Rothamsted Experimental Station Report for 1968 - Part 2

ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1968

PART 2

HARPENDEN
HERTS
Harpenden 4671

LAWES
AGRICULTURAL
TRUST

Full Table of Content

The Minerology of Broadbalk Soils

A. H. Weir, J. A. Catt and E. C. Ormerod

A. H. Weir, J. A. Catt and E. C. Ormerod (1969) *The Minerology of Broadbalk Soils ;* Rothamsted Experimental Station Report For 1968 - Part 2, pp 81 - 89 **- DOI: https://doi.org/10.23637/ERADOC-1-2**

is evidently a grey-brown podzolic soil, whereas the dominant *Batcombe* variants (A and B) could be classed as red-yellow podzolic soils.

In the new U.S.D.A. classification (Soil Survey Staff, 1960; 1967), soils of humid regions with an argillic (Bt) horizon are divided between the Alfisol and Ultisol orders. Using current (1967) criteria, profiles 2 and 3, and presumably also profile 4, are Alfisols because the base saturation at 50 in. below the top of the argillic horizon exceeds 35%. Their morphology, and temperature and moisture regimes, place them in the sub-order of Udalfs. At the great group level, profile 2 (variant A) conforms to the provisional definition of Paleudalfs, comprising Udalfs that have thick argillic horizons with stronger chromas and redder hues than in Hapludalfs (typical grey-brown podzolic soils). The prefix *Pale* associates them with old ground surfaces, and implies that the B horizons may be relict formations. Profiles 3 and 4 are difficult to classify satisfactorily at this level because no allowance is made for the occurrence of lithological discontinuities in distinguishing Paleudalfs from Hapludalfs, and because the lower boundaries of the argillic horizons are ill-defined. On current definitions profile 3 could be a Hapludalf and profile 4 a Paleudalf, but these identifications are not consistent with the apparent genetic relationships of the soils.

An essential difference between the *Batcombe* profiles and profile 4 appears to lie in the fabric of the B horizons, which are bracketed as 'argillic' in the U.S.D.A. system. The brightly coloured Clay-with-flints B horizons in the former profiles have a predominantly sepic plasmic fabric with much moderately to strongly oriented clay, but with only a small proportion of identifiable argillans. In contrast, the brown B-horizon fabric in profile 4 has a predominantly asepic fabric with much less strongly oriented clay, most of which occurs as well defined argillans.

The Mineralogy of Broadbalk Soils

By A. H. Weir, J. A. Catt and E. C. Ormerod

Introduction and analytical methods. The mineralogy of Chiltern soils similar to those of Rothamsted Farm was first studied by Brown *et al.* (1956, 1957), Loveday (1958) and Avery *et al.* (1959). Stephen (1961) analysed the sand fractions from a profile in Broadbalk Wilderness, and Greene-Kelly (1954, 1956) studied clays from profiles in the Wilderness and surface soils of the arable plots. Weir & Ormerod (1968) described the clay mineralogy of surface soils from plots 3, 10 and 13 of Broadbalk sections IA, II, III and IV. However, the mineralogical composition of all the important size fractions from the various horizons of Broadbalk soils has never been published, and it is therefore necessary to fill in many of these details.

Samples from profiles 2, 3, 4 and 5 (see pp. 71–74), and surface soils (0–8 in.) from plots 3, 10, 13 and 15 of section II (sampled by the Chemistry

Department, 1966) were separated into coarse sand (>250μ), fine sand (50–250 μ), coarse silt (20–50 μ), fine silt (2–20 μ) and clay (<2 μ) fractions. Calcium carbonate was first removed from the samples by treatment with acetic acid buffered at pH 5 with sodium acetate, and organic matter was destroyed with hydrogen peroxide. The remaining mineral soil was then dispersed in a weak (0·1% w/v) solution of sodium hexametaphosphate by shaking for 16 hours followed by ultrasonic agitation for 5 minutes. The sand fractions were separated from the finer soil by sieving, and the clay and silt fractions were separated by repeated settling under gravity. The clay fractions were flocculated and Mg-saturated with magnesium chloride solution, then washed twice with water, twice with acetone, and finally dried from benzene. Clays from the four surface soils, and from selected horizons of profiles 2, 3 and 4 were further divided by centrifugation into coarse (0·1–2 μ) and fine (<0·1 μ) fractions after redispersion in dilute sodium hexametaphosphate solution.

The fine sands and coarse silts were separated into light and heavy fractions with bromoform (specific gravity 2·9) and analysed mineralogically with a petrographic microscope. The fine silts and clays were analysed by X-ray diffractometry of lightly compressed powders and oriented aggregates that were air-dried, treated with ethylene glycol vapour at 60° C for 4 hours or heated at 335 or 525° C. Quartz and felspar in the clays and both coarse and fine silt fractions were determined by the bisulphate fusion technique of Kiely & Jackson (1965). Amounts of amorphous silica and alumina, kaolinite and soluble iron oxides in the clay fractions were measured by the selective dissolution technique of Hashimoto & Jackson (1960). The quantities of potassium, sodium and calcium in hydrofluoric/sulphuric acid digests of the clays and in the quartz/felspar residues from the bisulphate fusions were determined by flame photometry. Cation-exchange capacities of the clay fractions were measured by a modification of Bascomb's method (1964).

Mineralogy of the fractions

Fine sand mineralogy. Table 5·3 shows the composition of fine sand fractions from the four profiles studied; sands from the four surface soils are mineralogically similar to that of the Ap horizon (0–7 in.) of profile 3. All the samples have somewhat similar assemblages of sand minerals, but there are a few small, yet significant, differences within profiles 2 and 3. The sands from higher horizons of these two profiles contain a little more felspar but rather less quartz than those from the deeper horizons, and in profile 3 the decrease of felspar content with depth is matched by a decrease in amounts of chlorite, garnet and epidote. Similar changes in the composition of sand fractions were noted in the Broadbalk Wilderness profile studied by Stephen, and also occur in the Batcombe series on other parts of the Chilterns (Avery *et al.* 1959).

