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The Concept of Soil Humus in the Past Three Centuries

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"Humus: What is it? The spirit of the soil. The product and the source of life. The go-between the fallen leaves and the salt of the earth. A section of the Bunyon-Leopold round river that flows into itself; the river of life transferring energy from soil to plants to animals and back to soil. One of the soil's components which like the philosopher's stone and the homunculus was a mysterious item of alchemists and which still remains one, electronic analyses notwithstanding".

(Wilde, 1971)

Summary

Widely different meanings are attached to the term "humus" which has persisted through the present time. The first meaning of humus was "soil" in Latin. By the middle of the 18th century, this original sense survived in the European scientific literature along with the sense of soil layer and soil "constituent", without any clear-cut distinction between these two last meanings which still are used nowadays. Thaer was the first to give a precise definition of humus as soil constituent.

The "humus-horizon" concept was largely developed by foresters and especially by Müller (1879, 1884) a brilliant forerunner of Soil Science. Various definite humus types were then described leading to classification proposals. All the existing soil classifications take into account humus types and humus classifications at different levels. From the 18th century, the "humus-constituent" concept varied up to now according to the type of analytical characterization. Schematically, it was possible to set three "approaches" apart: chemical, biological and physical. Modern approaches about soil organic matter include physical and biochemical methods as well as micromorphological and dynamic ones.

To date, humus still represents more a concept than a well-identified and specific family of substances. If the chemical approach (humic fractionation) prevailed from the 18th century to 1970, it may in the future become supplemented by bio-physical, micromorphological and dynamic ones.

This paper deals specifically with soil humus and, therefore, does not consider works related to humus of paleosoils, sediments and aquatic ecosystems.

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1 The different meanings of the word humus

At the entry "Humus" in the Encyclopaedia Universalis (Vol. 8, 411), Duchaufour (1970a) reports that:

(1)[1] *- " ... le mot "Humus" désigne dans son sens le plus étroit, la fraction de la matière organique du sol qui a subi une transformation plus ou moins rapide, d'origine biologique et aussi physico-chimique ... Au sens le plus large du terme" ... (l'Humus) ... "désigne l'ensemble des horizons organiques ..."*

Thus the same word is used to describe two very different concepts. Before assessing these two notions of "humus-constituent" and "humus-horizon" separately, it is important to understand how the Latin word "humus" and its different meanings have found their way into the scientific vocabulary over the centuries.

1.1 From ancient times to the beginning of the 18th century

For the Roman writers, "humus" meant soil or earth. Vergil (79-19 B.C.), in his Georgics (Billard, 1928, p.36), named the loamy soil *pinguis humus* and used the words *humus, solum* or *terra* indifferently for the notions of soil and earth. Similarly, in Book 18 of his "Natural History" (Ed. Belles-Lettres, 1978), Pliny the Elder (23-79 A.D.), mentioned for the lupin that "its root penetrates the *humus*"; as to Columella (1st century A. D.), "wheat needs two feet of good *humus*" (Feller & Boulaine, 1987).

With the beginning of the 1st century, "humus" in the sense of "soil" progressively died out after Cicero (106-43 B.C.) and was replaced by "terra", source of French "*terre*" (earth), "*terreau*" or "*terre végétale*" (mould) which survived until the 18th century (Martin, 1941). On the other hand, "*inhumer*" (to bury, to deposit in the earth), can be traced back to 1413 and its derivatives "*inhumation*" (burial), "*exhumation*", "*exhumer*" (to exhume) have been used up to the present.

The word "humus" probably re-entered the European scientific vocabulary in the 18th century. According to the T.L.F (1981) and the Robert dictionary (1967), "humus" reappeared in Diderot's and d'Alembert's Encyclopaedia (vol. 8), in 1765:

(2) - "Humus", Histoire naturelle, les naturalistes empruntent souvent ce mot latin, même en français pour désigner le terreau, la terre des jardins, ou la terre formée par la décomposition des végétaux; c'est la terre brune ou noirâtre qui est à la surface de la terre. Voir terre végétale et terreau".

[1]The French quotations (number in parentheses) are translated into English in the Notes, at the end of the following text.

However, we shall see that the term "humus" did not pass immediately into the scientific (naturalist or agricultural) language, which implies that it was not in widespread use at that time. It was not much used in the sense of "surface organic horizon" (as quoted by the Encyclopaedia); "humus" meant either soil, surface organic horizon or soil organic constituent, without precise details.

The following literature review is organized around three reference dates corresponding to the publication of widely distributed works:

- 1765: Diderot's and d'Alembert's Encyclopaedia for the earliest quotation of the word "humus",
- 1781: first volume of "Abbé" Rozier's "*Cours complet d'agriculture*" (Full course in agriculture), an excellent encyclopaedia of agriculture,
- 1809: first edition in German of the "*Principes raisonnés d'agriculture*" (Rational principles of agriculture), not translated into French until 1811; the author, Thaer, a German agronomist, was the father of the "Humus theory" which deeply influenced the doctrines of agriculture at the beginning of the 19th century.

1.2 Before 1781: "Humus" was not often quoted

More than twenty agronomy books or dictionaries published from 1711 to 1783 have been reviewed by Feller and Boulaine (1987) about the word "humus". The only writers to quote the word humus were:

- Wallerius (1753), who in his "Mineralogy" (vol. 1, pp. 9-19 and 26) used the latin word "humus" for "loam" or "mould" when dealing with earth classification, and,
- Valmont de Bomare (1768), who used the word in the sense of "soil" or "soil horizon".

