A study of the humic compounds of some tropical and subtropical soils
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I. INTRODUCTION

The vital role played by organic matter in soil development is well known—it is so important that most recent soil classifications based on soil genesis make type of humus one of their fundamental criteria. But it remains to give a precise definition to " type of humus " as it is evident that in many cases morphological or purely chemical characteristics are insufficient: **the biochemical processes of humification** by which fresh organic matter is transformed into **compounds of neoformation or of bacterial degradation** (which we shall refer to as " humic compounds ") constitute one of the best guides to the characterisation of these types of humus. Unfortunately, the above-mentioned processes are complex and, in general, little known. Thus the extraction and classification of these humic compounds is extremely difficult. The methods used vary and give results which, depending on the type of humus studied, are very often not comparable. For these reasons, extraction of humic compounds with dilute soda and their separation by turning the solution into (non-precipitable) fulvic acids by acidification is not entirely satisfactory as the considerable alkalinisation of the medium often provokes purely artificial formation of humic compounds from the fresh organic matter. Furthermore, the notion of humic acids is not sufficiently precise as some humic acids in a free state in the soil and very slightly polymerised are very near to fulvic acids whilst others, with a very large molecule, are intimately linked with clay minerals and form a very stable flocculated clay-humic complex. The problem is to separate these two types of humic acid which contribute very different physico-chemical properties to soils. It is recalled that numerous authors have pointed out the existence of these humic acids which present different properties, and refer to them as brown, slightly polymerised humic acids and grey, strongly polymerised humic acids. Tiurin (1951) has evolved a technique for their separation, but his method presents the disadvantage of using soda as the extraction reagent.

We therefore proposed to work out a method of extraction and fractionation of humic compounds contained in various soils and based on their differences in chemical properties and on their migratory power in an electrical field, measured by **paper electrophoresis.** Next, in order to judge the effectiveness of the method and the value of the information on pedogenesis thus obtained, we undertook to apply it to soils which had developed in environments as different as possible one from another. **Soils of temperate regions** were the object of a previous study. We here propose to apply this method to subtropical (Mediterranean) and tropical soils and compare them with the first-mentioned, i.e. temperate region, soils.

II. CHOICE OF MATERIAL: SOILS AND TYPES OF HUMUS STUDIED

Four or five samples, as characteristic of various well-defined pedological types as possible, were studied so as to obtain statistically useful data enabling valid comparisons. The soils studied all came from Africa excepting three soils of climactic Mediterranean forest at Port-Cros island which present a special interest and which, in the authors' opinion, represent an intermediate soil type between temperate region soils and true subtropical soils.

The soils studied can be grouped into the following basic types:

Bm	Mediterranean brown soils. Climactic forest of evergreen oaks—Port-Cros.
T	" Tirs "—temporarily hydromorphic soils with swelling clay fraction (Morocco).
V	Vertisols (black tropical clays) and " vertisolic " soils (Senegal).
BS	Brown soils of sub-arid regions (Senegal).
Ft	Ferruginous tropical soils, not leached or slightly leached (Senegal).
Ftl	Leached ferruginous soils (Senegal).
Falt . . .	Transitional ferrallitic soils (Senegal).
Fal . . .	Ferrallitic soils (Ivory Coast).
Alh . . .	Hydromorphic alluvial soils.

N.B.: **All samples were taken from the surface horizon between 0–10 cm.**

List of Soils Studied

1. Mediterranean brown soils

Bm_1 . . .	Port-Cros-Rocher, alt. 565 feet. Mediterranean brown soils on sericitoschists. Typical evergreen oak forest.
Bm_2 . . .	Port-Cros-Rocher, alt. 568 feet. Mediterranean brown soils on micaschists. Evergreen oak forest partly degraded to *Erica* tree scrub.
Bm_3 . . .	Port-Cros-Rocher, alt 550 feet. Mediterranean brown soil on sericitoschists. Evergreen oak forest partly degraded to strawberry trees (Arbutus) and heath.

