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ESSAYS IN APPLIED PEDOLOGY

II—SOME FACTORS IN SOIL MECHANICS

BY

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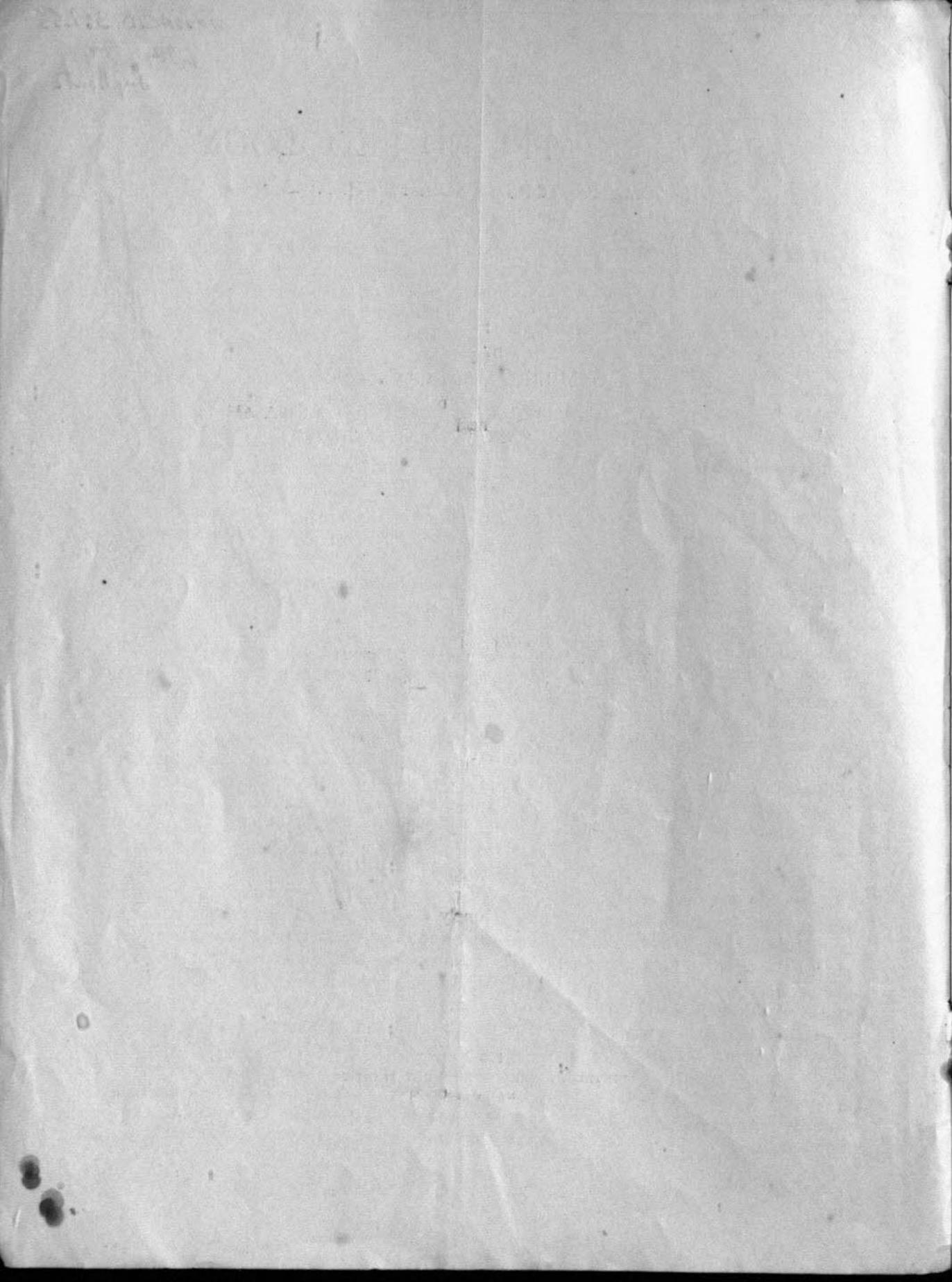
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Essays in Applied Pedology

II—Some Factors in Soil Mechanics

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[In the May, 1937, number of this Journal (Vol. II, pp. 465-469) extracts were given from a survey by Sir John Russell, written for the Royal Agricultural Society of England, summarizing certain recent advances in soil physics. The headings concerned the significance of soil crumbs, and moisture relationships. In the present article the first of these subjects is dealt with more fully, in an East African setting.]