It is evident that the word "humus" was scarcely used before 1781. It essentially meant "earth" or "horizon" (mould). Soil fertility was in general attributed to "*sels*" (salts), "*huiles*" (oils), "*substances bitumineuses*" (tarry substances) or to a "*limon subtil, onctueux et salin*" (oily and salty fine loam) (Bonnet, 1764).

1.3 1781 - 1809: Latin "humus" passes into French

a) Abbé Rozier's "*Cours complet d'agriculture*"

The word "humus" was widely quoted in this book, the publication of which (supplements included) lasted from 1781 to 1801. However, "humus" was not indexed at the letter H which would prove that this term was probably little used at that time, but appeared in various articles of volume 1: "*amender*", (to amend, p. 506); "*arbre*", (tree, p. 627); "*argile*", (clay, p. 668), volume 2: "*cendre*", (ash, p. 624), volume 3: "*chaulage*", (liming, p. 184); "*clôture*", (fence, p. 408); "*coquillage*", (shell, p. 481); "*culture*", (cultivation, p. 602), volume 4: "*engrais*", (fertilizer, p. 194), volume 6: "*marne*", (marl, p. 430), volume 9: "*terre*", (earth, pp. 390-401).

The meaning of the term "humus" is still not precise, denoting either "vegetable mould", "mould" or "constituent". Thus:

(3) - ... "créer le terreau ou humus ... seule terre végétale" (t1, p. 506) ...
- ... un sol auquel il ne manque plus que l'humus ou terre végétale ou terre soluble ... c'est la seule terre végétative. Les autres terres servent seulement de matrice aux plantes" ... (t1, p. 568) ...
- ... "la terre calcaire est donc la seule terre végétale, le véritable humus soluble dans l'eau et la seule qui établisse et constitue la charpente des plantes ... si on amoncelle les plantes ... si on les laisse se décomposer ... on obtiendra en dernière analyse, la terre calcaire pure, le véritable humus ... Cultivateurs ne songez qu'à créer ce précieux humus ... qui est une vraie terre animalisée ... la seule qui entre dans leur composition ..." (les plantes), (t9, pp. 390-401, p. 796).

From the quotations of volume 1, "humus" was regarded as the principle of vegetation announcing the "humus theory" of Thaer (Cf. paragraph 1.4).

b) Other works

For Patrin (1803), "humus" referred to "soil": *(4) - ... c'est la couche la plus extérieure de la terre ... qui forme le sol ... où le roc n'est pas à découvert ... son épaisseur varie de deux ou trois doigts jusqu'à plusieurs pieds"* ... As for Virey (1803), "humus" meant "remains of organized bodies". De Saussure (1804) ascribed a wide meaning to the word "humus" (the whole vegetative cover undergoing decomposition) and a restricted one to the word "mould" which is *(5) - "la surface noire dont les végétaux se recouvrent"*. "Humus" has not been found in other very general works written by naturalists or agronomists (Douette-Richardot 1803; Yvart 1807) but was used in literary ones: Chateaubriant, in Atala (1801), spoke about *(6) - "l'épais humus composé de débris de végétaux"* (cited by Luginbuhl 1989, p. 47).

In conclusion, it can be said from this brief bibliographical survey that the meaning(s) of the word "humus" had not yet been well-defined by 1800 but that "humus" taken as a component, was more and more recognized as being the vegetative principle. Hassenfratz (1792) attributed *(7) - "l'accroissement du carbone* *dans les plantes par l'acte de végétation"* to *(8) - "la dissolution du charbon dans l'eau, sucé ensuite par les racines et déposé dans l'intérieur des plantes ... le charbon dissous est une des substances nutritives des plantes".*

1.4 1809: Thaer adopts the word "humus" as a soil component

In 1809 Thaer's work "*Principes raisonnés d'agriculture*" was published in German and translated into French in 1811 by E.V.B. Crud. This work, noteworthy in many respects but criticized for its "Humus Theory", was referred to by numerous agronomists and farmers up to 1840. Its qualities: an array of experimental data, a precise vocabulary, the effort made, in quantifying, in order to achieve a "rational agriculture". Its major effect : the use from the beginning of a wrong hypothesis, previously developed by Hassenfratz (1792), which postulated that most of the plant dry matter, or all of it, originated from soil organic matter. Therefore managing fertility meant managing humus.

In Thaer's mind, what was humus? In the chapter dealing with "humus" (volume 2 of the French edition, pp. 102-114), it is reported that:

> *(9) - "Le nom qu'on donne ordinairement à cette substance est terreau. Cette expression a été mal comprise par beaucoup de gens lorsque par là, il ont entendu la couche de terre végétale et non cette partie particulière des substances qui la constituent. Cette méprise a été faite, même par quelques écrivains savants agronomes, et cela a augmenté d'autant l'obscurité qui planait déjà sur cette partie de la science. C'est pour cela que j'ai adopté la dénomination d'humus, sur laquelle il ne peut pas y avoir d'équivoque. En général dans la science, la dénomination terre ne lui convient pas; ce n'est, à proprement parler, point une terre; elle n'a été désignée sous ce nom qu'à cause de sa forme pulvérulente. ... L'humus est le résidu de la putréfaction végétale et animale, c'est un corps noir ..."*

Thus probably for the first time, the term "humus" was definitely restricted to the notion of constituent, the properties of which (composition, reactivity, extractibility) were greatly detailed by Thaer through an approach very complete for that time and still acceptable today.