2. " Tirs " (Mediterranean vertisols)

T_1 and T_2 ..	Hydromorphic " tirs " at Ouled Ziane, Morocco. Two samples, taken at two different points of the crumb-structured surface horizon (15 cm.) above the prismatic-structured horizon.
T_3 . . .	Hydromorphic " tirs " at Mediouna (Morocco). Sample taken in the very black, crumb-structured surface horizon.
T_4 . . .	" Tirsified " brown soil at El Garo (Morocco). Less hydromorphic than the foregoing soils, intermediate between chestnut steppe soils and tirs *sensu stricto*.

3. Vertisols (black tropical clays) and " vertisolic " soils

V_1	Magnesian vertisol on recent alluvia of fluvio-marine origin at Joal, Senegal. Very pronounced gilgai microrelief. Annual rainfall about 600 mm. Savanna with very scattered *Acacia seyal*.
V_2	Vertisol on marly limestone at Rufisque, Senegal. Annual rainfall 400 to 600 mm. Fallow after cropping to sorghum.

V_3	Vertisol on sandy clay colluvium overlying marly limestone at Pout, Senegal. Annual rainfall from 400 to 600 mm. Fallow after cropping to cassava, considerable regrowth of *Bauhinia* spp. and *Zizyphus* spp.
V_4	" Vertisolic " soil on deep sandy clay colluvium overlying marly limestone (Ban) at Bambey, Senegal. Annual rainfall from 600 to 700 mm. Savanna with very scattered *Acacia seyal.*
V_5	" Vertisolic " soil on sandy clay colluvium (not very deep) overlying marly limestone, Senegal. Rainfall and vegetation : same characteristics as V_4.

4. Sub-arid soils

BS_1	Sub-arid brown soil on calcareous products of lacustrine origin at Ouarak, Senegal. Annual rainfall about 500 mm. Savanna with very scattered *Acacia albida.*
BS_2	Sub-arid red-brown soil on dune sands at Dahra-Djoloff, Senegal. Mean annual rainfall 520 mm. Savanna with scattered *Combretum glutinosum*, *Guiera senegalensis* and *Balanites aegyptiaca.*

5. Little-leached ferruginous tropical soils

Ft_1	Little leached ferruginous tropical soils on reworked Continental Terminal sands at Dahra-Djoloff, Senegal. Rainfall and vegetation : same characteristics as BS_2 (above).
Ft_2	Little leached ferruginous tropical soil on reworked Continental Terminal sands (" Dior " soil) at Boulal, Senegal. Mean annual rainfall about 500 mm. Dense savanna.
Ft_3	Little leached ferruginous tropical soil on sandy material (" Dior " soil) at Bambey, Senegal. Mean annual rainfall 600 to 700 mm. Grass fallow after cropping to groundnuts.
Ft_4	Little leached ferruginous tropical soil, slightly and temporarily hydromorphic, on marly limestone (" Dek " soil) at Bambey, Senegal. Rainfall and vegetation : same characteristics as Ft_3.
Ft_5	Little leached ferruginous tropical soil slightly and temporarily hydromorphic, on sandy material at Bambey, Senegal. Rainfall and vegetation : same characteristics as Ft_3.

6. Leached ferruginous tropical soil

Ftl	Leached ferruginous tropical soil with stains and concretions on clayey Terminal Continental sandstones at Sefa, Casamance. Annual rainfall : 1,350 mm. Cropped to cassava.

7. Transitional ferrallitic soils (Senegal)

$Falt_1$	Transitional ferrallitic soil at Djibelor Forest, Casamance (Southern Senegal). Rainfall : 1,600 mm. Dense savanna forest with *Parinari excelsa.*
$Falt_2$	Transitional ferrallitic soil at Forêt des Bayottes, Casamance (Southern Senegal). Annual rainfall : 1,600 mm. Replanted to 9 year old teak.
$Falt_3$	Transitional ferrallitic soil at Bignona Forest, Casamance (Southern Senegal). Annual rainfall : 1,500 mm. Dense savanna forest with *Parinari excelsa*, *Khaya senegalensis*, *Acacia sieberiana.*

