nearby Hoosfield Continuous Barley Experiment grain yields have always been between 1 and 5 cwt/acre larger on the NPK Na Mg plot (4/A) than on the NPK plot (5/A) (Warren & Johnston, 1967). Potatoes were the most responsive crop to magnesium at Woburn but no increases in tuber yields were measured in the 1964 crop at Rothamsted, even with the largest potassium dressing—possibly because all yields were low (mean 16·6 t/ha of fresh tubers) in this very dry season.

The sodium carbonate treatment lessened barley yields in 1967 especially on the more acid plots. Kale and ryegrass yields were unaffected by the sodium fertilisers, even where no potassium was given.

https://doi.org/10.23637/ERADOC-1-7

TABLE 4

Concentrations of cations in the dry matter of the harvested crops

	Treatment		% K				% Mg				% Na				% Ca		
			K_0	K_1	K_2	S.E.	Mg_0	Mg_1	Mg_2	S.E.	Na_0	NaCl	Na_2CO_3	S.E.	Ca_1	Ca_2	S.E.
1960	Ryegrass	cut 1	2·0	2·7	3·0	±0·03	0·10	0·12	0·13	±0·001	—	—	—	—	0·56	0·58	±0·01
		cut 2	1·6	2·2	2·5	±0·02	0·13	0·14	0·16	±0·002	—	—	—	—	0·57	0·62	±0·01
		cut 3	1·5	2·3	2·5	±0·03	0·11	0·12	0·13	±0·002	—	—	—	—	0·39	0·44	±0·01
1961	Ryegrass	cut 1	1·6	3·2	4·1	±0·04	0·19	0·23	0·25	±0·003	—	—	—	—	0·63	0·64	±0·01
		cut 2	1·1	2·4	2·9	±0·04	0·19	0·20	0·22	±0·004	—	—	—	—	0·82	0·93	±0·02
1962	Clover	(sample)	1·0	2·2	3·1	±0·06	0·30	0·49	0·49	±0·006	—	—	—	—	2·36	2·36	±0·03
1963	Clover	cut 1	0·8	1·8	2·7	±0·03	0·23	0·33	0·39	±0·007	0·12	—	—	—	1·59	1·68	—
		cut 2	1·0	1·7	2·7	±0·02	0·26	0·34	0·37	±0·006	0·19	—	—	—	1·55	1·62	—
		cut 3	1·3	1·9	2·6	±0·05	0·29	0·38	0·44	±0·006	0·14	—	—	—	1·49	1·52	±0·01
1964	Potato tubers		1·0	1·3	1·8	—	0·07	0·08	0·08	—	0·03	—	—	—	0·02	0·03	—
1965	Barley	grain	0·4	0·4	0·4	—	0·13	0·13	0·13	—	0·02	—	—	—	0·06	0·07	—
		straw	0·2	0·4	0·6	—	0·06	0·07	0·09	—	—	—	—	—	0·53	0·62	—
1966	Kale		0·2	2·1	2·3	±0·10	0·11	0·13	0·15	±0·004	0·31	0·32	0·35	±0·064	1·29	1·42	±0·037
1967	Barley	grain	0·5	0·5	0·5	—	0·12	0·13	0·13	—	0·02	0·03	0·03	—	0·05	0·07	—
		straw	0·4	0·8	1·0	—	0·06	0·07	0·07	—	0·24	0·36	0·38	—	0·38	0·36	—
1968	Ryegrass	cut 1	1·4	2·5	3·0	±0·03	0·12	0·13	0·15	±0·002	0·34	0·60	0·55	±0·019	0·64	0·65	±0·010
		cut 2	1·1	2·0	2·4	±0·03	0·14	0·16	0·18	±0·002	0·33	0·50	0·45	±0·017	0·71	0·73	±0·014
		cut 3	1·2	2·0	2·9	±0·04	0·16	0·18	0·20	±0·004	0·54	0·77	0·74	±0·021	0·83	0·87	±0·018
		cut 4	1·3	2·1	3·2	±0·04	0·17	0·20	0·22	±0·004	0·66	0·86	0·90	±0·026	0·77	0·85	±0·008

https://doi.org/10.23637/ERADOC-1-7

The extra lime given to four blocks of the experiment increased kale yields by 9% in 1966 and barley yields by 50% in 1967. These two crops are generally considered more sensitive to soil acidity than ryegrass or potatoes. The latter crop yielded less on the plots given most chalk and least potassium:

Total yields of fresh tubers (t/ha)

	K_0	K_1	K_2
Ca_1	7·7	20·0	23·9
Ca_2	5·3	18·3	24·7
S.E.		± 0·52	

Interaction effects of liming and potassium on yields of potatoes have been observed in other experiments at Rothamsted and Woburn (Bolton, 1971).

