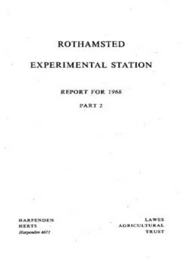
ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1968 - Part 2


ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1968

PART 2

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The Origin and Development of the Soils

J. A. Catt

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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.

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in superficial deposits overlying the Chalk can only be completely reconstructed by the study of profiles selected after soil mapping of much larger and geomorphologically more diverse areas than a single field.

Origin of the soil parent materials. The soils that occupy most of Broadbalk (the Batcombe series) have an evident textural change from a flinty, loamy topsoil to clay-rich subsurface horizons; this results partly from the occurrence of two lithologically distinct superficial deposits, which have been incompletely mixed, and partly from the translocation of clay from upper to lower horizons. Loamy soil extends to the base of the lowest horizons studied in soil variants C and D. All the loamy horizons have a predominantly asepic fabric, and their skeletal fractions ($>2\ \mu$) are dominated by silt composed of angular quartz and significantly larger amounts of alkali felspar, epidote, chlorite, garnet and hornblende than occur in silt fractions from the underlying clay-rich horizons. This mineral assemblage resembles that found in upper horizons of Batcombe soils and in other silty superficial deposits in many parts of southern England. The petrographic unity of this silt, which occurs in various physiographic situations, is consistent only with wind transportation, and the deposit is therefore best described as loess. However, the loess in the higher horizons of Broadbalk soils is strongly contaminated with material derived from the underlying superficial deposit (Clay-with-flints); for example, the surface soil contains many flints, and the B1t horizons of profiles 2 and 3 (p. 77) and the Bt horizons of profile 4 contain more clay than is usual in comparable horizons of *sols lessivés* in deep loess (Maréchal, 1958, pp. 105–129). This mixing probably resulted from disturbance by cryoturbation and/or solifluction under periglacial conditions during or after deposition of loess. The concentration of stones and sand in the surface soil relative to subsurface horizons possibly also resulted from periglacial disturbance, but may reflect the removal of fine soil fractions by lateral water movement. Some rearrangement of soil material by lateral movement after deposition of loess is indicated in soil variant D (profile 5 (page 74)), in which an upper, flinty colluvial layer is locally separated from a mainly stone-free horizon by a stone line.

The Clay-with-flints, which forms the lower horizons in the Batcombe profiles and also probably occurs at depth beneath soil variants C and D, has a dense sepic microfabric, and contains silt and fine sand fractions composed mainly of quartz and other extremely resistant minerals. The flint and chalcedony in these and in coarser size fractions are derived from the Chalk, but most of the silt and sand in the Clay-with-flints is mineralogically unlike non-calcareous residues from the Upper Chalk (cf. Weir & Catt, 1965). On geomorphological evidence the most likely source of this material is the basal Tertiary deposit (the Reading Beds), and the non-opaque heavy mineral suite in both the fine sand and coarse silt fractions of the Clay-with-flints is indeed similar to that of the Reading Beds in many parts of S.E. England. However, the extent to which younger formations (e.g. early Pleistocene marine or fluviatile sands) have contributed to the more sandy subsoil horizons cannot be determined; such deposits also

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might have been derived mainly from the Reading Beds, and would not necessarily differ mineralogically from the Clay-with-flints.

Development of profile morphology. The partly reddened fabric of the Clay-with-flints horizons in Broadbalk soils suggests that soil formation in a warmer climate than that of present day Britain occurred before the deposition of loess. Pedological reorganisation after deposition of loess is indicated by the local translocation and segregation of iron and manganese and by the development of well-defined Bt horizons in profiles 3 and 4 (pages 72–73). The large clay content of Bt compared with overlying horizons is partly attributable to illuvial accumulation, because thin sections of Bt horizons of these two profiles show many illuviation cutans; evidence of similar reorganisation in profile 2 is obscured by the fine texture of the B horizon and its predominantly sepic plasmic fabric. Much of the plasma in Bt horizons of the Batcombe profiles has also been modified by stresses resulting from alternate swelling and shrinking. Well-developed argillans also occur in the lower Clay-with-flints horizons; for example, at 21 in. and below in profile 3 there are thick bleached channel cutans similar to those that line channels containing remains of woody roots in soils under old woodland. However, it is not certain whether these formed during the same recent period of soil development as the argillans in the loess-containing horizons, or during the earlier period of pedological reorganisation before the deposition of loess.

Under natural woodland of the Chilterns, the Batcombe soil is strongly leached and characterised by the development of an Eb horizon. However, on Broadbalk the surface cultivation and additions of lime have produced a base-saturated soil, in which the Ap horizon normally rests directly on the Bt. Soil variants A, B and C are classified as *sols lessivés* with gleying, because there is evidence of gleying in their Bt horizons. Gleying also occurs at depth in variant D, but as this soil lacks a Bt horizon it is included in the group of undifferentiated brown earths (*sols bruns*) with gleying.

Origin and development of the soil clays. The clay fractions of British soils are complex multimineralic mixtures, because they are not equilibrium mineral assemblages. Some contain minerals inherited from two or more deposits, which accumulated in different physico-chemical environments from the present soil; others include minerals formed in the soil under past and present weathering regimes. Even the present physico-chemical environment of soil clays is continually changing in response to seasonal and daily changes of weather, to changing soil management and nutrient demand of crops. Changes leading to homogeneity of clays require higher temperatures and much longer periods of uniform physico-chemical conditions than occur in British soils, in which reactions rarely go to completion without temporary halt or reversal.