8. Ferrallitic soils (Ivory Coast)

Fal_1	Ferrallitic soil on schists at Yapo, Ivory Coast. Annual rainfall exceeding 1,700 mm. Dense savanna forest—*Mapania*.
Fal_2	Ferrallitic soil on schists at Téké, Ivory Coast. Annual rainfall about 1,700 mm. Dense forest.
Fal_3	Ferrallitic soil on granite at Agboville, Ivory Coast. Annual rainfall: 1,400 mm. Savanna forest with *Celtis*.
Fal_4	A typical ferrallitic soil on neogenic sands at Adiopodoumé, Ivory Coast. Annual rainfall: 1,900 mm. Sublittoral forest.

9. Hydromorphic Soil

Alh	Hydromorphic soil on early Quaternary alluvia at Santiaba Mandjak, Casamance (Southern Senegal), Dense savanna forest with *Parinari excelsa, Detarium senegalense, Chlorophora regia*.

III. METHODS OF EXTRACTION AND FRACTIONATION OF HUMIC COMPOUNDS

These methods were perfected at the time of the study of the types of humus characteristic of certain temperate soils and were critically discussed in a previous paper (Duchaufour and Jacquin, 1963). We will limit ourselves to a brief outline of them here.

(1) Choice of Extraction Reagent

The reagent used was sodium pyrophosphate in a 1% solution. The advantages of this reagent have led to its adoption in numerous laboratories (Kononova *et al.*, 1961). Thanks to its great clay-dispersing power and to its capacity for rendering iron and calcium insoluble, it gives a maximum degree of solubility, to the humic compounds contained in organo-mineral complexes. But due to its fairly high alkalinity there is a likelihood of its provoking neoformation of humic compounds from the original vegetal matter and of thereby increasing artificially the amount of humic compounds extracted. We will come back to this problem later on.

The humic acids are separated from the fulvic acids by precipitation using H_2SO_4 (or HCl) at a final concentration of 1%. Titration is effected by reduction with N/10 $KMnO_4$ by the usual method. This method, applied to extraction solutions of necessarily low concentration, is more sensitive than that of Anne which aims at measuring organic carbon content by reduction of the potassium dichromate and sulphuric acid mixture. However, it presents a serious drawback, viz. reduction is incomplete and the correlation between the reduced permanganate and the weight of humic acids varies according to type of humus. In our previous paper, we demonstrated that **this correlation is characteristic of the types of humus—the reducing power of humic acids varies in inverse ratio to the degree of polymerisation.** As for the reducing power of fulvic acids, it generally varies in a parallel manner to that of the corresponding humic acids though remaining less strong.

We tried to determine, for the humus types, the correspondence between weight of carbon and volume of reduced N/10 $KMnO_4$ for both humic and fulvic acids. This correspondence was established by concurrent use of the two methods (permanganate and Anne's method) on two equal, sufficiently concentrated fractions of the same humic solution. Table II established after a sufficient number of repetitions, gives this correspondence in mg. of humic carbon compounds per ml. of $KMnO_4$.

(2) Chemical Fractionation of Humic Acids

The method perfected by the authors consists in effecting four successive extractions (1, 2, 3, 4) on the same soil sample (5 g. per 100 cu. cm. of extraction reagent if the soil is fairly rich in organic matter, 10 g. per 100 cu. cm. if the soil is very poor in organic matter, e.g. the black tropical clays and certain ferruginous soils). The first two extractions are obtained using 1% $Na_2P_2O_7$ with an admixture of NaCl at 5% concentration. The extracts obtained are then combined for titration (1 + 2). The other two extractions are effected with pyrophosphate alone and are also combined for titration (3 + 4). We have shown that during the first two extractions (1 + 2) the greater part of the fulvic and **brown humic acids** were extracted, whereas during the other two extractions (3 + 4) it was mainly the most polymerised **grey humic acids** which were rendered soluble. Extracts (1 + 2) were red-brown and limpid whereas extracts (3 + 4) were dark and turbid due to the dispersed clay. In the case of soils very rich in clay, e.g., black tropical clays, the clay must be flocculated after the extraction has been effected by adding 1% NaCl (even 2% in the case of V_1) so as to make titration possible.