The small amounts of chalcedony in many of the fine sands are, like the flint fragments, ultimately derived from the Chalk. Larger pieces of chalcedony are the main constituent of coarser fractions (>250 μ) from some of the deeper soil horizons (e.g. profile 2, 38–68 in.), and tabular

TABLE 5·3

Mineralogical composition of fine sand (50–250 μ) fractions from Broadbalk soils

	Profile 2		Profile 3					Profile 4			Profile 5	
Minerals	IIB1t (g) 8–20 in.	IIBt (g)/C 38–68 in.	Ap 0–7 in.	B1t 7–19 in.	IIB2t (g) 19–28 in.	IIB 3tg 28–40 in.	IIIBt g/C 40–60 in.	Eb/Bt (g) 9–16 in.	B1 t(g) 16–26 in.	IIB 3tg 37–46 in.	B1 10–16 in.	IIB′1g 21–28 in.
Light minerals (as % of fine sand)												
Quartz	91	94	92	92	93	95	95	90	90	90	92	90
Flint	2	2	2	2	2	3	2	1	1	2	2	2
Chalcedony	<1	1	<1	—	—	—	—	<1	<1	<1	<1	<1
Alkali felspar	5	2	4	5	4	1	2	6	6	6	5	6
Muscovite	1	<1	<1	<1	<1	<1	—	2	2	1	<1	1
Collophane	<1	—	—	—	—	—	—	—	<1	<1	—	<1
Calcite	—	—	1	—	—	—	—	—	—	—	—	—
Heavy minerals (as parts per thousand of heavy fraction)												
% heavy minerals in fine sand	0·6	0·6	0·6	0·6	0·5	0·8	0·8	0·4	0·4	0·6	0·6	0·6
Limonite	518	396	345	498	430	160	116	303	543	516	272	336
Haematite	145	127	215	74	122	88	43	120	103	108	106	170
Magnetite	110	134	135	152	138	200	264	180	128	120	198	157
Ilmenite/Leucoxene	52	47	42	52	77	66	45	88	72	45	61	93
Zircon	118	194	143	158	138	384	425	207	103	128	264	169
Tourmaline	14	27	12	8	22	17	20	34	9	18	10	16
Yellow Rutile	17	30	27	20	20	37	34	22	10	25	30	19
Red Rutile	5	11	11	3	12	14	19	12	6	8	14	6
Staurolite	8	14	9	7	11	12	12	8	9	10	18	10
Kyanite	4	6	6	5	6	8	7	7	4	8	6	7
Epidote	3	7	8	6	4	4	4	4	6	8	7	6
Garnet	1	1	4	2	2	1	—	—	2	1	4	5
Hornblende	—	—	2	—	1	—	—	—	—	—	—	1
Chlorite	2	—	27	11	8	—	—	7	4	2	2	2
Biotite	—	—	—	—	1	1	—	4	—	—	—	—
Andalusite	2	3	1	2	3	6	4	4	1	2	5	3
Anatase	1	3	—	2	4	2	4	—	—	1	2	—
Brookite	—	—	—	—	—	—	1	—	—	—	1	—
Sillimanite	—	—	—	—	—	—	1	—	—	—	—	—
Monazite	—	—	1	—	1	—	1	—	—	—	—	—
Bone fragments	—	—	12	—	—	—	—	—	—	—	—	—
Number of grains counted in light fraction	1322	1531	1514	1158	887	1314	1323	1143	1259	1328	1272	1415
Number of grains counted in heavy fraction	1587	1421	1955	1416	1397	1403	1124	835	1426	1595	1261	1185

fragments of optically similar chalcedony as large as 4 cm across are common in subsoil horizons of the Batcombe series in many parts of the Chilterns (Loveday, 1958, p. 128). These larger pieces often superficially resemble fragments of the shells of *Inoceramus* spp., which are common fossils in the Chalk. Further, thin sections of *Inoceramus* fragments from the Upper Chalk exposed near Redbourn (TL 124103) and elsewhere clearly show the partial replacement of the columnar calcite layer by chalcedony, and acid treatment of other fragments leaves a siliceous residue that is both macroscopically and microscopically similar to the chalcedony found in the Batcombe subsoil.

Pieces of microcrystalline calcite and partly mineralised bone fragments occur in all the surface soils examined, but are absent at greater depths. The calcite is the remains of chalk spread on the field at various times past. The bone fragments are probably also the remains of a crude fertiliser, but one used mainly before the beginning of the wheat experiment, because the fragments are as abundant in soil from plot 10 (no phosphate treatment since 1843) as in soil from the treated plots 13 and 15. They are composed of extremely thin fibrous weakly birefringent crystals. Some of the fragments are colourless, but others are partly impregnated with yellowish or reddish brown iron compounds. Their mean refractive index is variable, but commonly near 1·62, suggesting that most of the non-phosphatic organic compounds (collagen, etc.) of the bones have been removed.

The collophane present in some of the sub-surface horizons of the soils differs from the bone fragments in being composed of much smaller interlocking crystallites, in having a smaller refractive index (1·59) and being much darker brown. This form of collophane resembles that described by Hodgson *et al.* (1967) from the Reading Beds of Sussex and from soils shown to be developed in a thin cover of Reading Beds Clay overlying Chalk.

Coarse silt mineralogy. The coarse silt fractions contain similar mineral assemblages to the fine sands, but the amounts of some minerals vary much more than in the sand fractions. In particular, the decrease in amounts of felspar, chlorite, garnet and epidote and concomitant increase of quartz with increasing depth in profiles 2 and 3 are more evident in the coarse silt fractions (Table 5·4) than in the fine sands. The coarse silts from the higher horizons of these two profiles also contain more hornblende, but rather less zircon and tourmaline, than those from lower horizons. The mineralogical differences between horizons in these two Batcombe profiles again

TABLE 5·4

Mineralogical composition of coarse silt (20–50 µ) fractions from Broadbalk soils