INTRODUCTION ON TERMINOLOGY

In this discussion we are to be concerned with the ideas of *texture*, *consistence*, *structure* and *tilth*. I therefore begin by explaining the senses in which I shall use the words, more especially as the first of the four, as applied to soil, has hardly yet outgrown a loose usage of the past that has been responsible for delaying a clear understanding of the subject.

Suppose we treat a soil sample, by prolonged shaking in water and other necessary means, so as to undo all its natural cohesion and liberate each sand, silt and clay particle from its neighbours. If we measure the coarseness or fineness of the assemblage of ultimate particles so obtained, the result is spoken of as the *texture* of the sample.

In classifying soils according to this property there is a difficulty in the terms of verbal description that have to be employed. Texture can be judged pretty well in the field, with practice, by rubbing moistened soil between finger and thumb until all lumps and compound granules have been worked down to a paste. In thus arriving by sense of touch at an opinion of texture the observer must be careful to separate his appreciation of the ultimate fineness of grain of the sample

from what he perceives at the same time of its other mechanical properties. These other properties are those described below as consistence and structure. They are of such interest and importance that practical men have long been accustomed to judge them along with texture by testing the "feel" of a sample picked up in the field. In doing so they have not usually analysed their result but have tersely described the total of the observation, and the words that have entered the language for this purpose express the "feel" as a whole, not merely the textural element in it.

When therefore, in looking more critically into soil properties, we come to describe texture as a separate character, the available words of common language fail us; in ordinary usage they imply too much. The difficulty is not seriously felt with coarse-grained soils, the gravels, grits and sands, but such descriptions as *sandy loam*, *loam*, *clay loam* and *clay*, which for lack of better are in common use for the medium and fine-textured classes, carry with them notions of friableness, crumbliness or stiffness from their ancient origin in the conversation of English farmers. It will be seen presently that to imply these qualities when texture alone is being described may be seriously misleading when the discussion is no longer of familiar English soils. We need in fact a new set of terms (When they are introduced they will be complained of as incomprehensible scientific jargon.) In the meantime, in a discussion of particle size irrespective of anything else, we have to be guarded and circumlocutory if we are to avoid misunderstanding, or else we

must abandon verbal description and report texture by means of graphs or lists of figures.

For this last purpose it is international practice¹ to state the percentages of five standard particle-size groups, the coarser ones separated by sifting, the finer by sedimentation in water. The finer particles are thus actually determined by their rate of settlement, not by their size; but we may reduce the definition of all five groups approximately to diameters as follows: gravel, above 2 mm.; coarse sand, above 0.2 mm.; fine sand, above 0.02 mm.; silt, above 0.002 mm.; and "clay", below 0.002 mm. "Clay" in this particular sense thus means nothing more than particles smaller than a certain limit. As has already been noted, it is unfortunate that a word implying so much more to the practical man has been chosen for this restricted purpose.

Consistence takes account of the hardness, softness, brittleness or toughness of soil lumps when dry, of greasiness, stickiness, tenacity or friability when moist, or compactness, looseness or porosity in the mass, of resistance to the spade or the ploughshare or the wheel. It is thus a very practical matter, and must have interested all workers on the land since first an ingenious nomad made his wife thrust a digging-stick into the ground for planting barley. Pigs, moles and ant-bears knew about it even before that. Words appreciative or abusive of soil consistence were probably amongst the earliest added to language after agriculture began. In English a farmer sums up the property by one or other of the words "heavy" (or "stiff"), "loamy" (or "mellow"), and "light". Consistence is, however, a complex character, and it is not easy to measure exactly the qualities that enter

into it. The soil analyst has much progress yet to make in this department.

Structure relates to the size and shape of the compound units such as grains, crumbs, clods, and roughly recognizable solid geometrical figures, into which the individual particles and the organic matter of many soils are bound together in their natural state. It is revealed by the forms of the separate fragments into which a shovelful of fresh earth falls as it is tossed to the ground, or by the system of cracks that develops when an undisturbed mass of soil dries out. It can be best studied in well-weathered sections, such as the bank of a hillside road or the wall of an old pit.

Finally, *tilth* is the physical condition into which the topmost layer of a soil is brought by cultivation. Clearly it depends on all the other three properties and also on the treatment the soil has received. To be able to achieve the right kind of tilth at a given time of the year is always a major problem in any system of crop husbandry. In long-established systems on which generations of thought have been bestowed the problem has usually been solved for each soil type and each crop by accumulated experience, and the solution is flexible enough to meet any probable event of seasonable or unseasonable weather to best advantage. In pioneer agriculture, however, and in farming systems that still have only a generation or two of experience behind them, mistakes are easily made and may be costly. The black dust to which great tracts of ex-prairie soils have been reduced in North America is nowadays the standard example, but there are others familiar enough in East Africa, as on certain over-cropped maize lands and clean-cultivated unshaded coffee plantations.