With regard to the agricultural doctrines, the "Humus Theory" prevailed over the first half of the 19th century, even though Thaer was being overtaken by his contemporaries, especially de Saussure whom Thaer interpreted exaggeratedly according to his own hypotheses. As a matter of fact, as early as 1804 de Saussure clearly noted (p. 269) that the proportions of dry matter in a plant originating from mould only represented 1/20th of that supplied by the atmosphere. In 1840 Liebig's "Mineral Theory of plant nutrition" rang the knell of the "Humus Theory" and led to the fertilizer era. The "mineralists" gained a victory.

During the 18th century, however, investigations were carried out both on the "humus-constituent" (in connection with the rise of chemistry, then microbiology), and later on the "humus-horizon" (in connection with the forestry research and the emergence of soil science). These two concepts are developed below.

2 Historical account of the "humus-horizon" concept

As shown earlier, this concept originated from the word "humus" itself, which first meant soil or surface layer of the earth (from the ancient times till the 18th century, no distinction existed between those two notions). Wallerius (op. cit.) is usually credited with presenting the first classification of the "humus" (in the overall meaning of the term). In the class "Earths" (terrae), he described the order "Dust Earths" (Terrae macrae)[2], the genus "Loam or mould" (or Humus), and the seven following species:

(10) - *"Terre noire des jardins (Humus extra).*
- *Terre rouge (Humus rubra).*
- *Terre d'ombre (Umbra).*
- *Terre noire (Attramentum scissele).*
- *Limon (Humus palustris).*
- *Tourbe (Coespes).*
- *Terre animale (Humus animalis)".*

Although it happened to be a "mineralogical" classification (the work was so entitled), constituent did not figure there as the only sense given by Wallerius to the word earth:

(11) - (... "Ce sont des substances minérales composées de particules ... on peut les regarder comme la matière primitive des pierres ..." p.9)

which also referred to layer:

(12) - "... elles (les terres franches) servent d'enveloppe à notre globe dont elles couvrent la surface ..."; the garden black earth is "no more than half a foot thick".

From 1753 to 1830, this humus approach was not particularly developed in any other work except for various classifications of earths (Feller & Boulaine, 1987).

According to Wilde (1971), Hundeshagen (1830) was the first to introduce a morphological classification of forest humus, quoting two types of humus with different effects on silviculture. In 1875, Emeis in his turn, described three humus types: one formed from organic materials incorporated in the mineral soil (the

[2]The order "Clayed or Heavy Earths" and "Mineral Earths" are also encountered.

present-day mull), another one from bulk, and raw organic remains.

At about the same time, Ebermeyer (1876) carried out a detailed study on forest humus of Bavaria. The main results (as reported by Grandeau, 1878), concerned the composition of the leaves (with a study on their browning before the fall), their turnover, the physical and chemical properties of litters. A classification of forest humus into the following groups was then proposed: "fertile" humus, "dust or peat" humus, "acid" humus, "astringent" humus.

In 1881, Darwin published his famous book on the "Formation of vegetable mould through the action of worms" with a lot of qualitative and quantitative data on soil fauna activity (edition of 1897 quoted here).

But it was Müller in his noteworthy works (1879, 1884) who laid the present day scientific bases of the study of the different forms of humus, and even of a general survey of soil genetic processes in cold and temperate climates. His book, "The natural forms of humus" (1889), which included in French the works previously quoted, can be regarded as a treatise, still valid nowadays, on the changes of brown soils to podzols. A few quotations of Müller's work (1889) are provided below:

(13) - (p. 11) "Pour l'étude des propriétés physiques du sol forestier ... le sol a été préparé de la même façon que pour des recherches sur les conditions de structure d'un organisme, et on s'est servi pour cela des mêmes moyens de dissection et des procédés microscopiques. Les parties séparées du sol ont été examinées en place dans leurs circonstances de gisement naturelles et l'analyse chimique n'a été appelée à l'aide que pour expliquer, quand c'était possible, les conditions pour lesquelles l'oeil ne pouvait donner aucun éclaircissement ... Au premier abord, il peut sembler déraisonnable de vouloir étudier comme un tout organisé et homogène, un mélange aussi complexe que celui des sols d'alluvion ... Mais l'étude montre que du conflit des actions multiples ne sont pas sortis des états chaotiques, mais des formes déterminées ... mais des types variés du sol forestier ... considéré comme un ensemble organisé ..."

(14) - (p. 13) "... je propose de donner aux deux types principaux ... d'humus ... des forêts de hêtres les noms de "Mull" (terreau) et de "Torf" (tourbe)[3]*.*

(p. 14) "Terreau de hêtre (Buchenmull)". Following the description of the vegetation,

(15) - "Aspects du sol ... le sol est recouvert d'une couche plus ou moins épaisse de débris (végétaux) ... isolés, éparpillés sur le sol. Lorsqu'on écarte la couverture, la surface brun-noirâtre ... du sol a un aspect

[3]In Danish "muld" and "mor" for Mull and Torf, respectively. The German expression "kohliger Humus" would be approximately synonymous with the word "Torf".

graveleux ou granuleux. La ligne entre la couverture et le sol ... est tout à fait tranchée ... Cette terre se montre aussi complètement meuble que la terre de jardin ... travaillée".