	Profile 2		Profile 3					Profile 4			Profile 5	
Minerals	IIB1t (g) 8–20 in.	IIBt (g)/C 38–68 in.	Ap 0–7 in.	B1t 7–19 in.	IIB2t (g) 19–28 in.	IIB3tg 28–40 in.	IIIBt g/C 40–60 in.	Eb/Bt (g) 9–16 in.	B1t (g) 16–26 in.	IIB 3tg 37–46 in.	B1 10–16 in.	IIB′1g 21–28 in.
Light minerals (as % of coarse silt)												
Quartz	86	94	86	84	89	95	96	85	85	87	90	88
Flint	2	2	2	3	3	2	2	1	2	3	2	2
Alkali felspar	9	3	11	11	6	1	1	10	10	8	6	8
Muscovite	2	<1	<1	1	<1	<1	<1	3	2	1	1	1
Heavy minerals (as parts per thousand of heavy fraction)												
% heavy fraction in silt	1·2	0·9	0·8	0·7	1·6	1·2	1·0	1·1	1·0	1·0	0·8	1·0
Limonite	250	313	364	265	370	272	428	141	200	298	177	266
Haematite	65	50	69	47	104	56	37	63	80	38	59	24
Magnetite	176	154	89	128	101	136	101	130	148	123	127	158
Ilmenite/Leucoxene	160	193	123	116	138	158	83	137	160	168	138	132
Zircon	90	186	68	94	112	244	218	110	94	90	122	100
Tourmaline	36	44	14	18	35	35	58	31	34	32	33	23
Yellow Rutile	14	29	27	15	19	37	35	25	12	13	28	22
Red Rutile	4	5	6	4	5	8	3	7	4	3	5	3
Staurolite	3	5	5	4	5	7	9	8	5	5	13	7
Kyanite	2	4	4	5	4	5	4	8	4	2	8	2
Epidote	131	10	160	189	72	20	9	177	145	138	187	204
Garnet	15	1	8	4	3	1	2	27	15	5	13	7
Hornblende	17	—	14	17	10	2	—	47	18	16	33	14
Chlorite	25	—	34	78	14	3	—	68	66	57	35	26
Biotite	—	—	1	—	—	—	—	—	2	1	—	—
Apatite	4	—	2	3	1	—	—	14	7	5	3	5
Anatase	6	5	9	10	6	13	9	6	5	5	17	6
Brookite	2	1	3	3	1	3	4	1	1	1	2	1
Number of grains counted in light fraction	1753	1480	2047	1764	1712	1710	1849	1612	1598	1946	1450	1684
Number of grains counted in heavy fraction	1390	1564	1543	1547	2033	1750	1391	1067	1223	1465	1106	1189

suggests that most of the soil of Broadbalk developed in a stratified succession of at least two superficial deposits. The lower deposit (Clay-with-flints) is characterised by fine sand and coarse silt fractions containing at least 94% quartz, small amounts of flint and felspar, and heavy fractions dominated by iron oxides, zircon, tourmaline, rutile, staurolite and kyanite. The higher deposit generally contains more silt than the lower (Fig. 5·3), and mineralogically is distinguished best by its coarse silt fractions, which contain 84–89% angular quartz, 6–11% felspar, and heavy fractions yielding chlorite, epidote, garnet and hornblende in addition to the assemblage typical of the lower deposit. This suggests that the upper superficial deposit is composed partly of material derived from the Clay-with-flints and partly of a silt-rich and somewhat felspathic sediment resembling loess.

The coarse silts from all horizons of profiles 4 and 5 are mineralogically similar to those from higher horizons of the Batcombe profiles. In profile 4 this merely indicates that the upper superficial deposit is so thick that the Clay-with-flints was not encountered even at the maximum sampling depth. However, the coarse silt from the B1 horizon (10–16 in.) of profile 5 contains slightly more quartz, zircon and tourmaline, and a little less felspar and epidote than the same size fraction from the IIB′1g horizon (21–28 in.). This apparent reversal of the usual mineralogical change with depth in Broadbalk soils suggests that the colluvial material, in which the higher horizons of this profile are probably developed (see p. 70), was derived partly from the upper superficial deposit and partly from the lower.

Fine silt mineralogy. X-ray diffractometry of the fine silt fractions showed that they consist mainly of quartz, with variable amounts of felspar, small quantities of layer silicate minerals and traces of lepidocrocite or goethite. Quartz and felspar were determined chemically in fine silts from profiles 2 (IIB1t(g) and IIBt(g)/C horizons), 3 (IIIBtg/C horizon) and 4 (Eb/Bt(g), B1t(g) and IIB3tg horizons); the amounts range from 66% quartz and 13% felspar in profile 4, Eb/Bt(g) horizon (9–16 in.) to 91% quartz and 1% felspar in profile 3, IIIBtg/C horizon (40–60 in.). The fine silt from profile 2, IIBt(g)/C horizon (38–68 in.) contains similar amounts of felspar to profile 3, 40–60 in., but the other fine silts analysed from profiles 2 and 4 are mineralogically similar to profile 4 (9–16 in.). The layer silicates, which mainly occur in silt-sized aggregates of clay minerals, are mica, kaolinite, chlorite, vermiculite and an interstratified mica-vermiculite in the more felspathic samples, but only mica and kaolinite in profile 3, 40–60 in.

Clay mineralogy. Table 5·5 shows the mineralogical composition of coarse and fine clay fractions from selected horizons of profiles 2, 3 and 4. As soil variant A, represented by profile 2, occupies approximately 55% of Broadbalk (Fig. 5·2), clay similar to that from profile 2 (8–20 in.) is probably quite common in horizons of Broadbalk soils immediately beneath the plough layer. The clay fractions from profile 4 (9–16 in.) and profile 3 (40–60 in.) are the most dissimilar of all the clays from the profiles studied, and are from horizons which, on the basis of sand and silt mineralogy, contain the largest and smallest amounts of the upper, silt-rich superficial deposit. The IIBt(g)/C horizon (38–68 in.) of profile 2 also contains little or none of this silt, and comparison of the clay from this horizon with clay from profile 3 (40–60 in.) provides an indication of the range in clay mineral composition of the Clay-with-flints beneath Broadbalk.

TABLE 5·5

Mineralogical composition of coarse and fine clay fractions from Broadbalk soils

	Profile 2, IIB1t(g), 8–20 in.		Profile 2, IIBt(g)/C, 38–68 in.		Profile 3, IIIBtg/C, 40–60 in.		Profile 4, Eb/Bt(g), 9–16 in.	
	Coarse clay, 0·1–2 μ	Fine clay, <0·1 μ	Coarse clay, 0·1–2 μ	Fine clay, <0·1 μ	Coarse clay, 0·1–2 μ	Fine clay, <0·1 μ	Coarse clay, 0·1–2 μ	Fine clay, <0·1 μ
% Expanding minerals, interstratified expanding minerals and chlorite	50	52	44	53	34	41	33	47
% Mica & interstratified mica layers	15	10	16	8	12	11	23	12
% Kaolinite	16	22	17	24	27	32	18	24
% Quartz	7	—	10	—	12	—	12	—
% Felspar	<1	—	<1	—	<1	—	4	—
% Amorphous SiO_2 (NaOH soluble)	1·8	4·9	1·9	4·5	2·1	4·1	1·6	4·1
% Amorphous Al_2O_3 (NaOH soluble)	1·7	4·3	1·8	4·0	2·2	3·7	1·0	3·9
% Crystalline and amorphous Fe_2O_3 (soluble in dithionite-citrate)	7·9 (G,L)	7·2 (G)	8·8 (G)	6·5 (G)	10·1 (G)	7·6 (G)	6·8 (G,L)	8·4 (G,L)
Cation exchange capacity, m-eq./100g	37	58	36	58	24	48	29	64

G = Goethite present. L = Lepidocrocite present.