¹ Except in the United States, where a somewhat more elaborate grading, of long standing there, has remained current.

Can the operations of ~~our~~ tillage, then, be rationalized, for the avoidance of such mistakes? We must obviously know more of the interrelations of texture, consistence and structure in our East African soils if we are to retain command of their expression as tilth.

OLDER IDEAS ABOUT TEXTURE

Texture, the proportion of coarse and fine ultimate particles in a soil, is of course a property that has been decided for us, mainly by the nature of the parent rock but also by the stage this has reached in breaking down to soil and the manner in which the resulting grains and particles have been shifted and sorted (if at all) by the action of gravity, water and wind. Except by impeding further shifting and sorting, we cannot control it but must accept what we find. Being thus a fundamental datum, texture early received attention when soil began to be a subject of laboratory study. The methods of what became known as "mechanical analysis" (another question-begging term which I should like to see replaced by the more straightforward "texture analysis") were developed on soils of the north-temperate zone: mostly young soils formed since the Ice Age, often on glacial deposits, or derived from older sedimentary rocks whose materials at some time long distant were assembled under water. It was in terms of such soils, a restricted group, distinctive rather than representative amongst the infinity of the world's soil types, that the results of "mechanical analyses" were first examined for their relevance to what was known of actual mechanical properties.

For English soils and Continental or North American soils of similar origin it became apparent that the proportion of "clay" particles as reported by the analyst went hand in hand with the degree of

stiffness experienced by the practical man in the field. Light soils consisted preponderantly of the sand fractions, and whenever the "clay" content went above 25 or 30 per cent, the sample could fairly be counted on to represent a heavy soil—strong land difficult to drain, needing considerable power for the draft of implements, not to be worked upon too soon after rain, and tending to afford a rough and cloddy tilth except under the most skilful management. Field behaviour could in fact be predicted from a mechanical analysis, with the aid also of information on such points as contents of organic matter and of lime carbonate.

Texture and consistence thus came to be regarded as closely correlated properties. Indeed, the first of the two words commonly did duty for both, and often, most regrettably, does so to-day. From about 1910 onwards advancing knowledge of clay as a chemical system led to some qualification of this too-simple view, but it remained substantially as the underlying assumption in textbook treatments of soil physics even in books published so lately as ten years ago. It played a large part in deciding survey methods in countries where organized soil survey was in progress.

TEXTURE AND CONSISTENCE IN TROPICAL SOILS

Let us now see how such an assumption works out on some representative East African soils. In Table 1 are given the textures of four pairs of samples, expressed in the customary manner by percentages of the four principal size grades; none of them contains an appreciable amount of gravel. In each pair the two sets of figures are seen to be closely similar. If it be added that none of the samples contains any lime carbonate or more than 4 per cent of organic matter, we should expect in each pair pretty

much the same working properties also. Actually, soils B, D, F and H are all friable and free-working. They readily part with excess water by drainage. Soils

TABLE 1
SOILS SIMILAR IN TEXTURE BUT DIFFERING
IN CONSISTENCE

	Coarse Sand	Fine Sand	Silt	Clay
	%	%	%	%
COAST BELT NEAR TANGA				
A 1998 Kasela ..	49.0	14.5	1.4	30.4
B 1984 Kange ..	47.5	18.3	1.7	31.3
USAMBARA HIGHLAND				
C 600 Baga ..	23.8	19.7	13.4	37.0
D 931 Sangerawe	24.4	21.6	11.3	34.5
USAMBARA FOOTHILLS				
E 418 Tengeni ..	27.0	14.2	3.3	52.0
F 2236 Mtingano	29.6	11.3	3.6	54.5
KIAMBU				
G 11 Uplands ..	0.1	3.5	6.5	75.7
H 1418 Kiambu	1.6	3.7	10.5	75.8

A, E and G, on the contrary, are intractably stiff, almost untillable when dry and waterlogged when wet, while soil C, not so extreme, is nevertheless a strong sandy-clay of considerable tenacity. Thus of each pair one is a light or fairly light soil, the other is a heavy one. Texture by itself in these samples is evidently no guide to mechanical properties as they manifest themselves in the field.

The simple assumption that heaviness is proportional to "clay"-content holds good in fact only so long as we are dealing with the same kind of "clay". The surprising differences exemplified above between texturally similar samples are due to fundamental differences in the nature of their finest fractions. Such differences readily come to notice in tropical soils. In the classical soils of

Britain, around which the familiar older textbooks were woven, they are less well marked and did not challenge attention.