However, this chemical separation, which gives an approximative idea of humus composition, is clearly not perfect and must be verified by a study involving **paper electrophoresis** enabling precise verification of the composition, in brown and grey humic acids, of the extraction solutions and, if need be, correction of the percentages obtained.

(3) Measurement of Humic Acids by Paper Electrophoresis

This method, described by Jacquin (1961), is here applied to humic acids obtained by precipitation in extraction solutions and redissolved in a minimum of N soda after washing to obtain a solution as concentrated as possible whilst avoiding any granulations. In electrophoresis, precipitation is obtained with HCl in preference to H_2SO_4.

Paper electrophoreograms are obtained in a medium buffered at pH 7·4 subjected to a tension of 200 volts for three hours. Movement takes place towards the anode. The details of this method have been described in a previous paper (1963).

Electrophoresis reveals the existence of three main categories of humic acids. Firstly, the brown humic acids (designated by B) which are the most mobile and form a diffuse band 11 cm. from the zone of deposition. Next, the intermediate humic acids (I) which are to be likened to the brown humic acids as regards colour but which are less mobile and form a brown band 5 or 6 cm. from the zone of deposition. Thirdly, the grey humic acids (G) which are much darker, often black, in colour and are immobile or migrate over a very small distance only, viz. 1 or 2 cm. Two types of grey humic acids, confused in quantitative evaluation, can be distinguished. One type is characteristic of ferruginous tropical soils. With it there is practically no movement and the band of deposition remains clear-cut, retains its black colour and extends only by gradual diffusion towards the anode. The second type (designated by G_{ch}) is characteristic of chernozems and, as regards the present study, of vertisols. With it, the very dark grey humic acids spread out on both sides of the zone of deposition forming an uneven, serrated band; some of these acids migrate over a very short distance (1 to 2 cm.) and form a second diffuse, uneven, grey-black band.

Quantitative evaluation of the percentages of the three types of humic acid was effected by measurements of the " optical density " of the electrophoreograms, measured by transparence using a Zeiss densitometer. Evaluation of the surfaces delimited by the zones corresponding to the various coloured bands gives the proportion of the three types of humic acid thus separated.

It is to be noted that, as regards tropical soils, the extractions (1 + 2) contain mainly B and I humic acids and very little G. Extractions (3 + 4), on the contrary, contain a large majority of G, generally no I, and a smaller though often non-negligible amount of brown humic acids (B).

(4) Verification of Chemical Fractionation by Electrophoresis and Discussion of the Method

It is thus seen that chemical separation is imperfect, and that the results obtained by that method can be " corrected " by electrophoresis.

The greater part of the **fulvic acids** are extracted during extractions 1 and 2 (75 and 90% depending on the soil). As for the **humic acids,** it was observed during the operations of extraction of humus from temperate region soils that separation did not take place in the case of horizons rich in fresh organic matter, e.g., peats, raw humus soils (A_0 horizon and therefore lacking a veritable clay-humic complex). In these types of humus there are no (or very little) grey humic acids, the proportion of brown humic acids remains almost constant or at any rate diminishes very little during the successive extractions. Under these circumstances fractionation is not possible. Chemical fractionation, on the other hand, is much more satisfactory in the case of evolved humus forming a stable argilo-humic complex. Nevertheless, it is imperfect for if the grey humic acids are almost exclusively extracted during extractions 3 and 4 the same cannot be said of the brown humic acids which still represent a large minority fraction in extractions

