OBSERVATIONS ON PEDOLOGICAL FACTORS THAT MAY LIMIT THE PRODUCTIVITY OF SOILS OF THE HUMID TROPICS

G. AUBERT,

Chief, Soils Services, National Office of Overseas Scientific and Technical Research, Paris, France

The following observations are directed only towards those soils that can be considered as characteristic of the well-drained soils of the inter-tropical humid regions. Intentionally left out of this rapid study are soils such as those with impeded drainage, peaty or highly organic, or even those more or less low in organic matter but presenting features of gleys or pseudo-gleys, leached or otherwise, or, rarely, of podzols and, more frequently, of sheet pseudo-podzols. Also excluded are young, little-developed soils from transported material, or rejuvenated by erosion.

The present paper is concerned mainly with Latosols (1), or more specifically with the more developed members which are described, in accordance with recently proposed terminology (2), as "Oxysols", and in part as "Ultisols". These are further described also, according to a classification that we have used in a general way (3), and which has been used in a condensed form in the legend of the 1 : 5,000,000 map of the soils of Africa (4), as Ferruginous Tropical Soils—or Leached Ferrallitic Soils—and Ferrallitic Soils in the broad sense comprising the Ferrisols. We refer also, in certain cases, to the Brown Eutrophic Tropical Soils, but not to the Vertisols which occur in places but are not characteristic of these regions.

We have consciously omitted any consideration of biological factors, except sometimes to note their secondary effects. These are, admittedly, very important, but knowledge of the biology of the principal tropical soils is yet rather poor and not well correlated. The absence, the scarcity, or even the inefficiency of the nodules which do develop on the roots of leguminous plants growing in some of these soils such as the Ferrallitic soils, for example, which are the most acid and poorest in P_2O_5, is an important factor limiting their fertility; perhaps equally important is the absence of *Azotobacter* in these same soils, but it does not appear possible to us to present a sufficiently complete picture of the influence of these biological factors in these soils.

Wherever the soil is studied it is never quite the same from one year to the other. Under a temperate climate, however, with natural vegetation or when cultivated without too great a disturbance, the changes remain slow, and many of the characteristics of the soil persist for a long time. It is not the same in the inter-tropical humid regions. For example, in the south of Senegal the organic-carbon content of the first 20 cm (8 in.) diminished by 58.5 per cent after some years of mechanised cultivation (5); and the pH, which was 6.2 to 6.4 in the first 10 cm (4 in.), was lowered to 5.1 to 5.8 after cultivation; even in Madagascar it has been observed that on Ferrallitic soils derived from basaltic rocks the organic-matter content is lowered greatly after putting them into cultivation. At Analaveloa, in the first 20 cm (8 in.), it is 13.6 per cent under forest, 8.5 per cent under young prairie after forest, and 4.5 per cent under old prairie (6).

In studying the factors of the fertility of the tropical soils it is necessary to take account of not only these under natural vegetation or not too degraded vegetation, but those which have evolved under cultivation.

Profile and Depth of Soil

It is well known that the soils of humid tropical regions are very deep. This is essentially a function of the conditions of humidity and temperature in which they form and evolve, and which intensify the processes of alteration. For the same reason they are generally made up of products of this alteration and, to a very limited extent, by particularly resistant minerals, which are, however, already more or less degraded, mainly quartz, and, more rarely, white mica. Further, particularly in Africa, many of these soils are very old; they have had time to become deep and for their constituents to alter. These processes are very marked in the Ferrallitic soils, but are much less pronounced in the Ferruginous Tropical Soils. The former may have 10 to 15 m (33 to 49 ft) of thickness on granitic rocks (7), sometimes a little less on schist; they are still 4 to 5 m (13 to 16 ft) deep on basalts of the West Cameroons. They have been described as being 30 to 40 m (100 to 130 ft) deep (8), but the original material, or altered rock, with constituents little altered, makes up a large proportion of this thickness. The depth of the Weakly Ferrallitic Soils, some of which are Ferrisols, cannot be more than 3 to 4 m (10 to 13 ft). The Ferruginous Tropical Soils are not more than 2 to 2½ m (6 to 8 ft) deep, particularly in Senegal on sandstone and sands (9).