This is followed by a very detailed description of the soil profile, microscopy (of clotted elements, in particular), mechanical and chemical analyses, and by a long study (pp. 20-28) on the litter decomposing organisms, mycelia and earthworms, with quantitative data.

(16) - (p. 29) "Tourbe de hêtre (Buchentorf)". After a description of the vegetation, very different from that of the "Mull", is the soil aspect. *"Si on creuse le sol à la bêche, on rencontre une couche d'humus noir-brun, tenace: la tourbe, puis en dessous, un sable gris-blanc, gris ou noir-gris ... d'autant plus clair que l'on s'éloigne de la couche tourbeuse ... (puis on trouve) ... une couche de terre colorée en rouge-brun ou brun ... et sous celle-ci, de l'argile sablonneuse, du sable".* The grey sand is denominated "bleichsand" (*"sable plombifère"*, plumb sand[4]) and the brown-red layer "Ortstein". This is followed, with drawings, by a very detailed description of the tenacious and felted peat, the importance of mycelia and the lack of earthworms (pp. 33 - 44).

Transient formations, mould-peat (mullartiger Torf) are then described (pp. 45-64); in general, they do not contain earthworms but numerous insects and mycelia.

The different forms of humus, based on the existence of two stages in the humification process (according to Müller), are then discussed:

1 - "The mechanical division of organic remains",

2 - "The mixture of organic remains and mineral earth",

hence the classification scheme proposed for humus present in beech forests:

(17) - "Echter Mull. Parfaitement divisé, meuble sans cohésion. Ne renferme pas plus de 10 % de substance organique, sans acides humiques libres ... bien mélangé avec la terre minérale ... par le travail des animaux et l'action de l'eau".

(18) - "Mullartiger Torf. Parfaitement divisé, meuble sans cohésion ..." (afterwards, idem to Echter Torf)

(19) - "Echter Torf. Imparfaitement divisé, ferme tenace, cohérent. Renferme 30 à 60 % de substances organiques, avec acides humiques libres et solubles; est mélangé avec la terre minérale d'une façon imparfaite, à peu près uniquement par l'action de l'eau".

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[4]"Sable plombifère" was the translation of "bleichsand" given by H. Grandeau in 1889. According to an anonymous referee who reviewed this paper, Grandeau confused "blei" (= plumb) with "bleich" (= colourless). Therefore "bleichsand" would mean "colourless sand".

These few quotations provide only an incomplete idea about this exceptional work which also provided colour and black-and-white plates of soil profiles, including changes between brown soils and podzols (Table III, upper part) and the plant-soil relationships over a few meters (Fig. 14, p. 159). In addition, as early as the first edition in 1879, it attached the greatest importance to biological processes, especially soil fauna. In 1879, Darwin's book, "The formation of vegetable mould through the action of worms", was not yet published though it was copiously quoted in Müller's second memoir (1884)[5]. Müller's study opened up the era of biological Soil Science[6], as far as uncultivated soils were concerned.

In addition to the three humus types, Mull, Mor and Mullartiger Torf - equivalent to Moder (Kubiena, 1953) -, Ramann (1893) described the "coarse humus" (Rohhumus) close, as a matter of fact, to that of Müller's mull-like mor (Mullartiger Torf) (in Wilde, 1971)[7]. A large study on forest humus from "forest soils" was also developed by Henry (1908): biological processes of litter decomposition (microflora and microfauna), incorporation in underlying horizons, and humus classification. This author observed (p. 150):

- soft humus or neutral mould,
- imperfect raw humus (of steppes, forest, heath),
- peaty humus (infraaquatic, supraaquatic).

According to Wilde (1971), during the first decades of the 20th century many humus types were proposed accompanied by a confusing terminology: ... "almost every expression of international use has now two or more meanings and the same form is known under several names ... In some writings the terms mull and mor were used to designate forms of organic matter (incorporated or free) rather than natural types of humus ... Waksman characterized the existing humus terminology by a single word, chaos".

The second half of the 20th century was characterized by the elaboration of various very detailed classifications. Kubiena (1953) characterized 17 types of humus, classified into three groups according to the importance of hydromorphic conditions during their formation:

- "Unterwasser-Humusformen", with "Unterwasser-Rohbodenhumus, Dy, Gyttja, Sapropel, Flachmoortorf",
- "Semiterrestrische Humusformen", with "Zwischenmoortorf, Hochmoortorf, Anmoor",

[5]In Müller's first memoir (1879), Darwin is only quoted through another author (Fogh). It seems that Müller had not been aware of the first short publication (1837) of Darwin, "On the formation of mould".

[6]The contribution of microbiology will be treated in paragraph 3 ("humus-constituent").

[7]It must be pointed out that the term "moder", already used by Hermann (1841, 1842) referred to a complex material of plant debris in varying stages of decomposition. (Waksman 1936, p. 65).

- "Terrestrische Humusformen", with "Rohbodenhumus (Syrosemhumus), Rohhumus, Tangelhumus, Moder (Silikatmoder), Mullartiger moder, Rendsinamoder, Mullartiger Rendsinamoder, Mull".

For Kubiena, the characterization of humus and biological activity was very important as a criterion for soil classification. At the highest classification level, the same approach was used for soils and humus, with distinctions between subhydric soils, semi-terrestrial soils and terrestrial soils.