3 and 4. The authors have assumed that this was due to an increase in the alkalinity of the medium during the extractions and that it is largely a question of artificial neoformation of brown humic acids in the presence of an alkaline extraction reagent. This assumption has been verified by various experiments discussed in a previous paper. It appears to be equally valid for those tropical soils which give rise to the same observation. In horizons rich in fresh organic matter this purely artificial neoformation takes place on a considerable scale and can falsify the results. On the other hand, it is very restrained, certainly **less than 10%** of total humic acids as regards soils with a developed argilo-humic complex, in which case it does not sensibly modify the **rate of humification.** All the tropical soils studied in this paper can be grouped into this category. The same remark does not apply, however, to the Mediterranean brown soils which are much richer in organic matter. The brown humic acids extracted from these soils by extractions 3 and 4 constitute 20 to 25% of the total humic acids. Thus, for these soils, it is possible that calculated " rate of humification " slightly exceeds the actual rate. Despite this, it will be seen that the value obtained is very low.

IV. CRITERIA USED FOR CHARACTERISING THE TYPES OF HUMUS

Combining of the two methods, i.e., chemical fractionation and electrophoresis, the latter amplifying and correcting the former, provides four fundamental criteria for the characterisation of the types of humus.

(1) Nature of the Humic Acids and their Percentage Repartition in the Three Categories : B—I—G

This criterion indicates the degree of evolution and **polymerisation** of humic acids as well as degree of liaison with mineral colloids, the most polymerised humic acids being very closely linked with clays. We must make a qualitative distinction between the two forms of grey humic acid: the form G properly so-called, characteristic of ferruginous tropical soils, and the form G_{ch} characteristic of the vertisols (and, among temperate region soils, of chernozems).

Calculation of the percentage of the three types of humic acid is effected as follows: chemical fractionation gives the carbon value of extracts (1 + 2) and then of extracts (3 + 4). Evaluation of the surfaces occupied by the three categories of humic acid on the optical density curves of the electrophoreograms gives the percentage repartition of the three categories of humic acid in each fraction. A **total percentage** can then be calculated with the maximum precision, the excellent reproductability of the results guaranteeing the practical value of the method.

(2) **The reducing power** (already mentioned) of humic acids, also used by Jacquin (1963), similarly provides an excellent criterion of degree

of polymerisation and can therefore be combined with criterion (1) above (see Table II).

(3) Ratio of Fulvic Acids : Humic Acids (FA : HA)

This ratio is low in the most developed, most polymerised types of humus, in vertisols for example. It is high in weakly polymerised types of humus such as occur in ferrallitic and Mediterranean brown soils.

(4) Rate of Humification

Rate of humification gives the percentage of humic compounds extracted as compared with total organic matter. It is expressed in **carbon,** the sum of carbon in fulvic acids and humic acids being compared with total carbon. This value gives a precious indication of the degree of evolution of organic matter. Rate of humification of humus rich in fresh organic matter is low, and this is so of the humus of Mediterranean brown soils. As regards other types of humus, it is observed that rate of humification is greatly influenced by the **environmental factors** conditioning the greater or lesser degree of activity of " humifying " microflora.

V. INTERPRETATION OF RESULTS

The results obtained concerning reducing power are set out in Table II; the results concerning the other three criteria are given in Table III.

Apart from a few rare exceptions, one notes the limited dispersion of certain characteristic values, in particular the percentage of the three categories of humic acid for a given soil group. Dispersion is somewhat greater as regards rate of humification, but the values obtained remain significant and the small number of abnormal values can generally be satisfactorily explained. For example, with V_1 a black tropical clay rich in magnesium and very rich in montmorillonite, extraction (3 + 4) of humic compounds proved very delicate and necessitated the addition of 2% NaCl instead of 1%. The amount of humus carried away in the clay flocculate was increased in proportion, thereby leading to a lower value of humification. Inversely, rate of humification is abnormally high for soil Fal_4 (Adiopodoumé) which is sandy, very quartzous and therefore little ferrallitised (Aubert *) and undoubtedly presents drier conditions of internal microclimate, at certain periods, than other soils. Furthermore, the soil in question showed lower humic acid reducing power than the other three ferrallitic soils.