2. Crop composition. Percentages of potassium, magnesium, calcium (and sodium from 1963) in the crops are summarised in Table 4. Potassium fertiliser increased potassium and decreased magnesium in all crops except potatoes. In this case, % Mg in the tubers was increased by the potassium treatments (Table 5)—an effect noticed also in the Woburn experiment. Addiscott (1972) has recently investigated this effect.

The percentage of potassium in ryegrass has been suggested as an indicator of the need for potassium fertiliser, but in this experiment yield responses were not always related to % K in the dry matter. The response was small with 2·0% K in the grass but with 1·1% K, yields were increased by 35% in 1961 (second cut) but only by 8% in 1968 (second cut). Hylton, Ulrich and Cornelius (1967) suggested that sodium as well as potassium in the grass must be considered and Nowakowski (1972) has shown that sodium and potassium are interrelated in their effects on the yield and composition of ryegrass, but sodium fertiliser residues did not increase yields in 1968, even when no K-fertiliser had been given. Unfortunately the early ryegrass crops were not analysed for sodium.

Magnesium fertiliser increased concentrations of magnesium in the crops but other nutrient concentrations were unaffected. Percentages of magnesium in grass and clover are important in ruminant nutrition and the dry matter should contain 0·2% Mg to eliminate the risk of hypomagnesaemia (Rook & Rowland, 1962). These crops of ryegrass contained less than this in all except the 3rd and 4th cuts in 1968 given the most Mg-fertilisers. There were large interaction effects between the potassium and magnesium fertilisers on % Mg in the grass. Some examples (Table 5) suggest that it would be difficult or impossible to produce maximum yields of grass containing the minimum requirement of 0·2% Mg in the dry matter. The clover contained much more magnesium than ryegrass or kale.

TABLE 5

Effects of potassium and magnesium fertilisers on concentrations of magnesium in the harvested crops

	Ryegrass				Clover		Potatoes	Kale
	1960		1968		1963		1964	1966
	Cut 1	Cut 3	Cut 1	Cut 4	Cut 1	Cut 3		
	% Mg in dry matter							
K_0 Mg_0	0·11	0·12	0·12	0·19	0·29	0·32	0·060	0·12
K_0 Mg_2	0·14	0·16	0·16	0·27	0·49	0·50	0·070	0·17
K_2 Mg_0	0·09	0·09	0·11	0·16	0·19	0·25	0·085	0·10
K_2 Mg_2	0·12	0·12	0·14	0·18	0·31	0·36	0·093	0·14
S.E.	±0·002	±0·003	±0·004	±0·008	±0·103	±0·010	±0·0010	±0·006

https://doi.org/10.23637/ERADOC-1-7

Extra lime given to half the blocks slightly increased % Ca in the crops. As with magnesium, the largest differences in calcium contents were between the different crops.

Sodium concentrations in crops grown after 1966 were affected more by potassium than sodium fertilisers, especially in the kale tops and barley straw (Table 6). There were no differences between effects of the two forms of sodium fertiliser.

TABLE 6

Effects of potassium and sodium fertilisers on sodium concentrations in the harvested crops

	Kale 1966		Barley straw, 1967		Ryegrass, 1968 (Cut 3)		Potato tubers, 1964
	O	Na*	O	Na*	O	Na*	O
	% Na in dry matter						
O	0·53	0·68	0·58	0·81	0·77	1·13	0·032
K_1	0·15	0·18	0·16	0·26	0·50	0·70	0·030
K_2	0·08	0·11	0·12	0·18	0·37	0·28	0·040
S.E.	±0·060		—		±0·068		—

* Mean of NaCl and Na_2CO_3 treatments

3. Soil analyses. The results of exchangeable cation and pH measurements made on soils sampled in 1961, 1964, 1967 and 1968 are summarised in Table 7.

Exchangeable K in air-dried soil from plots not given potassium fertiliser remained fairly constant at 3·8–4·5 mg/100 g throughout the experiment despite the removal of 586 kg/ha in harvested crops. This is less than measured in the nil and NP plots of other 'Classical' and long-term experiments at Rothamsted.

Exchangeable K (mg/100 g)

	Nil plot	NP plot	
Broadbalk (wheat)	10·2	8·2	Johnston, 1969
Hoosfield (barley)	8·7	6·2	Warren & Johnston, 1967
Park Grass (grass)	8	6	Warren & Johnston, 1964
Barnfield (root crops)	18	12	Warren & Johnston, 1962
Agdell (rotation)	10·4	—	Johnston & Penny, 1972
Reference plots (rotation)	6·3	6·5	Williams, 1973

Potassium in the treated soil was increased most in 1967 but the large crop of ryegrass in 1968 feeding on the residues lessened exchangeable K in the K_1 plots almost to the same as in the K_0 plots. Exchangeable K in the K_2 plots was also lessened from 14·8 to 8·3 mg/100 g by the final ryegrass crop. Assuming the top 0–23 cm of soil weighed 3400 t/ha, this corresponds to a loss of 220 kg/ha of potassium. The harvested ryegrass actually contained 480 kg/ha, therefore some potassium was removed from non-exchangeable resources or from the subsoil during 1968.

