

# CULTIVATION PROPERTIES OF TROPICAL RED SOILS\*

## INTRODUCTORY: GENERAL DESCRIPTION OF SOME EXAMPLES

**I**T must have been the common experience of many tropical agriculturists that red soils generally possess field properties quite distinct from those exhibited by brown and grey soils occurring even in the same district. The writer's attention was drawn to this distinction many years ago in Barbados, where residual red soils overlying and derived from coral limestone occur in regions of highest elevation and greatest geological age. Here, the red sugar-cane lands frequently show a remarkable natural crumb structure, which appears to be enhanced by tillage. Although many of the Barbados red soils may be classed as agricultural clays, their free drainage presents a striking feature, enabling the land to be ploughed or forked very soon after heavy rains have fallen.

It is only in recent years, however, that the peculiar physical properties of red soils have been specifically stressed in the literature of soil science. Although red soils were differentiated from other types by Hilgard, in his book *Soils*, few early writers gave any special consideration to them, and none attempted to explain their peculiarities in terms of physico-chemical composition. During the past fifteen years, however, red soils have been studied in greater detail, particularly by workers in the tropics and sub-tropics. The following selected references to some of the more recent work will serve to indicate the scope of the various contributions, and the opinions of various authorities.

*Hawaii.*—The soils of Hawaii have been studied by several investigators particularly by Burgess, who has stressed the peculiar features of dark red soils derived from basaltic lava. These soils are described as light and easily worked. Although clay-like when wet, they drain with great facility, and do not become compacted on drying, so that they may be tilled under conditions of rainfall impossible with clay soils of temperate regions. Their pore space is exceptionally high, and their high degree of aeration encourages root-development of sugar-cane, which produces large crops as a direct result of the effects of these desirable physical soil properties.

*South Africa.*—Some Transvaal red soils (derived mainly from dolerite) have been described by Marchand and his collaborators, in various papers published in 1924 and 1925. These soils have been contrasted with grey and black soils as regards physical properties. The red soils 'show on mechanical analysis much higher percentages of clay than one would suppose them to contain, judging from their behaviour in the field', and thus 'it is evident that the finally-divided hydrated ferric oxides which form such a considerable portion of the clay fraction do not behave as clay'. 'The

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grey and the black soils swell up enormously when wetted, while the red soils do not expand to any great extent, and have a much lower water capacity and pore space'. 'The field behaviour is also quite different. The red soils assume under proper cultivation a granular structure, and some of them have even been described by casual observers as sandy soils'

The peculiar properties of iron oxide in the red soil are regarded by the South African investigators as responsible for these differences. 'Not only do the ferric hydroxides have a flocculating effect on the clay, but a considerable portion of the so-called clay consists of ferric hydroxides or oxide which has not the properties of true clay'.

The coefficient of expansion of the Transvaal red soils on wetting varies from 4 to 14 per cent., whilst the black and the grey soils, containing the same range of clay, show expansions varying from 10 to over 45 per cent. of their original volume.

*Central America.*—In a paper published in 1926, H. H. Bennett, of the U. S. Bureau of Soils compared some of the physical properties of humid tropical and temperate American soils, and attempted to correlate them with the chemical composition of representative samples. To quote from Bennett's paper: 'In extensive areas from Guatemala to Columbia, the soil consists of red, buff and ochreous-yellow (mostly red) clay, showing frequently no conspicuous physical difference from place to place even though there is wide variety in the underlying rocks'. The chief characteristics of these Central American soils comprise '(a) greater friability and permeability than is commonly found in fine-textured soils of similar origin in the temperate zone, (b) the development of uniform red, yellow, and buff colours, and (c) exceptional profile uniformity.' Zonation is only faintly developed, a feature ascribed by Bennett to difficulty in elutriation and eluviation of the finer particles of these peculiar soils, which are immiscible with water, and therefore resist downward transportation into sub-soil layers.

The soils of eastern Costa Rica are so open and flocculent that 'rain water rapidly passes into and through the ground; and the soil exhibits such slight stickiness that the land can be ploughed during or immediately after a heavy rain to form a very granular tilth'. The texture is exceedingly fine (only 0.7 per cent. of the soil consists of particles coarser than silt), yet 'it is as friable as the mellowest loam, and, in the practical sense, is not susceptible to erosion.'