It is now proposed to compare the characteristic values obtained for the various groups of soils. As regards the types of humic acid, B and I (very similar to B) are grouped together.

(1) Mediterranean Brown Soils

These climactic soils, rich in organic matter, present characteristics more like those of temperate region forest soils than of the other subtropical

* Verbal communication.

and tropical soils. Their grey G humic acid content scarcely exceeds that of temperate region mull soils, their very high FA : HA ratio is quite comparable to that of mull soils whilst their rate of humification is exceptionally low (about 10%) whereas that of temperate forest mull soils and mull rendzinas oscillates between 15 and 20%. Thus all these characteristics indicate a slightly evolved type of humus but slightly transformed as compared with fresh organic matter and containing very weakly polymerised humic compounds.

(2) "Tirs" (T) and "Vertisolic" (V) Soils

The completely identical results obtained justify a commentary common to both groups of soils; moreover, there is nothing astonishing in this fact as the "tirs" are Mediterranean vertisols. The characteristics of the humus, as revealed by the authors' method, can be summed up as follows: low reducing power of the humic acids, very low fulvic acid content, very marked dominance of grey very-polymerised humic acids (75%), and a high rate of humification, about 35 to 50% (the aberrant character of V_1, a black magnesian clay has already been explained in this respect). It should be added that actual rate of humification must in fact be higher for all vertisols as a large part of the humic acids carried away during clay flocculation in extractions 3 and 4 escapes titration.

The liaison between humic acids and montmorillonite is so close that extraction of the first-mentioned is necessarily incomplete. Nevertheless when montmorillonite content diminishes in comparison with the other clays, as occurs in the case of the two vertisols V_4 and V_5 (with a much lower T value) this extraction is almost total with the result that rate of humification (about 50%) is increased.

The "tirsified" brown soil T_4 stands apart from the other tirs and vertisols by reason of its lower grey humic acid content (66%). This soil is less hydromorphic.

The marked analogy between the general results characterising the vertisols and the results obtained for the temperate region **chernozems** is to be noted. Not only were comparable values obtained (the percentage of grey humic acids is, however, higher for the black clays), but even qualitatively **their grey humic acids belong to type G_{ch}** which had never previously been encountered by the authors except in chernozems. All these characteristics constitute the index of a very evolved, very polymerised humus. In this regard, the values obtained attain the maximum for all the soils studied.

(3) Brown Sub-arid and Ferruginous Tropical Soils

Here again, we group two soil families which gave comparable results as regards humus properties, viz. increased amount of fulvic acids and a FA : HA ratio approaching or exceeding 1. Grey humic acids content was again high (60–70%) but the electrophoresis showed them to be very different from the grey humic acids of chernozemic soils. The acids in question formed a long very distinct black band at the level of the zone of deposition. Lastly, the high rate of humification is yet another indication of the marked degree of evolution of this humus towards polymerisation and condensation.

The leached ferruginous tropical soil presents characteristics foreshadowing those of the next-mentioned category with which it is transitional.

(4) Transitional Ferrallitic Soils

These soils present characteristics intermediate between those of ferruginous soils and true ferrallitic soils (occurring in the Ivory Coast). For the three soils studied the percentage of grey humic acids drops to 51–53% whilst rate of humification drops to less than 30%. The slight increase in the reducing power of the humic acids confirms their repartition. The types of humus concerned are less evolved and less polymerised than the preceding types.

(5) The Ferrallitic Soils

If exception is made of the Adiopodoumé soil, whose somewhat aberrant character has already been noted, the following trend tends to become more marked in the soils of the Ivory Coast: the soluble slightly polymerised compounds predominate; fulvic acid content attains and sometimes even exceeds that of humic acids; the grey humic acids are in the minority. It is to be noted, however, that the rate of humification and the indices of polymerisation of these soils are on the whole markedly higher than those which characterise the climactic Mediterranean brown soils and the temperate mull soils.