Exchangeable magnesium in plots not given magnesium fertiliser remained between 3·4 and 5·5 mg/100 g throughout the experiment despite removals in the crops equivalent to 2·4 mg/100 g in the topsoil. This could indicate some release of non-exchangeable magnesium or uptake from the subsoil. Part of the difference can be accounted for by magnesium in the rain (about 2·5 kg/ha annually). Soil from plots given the most magnesium fertiliser contained 10·9 mg/100 g of magnesium in 1961 and 15·1 in 1967 but only 12·2 kg/100 g after the ryegrass crop in 1968.

Exchangeable calcium in the Ca_1 plots was only slightly more in the 1968 than in the 1960 samples despite the application of 2·35 t/ha of Ca as chalk. In the Ca_2 plots in 1968 there were large differences in both pH and exchangeable Ca remaining from the chalk dressings given in 1959 and 1961.

https://doi.org/10.23637/ERADOC-1-7

TABLE 7

Effects of the treatments on exchangeable cations (mg element/100 g soil) and soil pH

	Potassium			Magnesium			Sodium			Calcium		pH (water)	
	K_0	K_1	K_2	Mg_0	Mg_1	Na_2	Na_0	NaCl	Na_2CO_3	Ca_1	Ca_2	Ca_1	Ca_2
1960	4·7	—	—	3·4	—	—	—	—	—	134	—	4·6	—
1961	3·8	5·9	13·0	5·5	8·0	10·9	1·4	—	—	141	182	5·1	5·5
1964	3·9	4·9	8·2	3·4	6·2	9·4	2·4	—	—	130	206	5·6	6·4
1967	4·5	8·0	14·8	4·0	9·6	15·1	3·8	6·4	6·9	143	210	5·4	6·5
1968	4·5	5·0	8·3	3·6	7·6	12·2	1·1	2·1	1·8	146	212	5·5	6·4

TABLE 8

Amounts of potassium, magnesium, calcium and sodium removed in the crops and the balance over the experimental period (kg/ha)

		Potassium				Magnesium				Calcium			Sodium			
Year	Crop	K_0	K_1	K_2	S.E.	Mg_0	Mg_1	Mg_2	S.E.	Ca_1	Ca_2	S.E.	Na_0	NaCl	Na_2CO_3	S.E.
1960	Ryegrass	141	208	237	±2·71	9·1	10·5	11·5	±0·13	42·3	45·5	±0·43	—	—	—	—
1961	Ryegrass	31	89	112	±2·17	5·3	6·2	6·5	±0·13	20·4	21·0	±0·46	—	—	—	—
1962	Clover	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1963	Clover	58	145	232	±2·64	18·2	25·9	28·6	±0·45	119·9	121·1	±1·61	10·2	—	—	—
1964	Potatoes	16	66	112	—	2·9	3·1	3·1	—	1·0	1·1	—	1·5	—	—	—
1965	Barley (grain + straw)	24	39	47	—	8·2	8·6	9·3	—	25·3	30·6	—	—	—	—	—
1966	Kale	146	211	225	±11·3	11·2	12·8	14·2	±0·55	119·9	143·1	±4·52	28·6	30·5	33·7	±6·16
1967	Barley (grain + straw)	14	31	37	±1·78	4·1	4·9	5·5	±0·31	6·1	9·2	±0·27	5·0	7·1	6·3	±0·71
1968	Ryegrass	186	370	480	±4·5	22·0	25·3	28·2	±0·28	113·2	119·9	±1·12	64·8	101·3	94·6	±3·74
(a)	Total	586	1159	1482		80·9	97·4	107·2		448	492		98·4	138·9	134·6	
(b)	In fertilisers	27	834	1643		0	288	576		2684*	6013*		0	291	291	
(c)	Gain (+) or Loss (−) in soil	−5	+10	+107		+7	+127	+266		+404	+2623		—	—	—	
	Balance (a)+(c)−(b)	+554	+331	−54		+88	−64	−203		−1832	−2898		—	—	—	

* Including superphosphate and 'Nitro-Chalk'

4. Nutrient balances. Total removals of potassium, sodium, calcium and magnesium in the harvested crops and gains or losses by the soil calculated from the soil analyses (assuming 0–23 cm of topsoil weighed 3400 t/ha) are shown in Table 8. From these data and the total nutrients given in the fertilisers, unaccounted gains or losses from the system were calculated.