The coarse clay fractions from both horizons of profile 2 are composed mainly of expanding minerals, which are best described as randomly interstratified montmorillonite-vermiculite, because glycollation of Mg-saturated specimens expands the interlayer spacings from 14 Å to 16 Å (in the IIB1tg horizon, 8–20 in.) or to 16·2 Å (in the IIBt(g)/C horizon, 38–68 in.). Heating specimens to 525° C collapses most of the 14 Å layers to 10 Å; however, the 10 Å reflection tails to slightly larger spacings, indicating the presence of a little randomly interstratified mica-chlorite, and in the clay from the higher horizon (8–20 in.) a very small residual 14 Å reflection indicates a small chlorite component. K-saturation of air-dried specimens also causes partial collapse to 10 Å, but subsequent glycollation re-expands many of these collapsed layers to 14 Å. The fine clay fractions from profile 2 are also composed mainly of expanding minerals; they contain more kaolinite and amorphous silica and alumina than the coarse clays, but less mica and no quartz or felspar. The expanding minerals have similar swelling properties to those in the coarse clay fractions, but give broader diffraction peaks because the crystals are smaller.

The coarse clay fraction of profile 4, Eb/Bt(g) horizon (9–16 in.) differs from those of profile 2 in containing smaller amounts of expanding minerals but more mica and felspar. The 14 Å reflection of the expanding minerals in air-dried Mg-saturated specimens is not changed by glycollation. However, heating to 525° C causes partial collapse to 10 Å; there is a small residual 14 Å chlorite reflection, and tailing of the 10 Å peak to larger spacings indicates the presence of interstratified mica-chlorite. K-saturation of air-dried specimens also collapses many of the layers to 10 Å, but subsequent glycollation causes little or no re-expansion. The expanding mineral thus resembles vermiculite. The fine clay of profile 4 (9–16

https://doi.org/10.23637/ERADOC-1-2

in.) contains more kaolinite than the coarse clay, but less mica and no quartz or felspar. The expanding mineral of this fraction expands to 16·2 Å, and thus resembles the expanding minerals of the fine clays from profile 2 rather than the vermiculite-like expanding mineral of the coarse clay.

Both clay fractions from the loess-free Clay-with-flints horizon (IIIBtg/C, 40–60 in.) of profile 3 differ from the same size fractions of the Clay-with-flints in profile 2 (38–68 in.) in containing smaller amounts of expanding minerals but more kaolinite. As in profile 2 (38–68 in.), the expanding mineral in the coarse clay of profile 3 (40–60 in.) is a randomly interstratified montmorillonite-vermiculite; however, glycollation of Mg-saturated specimens cause expansion to nearly 17 Å, which suggests that the proportion of montmorillonite-like layers is greater than in the expanding mineral of profile 2 (38–68 in.).

The clay fractions of soil horizons containing appreciable quantities of loess-like silt (e.g. profile 4, 9–16 in.) therefore differ from those of the loess-free Clay-with-flints horizons (e.g. profile 2, 38–68 in.; profile 3, 40–60 in.) in containing vermiculite, chlorite and felspar. These clay minerals were probably introduced as part of the loess. A further difference between these two clay mineral assemblages was found by examining the *d*(06) reflections of the coarse clays by X-ray diffractometry by transmission through oriented aggregates. This gave reflections from kaolinite (1·488 Å) and dioctahedral 2:1 layer silicate minerals (1·498 Å). Coarse clay from profile 4 (9–16 in.) also gave a weak reflection at d = 1·533 Å, which represents not more than 10% of a trioctahedral 2:1 mineral. This may be the chlorite deposited as part of the loess, because a trioctahedral ferromagnesian chlorite occurs in silt and fine sand fractions of the same sample.

The clay fractions of surface soils (0–8 in.) from plots 3, 10, 13 and 15 of section II are mixtures of minerals typical of both the Clay-with-flints and of horizons containing loess. In particular, the expanding minerals in the coarse clays are partly vermiculite and partly interstratified montmorillonite–vermiculite. The coarse clays also contain small amounts of chlorite and felspar.

The subsoil horizons of profile 4 contain coarse clay minerals derived from loess, but the amounts of these decrease with depth. The only two horizons of profile 5 that were analysed mineralogically (B1 and IIB′1g) also contain coarse clay minerals derived from loess.

Distribution of potassium between size fractions of Broadbalk soils

Table 5·6 shows the amounts of potassium in Mg-saturated size fractions of four surface and six sub-surface samples of Broadbalk soils. The separation of total K into mica K and felspar K in the sub-surface soils is based on chemical analyses of the residues from bisulphate fusions and mineralogical analyses with the petrographic microscope. All the non-exchangeable, non-felspar K is given as ‘mica K’. Part of this occurs in micas that give a sharp 10 Å basal reflection in diffraction traces, and part is in mica layers interstratified with expanding or non-expanding 2:1 silicate layers. With present techniques we cannot measure the amounts of potassium occurring in these two forms. Differences between the percentage weights of size fractions given in Table 5·6 and the particle size distributions of the same samples (p. 77) result mainly from the different methods of particle size analysis used; in particular, the ultrasonic dispersion after shaking for 16 hours consistently increases the amount of clay at the expense of fine silt.

