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Potassium reserves in British soils

II. Soils from different parent materials

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SUMMARY

Twenty-six soils from different parent materials were exhaustively cropped with ryegrass in the glasshouse. Soil and crop measurements revealed inter-relationships similar to those observed with Rothamsted soils (Part I) generally, except that 12 of 20 soils, 'poor' in K (as defined by the K intensity of the uncropped soil and the change in soil K intensity with cropping), gave patterns of K uptake by the ryegrass crop similar to those of soils 'rich' in K. This indicates that these soils contain some K reserves not differentiated from those accumulated by K-manuring in Rothamsted by laboratory measurements.

The cumulative K yield of ryegrass was very significantly related to the K intensity of the uncropped soil. The relationships were improved slightly by allowing for differences in soil pH and organic carbon content. The cumulative K yields at 16 weeks and at 60 weeks were better related to the total clay ($< 2\,\mu$) content than to the fine clay ($< 0{\cdot}2\,\mu$) content of the soil. The K intensities of the cropped soils decreased to nearly 10^{-3} (AR) units after 16 weeks cropping (except the Harwell soil which took 3 years to do so), although large differences in K yield persisted until much later.

Potassium-buffer capacity per unit clay content of the soil (by a laboratory method) was *inversely* related to the K intensity of the uncropped soil and to K uptakes at 16 and 60 weeks. The reasons for this apparent anomaly are discussed and a more correct basis for the units for K-buffering capacity is suggested. The buffer capacities of 'rich' soils in the laboratory and glasshouse experiments were significantly related but not of 'poor' soils.

Soils exhausted by cropping released more K to ryegrass after a drying-and-wetting cycle in amounts proportional to the clay content of the soil. This points to the need for caution in measurements to assess status after air-drying soils.

Part I of this paper examined the effect of continuous long-term manuring of genetically similar soils on properties related to their potassium status. This paper extends the work to soils derived from different parent materials which received little or no K manuring up to the time of sampling.

Rouse & Bertramson (1950, on Indiana soils), Arnold (1960) and Arnold & Close (1961*a*, *b*, on English soils) suggested that the K-releasing powers of soils differed mainly because of differences in the amount and K-content of the fine clay, and that the coarse clay was of little value. Arnold suggested that the fine clay in heavier soils may often be relatively less weathered. However, Smith & Matthews (1957) related the *total* clay content of Canadian soils to their K-releasing power, and Brown (1966), who re-examined Arnold and Close's results, found no significant difference between K release from fine and coarse clay fractions. This aspect of K release from soils is also discussed in this paper.

MATERIALS AND METHODS

Twenty-six soils from different series in England and Wales sampled 0–20 cm deep in autumn 1962, from arable land are described in Table 1. These had been given little or no K for at least 5 years before sampling; some had been limed.

The procedures used for exhaustive cropping in the glasshouse and for measuring equilibrium activity ratios $(AR)_0$ and buffer capacities of soil K and K uptake by ryegrass were described in Part I (Talibudeen & Dey, 1968).

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Table 1. *Description of soils from different parent materials**