A priori, depth is not a limiting factor in the fertility of these soils. They frequently contain, often quite close to the surface (less than 1½ m, 5 ft), a layer rich in quartz pebbles and ferruginous or manganoferric gravels—the "lit de graviers" or "stone-line" (10) often described by pedologists—or concretionary or cemented horizons which limit the penetration of the root systems of plants, whether of natural or cultivated vegetation. Some of these, such as cocoa and cinchona, are particularly sensitive (11), while others, such as coffee, are much less sensitive.

The depth at which this layer, impenetrable to roots and limiting the thickness of ground available for cultivation, is a restriction depends very largely on the characters of the cultivated plants themselves. It is generally considered that at less than 1 m it is a serious obstacle to the development of most plants and at more than $1\frac{1}{2}$ m (5 ft) it has a very weak effect. The figures can be reduced if the soil is chemically very rich and has a good structure, and if at the same time there is a regular rainfall, as, for example, in the South Cameroons or North Gabon, where 60 cm (24 in.) of a rather gravelly soil is sufficient for cocoa, while in the central Ivory Coast, with a dry season more strongly marked, it is necessary to have 1.2 to 1.5 m (4 to 5 ft) of very open soil (11).

The thickness of ground necessary for cultivation depends very largely on the hydric profile which is present during the whole year.

The proportion of gravels, pebbles, or concretions which can exist in the Leached Ferruginous Tropical Soils or in the Ferrallitic Soils is very variable. Up to 25 or 30 per cent by weight of the soil mass, they improve the permeability by the mechanical effect of their presence, without lowering markedly the quantity of constituents available for the roots. Present at more than 60 per cent they become an absolute obstacle (12).

Whatever is the influence of the hardened horizons, which may be, in many cases, made up of shells or plates (13), we have no precise information as to the state of hardening beyond which only fissures and fractures permit roots to penetrate or traverse them. They need only to be weakly indurated to arrest the roots of certain cultivated plants, such as cotton, peanut, and certain legumes used as green manure. For example, this is observed at the time of the appearance of a cultivation layer which is often initiated by the passage of certain cultivation implements, or by excessive mechanical working of the first 20 to 30 cm (8 to 12 in.) of a clayey soil, as in the Niari Valley of the Congo (Brazzaville) (14).

In certain soils, one of these horizons forming a hindrance or an obstacle to the development of cultivated plants exists already, even from the first cultivation. In others it appears or forms only gradually and after the soil has been cultivated for a long time. In natural conditions it may be sufficiently deep not to be troublesome, but after cultivation which favours the development of erosion—a phenomenon capable of causing a loss of more than 20 cm (8 in.) in a few years even on a rather gentle slope, as in the Central African Republic (15)—it may be found less than 50 cm (20 in.) from the surface, sometimes at the surface. Finally, as we have seen in Dahomey, in the Ivory Coast, and elsewhere (16), and as has been observed in numerous other countries (17), erosion, by removing an important part of the upper horizons, can permit the lower horizons of a Leached Ferruginous Tropical Soil or a Ferrallitic Soil, very rich in sesquioxides, to harden. The two phenomena have been confused as in the Ivory Coast (16). Without being a real obstacle to the development of cultivation the texture of the Ferrallitic Soils can be unfavourable. Often very rich in colloidal constituents as a consequence of the intensity of alteration undergone by their mineral components, the size distribution of fundamental particles is very unbalanced. This is a consequence of the small amount of silt present, which is moreover, in the more mature soils, made up for the most part of particularly resistant aggregates, mainly metallic oxides (18).