TABLE 5·6

Distribution of potassium between size fractions of Broadbalk soils

	Coarse sand (>250 μ)	Fine sand (50–250 μ)	Coarse silt (20–50 μ)	Fine silt (2–20 μ)	Coarse clay (0·1–2 μ)	Fine clay (<0·1 μ)	Total K in whole soil
Surface soils							
Section II							
Plot 3:							
(*a*) % weight of size fractions	3·7	12·0	36·3	26·0	10·4	11·7	
(*b*) % K in size fractions					2·23	1·21	1·16
(*c*) K in fractions as % of K in whole soil					20	12	
Plot 10:							
(*a*) % weight of size fractions	4·1	14·0	34·9	24·2	9·3	13·5	
(*b*) % K in size fractions		0·27	1·02	1·47	1·83	0·95	1·06
(*c*) K in fractions as % of K in whole soil		4	34	34	16	12	
Plot 13:							
(*a*) % weight of size fractions	4·9	14·8	35·1	23·8	9·2	12·2	
(*b*) % K in size fractions					2·15	1·23	1·10
(*c*) K in fractions as % of K in whole soil					18	15	
Plot 15:							
(*a*) % weight of size fractions	4·3	14·8	34·0	24·1	9·9	12·9	
(*b*) % K in size fractions					1·98	1·06	1·09
(*c*) K in fractions as % of K in whole soil					18	13	
Sub-surface soil horizons							
Profile 2, horizon IIB1t(g), 8–20 in.							
(*a*) % weight of size fractions	1·1	5·9	17·4	12·5	16·4	46·7	
(*b*) % K in size fractions		0·42	1·06	1·42	1·56	0·98	1·20
(*c*) % felspar K in size fractions		0·36	0·88	0·58	0·07	0	
(*d*) % mica K in size fractions		0·06	0·18	0·84	1·49	0·98	
(*e*) K in fractions as % of K in whole soil		2	15	15	21	38	
Profile 2, horizon IIBt(g)/C, 38–68 in.							
(*a*) % weight of size fractions	1·6	8·5	8·7	7·3	18·2	55·5	
(*b*) % K in size fractions		0·20	0·49	0·85	1·60	1·19	1·16
(*c*) % felspar K in size fractions		0·15	0·39	0·22	0·03	0	
(*d*) % mica K in size fractions		0·05	0·10	0·63	1·57	1·19	
(*e*) K in fractions as % of K in whole soil		1	4	5	25	57	
Profile 3, horizon IIIBtg/C 40–60 in.							
(*a*) % weight of size fractions	5·8	27·3	19·1	9·6	10·2	28·0	
(*b*) % K in size fractions		0·07	0·13	0·21	1·24	1·12	0·49
(*c*) % felspar K in size fractions		0·07	0·08	0·12	0·02	0	
(*d*) % mica K in size fractions		0·00	0·05	0·09	1·22	1·12	
(*e*) K in fractions as % of K in whole soil		4	5	4	26	53	
Profile 4, horizon Eb/Bt(g), 9–16 in.							
(*a*) % weight of size fractions	1·6	5·6	36·2	27·0	13·0	16·6	
(*b*) % K in size fractions		0·60	1·20	1·73	2·78	1·24	1·47
(*c*) % felspar K in size fractions		0·50	1·00	1·38	0·49	0	
(*d*) % mica K in size fractions		0·10	0·20	0·35	2·29	1·24	
(*e*) K in fractions as % of K in whole soil		2	29	32	25	14	
Profile 4, horizon B1t(g), 16–26 in.							
(*a*) % weight of size fractions	0·2	2·2	30·0	25·7	14·4	27·4	
(*b*) % K in size fractions		0·72	1·14	1·77	2·48	1·21	1·55
(*c*) % felspar K in size fractions		0·54	0·80	0·73	0·14	0	
(*d*) % mica K in size fractions		0·18	0·34	1·04	2·34	1·21	
(*e*) K in fractions as % of K in whole soil		1	22	29	23	21	
Profile 4, horizon IIB3tg, 37–46 in.							
(*a*) % weight of size fractions	3·4	6·2	29·7	21·9	11·8	27·2	
(*b*) % K in size fractions		0·42	1·06	1·57	2·20	1·17	1·35
(*c*) % felspar K in size fractions		0·37	0·84	0·75	0·11	0	
(*d*) % mica K in size fractions		0·05	0·22	0·82	2·09	1·17	
(*e*) K in fractions as % of K in whole soil		2	23	25	19	24	

Most of the potassium in the surface soil from plot 10, section II occurs in the silt fractions, and this is probably true of the three other surface soils from section II, because all four have similar particle size distributions and similar percentages of their total potassium in fractions coarser than 2 μ. The distribution of potassium between size fractions of soil from profile 4 (9–16 in., 16–26 in. and 37–46 in.), is also similar to that of the surface soil from Plot 10, except that the amounts of fine clay, and consequently of fine clay potassium, increase with depth. In contrast, most of the potassium in the IIBt(g)/C horizon (38–68 in.) of profile 2 and the IIIBtg/C horizon (40–60 in.) of profile 3 occurs in the clay fractions, mainly because the silt and fine sand fractions contain very little felspar. These differences in potassium distribution are essentially inherited from the two main parent materials in which the soils of Broadbalk have developed. Potassium-bearing sand and silt minerals are comparatively rare in the lower superficial deposit (Clay-with-flints), which forms the subsoil horizons of the Batcombe series; most of the potassium reserves in these horizons are therefore in the clay micas. In contrast, the large amounts of potassium in the silt fractions of the surface soils and of the sub-surface horizons of profile 4 are attributable mainly to the alkali felspar deposited as part of the overlying superficial cover of loess.

The felspar and mica in the coarser fractions of Broadbalk soils weather too slowly to provide an effective supply of potassium to plants, and the main natural source of potassium is probably the fine clay mica. However, we cannot confirm this by comparing the potassium distribution in soil from plots receiving no potassium fertiliser (3 and 10) with that of soil from the treated plots (13 and 15), because the lateral variation of the soils is too great and the exact depth of soil from which the wheat extracted potassium is not known. For example, the figures given in Table 5·19 show that approximately 0·6 tons K/acre have been removed in crops from plot 3 in 120 years; this is equivalent to 12% of the non-exchangeable potassium in the total clay fraction of the highest 9 in. of soil, yet the amounts remaining in the clay are as large as those in the clay from the surface soil of plot 13, which has received more potassium in fertiliser over the same period than has been removed in crops. Similarly, plot 10 has yielded 0·8 tons K/acre, which is equivalent to 16% of the non-exchangeable potassium in the clay of the highest 9 in., but the amount still in this clay is only 7% less than in that of plot 13. The potassium extracted by plants from the soil of plots 3 and 10 was therefore derived either from the clay micas from a much greater depth of soil than 9 in., or from micas and felspars in coarser fractions of the soil.