THE NATURE OF "CLAY"

I have persisted with the inverted commas because so far I have used the word "clay" in the restricted sense of an item in a textural analysis, in which it denotes merely particles that fall below a certain limit of size. The materials included in this arbitrary group are not, however, a single kind of substance of universal properties. From soil to soil they may be chemically different bodies and be built to different patterns as crystalline minerals. From soil to soil also, and even from time to time in the same soil, these smallest particles may be in different states of individual and collective organization as complex colloidal systems, just as houses may differ in materials of construction and in plan, be differently furnished and be found detached from each other or connected up in streets and squares. (To make the analogy more perfect the collective organization should be thought of as mobile, like that of a houseboat town on a Chinese river.) Evidently we must know more about this "clay" complex than merely that the size of its ultimate grains is very small.

Clay (using the word now in a more general sense) results from the decomposition of the silicates of crystalline rocks. It may be a residue or it may be a re-compounded product. The chemical reactions that produced it may have followed their whole course in one place on a land surface during soil formation, or may have been resumed under water after the primary soil had been dispersed by erosion, or may have originated far underground. As an evolving constituent of a soil, a clay has been influenced by climate, acting through temperature

effects and through the amount and distribution of rain. It has been influenced by the chemical nature of the original silicates, and by the porosity of the decomposing mass. The topographic situation of the site has influenced it, according as surplus water has drained away freely, carrying off soluble products, or has tended to accumulate. The vegetation has influenced it—whether forest (and, if so, what type) or scrub, or heath, or grass, or the sparse cover of semi-arid country. It may be that man himself has been in occupation long enough to rank as a factor alongside these or in modification of them. In one or more of the respects mentioned the clay of to-day may in the past have had vicissitudes and a variety of experience, even to having been rebuilt temporarily into rock as a shale, or as the earthy ingredient in a limestone or the cementing agent in a sandstone. Finally, there is the question of maturity: how effectively have these various influences impressed themselves? Is the clay an end-product or is it an intermediate phase still evolving further?

It cannot yet be said that we understand the effects of all these possible factors in the genesis of a clay. But tropical soils form an especially favourable field for their observation, owing to the comparatively rapid pace of soil evolution in the tropics and the fact that certain extremes come under notice. With the aid of the advances made in European and American laboratories by specialists in the mineralogy and physical chemistry of clays, it becomes more and more possible to recognize in any given soil the kind of clay we are dealing with, and to limit expectations or guide practice accordingly.

At one end of the scale we have highly plastic clays characterized by minerals whose crystal structure and chemical composition confer a high capacity for

base exchange and for water absorption. Such clays respond markedly by swelling and shrinkage to changes in moisture content, and in their cohesion and perviousness they are sensitive to changes in the chemical bases that they hold exchangeably, especially to whether the predominant base is lime or soda. Clays near this end of the range have a high content of combined silica and, as originally formed, of bases also. We look for them in circumstances where silica and bases have never been lost from the parent-rock silicates, or alternatively where there has been opportunity for recombination with silica-bearing and alkaline waters. For various reasons the soils in North-European latitudes have often originated under such conditions.

In the humid tropics the conditions for the formation of plastic high-silica clays are fulfilled more rarely. Decompositions are rapid, leaching is exhaustive; with a few exceptions due to local causes the clays present in soils with free drainage in high-rainfall areas are far gone in development towards the more inert types presently to be considered. From swampy sites in humid country there is a copious output of overflow water which keeps the accumulating sediment in a leached and acid state, and although some rebuilding to secondary clay can take place, highly plastic clays are not formed.

As country of lower rainfall and drier atmosphere is entered, both the residual and the secondary clays of this group are more likely to be found. The climate of the present day being, however, only one factor, and not necessarily the determining one, the nature of the parent material and of the topography and the weathering and erosion of past times also play a large part in deciding whether the clay fraction of a given soil is of the highly reactive, base-binding, shrinking-and-swelling kind,

or not. In semi-arid East Africa such clays are to be looked for in the fine-textured dark-coloured soils of open rolling plains such as the Athi and Kapiti Plains and the part of Masailand that lies between Arusha and Lake Manyara. Here the parent rocks are basic volcanics and the leaching-factor has been low. Other extensive occurrences are in the calcareous grey soils of inland-drainage basins such as the Wembere Steppe and the Lake Rukwa Trough, where drainages from the surrounding highlands and plateaux have accumulated and evaporated after bringing in dissolved bases and silica.