Another limiting factor which intervenes in many cases is the heterogeneity of the soil profiles. Often this is only the result of the reworking over a short distance of the upper horizon of the soils, mainly ferrallitic (19), or colluvial or alluvial deposits (20, p. 17), or even the action of animals, termites, or worms, which have built up the upper horizon of the soil to give it its particular characteristics. In the first case the upper layer is coarser and contains less clay. It is often the inverse in the second case, and always in the third.

The variation in texture of the horizons of the profile can be due to its pedogenesis, in particular in all the Leached Ferruginous Tropical Soils and in most of the Leached Grey Ferrallitic Soils (3).

In the first, the accumulation of clay and sesquioxides is found mostly, frequently at a fairly shallow depth—40 to 60 cm (16 to 24 in.). In the Ferrallitic Soils, when they exist, it is often close to 1 m (40 in.). A rapid transition between two horizons of different texture is in any event unfavourable for many cultivated plants; cocoa, *Hevea*, ramie, cotton, for example. It can also have secondary effects, particularly by creating, rather close to the surface, hydromorphic conditions of impediment, very unfavourable for such plants as coffee, manioc, peanut, cotton, etc. The phenomenon also favours the appearance of a horizon at first compact, then indurated, and finally concretionary—processes which we have already noted seem to be important.

Physical Properties

In the well drained soils of the humid tropical regions the factor limiting the development of cultivation is very often connected with their physical properties. The most important amongst these is structure. Its form is relatively constant for each horizon in each group or subgroup of the soil. In the typical Ferrallitic Soils it is gravelly on the surface, then rather nutty, sometimes medium to fine polyhedric at depth, and tends to become less defined, assuming the characteristic of a compact mass, only in mottled clay (19). It becomes gravelly with great thickness and sometimes granular on soils which are moderately developed, these being derived from rocks less rich in bases, particularly calcium (6). These characteristics are favourable for cultivation. In some cases this structure of Ferrallitic Soils can become unfavourable for vegetation. In some well developed soils on basalt, as in the West Cameroons, or on varied rocks, as in Central Africa and in the Congo (Leopoldville), the clayey mass is mainly made up of sesquioxides, which give it a structure of rather stable small grains often qualified as farinaceous, which causes an excessive increase in the permeability. They become very dry soils. A structure somewhat analagous with very hard grains has been available for study in the soils of the Niari Valley, following a cultural degradation which had caused the release of an appreciable proportion of manganese (14). In the Leached Ferrallitic Soils it tends to become lamellar in the sub-superficial horizons, and to be larger and less clearly defined at depth. This is the same in the Leached Ferruginous Tropical Soils, where under a humiferous, rather gravelly superficial horizon are found two others, one still a little humic, and the other mainly mineral, with a more or less developed lamellar structure which rests on the horizon of accumulation with a polyhedric or prismatic structure, often rather large.

Amongst the qualities of soil structure which are essential from an agronomical point of view is stability. It is possible to put a figure to this character, either by the index of stability (I_s) of S. Hénin, applied by A. Combeau to the soils of tropical regions (21), or by the index of structure (S_t) of B. Dabin (22). Correlations established between these indices and the yields of cotton in the Central African Republic for the first, and of banana and cocoa for the second, underline their practical importance.

These two indices show very good values (index of stability less than 0.4—index of structure above 1,300 to 1,400) in the case of Ferrallitic Soils under forest, and still good in those Leached Ferruginous Tropical Soils under dense savannah. But the cultivation of these soils provokes a degradation of their structure which is expressed very clearly by the variations which these indices undergo. They are also related to various other properties of the soils, in particular to their organic matter content. The following results of A. Combeau and G. Monnier (21), in collaboration with P. Quantin and G. Martin, obtained on superficial horizons of soils having undergone various treatments, are very significant.