The Origin and Development of the Soils

By J. A. Catt*

The origin of Broadbalk soil parent materials and the changes they underwent during soil formation can be inferred partly from the morphological and petrographic characters described in the two previous sections, and partly from analogous studies of soils in similar geomorphological situations elsewhere in S.E. England. Comparison with similar soils in other areas is necessary because the complex history of soil development

---

* Written in consultation with the authors of the two previous articles and G. Brown.

Soil phosphorus. There have been studies by:

1. Dean (1938) who used the Broadbalk soils for his pioneering work on the fractionation of soil phosphorus.
2. Aslyng (1954) illustrated his ideas on phosphate potentials in soils by analyses of the Broadbalk soils.
3. Nagelschmidt and Nixon (1944) used an X-ray diffraction technique to show that superphosphate applied as fertiliser reverted to apatite in soil.

Soil potassium. K studies on Broadbalk soils are more recent. They include work by Talibudeen & Dey (1968) on activity ratios, by Addiscott (in press) on quantity/intensity curves and the relationship of buffer capacity to K saturation of the cation exchange complex, and by Arnold (1962) on potassium potentials.

Other elements. Rickson's unpublished work done in 1948 on the fluorine content of the Broadbalk soils showed that, though plots treated with superphosphate contained slightly more F (mean 0·022% F) than the untreated plots (mean 0·017% F), the individual figures fluctuated considerably. However, much of the added F had been lost from the 0–9-in. layers. Though there was no relation between F content and pH of the soil, there was an indication that F content was related to $CaCO_3$ content.

Little (1953) used some of the soils in his study on readily soluble sulphates in soils.

REFERENCES

ADDISCOTT, T. M. (1969) The potassium Q/I relationships of soils given different K manuring. *J. agric. Sci., Camb.* (In the press.)

ARNOLD, C. W. B. & PAGE, H. J. (1930) Studies on the carbon and nitrogen cycles in the soil. II. *J. agric. Sci., Camb.* **20**, 460–477.

ARNOLD, P. W. (1960) Nature and mode of weathering of soil potassium reserves. *J. Sci. Fd Agric.*, **6**, 285–292.

ARNOLD, P. W. (1962) The potassium status of some English soils considered as a problem of energy relationships. *Proc. Fertil. Soc.* No. 72, 25–37.

ASLYNG, H. C. (1954) The lime and phosphate potentials of soils; the solubility and availability of phosphates. *K. Vet. or Landbohøisk. Aarsskr.* 1–50.

AUBERT, G. (1965) La classification pédologique utilisée en France. *Pédologie, Gand* No. spéciale, 3, 25–56.

AVERY, B. W. (1964) *The soils and land use of the district around Aylesbury and Hemel Hempstead. Mem. Soil Surv. Gt Br.* 216 pp.

AVERY, B. W., STEPHEN, I., BROWN, G. & YAALON, D. H. (1959) The origin and development of brown earths on Clay-with-flints and Coombe deposits. *J. Soil Sci.* **10**, 177–195.

BASCOMB, C. L. (1961) A calcimeter for routine use on soil samples. *Chemy Ind.* 1826–27.

BASCOMB, C. L. (1964) Rapid method for the determination of cation-exchange capacity of calcareous and non-calcareous soils. *J. Sci. Fd Agric.* **15**, 821–823.

BLOOMFIELD, C. (1951) Experiments on the mechanism of gley formation. *J. Soil Sci.* **2**, 196–211.

BLÜME, H. P. (1968) Zum Mechanismus der Marmorierung und Konkretionsbildung in Stauwasserboden. *Z. Pfl-Ernähr. Düng. Bodenk.* **119**, 124–134.

BOALCH, C. H. (1953) *The manor of Rothamsted.* Harpenden : Rothamsted Experimental Station. 72 pp.

BOYD, D. A., COOKE, G. W., DYKE, G. V., MOFFATT, J. R. & WARREN, R. G. (1962) The Rothamsted Ley Arable Rotation Experiment. *Rep. Rothamsted exp. Stn. for* 1961, 179.

https://doi.org/10.23637/ERADOC-1-2

Bremner, J. M. (1949a) Studies on soil organic matter I. *J. agric. Sci., Camb.* **39**, 183–193.

Bremner, J. M. (1949b) Studies on soil organic matter III. *J. agric. Sci., Camb.* **39**, 280–282.

Bremner, J. M. (1950) The amino acid composition of the protein material in soil. *Biochem. J.* **47**, 538–542.

Bremner, J. M. (1955) Studies on soil humic acids. I. *J. agric. Sci., Camb.* **46**, 247–256.

Bremner, J. M. (1957) Studies on soil humic acids. II. *J. agric. Sci., Camb.* **48**, 352–360.

Bremner, J. M. (1959) Determination of fixed ammonium in soil. *J. agric. Sci., Camb.* **52**, 147–160.

Bremner, J. M. & **Harada**, T. (1959) Release of ammonium and organic matter from soil by hydrofluoric acid and effect of hydrofluoric acid treatment on extraction of soil organic matter by neutral and alkaline reagents. *J. agric. Sci., Camb.* **52**, 137–146.

Bremner, J. M. & **Jenkinson**, D. S. (1960) Determination of organic carbon in soil I. *J. Soil Sci.* **11**, 394–402.

Bremner, J. M. & **Lees**, H. (1949) Studies on soil organic matter II. *J. agric. Sci., Camb.* **39**, 274–279.

Bremner, J. M. & **Shaw**, K. (1954) Studies on the estimation and decomposition of amino-sugars in soil. *J. agric. Sci., Camb.* **44**, 152–159.

Brewer, R. (1964) *Fabric and mineral analysis of soils.* New York: John Wiley, 470 pp.

Broek, J. M. M. van den & **Waals**, L. van der (1967) The late Tertiary peneplain of South Limburg (The Netherlands). *Soil Survey Papers* No. 3. Netherlands Soil Survey Institute, Wageningen.

Brown, G. (1953) The dioctahedral analogue of vermiculite. *Clay Miner. Bull.* **2**, 64–70.

Brown, G. (1954) Degrading illite and potash fixation. *Nature, Lond.* **173**, 644.

Brown, G. & **Ollier**, C. D. (1957) *Rep. Rothamsted exp. Stn for 1956*, 62–63.

Brown, G. & **Yaalon**, D. H. (1956) *Rep. Rothamsted exp. Stn for 1955*, 57.