On a more local scale the same effect appears in the many *mbugas*¹ whose black, grey or dark brown soils are so familiar to motorists and to road engineers under a general title of opprobrium: "black cotton soil". The notorious quality of earth roads on *mbuga* soils illustrates the characteristic qualities of this group of clays very well. When wet, a "black cotton soil," comparatively sandy-textured though it often is, is highly plastic and offers neither resistance to deformation by wheel-pressure nor friction against spin. It drains badly, being almost impervious once swelling has closed the pores. When drying after being kneaded under traffic, it sets into ruts that are first tough, then iron-hard. The change from the plastic to the tough state is brought about over a comparatively small range of actual moisture-content, and proceeds rapidly once drying has begun. If the wet soil has not been kneaded it retains its natural structure and splits into its structural units again, as it dries, by the reopening of cracks. It is clear that in cultivation such a soil needs very careful and well-timed handling, at a certain state of moistness only, if a reasonably good tilth is to be obtained.

There are also soils of quite coarse texture in which a little clay of this kind goes a long way in influencing mechanical properties, particularly in rendering sloping ground liable to destructive erosion. Examples occur in areas of badlands, as in the neighbourhood of Kondoa Irangi, and in certain unstable cuttings through the Pugu Hills on the Central Railway in Tanganyika. The conjunction of a coarse-sandy texture with a swelling-and-shrinking type of clay allows a porridge-like consistence to be developed at any surface that is wetted by heavy rain after drought; and if the slope and the bareness of the ground permit, the porridge rolls downhill, to be finally dissipated into clean sand and turbid floodwater.

The presence of a clay of this kind in soils not extremely coarse in texture reveals itself in dry weather in characteristic structural cracks. Sometimes the soil mass is split deeply into prisms and columns parted by fissures wide enough to thrust the hand into; sometimes it is divided into smaller angular units regularly packed. It will be seen later in this discussion that the structural pattern is determined not only by the nature of the clay and its quantity, but also by the amount of humus present and by the lime-status of both the clay and the humus. In general, soils containing high-silica reactive clay rank as *heavy* soils, within a given textural group. If not acid they are potentially very fertile, but often lie uncultivated because of their difficult mechanical properties and poor drainage. Their most usual natural vegetation in East Africa is grass of a tufted and erect habit, with or without an open scattered stand of acacia, frequently one or other of the gall-acacias or the large umbrella-thorn, *Acacia spirocarpa*.

¹ *Mbuga*, an open, grassy and seasonally wet lowland.

At the other end of the scale we have inert materials akin to china-clay, which bestow hardly any cohesion or base-binding power and give little sign of their presence in a soil except mere fineness of texture. Sandy soils containing up to 25 or 30 per cent of such clay are known which are hardly modified at all from a character of extreme lightness. Such are a widespread group of pale-coloured soils derived indirectly from granite and found under deciduous savanna woodland or closed deciduous thicket in the Central Province of Tanganyika. The same inert type of clay probably contributes much to the fine texture, but almost nothing to the total stiffness and reactivity, of the Kiambu red loam and its group in Kenya. Unless other clay types are simultaneously present, or there is sufficient organic matter in the right condition, the soil is structureless. It may cohere in irregular lumps on drying, but such lumps are brittle and easily powder down to dust.

Then, beyond the range of the true silicate clays, and doubtfully to be admitted under the name clay at all, are the sesquioxides, the oxides of aluminium and (ferric) iron, which bulk largely in the laterized red and yellow-brown earths of humid forested regions in the tropics and of some humid plateau grasslands. They are breakdown products of the silicate clays, from which silica has been removed. Like the inert true clays just considered, they contribute little to base-absorbing power or to stickiness, and soils containing even large amounts of them drain freely and remain friable.¹ They have their own qualities of weak cohesion which are manifested, in soils containing much material of this kind, as a fine porous structure not unlike the

weave of a rough towel. A well-weathered section of a sesquioxide soil shows the lines of parting of what might be large ill-defined pillar-like clods, but on digging the clods crumble, and if moist fall down to little more than a coarse meal.

Amongst materials that in particular soils come into the "clay" fraction must also be mentioned very finely abraded quartz dust, and amorphous redeposited silica in uncombined form. Certain crystalline secondary minerals such as talc also play a small part.