Red Ferrallitic Soils—BAMBARI (Central African Republic)

Soil Treatment	I_s	C (%)
Degraded savannah	0.77	1.44
Plot cultivated with farmyard manure	1.19	1.42
Plot cultivated with fertiliser	1.49	1.21
Plot cultivated without fertiliser or manure (cotton)	1.91	1.14

Yellow Weakly Ferrallitic Soil of the NIARI Valley (Congo, Brazzaville)

Character of the Soil	I_s	C (%)
Soil with stable structure	0.22	5.2
Soil with regenerated structure	0.49	3.7
Soil with unstable structure	1.49	1.8
Soil with very unstable structure	1.87	1.7

Similar results have been obtained on the Leached Ferruginous Tropical Soils, in Casamance (Senegal), the stability of which was good while under savannah, their organic carbon content being 1.7 to 1.9 per cent, but which after 2 years' cultivation of peanuts presented a structure whose stability had decreased by 25 per cent, with an organic carbon content of less than half (0.8 to 1 per cent).

The use of dung and manures, or green manures, combined with chemical fertilisation, or fallowing, makes it possible to recreate stable structure in a soil degraded by cultivation. It is necessary, however, particularly in this last case, that the fallow attains a certain stage of development of deeply rooting graminaceous species (23) or even shrubby species.

In the Central African Republic the following results have been obtained:

Stage of Plot	Structure	I_s
end of 4-year cultural cycle	massive	> 1.3
fallow with shallow rooting graminaceae	massive, a little improved on the surface (5 cm)	> 1.3
fallow with erect medium rooting graminaceae—		
with *Pennisetum*	aggregated at the surface, massive at depth	1–1.3
with *Roethelia* and *Pennisetum*	aggregated at the surface, polyhedric tendency at depth	0.8–1
fallow with *Penicum*	well structured soil 5–10 cm, polyhedric at depth	0.4–0.8
old fallow	well structured soil to 20–25 cm; friable to 50–60 cm	< 0.4

This degradation of the structure—practically almost inevitable—is always accompanied, at least in its most unfavourable form, by modifications of other physical characteristics of soil which are very important from the cultivation point of view, namely:

The permeability decreases, particularly in Ferrallitic Soils, which normally are rather permeable (K = 5 to 25 cm/h in general); the soil packs down and its hydric profile becomes less favourable (e.g., available water decreases from 7.5–8 per cent to 6–6.5 per cent (24) in certain soils of the Central African Republic); and the degradation of soil structure very noticeably increases its susceptibility to erosion as well as the clay content of the material removed (25).

The Leached Ferruginous Tropical Soils and the Weakly Ferrallitic Soils appear particularly susceptible to erosion. In Casamance, on Leached Ferruginous Tropical Soils under cultivation carried out without particular precautions against erosion, it is possible to measure a loss of soil of 624 metric tons/km^2/yr on a slope of 1 per cent and 975 metric tons/km^2/yr on a slope of 1.5 per cent under peanut, and 556 tons and 760 tons respectively under rice in wet cultivation (5). Under typical Ferrallitic Soils, in Guinea, slopes of 6 per cent are necessary to obtain similar losses.

Various measures permit this erosion to be limited, such as mechanical measures, which are now practically standard, and cultural measures such as the choice of crop rotation (27). They are sometimes not very economical and it is necessary then to limit cultivation in Casamance (5) to very gentle slopes (1.5 to 2 per cent).

Absorbing Complex and Reaction

An essential difference between Ferruginous Tropical Soils and Ferrallitic Soils lies in their absorbing complex, and consequently in their reaction. In the former, even the members have, with very rare exceptions, a degree of saturation $V = \frac{S}{T}$ above 40 per cent. In the latter, it is nearly always less than this (4). Also their pH in water is less than 6, except in certain cases, and can sometimes be found less than 4, except that in the first-named soils it is most often above 5.5. The strong acidity of the Ferrallitic Soils, and more particularly of those which are leached of bases and even of mineral colloids, can then limit their fertility and constitute an important obstacle to the development of cultivation. This strong acidity is not generally constant throughout each profile.