(6) Hydromorphic Alluvial Soil

Although occurring at the same latitude as the ferruginous tropical soils this hydromorphic soils of Senegal presents, in respect of the repartition of the types of humic acid, the same characteristics as the ferrallitic soils of wetter regions: the grey humic acids are still in the minority but rate of humification drops considerably. This is characteristic of humus evolving in conditions of partial anaerobiosis as a result of which the evolution of fresh organic matter is slowed down.

VI. DISCUSSION

(1) Comparison of the Types of Soil Studied

If exception is made of the Mediterranean brown soils, the humus of which presents characteristics very similar to the humus of temperate mull soils, the subtropical and tropical types of humus taken as a whole are more evolved than the humus of temperate soils—their rates of humification are higher than those of temperate forest mull soils and their grey humic acid content is always considerably higher than that of these latter soils. But from both these points of view, great variations are observed depending on type of soil. In this regard, the ferruginous, transitional ferrallitic and ferrallitic soils constitute a continuous series, the humification and the polymerisation of which decrease going from north to south. This observation is summed up in the following table.

Soil	FA : HA	% Grey	Rate of humification
Ferruginous tropical	< 1	60–70%	> 30%
Transitional ferrallitic	Variable	52%	< 30%
Ferrallitic	⩾ 1	30–40%	< 30%

Lastly, the vertisols and the Moroccan " tirs " present the highest values, particularly as regards the predominance of grey humic acids which become almost exclusive. The humus of these soils presents the characteristics of chernozem humus but to a more marked degree.

(2) Influence of Ecological Factors

Here, as in a previous study of temperate soils, the authors try to explain the characteristics of humus as a function of the ecological conditions governing its evolution, viz. general climate; local conditions obtaining at stations.

General climate

With reference to temperate soils, one of the authors (Duchaufour and Jacquin, 1963) has previously stressed the influence of seasonal contrasts presenting a more or less marked alternance of wetting and drying of humus: the more the alternance is marked, the more the processes of humification and polymerisation are developed. Thus, in this respect, highland humus contrasts with Atlantic plains soils humus which, due to feeble variations in microclimate, is little evolved from both these points of view.

In tropical and subtropical climates **the length of the dry season** manifestly governs the processes of humification. The sequence: ferruginous tropical soils, transitional ferrallitic soils and ferrallitic soils clearly illustrates this law. The length of the dry season gradually diminishes, going from the first to the last-mentioned soils. There is practically no dry season in the Ivory Coast and its effect there is apparently limited to sandy soils with a low moisture reserve, and even in the case of sandy soils its effect is very relative. Now a correlative decrease in humification and polymerisation takes place though it never attains the low values characterising the soils of the Atlantic climatic region and the three Port-Cros Mediterranean brown soils which have been included for purposes of comparison.

As regards these latter soils, their slow evolution and weak degree of humification may, *a priori*, appear astonishing in view of the marked dry season of the Mediterranean climate. But in this example, the influence of the general climate is offset by local micro-climate which is that of **a relic Mediterranean forest** very closely approaching the original type which has practically disappeared in France and North Africa. Soil types Bm_2 and Bm_3 show only incipient degradation of recent origin and not strongly marked. Numerous ecologists have insisted on the protective influence of climactic Mediterranean forest which forms a barrier to the sun's rays and attenuates summer desiccation. Under these conditions the humus, thanks to its fairly gradual evolution, is preserved. But it is known that once this association is destroyed it is replaced by much more xerophilous associations. At the same time the organic horizons become mineralised or are carried away by erosion and finally there only remains a soil truncated of its upper horizons.

Effect of conditions obtaining at stations

By " stations " the authors mean **local conditions** linked with topography and parent rock. Station conditions are opposed to general conditions of climate and vegetation.

The station can intervene in two ways: firstly, by favouring more or less complete (temporary or permanent) surface hydromorphism, and secondly by the abundance of bivalent ions furnished by the parent rock. As is known, these ions play an important role in the processes of humification.