Chemically, the *friable* soils 'show a tendency towards an end-product having relatively low contents of silica and of bases, and comparatively high contents of iron and alumina.' Chemical analytical data for 24 representative samples taken from 7 soil profiles occurring in Honduras, Nicaragua, Costa Rica, and Panama, yield molecular ratio values for silica/sesquioxides that lie between 0.15 and 1.96 (average, 1.25). On the other hand, silica/sesquioxide ratios for *non-friable* Central American soils (24 samples) range from 2.00 to 11.60 (average, 3.71). In general, the higher the ratio, the more sticky and plastic is the soil, an observation which substantiates the less extensive previous data published by van Bemmelen for Javan soils, and later data presented by Joseph for Sudanese clays, and which is in accordance with results tabulated by Bennett for certain soils of the humid south-eastern region of the United States.

*Cuba.*—Bennett's description of tropical Central American soils was followed by the publication, in 1928, of the results of his extensive investigations (with R. V. Allison) of the *Soils of Cuba*. The range of Cuban soils is wide; at one end of the series, red ('sesquioxide') soils having low silica/sesquioxide molecular ratios (e.g. Nipe Clay; ratio, 0.31) are characterized by pronounced friability, and at the other end, brown, yellow, and grey ('siliceous') soils, having high ratios (e.g. Truffin Clay; ratio, 1.90 or over), exhibit high plasticity, stickiness, shrinkage and cracking on drying. Certain intermediate types (e.g. Limones series; ratio, 1.73), although red in colour, are siliceous in composition; they also are somewhat plastic and sticky.

A very extensive type of red soil occurring in Cuba is the *Matanzas Series*, derived from calcareous rock. 'This remarkable type, although containing in places more than 90 per cent. of clay, is so open-natured that it frequently takes up and rapidly disposes of nearly the entire rainfall, which in places exceeds 70 in. annually. Furthermore, it often shows no visible change in colour, texture, or stickiness from the surface to the underlying limestone rock at depths in places exceeding 25 feet.' The *Nipe* soil-type (derived from serpentine rock), already mentioned, is still more remarkable. The profile is uniform, often to a depth of 50 feet, and the soil 'is so friable and absorptive of moisture that pick marks exposed in sections to months of rain continue to stand out in almost perfect state of preservation, showing the negligible importance of erosion. Nowhere has a soil been found which shows a stronger resistance to erosion.' On the other hand, there occur in Cuba large areas of clay soil which are wholly different from the friable red types. These soils contain often more than 70 per cent. of clay, and are 'extremely plastic and sticky when wet, become extraordinarily hard, and shrink and crack violently on drying; they are relatively high in silica and low in iron and alumina, and show important physical zonation and chemical changes downward through the vertical section.' Sub-soil conditions, which control the success of cultivation methods in Cuban sugar-cane lands, naturally differ enormously in the different soil-types. Thus, in the *Matanzas* red soil, tillage can safely be carried to great depths, although not generally needed beyond depths of 12 to 16 inches, because of 'the good natural permeability of the soil.' The soil, moreover, 'can be cultivated within a few hours after saturating rains, without ill-effects, and without exhibiting undue stickiness.

*Barbados.*—The writer's experimental results for a typical Barbadian red clay soil, derived from coral limestone, are brought together in the accompanying table, where they are compared and contrasted with results obtained for a red soil derived from andesite in Dominica and for two grey soils occurring in Antigua. They indicate differences similar to those indicated by Marchand for the soils of the Transvaal, described in a previous section.

Recent work by Saint has further characterized the red soils of Barbados. Clay fractions separated from red and black soils showed silica/sesquioxide molecular ratios of 1.91 and 2.09 for the red soils, and 2.19 and 2.21 for the black. The black soils possess a greater base-exchange capacity than the red and, in each case, calcium comprises above 70 per cent. of the total exchangeable bases. On the other hand, the two types have almost identical mechanical composition (silt-and-clay content). 'The

behaviour of the red and black soils in the field, however, is more in accordance with their base-exchanging properties, and, from the practical standpoint, the red soils would be judged to have less colloidal properties than the black; they are more easily worked after rain than the black soils, and they are more quickly affected by drought. It appears that the inorganic colloidal matter of the red soils is of a different nature to the inorganic colloidal matter of the black soils; this matter is being further investigated.'