In the Ferrallitic Soils as well as in the Ferruginous Tropical Soils, even when leached, mineralisation of organic matter is rapid, particularly in the surface horizon. Also this horizon, enriched with bases liberated during this process, often has a pH higher than that of the lower horizons (28). However, the Leached Ferrallitic Soils or "Oxisols" in general are much more acid than the typical Ferrallitic Soils or "Ochrosols".

If the Leached Ferruginous Tropical Soils and Ferrallitic Soils, leached or not, are acid and often very much so, under natural vegetation, they become even more so when they are cultivated, as a consequence of further desaturation of their exchange complex (29, 5, 6, 14). As an example we may cite observations made on Weakly Ferrallitic Soils of Niari (Congo, Brazzaville):

After only one year of mechanical cultivation the pH of the upper horizons changed from 5 to 4.55 to 4.85.

In three years of peanut culture the exchangeable base content showed the following changes: Ca from 1.7 to 0.8 me./100g

Ca	from	1.7	to	0.8	me./100g
Mg	„	0.2	„	0.04	„
S	„	2.2	„	1	„

In the same time interval the carbon content decreased from 2.8 per cent to 2.15 per cent (29).

However, in certain very acid Leached Ferrallitic Soils under forest, as in Gabon, cultivation may decrease this acidity; for example, the pH increasing in the upper horizon from 3.6 under forest to 4.9 under 4-year-old coffee (30).

This strong acidity may be by itself harmful to cultivation. Whereas *Hevea*, tea, oil palm, etc. give excellent yields in very acid soils with a pH of 5 and even lower, and can benefit from a strong exchange acidity (31); on the contrary, cotton, cocoa, and bananas are better adapted to reactions closer to neutrality (32). Thus in the Central African Republic on Ferrallitic Soils a very highly significant correlation has been established between pH and the sum of exchangeable bases (S) of the soil, and with respect to the relation between S and the yield of cotton it is possible to write yield equals 193 S + 1,363 (24).

Analagous facts have been observed in Western Africa and the Cameroons for bananas (32).

An excessive acidity in the soil also allows the liberation and the solubilisation of certain metals such as Al and Mn, toxic by themselves and also capable, particularly Al, of causing the fixation of essential plant-nutrient elements, such as phosphorus. Sherman has recently demonstrated the problem of toxicity of Al in certain soils of Hawaii; that of manganese is particularly important in the Niari Valley (14, 29, 33).

On the one hand liming permits increasing the pH of the soil to values which can be considered as optimal for the cultivation of these regions, i.e., 5.5 to 6 (34). On the other hand, Sherman has shown the undesirable effects of excessive use of calcium treatments (lime or calcium silicate).

Therefore, besides certain very unfavourable characteristics of the soils of the humid tropical regions, whether physical or morphological, it is necessary to consider the excessive acidity that they present, often along with their very marked desaturation, as one of the most serious factors limiting their fertility.

Chemical Factors

It is often admitted that in temperate climates the chemical factors of soil fertility are essential and more important than all others, while in tropical countries physical factors become dominant. It is true that in the Ferrallitic Soils and in the Ferruginous Soils the physico-chemical and physical factors are frequently responsible for their degree of fertility; nevertheless, their chemical status is not without influence.