Chambers, W. E. (1953) Nutrient composition of the produce of the Broadbalk continuous wheat experiment, I. Changes over seventy years. *J. agric. Sci., Camb.* **43**, 473–478.

Crowther, E. M. (1947) The study of soil organic matter and organic manures by means of field experiments. *C.R. Conf. Pedologie mediterranéenne.* Montpellier & Algiers, 123–139.

Dean, L. A. (1938) An attempted fractionation of the soil phosphorus. *J. agric. Sci., Camb.* **28**, 234–246.

Deb, B. C. (1950) The estimation of free iron oxides in soils and clays and their removal. *J. Soil Sci.* **1**, 212–220.

Dehérain, P. P. (1891) L'acide phosphorique du soil. *Annls agron.* **17**, 445–454.

Dines, H. G. (1931) Geology of the Rothamsted experimental fields. *Rep. Rothamsted exp. Stn for 1930*, 59–61.

Dines, H. G. & **Chatwin**, C. P. (1930) Pliocene sandstone from Rothamsted (Hertfordshire). *Mem. geol. Surv. Summ. Prog. for 1929*, Pt. 3, 1–7.

Dyer, B. (1894) On the analytical determination of probably available 'mineral' plant food in soils. *J. chem. Soc. Trans.* **65**, 115–167.

Dyer, B. (1901) A chemical study of the phosphoric acid and potash contents of the Wheat Soils of Broadbalk Field, Rothamsted. *Phil. Trans. R. Soc. B* **194**, 235–290.

Dyer, B. (1902) Results of investigations on the Rothamsted soils. *Bull. Off. Exp. Stns. U.S. Dep. Agric.* No. 106, 180 pp.

Gasser, J. K. R. (1962) Effect of long-continued treatment on the mineral nitrogen content and mineralizable nitrogen of soil from selected plots of the Broadbalk experiment on continuous wheat, Rothamsted. *Pl. Soil* **17**, 209–220.

Gerasimov, I. P. & **Chichagova**, O. A. (1960) Two soil profiles at Rothamsted Experimental Farms. *Soviet Soil Sci.* 296–301.

Greene-Kelly, R. (1954) *Rep. Rothamsted exp. Stn for 1953*, 53.

Greene-Kelly, R. (1956) *Rep. Rothamsted exp. Stn for 1955*, 61–62.

Haines, W. B. & **Keen**, B. A. (1925) Studies in soil cultivation. III. Measurements on the Rothamsted classical plots by means of dynamometer and plough. *J. agric. Sci., Camb.* **15**, 395–406.

Hall, A. D. (1905) *The book of the Rothamsted experiments.* 1st edition, London: John Murray. 294 pp.

Hall, A. D. (1917) *The book of the Rothamsted experiments.* 2nd edition, revised by E. J. Russell. London: John Murray. 332 pp.

HALL, A. D. & AMOS, A. (1906) The determination of available plant food in soil by the use of weak acid solvents. *J. chem. Soc. Trans.* **89**, 205–222.

HALL, A. D. & PLYMEN, F. J. (1902) The determination of available plant food in soils by the use of weak acid solvents. *J. chem. Soc. Trans.* **81**, 117–144.

HALL, A. D. & MILLER, N. H. J. (1905) The effect of plant growth and manures upon the retention of bases by the soil. *Proc. R. Soc. B*, **77**, 1–32.

HASHIMOTO, I. & JACKSON, M. L. (1960) Rapid dissolution of allophane and kaolinite-halloysite after dehydration. *Clays Clay Miner.*, Proc. Seventh National Conference, London, 102–113.

HOBSON, R. P. & PAGE, H. J. (1932a) Studies on the carbon and nitrogen cycles in the soil. V. *J. agric. Sci., Camb.* **22**, 291–299.

HOBSON, R. P. & PAGE, H. J. (1932b) Studies on the carbon and nitrogen cycles in the soil. VII. *J. agric. Sci., Camb.* **22**, 497–515.

HOBSON, R. P. & PAGE, H. J. (1932c) Studies on the carbon and nitrogen cycles in the soil. VIII. *J. agric. Sci., Camb.* **22**, 516–526.

HODGSON, J. M. (1967) *Soils of the West Sussex Coastal Plain. Bull. Soil Surv. Gt Br.*, 148 pp.

HODGSON, J. M., CATT, J. A. & WEIR, A. H. (1967) The origin and development of Clay-with-flints and associated soil horizons on the South Downs. *J. Soil Sci.*, **18**, 85–102.

JACKSON, M. L. (1963) Aluminium bonding in soils; a unifying principle in soil science. *Proc. Soil Sci. Soc. Am.* **27**, 1–10.

JACKSON, M. L., HSEUNG, Y., COREY, R. B., EVANS, E. J. & VANDEN HEUVEL, R. C. (1952) Weathering sequence of clay-size minerals in soils and sediments: II. Chemical weathering of layer silicates. *Proc. Soil Sci. Soc. Am.* **16**, 3–9

JENKINSON, D. S. (1965) Studies on the decomposition of plant material in soil. I. *J. Soil Sci.* **16**, 104–115.

JENKINSON, D. S. (1966) Studies on the decomposition of plant material in soil. II. *J. Soil Sci.* **17**, 280–302.

JENKINSON, D. S. (1968) Studies on the decomposition of plant material in soil. III. *J. Soil Sci.* **19**, 25–29.

JENKINSON, D. S. (1969) *Rep. Rothamsted exp. Stn for 1968.*

KIELY, P. V. & JACKSON, M. L. (1965) Quartz, felspar and mica determination for soils by sodium pyrosulfate fusion. *Proc. Soil Sci. Soc. Am.* **29**, 159–163.

KUBIENA, W. L. (1953) *The Soils of Europe.* London: Thomas Murby. 317 pp.

LAWES, J. B. (1847) On agricultural chemistry. *Jl R. agric. Soc.* **8**, 226–259.

LAWES, J. B. & GILBERT, J. H. (1864) Report of experiments on the growth of wheat for 20 years in succession on the same land. *Jl R. agric. Soc.* **25**, 93–185.

LAWES, J. B. & GILBERT, J. H. (1882) Determinations of nitrogen in the soils of some of the experimental fields at Rothamsted, and the bearing of the results on the question of the sources of the nitrogen of our crops. (Paper read at the American Association for the Advancement of Science, Montreal, 1882.) *Rothamsted Mem. agric. Sci.* **5**, No. 19.