### COMPARISONS BETWEEN RED AND GREY SOILS

Chemical and Physical Soil Constants	Sesquioxide soils		Siliceous soils	
	Barbados red soil	Dominica red soil	Antigua grey soil (calca- reous)	Antigua grey soil (non- calcareous)
Molec. ratio; silica/sesquioxides	1.82	1.65	5.25	4.83
Mechanical composition (silt + clay%)	75.0	70.0	63.3	62.0
Relative settling rate (water-column)	100.0	98.0	92.0	0.6
Moisture-content at sticky point (P)	48.8	59.3	45.9	46.7
Hydrosopic coefficient (H)	20.6	17.8	12.0	13.0
Vesicular coefficient (P/H)	2.4	3.3	3.8	3.6
Maximum water-retaining capacity (M)	75.1	85.3	85.0	93.2
Shrinkage coefficient (linear%)	8.6	10.2	12.5	12.7
Volume-expansion (box)	17.2	23.2	61.3	66.8
Crushing stress (kg.) kneaded; dry	11.9	35.0	120.6	126.6
Crushing stress (kg.) unkneaded; granular	4.5	nil	12.9	30.2
Parting stress (kg. sq. in.), moist	2.1	0.8	5.0	6.3
Parting stress (kg. sq. in.), oven-dry	3.6	1.7	12.3	9.6
Green and Ampt percolation constants:				
Dist. (cm) traversed in 10 hrs.	23.4	12.4	6.8	1.9
Permeability constant for water	0.47	0.10	0.06	0.001

*Australia.*—In a recent bulletin describing the soils of Australia, Prescott states that deep-red loams, derived principally from basalt, occur within a zone of high rainfall in the east of the continent. These red soils contain a high proportion of fine particles, yet they are 'highly permeable, and possess a loamy texture; they are usually very deep and uniform, the parent basalt in many cases being 50 to 80 feet from the surface.' Prescott ascribes their high permeability to 'the flocculating effect of the free ferric hydroxide on the clay, a presumption which can be proved qualitatively by treating these soils with a reducing agent, such as zinc and dilute sulphuric acid; the iron is removed under these conditions, and the soils become much more plastic.' Sandy soils, derived from laterite, occur extensively in Western and Northern Australia. Prescott considers the soils of the western region as 'fossil podsol'; they are said to cover both granite and sedimentary formations.

*East Africa.*—Robinson mentions some unpublished results obtained by Milne for red soils of Tanganyika, two of which 'do not indicate a pronounced laterite development', but the third 'indicates a definitely

lateritic type of weathering complex.' Gracie has described the red soils of Kenya, which occur in the highland districts, where they are sometimes employed for growing coffee. The red soils are stated to be very absorbent, and to behave in the field as loams, although appearing from mechanical analysis to be heavy clays. Hornby has studied some soil series of Nyasaland, including the Cholo red loams, whose deep sub-soils 'may consist almost entirely of kaolin and quartz', and the Zomba soils, considered to be semi-humid lateritic soils. He considers that the colloidal iron-oxide component of these red soils, 'by flocculating the clay proper, often causes the soil to appear much sandier than it really is.'

*West Africa.*—The laterite and lateritic soils of Sierra Leone have been discussed by Martin and Doyne mainly with regard to the chemical aspects of their formation from norite. The results of these studies have greatly stimulated the investigation of tropical red soils within the British Empire. Similar soils probably occur within other humid regions of equatorial West Africa, but they appear so far to have received little detailed consideration.

*India.*—Soils that may be laterite, and lateritic types, appear partly to occupy the southern area of the peninsula, and also to occur in Assam and near Bombay; similar soils also occur in Ceylon. Detailed information regarding their origin and field behaviour seems, however, to be lacking, although the recent work of Eden in Ceylon has indicated that, in some respects, certain tea soils of that country somewhat resemble the lateritic soils of Sierra Leone.

### CLASSIFICATION OF RED SOILS

Following modern authorities (G. W. Robinson, E. J. Russell), red soils may broadly be classified according to the degree of hydrolytic weathering, and the nature of the parent rock, and according to their chemical composition, into the following main types:

- A. *Red soils derived chiefly from basic and intermediate igneous and metamorphic rocks.*
  - 1. Laterite soil.
  - 2. Lateritic soil (red earth).
  - 3. Red loam.
- B. *Red soils derived from calcareous rocks.*
  - 4. Tropical limestone soil.
  - 5. *Terra rossa.*
- C. *Red soils derived from sedimentary rocks.*
  - 6. Soil whose parent material is red.

A brief description of the chief features and probable mode of origin of these soil-types may aid in a better understanding of their chemical relationships and physical properties.