Soils not characterized to an extreme by any one of these main kinds of clay, but containing two or more of them simultaneously or intermediate forms not so well defined, are of course in a majority in cultivated lands. Only here and there does the cultivator deliberately select extremes amongst soil types, and then for some special crop or special farming system. Mixed agriculture flourishes best on soils that display a blend of mechanical properties imparted by more than one type of clay-substance. The blend is the result to date of various successive or concurrent processes of soil formation that have been at work on the given parent materials. Alternatively, it is desirable that a range of different soils, with its corresponding variety of clay types, shall be found within a short distance, so that a holding of reasonable size shall include all. This is often the state of affairs in undulating country where hillslopes alternate with broad bottom-lands. Two East African examples may be cited: the country of the Wasukuma, to the south of Speke Gulf on Lake Victoria, and that of the Wabondei in the foothills of Usambara. In such districts success in land-utilization requires a suitable adaptation of crops and their tillages to the

¹ For a description of a typical sesquioxidic soil as found under forest in East Usambara, see the previous Essay in this series, *E. Afr. Agr. J.*, Vol. III, pp. 11-16, 1937.

different soils, and especially to the different sets of physical conditions that go with clay characters.

A particular case of mixture of clay types must be briefly referred to as of common occurrence in tropical soils. The "clay" fraction of most well-drained soils derived directly from rocks containing iron-bearing minerals consists to some extent of ferric oxide in free condition. Especially is this true of soils that have evolved under equable and moderate to high temperatures, as in the tropics. In the warmer situations, or alternatively where there is a season of deeply penetrating drought, the presence of ferric oxide is shown by a red colour; but it may equally be present in hydrated condition in yellow, brown and chocolate soils. The statement applies even though the clay of such soils does not happen to be mainly of a sesquioxidic type and may contain no free alumina. The presence of a proportion of free iron oxide in the "clay" fraction partly accounts for the relatively free-working properties of tropical (well-drained) soils in general within their textural groups.

THE PART PLAYED BY HUMUS

The amount of clay and its nature, considered together, thus in a general way accounts for why one soil is stiff, another is moderately friable and a third is hardly held together at all. Twenty-five per cent of true plastic clay will make a soil effectively heavier than seventy-five per cent of fine material of less reactive type. The colloidal part of a soil, i.e. the sticky part (Greek *kolla*, glue), is not, however, only the clay. It is also the humus. Humus, like clay, has powers of absorption of water and of the chemical bases. It displays a very marked shrinkage as its water content falls. It becomes the

seat of acidity when the bas^es it holds are washed out by the long-continued action of percolating rain water. These properties it possesses in greater degree per unit weight than clay, even than the most highly reactive of the clays. According to estimates made on European soils, the maximum base-binding capacity per unit of humus is somewhere about five times as great as that per unit of the clay accompanying it, and where, as often in East Africa, a soil is fine-textured but friable, the ratio is likely to be higher. A small increase or decrease in humus-content therefore has a relatively large effect on the total manifestation of colloid properties.

Now the cohesive or structure-forming activity of both kinds of colloid depends on this base-binding capacity. Recently a very clear picture has been suggested¹ of the way in which electrical forces link together the colloid particles, which are electro-negative, through the basic ions which are electro-positive and the water molecules which are "dipoles". This picture does not yet lead to an explanation of the sizes and shapes of the resulting compound structural fragments that are revealed as the moist soil dries, but one important difference between the effects of clay colloid and of humus is a matter of common observation. Clay particles, if of the reactive kind, by themselves tend to form dense compact aggregates which are soapy when moist and which dry hard. These are the familiar clods of a clay subsoil; they vary in size and shape and in toughness or brittleness according as lime or magnesia or soda predominates amongst the active bases, and also according to the proportion of silt and sand particles included. Humus, on the other hand, renders the structural units porous and cellular; they become crumbs. The

¹ By E. W. Russell of the Rothamsted Experimental Station.

presence of humus therefore tends to modify either extreme of a purely clay-caused consistence in the direction of mellowness. A merely friable mineral soil, plus humus, becomes a loam; a stiff clay is puffed out and becomes a clay-loam; a sand or a fine-textured sesquioxidic material is bound together and becomes a light loam. In all three cases a satisfactory tith becomes possible, and with it are achieved greatly prized agricultural advantages in such matters as ease of cultivation, suitable seed-bed, efficient incorporation of manures, absorption of rain, resistance to shifting by water, admission of air to roots, and so on.

We have here the proper and original usage of the word *loam*, in which it denotes not a particular textural class but a certain kind of consistence and structure, a quality of mellow crumbliness imparted by a sufficiency of lime-saturated humus.

STRUCTURE UNDER DIFFERENT VEGETATION TYPES

A loamy structure, then, in whatever textural grade a soil may fall, is the ideal. It is not by any means universally provided by nature in virgin soils.