Various authors (35) have insisted on the fact that in forested zones with Ferrallitic Soils the reserve of nitrogen in the soil is very high when first cultivated. In the Ferruginous Tropical Soils of the savannah it is lower, and the organic matter which contains most of it has a somewhat higher C/N ratio. In the forested zone this nitrogen is already found, even under natural vegetation, in an easily removable form where there is a risk of losing it very rapidly. Also it is necessary, to avoid the loss of this element, to cover the soil immediately after cultivation with a plant which can use it and hold it in reserve. Legumes (*Mucuba, Puerania, Desmodium*) can play this role admirably (numerous examples are found in the Congo). If not, the nitrogen compounds disappear from the soil and at the end of a few years this deficiency becomes one of the most severe, mainly for crops such as coffee (36) or cereals. In Madagascar, for example, in a Ferrallitic Soil on basalt, under forest, the nitrogen content of the surface horizon is 0.395 per cent; it passes under young neighbouring prairie to 0.16 per cent; and under cultivation it decreases below 0.10 per cent (6). In Casamance at 10 cm (4 in.) it is 0.07 per cent, under degraded forest savannah; after 4 years of cultivation it is only 0.03 per cent (5). In graminaceous savannah regions the variation is slower. At Niari (Congo) it is still 0.14 per cent after 3 years of peanut cropping, being 0.17 per cent under natural vegetation (29).

In temperate or sub-tropical regions, legumes play a fundamental role in providing nitrogen for cultivated soils. It is not always the same in tropical regions, because very often, particularly in Africa, the roots of these plants do not carry bacterial nodules, or those that are present are relatively inactive. Numerous chemical, physico-chemical, or biochemical factors intervene that do not seem to work together in the soils of certain tropical regions, as in the Indies, where the legumes can play their enriching part for the soils which support them.

In Ferrallitic Soils or Leached Ferruginous Tropical Soils, the agents responsible for the non-symbiotic fixation of nitrogen are no longer the same in general as in the soils of temperate regions. *L. Beijerinckia*, for example, take the place of *Azotobacters*, but are much less active.

The dynamics of phosphates also presents very special characteristics in the soils of the tropical regions, in Ferrallitic Soils and Ferruginous

Tropical Soils, for example. In these environments, very rich in sesquioxides of iron or aluminium in a crystalline form or in the form of colloidal complexes or even simple gels, phosphates are most often in an insoluble state. They are found partially as constituents included in the sesquioxides (37). Even added to the soil as fertiliser they degrade and are immobilised (38). Kaolinite, so abundant in these soils, participates equally in fixation processes. However, according to the pH of the environment and the concentration of P_2O_5 in the soil solution, it can be either mainly the crystalline form of these various bodies which is responsible or mainly the gel form (39). However, the environmental conditions in these soils are such that even insoluble phosphates can be, at least partially, used by crops; also the yields obtained often correlate better with the total P_2O_5 content of the soil, or P_2O_5 extracted by energetic reagents, than with the available P_2O_5 content as extracted by oxalic acid (40). The almost proverbial poverty of tropical soils in phosphoric acid still remains in many cases one of the limiting factors in their fertility (5, 41).

Although the dynamics of sulphur in tropical soils has been less completely studied than in soils of temperate regions, it is nevertheless true that it is also an essential nutrient element (42), and that its deficiency in certain soils is one of the limiting factors in their fertility, and responsible for the poor yields of certain crops such as cotton, peanut, etc.

It is not only the absolute content of N, P, and S in the soils in one form or another which can be one of the limiting factors in their fertility; it is necessary also that there exists an equilibrium between these three elements more or less stable according to circumstances. This fact, so well discussed in a general fashion by agronomists and physiologists, such as Prof. Homès (to quote only one), has been studied precisely in the case of various soils and crops of the tropical regions, under conditions of an irrigation and pluvial regime (43).

This indispensable equilibrium between those soil anions which contain plant-nutrient elements must also be found between the principal nutrient cations—K, Ca, Mg. It seems, up to the present, that this balance must be established essentially between their exchangeable forms. However, it is readily admitted that in the soils of the humid tropical or equatorial regions the exchangeable forms are not the only ones to consider in the understanding of their chemical fertility (44). Even when present in very small amounts, for example less than 1 me./100g in sum, they cannot limit the fertility of the soils if they are rather deep and have good physical constitution, and contain a sufficient quantity of reserve capable of being rapidly liberated through the intense weathering of minerals in such pedological climatic conditions (45).