On the other hand, Wilde (1954, 1971) based his classification: (i) on the position of the surface organic horizon in relation to the mineral horizons, (ii) on its pigmentation; which led to the following:

- holorganic layers (ectc),
- amphimorphic (or ectendorganic) layers,
- melanized layers and cryptoorganic layers (endo).

Morphological data, importance of biotic factors, and station criteria, were then used as a basis for subdivision. With reference to Müller's concepts, the endings "l" and "r" characterized the endo- and ecto-organic horizons, respectively. The addition of letter "m" indicated a melanized horizon; e.g.: Vermiol = earthworm mull, Rhizol = root mull, Lentar = matted ligno-mycelial mor etc.

Duchaufour's humus classification (1956) was based on (i) aeration conditions (aerobic or anaerobic), and (ii) acidity; this gave rise to the following, respectively:

- calcareous mull, forest mull, moder and mor;
- anmoor;
- mesotrophic and oligotropic peats.

Prévot (1970) used the same approach.

The Delecour system (1980) is appreciably different, presenting subdivisions based essentially on morphological criteria and field tests (pH, effervescence). This classification does not mean to be "explanatory" or functional but "descriptive". At the class level "submerged humus" is distinguished from "emerged humus". The "emerged" humus is "semiterrestrial" (anmoor, peat) or "terrestrial" (forest and herbaceous humus) with the classic subdivisions (family) of: Mor, Moder, Mull, Anmoor, Peats, Muds. On the whole, 37 "forms" have been recognized. The nomenclature of horizons were derived from earlier works of Hesselman (1926), Kubiena (1953), and Babel (1971). The scale of Von Post (1924) was used to appreciate the state of decomposition of plant debris (Delecour & Kindermans, 1977):

- non-peaty holorganic horizons (O): Ol, Of, Oh (equivalent to L, F, H).
- peaty holorganic horizons (H): Hl, Hf, Hh (fibrist, hemist, saprist).
- hemiorganic horizons Ah: Ah1, Ah2 and OAh (transition O-Ah).

This nomenclature is approximately reproduced in the French system of soil classification, now being revised (R.P.F.,. 1990) with some additional subdivisions according to the works of Toutain (1981), Brun (1978),and Loustau (1984).

In Soil Taxonomy (Soil Survey Staff, 1975) the different types of humus are also taken into consideration to characterize the "diagnostic horizons", the "epipedons", and especially the "organic materials".

In short, from the notion of "humus" meaning either soil, layer or constituent as well-expressed by Wallerius in 1753, arose that of "humus-horizon" (or group of horizons) during the second half of the 18th century. At the same time, there were the pioneering and brilliant investigations of Müller and the emergence of Soil Science (Dokuchaev, 1883), a discipline based on the characterization of horizons. Foresters contributed the most with systematic studies in cold and temperate areas. Surprisingly, it looks as if there was no similar approach in intertropical areas[8], except for a few detailed studies (Hardon 1936, Richards 1941, de Boissezon 1962, de Boissezon & Gras 1970, Perraud 1971, Turenne 1977, Schwartz 1988). According to Klinge (1966, 1968), this is due to the fact that tropical soils were considered as generally low in humus with a rapid decomposition rate of organic matter and thus no forms of humus such as "moder" or "mor" developed.

In conclusion for the "humus-horizon" concept, we can say that the different types of humus-horizons are now relatively well-established and taken into consideration in all soil classification systems.

3 Historical account of the "humus-constituent" concept

Preliminary remark. In this section, the word "humus" - when used for organic constituent, without going into details - has the broad meaning of "soil organic matter" (SOM). It refers to the organic material present in a soil sample (<2 mm, generally), in the form of dead or living organisms, transformed or not, and restricted to microflora and microfauna. Although often criticized - scientifically speaking - for not being restrictive enough (which will be discussed later), this definition is convenient in such an historical review (Waksman 1936, Vaughan & Ord 1985). The terms "humus" and SOM will thus be used interchangeably.

Until the mid- and even the late 19th century, the studies conducted on humus as a constituent involved primarily chemistry and occasionally physical chemistry. Starting in 1870, the advent of microbiology (Pasteur's works) and the development of biology in general, initiated series of investigations on the interactions of bio-organic substances with other soil components. Since about 1950, the relatively easy approach of radioisotope techniques on the one hand (by ^{13}C, ^{14}C, ^{15}N natural

[8]However, no thorough bibliographic search concerning this suject was done by the present writer.

labelling and enrichment), and electron microscopy and micromorphology on the other hand, have contributed to great advances in the investigations on the nature, origin and dynamics of the different soil organic substances and components.

Without going into technical and methodological details, this discussion will help us to analyze how the concepts evolved about humus characterization.

3.1 "Chemical approach" of humus

Few natural substances attracted chemists' attention as did humus. Thus, this subject easily lends itself to historical studies. Among the numerous detailed studies, we shall refer here to those of Maillard (1913), Waksman (1936), Kononova (1961), and Vaughan & Ord (1985). Most references cited in this section, but not read by the author, originate from Waksman's work (1936) which is exceptional for the exhaustive literature it presents (more than 1300 references).

a) The glossary of humic substances

Achard (1786), who extracted peat with alkali and obtained a dark amorphous precipitate upon acidification, was probably the first to initiate a long series of studies on the fractionation of soil organic matter: the era of humic fractionations of soil organic matter was born. The qualifier "fulvic", in continued use with the terms "humic" and "humin", did not enter the "fractionation" vocabulary before 1919 with Oden.