1. *Laterite soil.*—This is directly derived from laterite, which may be regarded, according to the simplest pedological definition, as a residuary rock produced by the weathering in hot humid climates (usually exhibiting alternations of wet and dry seasons), of basic and intermediate igneous rocks chiefly. It consists essentially of sesquioxides of iron and aluminium (particularly hydrated alumina, of which gibbsite  $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ , and diaspore,  $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ , are types), together with secondary crystalline quartz and certain other less characteristic components; such as manganese oxide and

titania. Kaolinitic minerals are generally absent and may indeed never have been formed, even as intermediate products. The structure of laterite is typically vesicular, vermicular or slaggy. The rock may be soft, but may harden on exposure, probably because of dehydration or of molecular rearrangement (ageing) of colloidal hydrous iron-oxide components. Chemically, therefore, laterite is characterized (*a*) by a low silica/sesquioxide ratio, (*b*) by a relatively high content of combined (constitutional) water, which, in the purer gibbsitic types of laterite (bauxite), may approximate to 33 per cent., and (*c*) by the almost complete absence of oxides of alkali and alkaline earth metals, and magnesia. Laterite soils are therefore generally infertile, and are seldom cultivated. They are not usually colloidal, and are porous and sandy in texture. Their distribution appears to be limited, and few examples have been accurately described.

2. *Lateric soil (red earth)*.—The origin and relationship to laterite of this soil-type are still largely subjects of conjecture, although evidence has been recently adduced that red earth may be derived from laterite by a process of re-silication by ascending ground water. Chemically, red earth is characterized (*a*) by a relatively high silica/sesquioxide ratio, due to the presence of aluminosiliceous minerals, (*b*) by a medium content of combined water, and (*c*) by low contents of bases. Frequently, small shot-like concretions, consisting of iron oxides, together with other components of laterite in smaller amount, occur throughout the profile, particularly in its upper layers, and especially when the soil has been exposed to downward leaching. In extreme cases, leaching may result in podsolization, yielding a quartzose, bleached, surface layer, underlying vegetable litter. Red earth is very deep, and often fairly fertile; its physical properties have already been described by references to examples that occur in many humid tropical countries.

3. *Red loam*.—This may be regarded as an immature lateritic type of soil, in which siliceous minerals greatly predominate, and sesquioxides are subsidiary. It is characterized chiefly by a high silica/sesquioxide ratio, which may approximate to that of typical temperate brown earth. Red loam is often fertile and deep; plastic and cohesive when wet, but hard and cloddy when dry. The lower layers may be mottled, and yellow or pink in colour.

Red loams frequently develop in regions of relatively low rainfall and low temperature, such as obtain in parts of East Africa (Tanganyika, Uganda), and even in the south-eastern United States of America (Carolina, Alabama), and in Indo-China. They may perhaps occasionally be derived from the more acidic igneous and metamorphic rocks, such as diorite and quartzose gneiss, or from their fragmental and sedimentary equivalents. Red loam may therefore be regarded as an intermediate type, linking up tropical lateritic soils with sub-tropical or temperate brown and grey soils, and they may include red soils derived from rocks with a relatively high content of silica.

4. *Tropical limestone soil*.—This type of red soil may develop in vast thicknesses from hard limestone, but apparently not from soft limestone, chalk, or marl, which usually yield black or dark-coloured (dull brown or grey) soils (rendzinas). Tropical red limestone soils occur notably in Cuba and other West Indian Islands (Puerto Rico, Haiti, Jamaica, Virgin Islands, Barbados, etc.). The profile is very uniform, and the transition between soil and parent rock is abrupt. Calcium carbonate may be almost entirely

absent, and the reaction is usually acidic. The soil closely resembles red earth in physical characters. Free sesquioxides, notably iron oxides, are often abundant, but the silica/sesquioxide ratio is usually relatively high (i.e. above 2.0). Concretions, rich in iron oxides ('shot', 'perdigon'), frequently occur therein, and may become concentrated in the surface layer through erosion or elutriation, thus enhancing the loose, open structure. Similar, though shallower red soil overlies hard limestone in sub-tropical or even temperate regions, such as North America and Europe.

5. *'Terra rossa'*.—This red soil, typical of the Mediterranean region, closely resembles in its composition certain red loams, although it may sometimes approximate to brown earth. Its origin is doubtful; illuviation processes may have contributed to its formation.

6. *Soils derived from red sedimentary rocks*.—These soils occur in regions where past climates have produced red rock-weathering products that have accumulated as sedimentary or colluvial deposits. Such parent materials may give rise to soil of red colour during some subsequent geological era. A typical example is the red soil derived from Triassic ferruginous sandstones in western Europe.

### MINERALOGICAL COMPOSITION OF LATERITIC SOILS IN RELATION TO THEIR PHYSICAL PROPERTIES

The chief mineral entities that occur in lateritic red soils appear to be: (1) hydrated alumina, (2) hydrated and hydrous alumino-silicates, (3) hydrated and hydrous ferric oxides, and, less conspicuously, (4) anhydrous quartz. Subsidiary minerals, such as manganese ores and titania, sometimes occur in addition. Alumino-silicates may perhaps be partly replaced by ferro-silicates (nontronite), and certain intermediate decomposition products (such as chlorite), or even unaltered primary minerals of the original parent rock, may occur in exceptional cases.