The clays in Broadbalk soils have been affected by all these complicating factors, and are consequently extremely difficult to characterise explicitly. They are mainly composed of expanding minerals, mica, kaolinite and free oxides of iron, aluminium and silicon. These minerals were either derived unaltered from the soil parent materials (mainly Reading Beds clay and

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loess) or attained their present form as a result of weathering and other pedological processes acting on clays and coarser mineral fractions. The full extent of mineralogical changes caused by weathering in Broadbalk soils cannot be described, because unaltered loess and Reading Beds clay needed for comparison with the soil clays are not available either on Rothamsted Farm or in its immediate neighbourhood. However, the changes in the clay fractions were probably similar to those described by Loveday (1958), Avery *et al.* (1959) and Hodgson *et al.* (1967) in other soils containing Clay-with-flints horizons. Loveday and Avery *et al.* showed that the clay fractions from Clay-with-flints of Batcombe profiles in Buckinghamshire contain more kaolinite but less montmorillonite than the Reading Beds clay, and attributed this to Tertiary or interglacial weathering. The main effects of prolonged weathering of the Reading Beds clay in Clay-with-flints of the Winchester series on the West Sussex Downs (Hodgson *et al.*) were a decrease in the size of clay particles and in the amounts of mica, and an increase in amounts of amorphous silica and alumina and of expanding minerals. Such changes are caused mainly by acid leaching, which would have affected the clay of Broadbalk soils for many thousands of years before the comparatively recent use of chalk and lime as soil dressings.

The main effect of acid leaching is to release potassium, silica, alumina and iron from the clay minerals. The removal of potassium from interlayer sites of micas allows the layers to expand; this may be regular expansion, as in vermiculite or montmorillonite (Walker, 1949), or irregular expansion, as in minerals in which the depleted layers are interstratified with potassium-retaining or other non-expanding layers (Jackson *et al.*, 1952; Arnold, 1960). There is evidence of both regular and irregular expansion in Broadbalk soil clays. The regularly expanding minerals might have been derived from the Reading Beds clay or the loess, or formed by the complete removal of potassium from micas. The irregularly expanding minerals were formed by partial removal of potassium from micas, or by interlayer precipitation of aluminium hydroxide (Jackson, 1963) in already depleted mica layers or in previously regularly expanding montmorillonite or vermiculite. The clay fractions, which largely determine the inherent fertility of Broadbalk soils and the response of crops grown on them to fertilisers, are therefore mineralogically complex, not only because they were derived from at least two different parent materials but also because of their weathering history. Both these factors are important in determining, for example, the distribution, release and fixation of potassium in the soils. The potassium taken up by crops grown on plots of Broadbalk not given potassium fertilisers was probably removed mainly from potassium-containing layers in fine clay formed largely by weathering of Reading Beds clay. However, some potassium was possibly derived from mica layers in coarser fractions or from the alkali felspar of the loess. Fixation of potassium from fertilisers applied to the treated plots probably occurs in potassium-depleted mica layers and in vermiculite-like expanding minerals (Brown, 1953, 1954; van der Marel, 1954).

Some of the iron oxides in the soil clays were probably derived from the Reading Beds, but the amounts of crystalline and amorphous sesquioxide

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minerals have been increased by precipitation of aluminium and iron mobilised from alumino-silicate clay minerals during the various weathering phases. Some of the aluminium freed by acid leaching subsequently entered the interlamellar space of 2:1 layer lattice minerals, and now occurs as hydrated cations in expanding layers, as polymerised aluminium hydroxide in non-expanding layers (chloritised layers), or in mixtures of and intermediates between these two forms. The complexity of X-ray diffraction patterns of the clays results largely from the intermingling of these various layers with non-expanding mica layers and freely-expanding montmorillonite or vermiculite layers. In Table 5·5 the 2:1 layers containing interlamellar aluminium are given as part of the interstratified expanding minerals and chlorite. Complex aggregations of different layers are typical of soil clays, but there is no satisfactory nomenclature for them. Minerals such as chlorite, mica, vermiculite and montmorillonite do occur in soils, but the exclusive use of such terms in describing soil clays inevitably involves oversimplifications.

Plant Nutrients in Broadbalk Soils

By A. E. Johnston

Soil sampling

The principal dates when the soils of all plots were sampled were 1881, 1893, 1914, 1944 and 1966; some plots were also sampled in 1856, 1865, 1904, 1923 and 1936. Although there are still a few samples at Rothamsted taken about the start of the Broadbalk experiment, suitable techniques for taking and storing samples were then unknown and it was not until 1856 that Lawes and Gilbert adopted a procedure they considered satisfactory. Samples were taken during autumn, after the crop had been removed but before ploughing, so that the soil was at its maximum compaction. The procedure, which was rigidly adhered to, was described in detail by Lawes & Gilbert (1882) and by Dyer (1902). It consisted of taking samples with an open-ended metal box of known volume; the depth was always 9 in., the cross-section usually 6 in. $\times$ 6 in., occasionally 12 in. $\times$ 12 in. The box was driven into the soil until the top edge was level with the surface. The enclosed soil was then carefully removed. Samples below 9 in. were taken by removing the soil from round the box so that it could be driven down again to the full depth of 9 in. Usually 3 or 4 depths were sampled but on some plots in October 1893, after the 50th crop, samples were taken to 90 in. To get these samples large holes 4 to 5 ft in diameter were dug. The soil from each depth was kept separately, back filled in correct order and consolidated with a wooden rammer. Manuscript notes indicate that it was impossible to detect the position of the holes from the appearance of the crop grown in 1894. Lawes and Gilbert subsequently regretted adopting 9 in. as the sampling depth for only shallow cultivations were possible with horses and on Broadbalk the plough layer was less than 6 in.

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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.

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