LAWES, J. B., GILBERT, J. H. & WARINGTON, R. (1882) On the amount and composition of the rain and drainage waters collected at Rothamsted. *Jl R. agric. Soc.* Ser. 2 **17**, 241–279, 311–350; **18**, 1–71.

LIEBIG, H. von (1872) Soil statics and soil analysis. *Z. landw. Ver.* (Abstract in: *J. chem. Soc.* (*Abstr.*) (1872) **25**, 318 and 837.)

LITTLE, R. C. (1953) Sulphur in soils. Pt. I. Determination of readily soluble sulphates in soils. *J. Sci. Fd Agric.* **4**, 336–345.

LOVEDAY, J. (1958) *A study of the soils and their relation to landscape form in the southern Chilterns.* Ph.D. Thesis: London University, 175 pp.

LOVEDAY, J. (1962) Plateau deposits of the southern Chiltern Hills. *Proc. Geol. Ass., Lond.*, **73**, 83–102.

MADOS, O. (1943) Eine Schnellmethode zur serienweisen Bestimmung der Adsorptionsungesattigtheit von Böden. *Z. Pfl-Ernähr. Düng. Bodenk.* **32**, 351–358.

MARÉCHAL, R. (1958) Contribution à l'étude des terrains superficiels de la région condrusienne. *Pedologie, Gand, Memoire* No. 1, 320 pp.

MAREL, H. W. van der (1954) Potassium fixation in Dutch soils; mineralogical analyses. *Soil Sci.* **78**, 163–179.

N.A.A.S. (1967) Fertilizer recommendations for agricultural and horticultural crops *N.A.A.S. Advisory Papers* No. 4.

NAGELSCHMIDT, G. & NIXON, H. L. (1954) Formation of apatite from superphosphate in the soil. *Nature, Lond.* **154**, 428–429.

PAGE, H. J. & WILLIAMS, W. (1925) Studies on base exchange in Rothamsted soils. *Trans. Faraday. Soc.* **20**, 573.

PETERSEN, G. W., CUNNINGHAM, R. L. & MATELSKI, R. P. (1968) Moisture characteristics of Pennsylvania soils. I. Moisture retention as related to texture. *Proc. Soil Sci. Soc. Am.* **32**, 271–275.

RICKSON, J. B. (1948) A semi-micro combustion method for the determination of organic carbon. *Analyst* **73**, 268–274.

RODÉ, A. A. (1960) How not to use analytic data in studying soil genesis. *Soviet Soil Sci.* 1250–1251.

RUSSELL, E. J. (1916) Chalking: a useful improvement for clays overlying the chalk. *J. Bd Agric. Fish.* **23**, 625–633.

SALTER, P. J., BERRY, G. & WILLIAMS, J. B. (1966) The influence of texture on the moisture characteristics of soils. III. Quantitative relationships between particle-size composition and available-water capacity. *J. Soil Sci.* **17**, 93–98.

SALTER, P. J. & WILLIAMS, J. B. (1969) The moisture characteristics of some Rothamsted, Woburn and Saxmundham soils. *J. agric. Sci., Camb.* (In the press.)

SIUTA, J. (1967) Gleying as an indicator of the water and air regime of the soil. *Soviet Soil Sci.* 356–363.

SOIL SURVEY STAFF (1951) *Soil Survey Manual.* United States Department of Agriculture. Washington: Government Printing Office. 503 pp.

SOIL SURVEY STAFF (1960; supplement 1967) *Soil classification: a comprehensive system, 7th approximation.* Soil Conservation Service, United States Department of Agriculture. 265 pp.

STEPHEN, I. (1961) *Rep. Rothamsted exp. Stn for 1960*, 77–78.

STUTZER, A. (1884) Bodenlösliche Phosphorsaure. *Chem. Ind., Düsseld.* February 1884, 37–42.

TALIBUDEEN, O. & DEY, S. K. (1968) Potassium reserves in British soils. *J. agric Sci., Camb.* **71**, 95–104.

THORP, J. & SMITH, G. D. (1949) Higher categories of soil classification: order, suborder and great soil groups. *Soil Sci.* **67**, 117–126.

TINSLEY, J. (1950) The determination of organic carbon in soils by dichromate mixtures. *Trans. 4th int. Congr. Soil Sci.* **1**, 161–164.

WALKER, G. F. (1949) The decomposition of biotite in the soil. *Mineralog. Mag.* **28**, 693–703.

WALKLEY, A. & BLACK, I. A. (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **37**, 29–38.

WARREN, R. G. (1956) N.P.K. residues from fertilizers and farmyard manure in long term experiments at Rothamsted. *Proc. Fertil. Soc.* No. 37, 3–33.

WARREN, R. G. & JOHNSTON, A. E. (1962a) The accumulation and loss of soil potassium in long-term experiments, Rothamsted and Woburn. *Proc. Fertil. Soc.* No. 72, 5–24.

WARREN, R. G. & JOHNSTON, A. E. (1962b) Barnfield. *Rep. Rothamsted exp. Stn for 1961*, 228–247.

WARREN, R. G. & JOHNSTON, A. E. (1967) Hoosfield Continuous Barley. *Rep. Rothamsted exp. Stn. for 1966*, 320–338.

WEIR, A. H. & CATT, J. A. (1965) The mineralogy of some Upper Chalk samples from the Arundel area, Sussex. *Clay Miner.* **6**, 97–110.

WEIR, A. H. & ORMEROD, E. C. (1968) *Rep. Rothamsted exp. Stn for 1967*, 70–71.

WHITAKER, W. (1889) *The geology of London and of part of the Thames Valley. Mem. geol. Surv. U.K.* Vol. 1, 556 pp.; Vol. 2, 352 pp.

WILLIAMS, R. J. B. (1968) *Rep. Rothamsted exp. Stn for 1967*, 237.

WILLIAMS, R. J. B. & COOKE, G. W. (1961) Some effects of farmyard manure and of grass residues on soil structure. *Soil Sci.* **92**, 30–39.

WOODWARD, H. B. (1904) The geological survey in reference to agriculture; with report on the soils and subsoils of the Rothamsted estate. *Mem. geol. Surv. Summ. Prog. for 1903*: Appendix I, 143.

YOUNG, A. (1813) *General view of the agriculture of Hertfordshire.* London: 236 pp.

https://doi.org/10.23637/ERADOC-1-2