Forest land sometimes possesses the desired structure in its top soil, but only when leaching has not been excessive. The wetter types of East African evergreen forest at moderate elevations usually have a top soil that is revealed as mealy rather than loamy when once the interlacing mass of living roots and still-organized debris has been worked out by the early cultivations. At higher altitudes, where lower temperatures impede decay, the structure of the humus layer becomes peaty or waxy, while that of the mineral soil just below it becomes powdery. The lime-status both of clay-colloid and of humus-colloid is kept low by frequent and prolonged rinsing with rain water, and one of the conditions of good crumb

formation is not fulfilled. What under leaf litter and moist shade has appeared to the land prospector to be a "rich forest loam" falls short of expectations when brought under tillage; such structure as exists is not of a stable kind and quickly breaks down. Under lighter rain-falls, or when the soil's parent material was rich in bases to start with and has been slow to show the effects of leaching, humus comparatively rich in lime may accumulate in forest, and the result is a true loam. Examples of such forest loams, of dark brown colour and of excellent structure, occur on Kilimanjaro between the mist-forest belt and the upper edge of the *Combretum* savanna belt. Some localities in the less humid parts of the West Usambara highland have similar forest loams, coarse in texture through being derived from gneiss instead of lava. The coffee areas of Kiambu and Ruiru seem to have had topsoils of good structure originally, under the Kikuyu evergreen forest and its moderate rainfall of 1,000-1,250 mm. (40-50 inches).

The high temperatures of tropical lowlands favour decomposition rather than retention of humus, but the right conditions for forest loam formation sometimes occur in conjunction: shade, humidity, a low leaching factor, a parent material providing sufficient lime and a circulation of mineral elements through trees or shrubs. Thus the shallow chocolate soils found under coastal thicket on coral rock are true loams; they will be familiar to suburban gardeners at Mombasa and Tanga (Ras Kazoni) and at Dar es Salaam (Oyster Bay), unless excessive zeal in watering, together with exposure, has spoilt them. They are utilized in a form of shifting cultivation in the extensive "Wanda" country in the south of Zanzibar Island. There are probably considerable areas of such chocolate loams in reserve under the dense secondary bush

that has taken possession of the former slave-worked cultivations of the Kenya coast belt. Further inland, in Tanganyika, there are examples of good loams both on sedimentary rocks and on Basement Complex gneiss under evergreen light forests of the daisy-flowered tree *Brachylaena Hutchinsii*. A final example that may be mentioned is the topsoil of some of the abandoned 25-30 year old plantations of Ceara rubber, which were usually sited on good red earths of middle texture in areas of medium rainfall and which by a generation of neglect have grown into a form of forest.

grasses / Loamy structures are also characteristic of the soils of non-sour and non-swampy grasslands, particularly when they form a close turf. Here the humus has accumulated by a somewhat different process; not by leaf-fall upon the surface as in forests, but by implantation of residues in the soil itself by the decay of many successive ephemeral root-systems of grasses and herbs. Everyone is familiar with the way the soil under such a sod hangs together in crisp, firm, yet porous crumbs. It is this property, so long as it lasts, that contributes to make a ploughed grassland of the prairie type so attractive to the wheat farmer. The same property is one of the several advantages sought when land is put up into temporary ley in rotation with arable crops, as in increasingly being done wherever possible in the mixed farming districts of the Rift Valley in Kenya. Similarly, it is achieved under elephant grass on the red-brown soils of Mengo, Uganda, and contributes to the benefits of planting temporarily unused land with this grass after a period under food crops and cotton.

The loamy structure is less commonly found under open stands of grass of tufted habit, such as occupy immense areas in Tanganyika and Northern Rhodesia under the light and seasonal shade of *miombo*¹ woodland. Amongst tufted erect grasses the conditions of soil exposure and surface soil temperature are more akin to those between the spaced plants of a wheatfield. In *miombo*, also, the soils are usually leached and acid in reaction; but on the sides of rocky kopjes in such country, where the conditions of shade and exposure are similar but surfaces of fresh silicate rock are contributing currently to the maintenance of soil's lime status, the true loam structure is again found. The significance of lime status is illustrated further by the sour grasslands of the sandstone ridges of Bukoba, whose soils under their 1,900 mm. (75 inches) of rainfall have almost no structural cohesion, rich though they are in organic matter. The humus and clay-complex being acid, in this case with the added disadvantage that the clay is of sesquioxidic type, the crumb-forming mechanisms are not in operation. Finally, in regard to grassland, it is a general observation that the dark-coloured heavy soils of low-lying basins and grassy seasonal swamps are found at their structural worst when acid, or when, though neutral in reaction, they contain no lime carbonate in the upper horizons. When lime is plentiful right to the surface, their hardness in the dry state is mollified by the development of a fine meshwork of cracks.