Series	Parent material	pH in 0·01 M-CaCl$_2$	CEC (m-equiv/100 g)	% K in CEC	% organic carbon	% clay (< 2 μ)	% fine clay (< 0·2 μ) in < 2 μ fraction
Denbigh	Silurian Greywacke	5·4	17·1	4·0	5·5	9·7	5·2
Blackmoor Gate	Devonian Slate	6·4	16·9	3·2	3·9	12·1	6·2
Cegin	Till	6·6	15·2	1·5	3·7	12·6	12·7
Dunsford	Carboniferous Shale	5·2	17·4	2·6	3·6	13·8	16·3
Bovey Basin	Loamy Drift	6·0	18·3	1·4	3·8	17·1	21·0
Lilleshall	Red Mudstone	5·3	11·2	5·9	2·5	21·6	23·2
Tedburn	Carboniferous Shale	6·4	12·4	5·8	3·2	24·5	24·5
Dale	Carboniferous Shale	7·3	12·4	8·1	3·1	22·4	26·3
Bromyard	Red Mudstone	6·9	11·7	3·0	1·8	17·0	30·6
Tasley	Carboniferous Shale	6·5	15·1	4·2	3·3	20·6	30·6
Bromyard	Red Mudstone	6·9	10·7	7·1	1·9	17·3	31·2
Worcester	Red Mudstone	6·4	9·2	6·1	2·1	13·9	33·2
Dunkeswick	Permian Till	7·0	16·6	1·5	3·4	25·7	41·0
Wothersome	Till	7·2	14·1	2·9	2·1	24·8	41·5
Long Load	Lower Lias Clay Shale	5·5	30·1	2·6	5·7	27·6	43·0
Banbury	Middle Lias Limestone	6·7	23·8	2·8	2·8	23·7	44·2
Newchurch	Weald Alluvium	7·0	22·0	7·1	3·2	41·4	45·7
Windsor	London Clay	6·1	15·3	5·1	3·2	22·5	46·6
Thorne	Weald Clay	6·3	16·9	6·0	3·7	30·3	51·2
Denchworth	Oxford Clay	5·4	19·4	5·3	4·0	42·6	51·4
Badsey	Lower Lias Drift	7·2	16·2	5·7	2·2	23·7	52·8
Honeybourne	Lower Lias Drift	6·9	14·2	5·6	1·7	27·1	53·5
Sherborne	Great Oolite Limestone	7·1	15·9	3·9	2·1	29·9	57·9
Harwell	Upper Greensand Sandy Clay	6·4	30·7	19·5	2·3	37·3	63·8
Wicken	Gault Clay	7·0	37·9	3·4	2·3	51·2	68·8
Weston Turville	Cretaceous Drift	6·8	24·9	2·7	2·6	30·3	74·8

* Samples and description from the Soil Survey of England and Wales through B. W. Avery

RESULTS AND DISCUSSION

Table 1 shows that the particle size distribution in the clay fraction of these soils (last column) depends qualitatively on the nature of the parent material from which the soil is derived (Column 2).

Tables 2 and 3 summarize the results of soil and crop analyses for 'poor' and 'rich' soils respectively. 'Poor' soils are defined with initial K intensities significantly less than 50×10^{-4} $(\mathrm{AR})_0$ units; 'rich' soils are those with such values equal to or greater than this limit. As with manured and unmanured soils described in Part 1, these two groups differed in the changes in soil K intensity with cropping (Fig. 3) and the K concentration of the crop in successive harvests. The K-rich soils gave linear increases in cumulative K uptake up to 16 weeks cropping (Figs 1 and 2, soil A). But of the 20 'poor' soils only 8 (Denbigh, Blackmoor Gate, Cegin, Bovey Basin, Long Load, Windsor, Sherborne and Weston Turville) gave rates of K uptake similar to those of the 'poor' Rothamsted soils (soil B). The remainder gave uptake patterns similar to those of 'rich' soils, contradicting that expected from their rates of change of soil K intensity with cropping (soil C; cf. Part I).

Effect of clay content and mineralogy on potassium release from soils

Cropping from 14 'poor' soils terminated sooner than 60 weeks, 12 of these had < 25 % 2 μ clay of which between one-twentieth and one-half was fine clay; two (Sherborne and Weston Turville) had ~ 30 % clay, most of which was fine clay, but yielded exceptionally small amounts of potassium. Conversely, in relation to its clay (13·8 %) and fine clay content (one-sixteenth of clay content) the 'Dunsford' soil yielded an abnormally large amount of K, equal to that released by the 'Thorne' soil (30·3 % clay) which had much more fine clay (half of clay content) and was classed as a 'K-rich' soil. All the other 'rich' soils except the 'Thorne' series soil were cropped for 56–60 weeks and yielded K > 700 ppm of soil in this time.