Meanwhile, the imagination of scientists led to an evocative and varied vocabulary to describe components always extracted (or not extracted) by sequential treatments with alkali and acid. It began with *ulmin*, a blackish substance found in the exudates of the wounded bark of elm (Latin "ulm"), discovered by Vauquelin (1797) but named by either Thomson in 1807 (according to Kononova 1961 and Waksman 1936) or Klaproth in 1804 (according to Maillard 1913). In 1822, Döbereiner created the term "humic" and, as early as 1830, the vocabulary became appreciably enriched. Depending upon the nature of the substrates under study, one can distinguish:

- from plants, the *ulmin* and *ulmic* acids of Boullay (1830);
- from soils, the *gein* and *geic acids* of Berzelius (1831);
- from waters, the *crenic* and *apocrenic acids* of Berzelius (1833, 1839);
- from manures, evidently the *fumic acids* of Thenard (1857,1859).

Mention is also made of Hermann's classification (1837, 1841, 1842) which was mainly based on the nitrogen contents of the extracted components and thus enriched the vocabulary with terms such as *torfic* and *apotorfic acids, nitrolin, nitro-* and *anitrohumins*, etc. Finally, the *hymatomelanic acids* (alcohol-soluble SOM) were described by Hoppe-Seyler in 1889.

It was soon established that blackish substances could be artificially obtained by alkali and acid treatments of various chemical compounds (gum, lignins, sugars, etc.): the *mucic acids* of Johnston (1840), *lignoïc acids* of Hesse (1859), *sacchulmin acids* of Sestini (1880) were thus added to the catalogue.

By 1930 the glossary of humic substances was almost complete. The terms then currently used were summarized by Waksman (1936, p.60, table 4). After 1930, Waksman (1936, p.70), in addition, referred to the α- and β-fractions of humus. In 1938, Springer defined "brown" and "gray" humic acids, and more recently "type P- humic acids" composed of "green" and "brown" humic acids have been studied by Kumada & Sato (1962).

Numerous procedures for extracting humic substances were tested in relation to different objectives (reviews of Kononova 1961, Schnitzer 1978, Stevenson 1982, Vaughan & Ord 1985). According to Stevenson (1982) "the ideal extraction method is one which meets the following objectives: ... complete extraction ... of unaltered materials ... free of inorganic contaminants ... and universally applicable to all soils" ... and, we can add, separation of "humic" and "non humic substances (or matter)" (Page 1930, Malcolm 1990).

The most common methods imply alkaline extraction with 0.1 M NaOH or/and 0.1 M $Na_4P_2O_7$. Some pretreatments may be used either to destroy mineral components such as $CaCO_3$ (Tyurin 1951, modified by Ponomareva 1957, Dabin 1971) or to separate plant or animal debris (Henin & Turc 1950, Duchaufour & Jacquin 1966; see section 3.3). Different organic solvents were also tested such as formic acid (Tinsley 1956), acetylacetone (Martin & Reeve 1957), pyridine (Hayes et al. 1975), dimethylformamide (Whitehead & Tinsley 1964).

It would appear that there is a need at the international level for standardized extraction procedures and agreement about definitions of humic substances. These are some of the objectives of the recently founded (1983) "International Humic Substances Society (I.H.S.S.)".

b) Progress in the nature and structure of humic substances

The progress in the knowledge of the nature and structure of humic substances is related to the development of chemistry, biochemistry and physical chemistry. These historical aspects were remarkably described by Kononova (1961) and only some important works or techniques will be discussed here.

During the 19th century, there was great interest in the elementary composition of humic substances. Examples of Mulder's formulas (1840) were quoted by Kononova for ulmin ($C_{24} H_{32} O_{11}$), humin ($C_{40} H_{30} O_{15}$) and apocrenic acid ($C_{24} H_{12} O_{12}$). Nitrogen was not considered as a natural element of humic substances but as a saline impurity, which was a conflicting subject during the second half of 19th century. In 1919 Oden proposed a formula for humic acid where nitrogen was still not represented.

In contrast, Maillard (1913), in his thesis "*Genèse des matières protéiques et des matières humiques*" ("Genesis of proteinaceous and humic materials") considered that humic compounds represented polymers principally made of amino acids and sugars that could react with one another. He also postulated that humic compounds isolated from soils or moulds: (i) differed from the blackish substances synthesized by heat (caramelization), acid and alkali treatments of plant components, and (ii) included organic nitrogen in their composition:

(20) "l'azote est au contraire le premier facteur de l'humification naturelle qui, sans lui, n'aurait pas lieu" (Maillard 1913, p.422).

This subject, largely discussed at the beginning of the 20th century, led to the development of methods involving acid hydrolysis (HCl, H_2SO_4) in order to characterize the organic forms of soil nitrogen (Jodidi 1909, 1911, 1912). These techniques are still widely employed (Bremner 1965, Jocteur-Monrozier 1984). Maillard's works were further advanced by the investigations conducted on the synthesis of humic constituents (Andreux 1978).

Concerning the chemical nature of humic substances, much data was obtained from the "proximate analysis" of Waksman (1936), the analysis of monomers obtained by hydrolysis (acid or alkaline) methods, the determination of functional groups and the application of various physico-chemical and spectroscopic methods. Therefore, special mention must be made of: (i) the works of Flaig and his collaborators (i.e. Flaig et al. 1975) on the process of lignin degradation into phenolic monomers and their subsequent oxidation to quinones that combine with amino acids to form humic substances, (ii) the overall work undertaken by Schnitzer (Schnitzer 1978, Schnitzer & Khan 1972, 1978) in the wide field of humic substance analysis, (iii) the study of Cheshire and colleagues (Cheshire 1979) on the role of carbohydrates in the humification processes and soil properties.