Slightly accentuated permanent hydromorphism, without any marked phase of desiccation, slows down the processes of humification. This frequently observed phenomenon is substantiated by the properties of the alluvial hydromorphic soil. Despite the fact that this soil occurs in Senegal its humus presents properties comparable with the properties of Ivory Coast soils formed under a regime without a dry season—it is aerated but is constantly moistened by capillary ascension from the water table and never dries out completely.

The same cannot be said of the " tirs " and vertisols which present **temporary surface hydromorphism** with periods of marked desiccation succeeding periods of almost complete anaerobiosis. The soluble compounds which develop during the latter phases become polymerised and then become closely associated with the swelling clays during the periods of desiccation. Moreover, the abundant bivalent calcium and magnesium ions catalyse the formation of grey humic acids which, as we have seen, become strongly predominant or even exclusive. Now it is to be noted that these ecological conditions of evolution are somewhat similar to those of the Ukranian chernozems in which the effect of strongly marked seasonal micro-climatic variations (Iarkov, 1956) is combined with that of the bivalent cations. This being so, it is in no way surprising that the two types of humus present very similar characteristics.

CONCLUSION

Study of the properties of the humic compounds of various types of soils presents a twofold interest. Firstly, such study makes it possible to define the laws governing the processes of humification and the influence of environmental conditions on these processes. Secondly, it provides information on the processes of humification themselves and, consequently, on the **genetic relationship** of certain soils, relationship which, *a priori*, might appear contestable. This latter remark applies to chernozems and vertisols. Despite the fact that they differ as regards several characteristics which it would be pointless to dwell on here (in particular: organic matter content, structure of deep horizons, etc.), they present, as has been noted by Scheffer *et al.* (1960), common, apparently fundamental characteristics, viz. the properties and the evolution of the clay-humus complex are similar for both soils. Now, these soils have been grouped in different orders in recent classifications: the order of Vertisols was created for the black tropical soils, but at least some of them could have been classified in the great order of " Mollisols " as their surface horizon is incontestably " mollic ".

SUMMARY

A method of chemical extraction and fractionation of soil humic compounds (fulvic and humic acids) has been perfected using sodium pyrophosphate as the extraction reagent. The first two extractions effected with pyrophosphate plus an admixture of NaCl enable extraction of the brown slightly polymerised humic acids whilst the other two extractions, using pyrophosphate alone, extract the more polymerised grey humic acids.

Verification of the above procedure by paper electrophoresis shows it to be efficient in the case of soils with evolved humus and presenting a stable clay-humic complex but not very efficient in the case of weakly developed humus rich in fresh organic matter.

Power of reduction with respect to N/10 permanganate, ratio of fulvic acids to humic acids, overall repartition of the humic acids in three categories (brown—intermediate—grey) according to chemical fractionation corrected by data obtained by electrophoresis and, lastly, rate of humification (humic compounds carbon: total carbon) serve to characterise the genesis and the properties of the various types of humus studied.

A sequence of subtropical (Mediterranean) and tropical soils were studied by this method. The soils were: Mediterranean climactic brown soils, Moroccan " tirs ", Senegal vertisols, ferruginous tropical soils, transitional ferrallitic soils, true ferrallitic soils from the Ivory Coast and, lastly, an alluvial hydromorphic soil from Senegal.

It is found that the types of humus of each group present very precise characteristics which are first of all linked with general climate or local climate. The ferruginous, transitional-ferrallitic and ferrallitic soils form a

continuous series characterised by weaker and weaker humification and polymerisation in liaison with a climate presenting less and less seasonal contrasts. In the same way, the humus of the Port-Cros Mediterranean climactic soils is little evolved and little polymerised as a result of the protection offered by the forest vegetation there integrally conserved. As for local station conditions they also intervene by way of the micro-climatic contrasts (moisture economy) which they impose on the soil as well as by way of the greater or lesser abundance of bivalent cations coming from the parent rock—maximum humification and polymerisation are attained in the case of the vertisols (to which the " tirs " should be attached) as in the case of these soils, the effects of the two foregoing factors combine. From this viewpoint, there seems to be a striking analogy between the vertisols (+ " tirs ") and the Ukrainian chernozems.

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