The 'Harwell' soil was cropped for 3¼ years and

Table 2. *Soils 'poor' in potassium: crop and soil results*

Soil series	K intensity in soil, $(AR)_0 \times 10^{-4}$ units, at				K concentration in crop, % dry matter, at			Cumulative K uptake ppm K in soil at		Initial exchange-able, K, ppm in soil	K buffer capacity $\times 10^{-3}$		Cropping period (weeks)
	0 wk	4 wk	16 wk	Final	4 wk	16 wk	Final	16 wk	Final		PBC	C_m	
'Normal' soils													
Denbigh	31	2	9	4	2·0	0·50	0·90	130	160	226	44	33	44
Blackmoor Gate	20	2	20	5	1·7	0·74	0·55	150	200	211	56	122	56
Cegin	10	3	10	3	0·9	0·42	0·30	60	70	86	50	35	28
Bovey Basin	16	2	10	4	1·3	0·48	0·37	80	90	102	52	16	28
Long Road	16	1	11	4	2·2	0·50	0·79	140	180	305	128	32	44
Windsor	25	2	16	3	2·0	0·61	0·37	140	160	305	63	18	48
Sherborne	7	1	7	5	1·7	0·78	0·92	110	190	242	118	154	44
Weston Turville	21	1	12	4	2·5	1·0	0·66	230	310	500	132	42	48
'Abnormal' soils													
Dunsford	33	4	18	6	3·0	1·6	1·3	420	600	180	45	67	44
Lilleshall	21	4	12	5	2·3	1·2	0·72	280	400	258	59	32	44
Tedburn	25	2	10	5	2·1	1·1	0·76	270	320	282	59	39	28
Dale	11	1	9	4	1·5	0·80	0·69	130	220	391	136	87	44
Bromyard	24	2	12	3	3·2	1·7	1·2	350	530	137	99	130	60
Tasley	25	3	12	11	3·2	1·3	1·1	320	440	250	58	27	44
Bromyard	37	2	14	9	3·3	1·8	0·83	370	550	297	45	374	44
Worcester	24	1	11	4	2·0	0·90	0·64	160	240	219	58	24	52
Banbury	12	2	11	5	2·9	1·1	0·73	260	380	258	156	105	56
Badsey	27	2	9	3	3·5	1·2	0·72	310	440	360	228	38	56
Honeybourne	24	2	10	6	3·2	1·5	0·70	310	490	313	80	54	56
Wicken	29	1	9	5	4·7	2·1	1·2	580	930	500	79	80	60

Table 3. *Soils 'rich' in potassium: crop and soil results*

Soil series	K intensity in soils $(AR)_0 \times 10^{-4}$ units, at				K concentration in crop, % dry matter at			Cumulative K uptake, ppm K in soil, at		Initial exchange-able K, ppm in soil	K buffer capacity $\times 10^{-3}$		Cropping period (weeks)
	0 wk	4 wk	16 wk	Final	4 wk	16 wk	Final	16 wk	Final		PBC	C_m	
Dunkeswick	168	58	17	8	5·0	1·9	1·0	580	800	98	44	17	60
Wothersome	53	10	12	10	4·3	1·9	1·1	510	740	160	78	52	60
Newchurch	89	27	10	12	5·2	2·6	2·4	700	1010	606	78	45	60
Thorne	48	8	11	5	3·5	1·5	2·1	480	610	399	69	35	44
Denchworth	48	8	10	10	4·2	1·8	1·0	540	720	399	78	49	56
Harwell*	367	78	23	17	5·3	2·9	3·6	740	1250	2346	56	43	60*

* Cropping continued up to 170 weeks; yield given is for 60 weeks (see text).