Knowledge concerning the nature of humic substances is periodically synthesized with the formulation of chemical models (Fuchs 1932, Thiele & Kettner 1953, Felbeck 1965, Haworth 1970, Schnitzer 1978). At the present time, new qualitative and quantitative information, which confirm or refute previous data, may be obtained with the powerful tool of ^{13}C-NMR spectroscopy (Theng et al. 1989, Malcolm 1990, Zech et al. 1990, Kögel-Knabner et al. 1991) and we can expect considerable progress in the study of the relationships between humic substance composition and environmental factors. "Soil organic matter - The next 75 years" is the title of a recent publication of Schnitzer (1991) in which the "SOM laboratory of the future" is essentially equipped with a solid-state NMR spectrometer to analyze solid soil (or soil fraction) samples.

3.2 "Microbiological approach" to humus

In 1877 Schloesing and Müntz conducted their famous sewage treatment experiment and proved, using chloroform as an antiseptic agent, the major role of bacteria in the nitrification process. The origin of humus was thus raised: plant and/or microbial? According to Kononova, the first attempt to "demonstrate" the contribution of bacterial metabolites to the formation of humic substances, appears to have been Kostychev in 1886. However, according to Waksman (1936, p.33), humic substances had already been found in fungi by Braconnot (1838) and Lucas (1841). Maillard (1913) considered that microorganisms only played a role during the stage of decomposition of plant residues and the release of monomers but:

> *(21) - "la formation des matières humiques consiste en une réaction chimique automatique où les microorganismes n'ont à intervenir en aucune façon ... c'est un phénomène aseptique ... et ... anaérobie"* (p.374).

In contrast and at the same time, Trusov's view (1916) on the origin of humus was that there existed two sources of organic matter; one deriving from microbial plasma, and the second being the remains of plant residues that resist attack by microorganisms (aromatic polymers, tannins, lignin, etc.). This view was further advanced by Dumont (1913, p.125) who distinguished: (i) the "inherited humus" formed by the plant debris or components that resisted humification, and (ii) the "microbial humus" formed by:

> *(22) - "les cadavres, dépouilles, moisissures et ferments qui pullulent dans la terre arable" ...,* and p.145 *"... c'est de là que proviennent et les composés humiques actifs, et la matière azotée nitrifiable. Dans ma pensée, je n'hésite pas à le dire, c'est l'humus microbien qui intéresse le plus directement la chimie agrologique".*

Syntheses of humus-like substances by bacteria or fungi (Haider & Martin 1967) are now well-described, as well as the incorporation of microbial metabolites with soil humic compounds (Amato & Ladd 1980, Ladd et al. 1981).

Throughout the 20th century, numerous studies have dealt with the role of microflora and soil enzymes in the processes of OM decomposition and synthesis of humic constituents. This is exemplified by Waksman's "lignin-protein theory": "a purely microbiological theory has been proposed in which even greater importance is attached to the activities of microorganisms in the formation of humus as agents of decomposition and of synthesis" ... (Waksman 1936, p.105).

Jenkinson (1966) was the one who developed a simple method for measuring microbial biomass, based on a soil fumigation with chloroform followed by an incubation of fumigated and unfumigated samples[9].

According to Sparling (1985), microbial biomass accounts for about 2 % of the SOM. It is surprising that, despite the recognized and important role of soil microorganisms, microbial biomass was not quantified earlier. Effectively since Pasteur's works, Müntz in 1875 and Schloesing & Müntz in 1877 had used chloroform (and other antiseptic agents or heat) to evaluate the participation of bacteria in the decomposition processes occuring in waters and soils. Numerous experiments were conducted on this subject by Wollny (1902). Furthermore, Deherain & Demoussy (1896) concluded for sterilized soils, compared to untreated ones, that the amount of CO_2 evolved was 2 to 5 times higher. Finally, for Stoklasa & Ernest (1905), the CO_2-C evolved represented a fraction of soil OM named "available". But probably the concept of "microbial biomass" could only appear when attention focused on soil organic matter dynamics, this aspect being strongly related to the development (since 1950) of isotopic techniques.

Other recent aspects of the microbial approach concern soil microbial habitats. A very important and large review was done by Stotzky (1986). This author emphasized the fact that many studies on the interactions between bacteria (for example) and mineral or organic components were done with laboratory models, or dispersed soils, with no consideration of the natural macro- and micro-aggregation. Therefore, extrapolation to natural environments may be limited. The development of electron microscopy on ultrathin sections of the rhizosphere zone (Foster & Rovira 1973, Guckert et al. 1975) or natural aggregates (or microaggregates) (Foster 1978, 1981, Emerson et al. 1986) led to considerable advances in the knowledge of bio-organo-mineral interactions.

3.3 "Physical and microscopic approach" to humus

Since the early 19th century, with the extraordinary development of chemistry, the techniques used to study soil organic matter to date have been inevitably dominated by chemical characterizations (alkali-acid extraction, and generally, chemical fractionations). The humus fractionations represented an essential tool in soil pedogenesis and soil ecology in temperate (Duchaufour 1970b) as well as tropical areas (Thomann 1964, Perraud 1971, Turenne 1977, Dabin 1980/81).