Plots untreated or given least potassium fertiliser (K_1) gained potassium from non-exchangeable or subsoil reserves. A small proportion (3%) of the fertiliser potassium was lost from the topsoil of K_2 plots. Relative to the K_0 plot, 70% of the fertiliser potassium was recovered in crops in the K_1 plots and 55% on the K_2 plots. Less than 10% remained as exchangeable potassium in the topsoil.

Magnesium was lost from plots given both amounts of magnesium fertiliser but without added magnesium 88 kg/ha was recovered from non-exchangeable reserves, from the subsoil or from other sources. As already mentioned, about 25 kg/ha would have been added in ten years rainfall. Extra magnesium in the crops from the fertilisers was less than 7% of the magnesium added as fertiliser to both the Mg_1 and Mg_2 plots. Increases in exchangeable magnesium in the topsoil were equivalent to about half the added magnesium at both rates.

Average annual losses of 174 kg/ha of calcium from the Ca_1 blocks and 304 kg/ha from the Ca_2 blocks were probably caused by leaching. Assuming that all the calcium in basal superphosphate dressings was leached, the average loss of $CaCO_3$ was 458 kg/ha (3·6 cwt/acre) at a pH of about 5·2 and 724 kg/ha (5·8 cwt/acre) at pH about 6·4. These could be overestimates because N-ammonium acetate may not have dissolved all chalk particles remaining in the soils from the initial dressings.

Discussion

The results of this experiment emphasise the importance of maintaining adequate potassium in Rothamsted soil, and the need for liming when acid-sensitive crops such as kale or barley are grown. The need to apply magnesium is still uncertain as barley was the only crop to give increased yields on the magnesium treated plots. Potatoes and kale are usually considered more susceptible to magnesium deficiency than barley, but they did not respond to the added magnesium in this experiment. Poor yields of potatoes, even on the K_2 plots, might have inhibited the magnesium response although no deficiency symptoms were evident on the leaves on any plot. Symptoms were seen on kale leaves in some plots in September 1966.

Magnesium fertilisers might be justified because of their effects on % Mg in fodder crops. However, these results show that if sufficient potassium is given to produce maximum dry matter yields of grass or kale, it is probably impossible to attain the 0·2% Mg in the dry matter needed to eliminate risks of hypomagnesaemia and grass tetany. It seems necessary therefore to use magnesium supplements of some kind to avoid deficiency diseases in cattle or sheep grazing high-yielding ryegrass pastures or kale. By contrast, the clover crops contained adequate magnesium concentrations even when grown with much potassium and without magnesium fertilisers.

A reasonable compromise between including magnesium in annual fertilisers for crops such as barley and the application of no additional magnesium, would be to use magnesium limestone ($>$ 4% Mg) instead of chalk (0·12% Mg) when liming is necessary about every five years. The extra cost would be less than applying kieserite or calcined magnesite directly to susceptible crops. Magnesium residues from fertilisers remain for many years after application and only occasional applications should be necessary.

These results support the recommended soil analysis classification (Ministry of Agriculture, Fisheries and Food 1967) under which this soil would be in the 'medium'

https://doi.org/10.23637/ERADOC-1-7

category (3–6 mg/100 g of exchangeable magnesium) rather than 'low' or 'high' in magnesium available to crops. On soils in this category deficiencies of magnesium are expected occasionally on sensitive crops and periodic liming with dolomite is recommended.

Summary

On an acid, potassium deficient silty clay loam, potassium fertiliser increased the yields of ryegrass, clover, potatoes, kale and barley. Increasing the soil pH to 6·5 instead of 5·4 (from an initial pH of 4·6) increased the yields of barley and kale but not of the other crops. Magnesium fertiliser increased yields of barley only and sodium had no effect. Crop analyses suggest that it would be difficult to produce maximum yields of ryegrass or kale containing the 0·2% Mg in the dry matter considered necessary to prevent hypomagnesaemia in ruminants.

Potassium other than exchangeable K in the topsoil was removed by crops given none or the smaller amount of potassium fertiliser. Some extranaeous magnesium was also recovered from plots not given magnesium fertiliser but there were losses from the treated plots. Calcium equivalent to 460 and 720 kg/ha of limestone (3·6 and 5·8 cwt/acre) was lost annually from topsoil limed to pH 5·2 and 6·4 respectively.

Acknowledgements

I am grateful for permission to use P. W. Arnold's early results, and for the help of J. R. Moffatt and his farm staff and to J. H. A. Dunwoody for statistical analyses.

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https://doi.org/10.23637/ERADOC-1-7