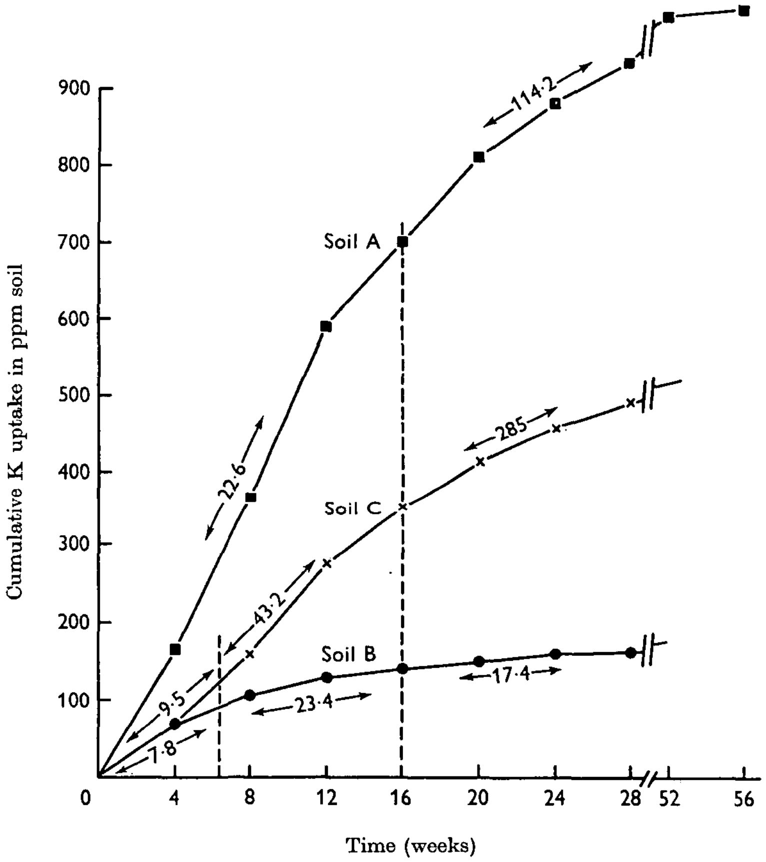

Fig. 1. Cumulative K yields for a 'rich' soil, A (Newchurch series) and two types of poor soils, B (Windsor series) and C (Bromyard series). Numbers on the yield curves indicate buffer capacities during cropping in the periods shown by dotted lines.

yielded 2364 ppm of K (Talibudeen & Weir, 1968), equal to the NH_4^+—exchangeable K, although the yield used in this paper for computations was for 60 weeks. The soil contains large amounts of unweathered glauconite; Brown (1965) also found large amounts of (K-rich) clinoptilolite in its fine silt and coarse fractions, separated by us, which explained its unusual K:Ca exchange isotherm (Deist & Talibudeen, 1967). Arnold (1962) also found that the relationships between the K content of the fine clay and the K-releasing power of the soil was not significant.

We said earlier that the fraction of fine clay ($< 0{\cdot}2\,\mu$) in the $< 2\,\mu$ clay in these 26 soils is qualitatively related to the nature of the parent material. Previous work (see 'Introduction') gives conflicting views on the importance of the finer particle size fractions in soils to K release. The K-yields at 16 and 60 weeks were significantly related to the fine clay content ($r^2 = 0{\cdot}345^{**}$ and $0{\cdot}346^{**}$), but much more so to the total clay content ($r^2 = 0{\cdot}413^{***}$ and $0{\cdot}435^{***}$) suggesting that the coarse clay ($0{\cdot}2$–2μ) plays an important role in supplying K to the crop ($r^2 = 0{\cdot}244^{**}$ and $0{\cdot}194^{*}$).

Soil-potassium intensity. Intensity values of the uncropped soils mostly ranged from 10 to 30×10^{-4} unit. Soils with greater intensities usually contained more clay. The Harwell soil had an exceptionally large intensity (367×10^{-4} unit). Soils with intensities $\geqslant 50 \times 10^{-4}$ unit are listed in Table 3. After 28 weeks exhaustive cropping, soil intensities were between 3·5 and $9{\cdot}7 \times 10^{-4}$, except the Harwell soil (16×10^{-4}) again indicating its exceptional mineralogy. At the other extreme, the 'Sherborne' soil released 165 ppm K at an almost constant rate over 28 weeks while its intensity did not exceed 6 to 7×10^{-4} unit.

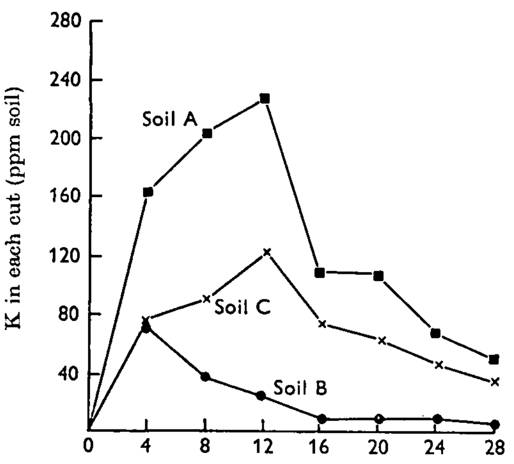

Fig. 2. K yields in successive harvests for a 'rich' soil, A (Newchurch series) and two types of poor soils, B (Windsor series) and C (Bromyard series.)

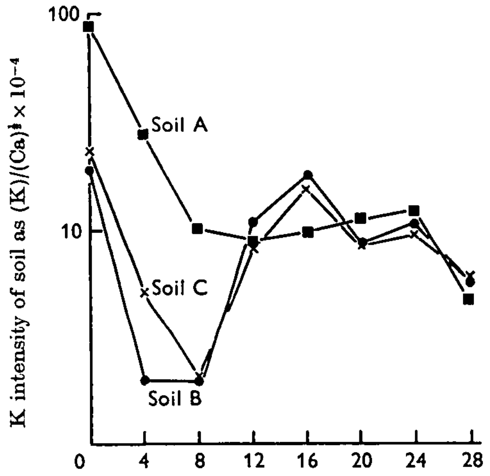

Fig. 3. K intensities after each harvest for a 'rich' soil A (Newchurch series) and two types of poor soils, B (Windsor series) and C (Bromyard series).