LOSS OF STRUCTURE IN CULTIVATION

In certain favourable circumstances, then, natural processes have been at work

¹ *Miombo*, a mixed open woodland of slender, spreading, mostly pinnate-leaved trees of a number of species, with *Isoberlinia globiflora* and the genus *Brachystegia* as dominants; leafless annually during four or five rainless months and towards the end of that period usually swept by fire.

in the virgin soil that make for the ready production of a good loamy tilth when the land is broken for agriculture. Many soils will actually be in a less favourable state, either as virgin land of poorer type or as land originally in good order structurally but deteriorated through errors of handling; but for convenience we may take such an idea loam as the starting point. We know that two at least of the factors of structure are amongst the more susceptible, or adjustable, of soil properties, namely the amount of humus-colloid and the degree of saturation of the total colloid with bases, especially its saturation with lime. What then happens to our ideal loam when the forest is felled or the grassland broken, and season succeeds season under arable cropping?

In certain more permanent respects the conditions are unaltered. Amongst these there are the broad influences of climate, that is to say "standard climate" as recorded by the instruments in a screen. It may be that we should allow for the well-known change for the worse in the annual weather that sets in after the pioneer has begun to take records. Apart from this misfortune, however, which is common to most newly settled districts, clearing for cultivation has immediate effects on the climatic experiences of the soil itself. They may be summarized thus: greater daily extremes of temperature, exposure to full sunlight, severe drying of the topmost spit of soil, exposure to wind, exposure to the direct beat of falling rain. Besides these climatic effects there are the mechanical effects of the acts of tillage, which on the whole tend to break and powder the structural aggregates rather than to rebuild them. The point of balance of soil organic matter is altered, against accumulation and in favour of chemical breakdown. The restorative circulation of bases through forest trees or other natural plant

cover is interrupted and the rate of loss by leaching during rainy weather is much increased. There is some removal of lime and potash in the harvested crop.

Most of the tendencies in an arable soil, cropped continually without return, are thus towards loss of loaminess, for the elements of stability of crumb-structure, especially humus and lime, are affected at many points, and always adversely.

STRUCTURE-MAINTENANCE AS A DEFINITE POLICY

The tropical agriculturist and his advisers have heard much about replenishing humus, and since the Howardian rationalization of the rubbish-heap they are increasingly learning how to do it. Here is the same policy presented in the guise of rationalized soil mechanics. The question of liming has usually been looked at more narrowly. It has been approached rather from the angle of the field experiment or of the demonstrable need for liming some particular crop for plant-physiological reasons affecting growth and yield. By such a test, and on a short view, liming is often uneconomic on tropical crops, especially when cheap lime is hard to come by. For certain crops such as tea, liming must, we are told, definitely be avoided for good reasons of the plant-physiological kind. Such special crops apart, I recommend fresh attention to the subject of liming in East Africa, in its due conjunction with humus-manufacture and on its long-term merits as a means of preserving soil structure; of preserving it, that is, if happily it already exists; of building it up against contrary environmental tendencies, if it does not.

From time to time in the long history of agriculture in the British Isles, liming has in turn been fashionable and in turn neglected. Always the need for it has again been felt by those who value having their land "in good heart", and arrears

have been made up on a general scale almost irrespective of particular crops or particular soil types. This has happened under a climate that in many respects is much less hard on soil structure than are our tropical climates, whether humid or semi-arid. The British climate also has an invaluable structure-restoring element which we altogether lack, namely winter frost. Frost, by the pressures it exerts within a freezing soil and their release at thawing, reconstructs the units of soil structure and at the same time ensures that they are internally shattered and porous. It also restores swelling power to humus, which lost that power as it dried during the preceding summer. In East Africa, not even at the dizzy heights of Timboroa¹ are frosts experienced that will do what the British arable farmer has

always relied upon to have done for him as an annual event.

The East African cultivator is thus under obligation to do for his land not only the tropical equivalent of all that his British colleague does in this branch of soil management, but a good deal more; for in these latitudes nature withholds help and in one way or another is destructive of exposed soils all the year round. At his least ambitious level as an agriculturist, man is but an agent of these destructive forces, an earth-scratching animal. In that capacity he deserves the use of no more land than is required for a burrow. On any higher claim he must put himself in control and see to it that natural forces work for him constructively. In the field of tropical soil mechanics there is ample scope for improved management in this sense.

¹ Timboroa, an arable-farming district of Kenya, near the equator, at 9,000 feet above sea-level.