1. *Alumina*.—In the free state alumina appears to occur almost exclusively in lateritic types of soil as a non-colloidal, inert, crystalline hydrate (e.g. gibbsite,  $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ), in which the elements of water or water molecules are intimately bound up in the space lattice, and are not removable by mere drying at air-temperatures.

2. *Alumino-silicates*.—Whether or no the alumino-silicate minerals of lateritic products are of the kaolinite type, or of the montmorillonite-beidelite-bentonite type seems not yet to have been determined by X-ray methods. According to Robinson 'it is to be regretted that most of the investigations by X-ray methods hitherto conducted have been on soils of secondary weathering. Results from soils formed by direct weathering of crystalline rocks would be of the highest interest and significance in elucidating the nature of the process of clay formation.'

Some indirect evidence, based on physical properties, may nevertheless be adduced in favour of the hypothesis that lateritic types of soils (red earth and red loam) contain kaolinitic minerals rather than minerals of the montmorillonite-beidellite-bentonite type. Lateritic clays and kaolin show striking resemblances. Thus, both seem to exhibit small total shrinkage and small 'residual' shrinkage, even though they can take up considerable amounts of water (sticky-point moisture); both have low base-exchange capacities; and both are extremely sensitive to flocculation. Furthermore, both types of clay possess small cohesiveness, at least over the low-moisture

range. The peculiar colloidal behaviour of kaolin thus stands out in marked contrast to that of the plastic, highly hydrous monmorillonite-beidellite-bentonite, alumino-siliceous clays, which appear to occur mainly in sedimentary types of soil, namely, brown and grey earths. Whilst general experience and sporadically recorded facts support these statements, there is urgent need of much further specific investigation of the physical properties of the contrasted types of clay before final pronouncement can be made. The fundamental difference between lateritic types of soil and the more siliceous, temperate types, may thus lie in the nature of their alumino-silicate components, and not solely in the occurrence in the former of free hydrous alumina, or even of hydrous iron oxide, as has sometimes been assumed.

3. *Ferric oxides*.—Mineralogists distinguish at least six naturally-occurring ferric oxides, namely, haematite ( $\text{Fe}_2\text{O}_3$ ), turgite ( $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ ), goethite ( $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ ), limonite ( $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ), xanthosiderite ( $\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ ), and limnite ( $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ). Of these, goethite alone is a definite crystalline mono-hydrate. Haematite is anhydrous, and limonite is regarded as an amorphous form of goethite. The others are hydrous mono-hydrates, containing variable and indefinite amounts of adsorbed water, which is lost on heating at relatively low temperatures.

The colours of hydrous ferric oxides vary between brown purplish-red, crimson, orange, and yellow. Haematite is generally bright red; turgite, yellowish-brown; goethite, crimson, or yellow; limonite, brownish-yellow; xanthosiderite and limnite, bright yellow. The coloration is generally attributed to particle size, yellow colours accompanying high dispersion, and red colours, agglomeration. The red colours of laterite and lateritic soils are usually ascribed to the presence of haematite or goethite.

Some evidence of the nature of the ferric-oxide component of red soils has been obtained by the writer by an alizarin-adsorption method, which has indicated that it is more reactive than either of the first four minerals in the above list, but not so reactive as artificial preparations of 'ferric hydroxide'. Since the reactivity of hydrous ferric oxide (including perhaps alizarin-uptake) is believed to increase with increasing adsorbed-water content, at least a part of the ferric-oxide component of red soils may be highly hydrous. Furthermore, since highly hydrous ferric oxides generally show yellow colours, most lateritic types of soil may contain, in addition, unreactive red ferric oxides of a lower degree of hydration.

If we accept the probable presence of reactive hydrous iron oxides in many red soils, the amphoteric properties of these substances might play a significant part in the flocculation phenomena of red soils, and may partly account for their peculiar and striking properties in the field. The isoelectric point of reactive hydrous ferric oxide is believed to lie near neutrality (i.e. at pH 6.5), so that, in red soils of high to moderate acidity (pH below 6.5), ferric oxide would tend to behave as an electro-positive colloid (or colloidal cation) and to precipitate electro-negative colloids, such as alumino-siliceous clays, including particularly flocculation-sensitive kaolin. Such a possibility should at least be amenable to experimental test.

Finally, the stabilization of the floccules into crumb-forms which appears to be characteristic of cultivated red lateritic types of soil, may be attributed to the irreversible dehydration of active hydrous ferric oxide precipitants or binders, which is a distinctive feature of these substances.