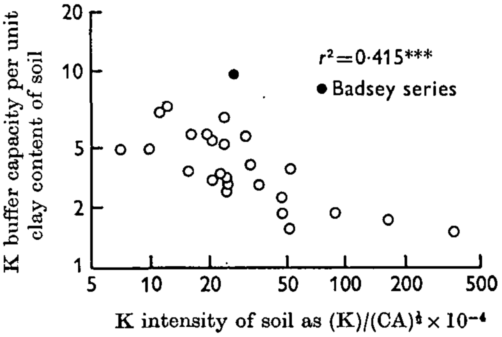

Fig. 4. The relation between K buffer capacity per unit clay content and K intensity of uncropped soils from different parent materials.

Potassium buffer capacity of the soil

The inverse relationship between K buffer capacity by instantaneous equilibration (PBC) and the K intensity of the uncropped soil $(AR)_0$ observed with the Rothamsted soils (Part I) was not significant. But, if the clay fraction of British soils governs their cation exchange properties, PBC per unit of clay in the soil should be more meaningful as an intrinsic soil property in K exchange. Figure 4 shows that the *inverse* relationship, log PBC/unit clay content of soil: log $(AR)_0$, is less precise ($b = -0{\cdot}636 \pm 0{\cdot}087$; $r^2 = 0{\cdot}415^{***}$) than for the more homogeneous group of Rothamsted soils (Part I), but the corresponding regression of log PBC/unit clay content of soil on log (%K saturation) was not significant. Similarly, the K yields after 16 weeks and after 60 weeks cropping were not significantly related to PBC values but were *inversely* related to PBC/unit clay content of the soil ($r^2 = 0{\cdot}243^{**}$ for '16-week' yield and $0{\cdot}213^{*}$ for '60-week' yield). Coupled with the other apparently anomalous *inverse* relationship with soil K intensity, this emphasizes (as with the Rothamsted soils) that the slope of the Q/I relationship is only comparable for different soils at the same fractional K saturation of their cation exchange capacity, when used as a characteristic soil property or to correlate with the K released by the soil. The CEC of soils of pH $< 6{\cdot}0$ in $0{\cdot}01$M-$CaCl_2$ (five of the 26 soils in Table 1) includes exchangeable Al ions. Earlier unpublished work showed that in such soils, the sum of cations exchanged out by M-NH_4Cl, adjusted to the soil pH, was not significantly different from the soil CEC determined by NH_3 distillation after NH_4^+ saturation at pH 7·0 (the method used for the results in Table 1). The change in the activity coefficient of adsorbed K ions with fractional K saturation of the soil CEC (Deist & Talibudeen, 1967) suggests that the only sound theoretical basis for defining the K buffering capacity of a soil is the amount of K released or added to the soil per unit change in the partial molar free energy of soil potassium, i.e. a constant *proportional change* in the activity ratio $(AR)_K$ of the soil, rather than a constant *difference* in $(AR)_K$ values. Thus, $\Delta K/\Delta \log (AR)_0$ values correlate *directly* but not significantly with log $(AR)_0$ ($r^2 = 0{\cdot}090$), '16-week' yield ($r^2 = 0{\cdot}019$) and final

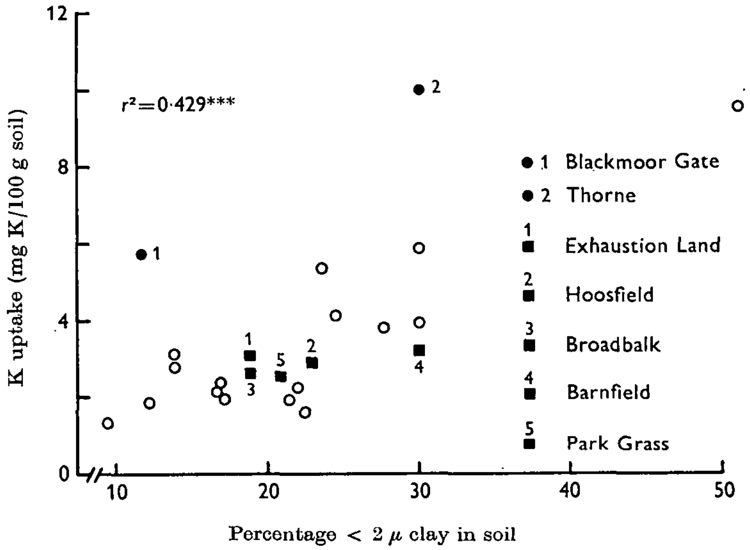

Fig. 5. K uptake in 12 weeks by ryegrass in the glasshouse from K-exhausted soils from different parent materials after one drying-and-wetting cycle.

yield (r^2 = 0·022), (r^2 = 0·104 at 0·1 significance level).