The importance of these various cations varies very largely with the crops grown. That of potassium is often very great and the results obtained, due to fertilisation with potassium of certain soils, either sandy or rather clayey but still very K-deficient, can be spectacular, in particular with such crops as peanut, manioc, oil-palm, and coconut (46). Finally a chemical factor which can be limiting for the fertility of a soil is its content of trace elements. Some of these can be almost absent in soils such as very leached Ferrallitics, or may be in forms not available to plants. Their distribution in these soils is most often very irregular, and in many cases recalls that of the major cations, having levels of accumulation at variable depths, occasionally at 1.5 to 2 m (5 to 6 ft). At the surface the content, according to circumstances, can be sometimes high, sometimes on the contrary very low (47).

Conclusions

Limiting Factors of the Fertility and Classification of Soils

In all that has gone before it has been shown that if the more or less Leached Ferrallitic Soils and the Leached Ferruginous Tropical Soils show some analogies from the point of view of their fertility characteristics, they are, however, very different from the following points of view: depth, physical factors, reaction and absorbing complex; and even the chemical factors are well differentiated. They show greater differences than are apparent in other large soil categories of the humid inter-tropical regions: Little Evolved Yellow Soils, Hydromorphic Soils, Humic Gley Soils, etc.

It is, however, essential to distinguish carefully between the different groups and subgroups of these sub-classes. For example, the Leached Ferrallitic Soils, which are particularly deep but with irregular profile, chemically poor and very acid, are much less fertile than the very rich Humic Ferrallitic Soils (although sometimes chemically out of equilibrium) and (in spite of their very good structure) will often be related to Ferrallitic Soils, indurated and hardly usable (13, 45).

Sherman has also given very clear examples of these differences in character, and of fertility and behaviour, of various types of latosols. In humid tropical regions even the most obvious morphological elements of their profiles, or the processes and conditions of their development, are not in themselves sufficient to define the fertility characteristics of the soils. The petrographic nature of their parent rock is very important. In the lower Ivory Coast, for example, the fertility of Ferrallitic Soils (which belong mostly to one group described as Weakly Ferrallitic—formed on ferruginous sands, on granitogneiss, or on more or less metamorphosed schists), depends largely on the petrographic and mineralogical characters of these various parent rocks (48). These always intervene, to a greater or less extent, in pedological classifications and apply equally to the families of our classification (3).

Research to be Developed and Undertaken

We believe we cannot do better in conclusion than to insist on some of the factors, still unknown or inadequately known, regarding this great problem of the fertility of the soils of the humid tropical regions and its limiting factors. The study of some of these is at present being carried out in some countries and in some laboratories; that of other points must be undertaken without delay.

It is a problem of a fundamental type, related to the phenomena of pedogenesis, mineral alteration, and evolution of elements; influence of the parent rock on the fertility of these soils and in the transformation of their organic matter; dynamics of constituents such as metallic sesquioxides. Other problems relate to the physical or chemical properties of soils, in particular the extension of our knowledge on the factors of the stability of their structure, or those which control the variation of their hydric balance during the year; the possibility of reducing losses of nitrogen, or of phosphate fixation, or even in certain cases, such as those of very leached soils, of the most useful cations for crops (49); the role of different reserve forms of these cations in the soil; the release of micro-elements in similar conditions of pedoclimate; different forms of organic matter and their influence on other properties of soils, etc.

It is necessary finally to recall the importance of the biology of these soils in deriving the more or less limited characteristics of fertility, a subject which we have deliberately omitted from this discussion.

Perhaps it may be thought sometimes that it is a question of very theoretical research; it is nothing of the sort. On these results depends the use which can be made of the soils of the humid tropical regions, a source, still incompletely used, of food for the whole world.

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By

G. AUBERT,

Chief, Soils Services, National Office of Overseas Scientific and Technical Research, Paris, France