Changes in K uptake and soil K intensity during cropping show that the buffering capacities of K (C_m) in 'poor' and 'rich' soils show patterns similar to that of Rothamsted soils; i.e. rich soils had a small buffer capacity value up to 16 weeks (mean 37, range 6–75) and a larger value thereafter (mean 65, range 31–119); poor soils had a small buffer capacity value in the first 4 weeks (mean 10, range 6–17), a *negative* buffer capacity between 4 and 12 weeks (mean −56, range −23 to −245), and a large buffer capacity (mean 161, range 52–228) thereafter. PBC and C_m values for rich soils were slightly better related (b = 0·959 ± 0·339**) than those for the K-manured soils at Rothamsted; for 'poor' soils this relationship was not significant.

Statistical relationships between the K intensity, as log $(AR)_0$, of the uncropped soil and cumulative K uptake after 16 and 60 weeks cropping were slightly improved by allowing for variance from soil pH and organic matter content:

	% variance accounted for	Regression (b)
'16-week' yield		
single	70·5	45·1 ± 5·79***
multiple (with pH and % C)	72·5	44·5 ± 5·60***
'60-week' yield		
single	71·1	69·2 ± 8·73***
multiple (with pH and % C)	76·5	67·9 ± 7·93***

Potassium uptake by ryegrass from 'exhausted' soils after one drying-and-wetting cycle. That after cropping in the field, soils partly recover their ability to release more K and P is well-known. Garbouchev (1966) and Blakemore (1966) recorded seasonal fluctuations in soil K and P intensity for Rothamsted and Woburn soils which show periods of nutrient exhaustion and recovery. Vaidyanathan & Talibudeen (1965) measured increases in P intensity and isotopically labile P when soils exhausted to various degrees by resin treatment were incubated. The exhausted, or partially exhausted, soils mainly 'recover' because nutrient ions diffuse out of the interior of soil particles along a concentration gradient at a well-defined rate into positions more accessible to 'free' soil water (Vaidyanathan & Talibudeen, 1968). Other processes, drying-and-wetting, freezing-and-thawing, etc., considerably aid 'recovery' of K in the soil by peripheral weathering of soil particles. At the other extreme, when micaceous minerals are saturated with K^+ ions above a critical level and dried-and-wetted several times (Chaussidon, 1963), or when K^+ ions are added to soils containing K-selective minerals (Deist & Talibudeen, 1967), the added K becomes less easily exchangeable to other soil cations.

To measure the 'recovery' of soil K in 'exhausted, soils, they were air-dried once in the glasshouse at 23–33 °C for several weeks, and then cropped with ryegrass as before. Potassium release was similar to that between 16 and 20 weeks in the exhaustive cropping of the original soil but then soon decreased. Cumulative K uptake in 12 weeks ranged between one-fiftieth and one-third of the total K removed by the initial exhaustive cropping. Potassium released by 'exhausted' Rothamsted soils (Part I) in this way did not vary greatly between the experiments:

	K (ppm of soil)
5 Exhaustion Land plots (19% clay)	30 ± 7
4 Hoosfield plots (23%)	28 ± 2
2 Broadbalk plots (19%)	28 ± 4
6 Barnfield plots (30%)	31 ± 3
11 Park Grass plots (21%)	25 ± 10

But K released by 'exhausted' soils from different parent materials increased regularly with increasing clay content (Fig. 5) suggesting that the peripheral weathering of clay minerals was mainly affected by the drying and wetting cycle. The 'Blackmoor Gate' and 'Thorne' soils released exceptionally large amounts of K, indicating that minerals in other particle size fractions are also affected.

The soils were supplied by B. W. Avery and others of the Soil Survey of England and Wales. Statistical analyses were done by J. H. A. Dunwoody, and potassium and calcium analyses by P. D. Salt. Mrs B. M. Jephcott and, later, D. Mitchell helped in setting up and running the glasshouse experiment.

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