[9]Alternative methods also exist which are not based on incubation but on the extraction of soluble compounds produced by the biocidal treatment (Sparling 1985).

However, in so far as soil functioning (aggregation, exchange dynamics, mineralization potential) is concerned, it is often difficult to ascribe definite and measurable functions to organic fractions obtained on the basis of solubility characteristics, because:

(i) - the actual procedures for chemical fractionation are highly denaturing, and the characteristics of the extracted fractions are still questioned. Are they representative of those found *in situ* in the soil? This is particularly important when the role of organic matter in the properties of the associations between organic and mineral substances is studied;

(ii) - owing to chemical structure and/or physical protections, the turnover of humic constituents is relatively low (a few hundreds to a few thousands of years) if compared to that of living soil organisms or their metabolites (0.3 to 3 years) (Anderson & Paul 1984, Duxbury et al. 1989). Thus, the humic constituents probably do not contribute much to the active soil organic matter compartment that is implied in short term processes (OM mineralization, seasonal variations of structure, etc.), and especially important in agro-pedological studies.

Accordingly, over the last 20 years as the validity of the SOM chemical approaches was questioned (Tiessen and Stewart 1983, Anderson et al. 1983), the use of a different characterization - based on particle-size and/or density fractionations of soil organic pools - has developed.

To my knowledge, and in contrast with chemical or biological approaches, there does not exist any exhaustive historical account on the physical approach. It was ignored by Kononova (1961) and slightly reviewed by Vaughan & Ord (1985). As for Elliott & Cambardella (1991), in their interesting article about methods applied to physical separation of SOM, they do not quote works prior to 1967, and 80% of the references correspond to the last decade. It explains therefore the importance of this section in this paper, especially for publications before 1980[10].

a) A few additional older works

In 1829 Martin (pp. 115-121) described a method of separation of "humus" by sedimentation: it was the solid material remaining in the supernatant, after shaking the soil in water for one minute[11] (1:8, w/v). The precipitate contained "silica" and "alumina".

Yet Gasparin (1843, p.125) questioned the significance of humic extractions:

[10]Just before sending the definite manuscript to the Editor, I discovered the recent review of Christensen (1992) more exhaustive than the other quoted works.

[11]This corresponds approximately to a fraction 0-50 μm.

(23) - "Pour étudier le terreau, on cherche à le séparer des matières minérales mais ... la séparation mécanique est presque impossible. Eller ... l'obtient" (le terreau) "en faisant bouillir la terre avec de la potasse ... le terreau obtenu ... ne peut être étudié avec sécurité comme identique au terreau contenu dans le sol. Il a sans doute été modifié ... c'est un corps nouveau".

But the first particle-size fractionation of OM was carried out by Schloesing in 1874 under suitable experimental conditions and criticism. This work could practically be published nowadays. Schloesing questioned the distribution of OM between sand and clay in natural samples. He pointed to a similar study which would have been undertaken by M. Masure (ref. not provided). Schloesing thus set out a particle-size fractionation of OM in five fractions: "*gros sable*" (coarse sand), "*sable fin*" (fine sand), "*écailles*" (scales), and "*deux dépôts d'argile*" (two clay deposits).

The results were shown in two tables with recoveries (99,98 %, w/w), C and N content per gram of fraction, and C and N content per gram of soil. It would not be better done today. One of Schloesing's conclusions was that:

(24) - "l'argile contient 69 % de matière organique, c'est assez pour qu'elle soit réellement modifiée dans sa manière d'agir comme ciment".

Using a separation technique of sands, Gain (1918, p. 160) briefly described a physical separation of soil OM in two fractions: (i) "humus" (plant debris), floating after *(25) - "trituration de la terre dans* $Ca\ (NO_3)_2$ *à 50 %"* and (ii) "humic materials" extracted afterward from the material precipitated with acid (oxalic acid, boiling 1 hr).

In fact, no concept has been established for the adequacy of "fractionation methods/nature of OM" in the other approaches, except in Schloesing's work (the other approaches did not postulate adequacy). From 1940 onwards, the need for a separation of the "soil plant debris" (or "free organic materials") from the remaining and more humified OM ("stable organic material"), has been clearly shown.[12]

b) Density fractionation

Before Henin and Turc's works, attempts to separate soil plant debris by densitometry (Finnell 1933, Lein 1940, Harris 1941), particle-size fractionation (Shively & Weaver 1939) or particle-size/density fractionation (McCalla et al. 1943), had already been published.

As early as 1949, Henin & Turc (1950) referred to the methodology developed

[12]Light fraction on the surface of the "fine sands", flaking off.

by Lein (1940) and to Kubiena's observations (1948, p. 72) who distinguished two organic "phases" in soil, "on the one hand, the plant debris that retained their cellular structure, on the other hand a material, more developed, the organic features of which are only visible to the naked eye by its dark colour", in an attempt to separate those two phases by densitometry in benzene-chloroform mixtures of known densities. A three page paper presented during the 4th Congress of Soil Science (1950) revealed the interest of physical fractionations in soil OM studies. These authors distinguished two types of fractions:

- "light" fractions (d < 1.75), named "*MO libres*" ("free OM"), characterized by a very high OM content (30-35g C/100g fraction), C/N ratios higher than 16, and essentially constituted of plant debris. These fractions account for 15-20 % of the total organic matter;
- "heavy" fractions (d > 1.75), named "*MO liées aux matières minérales*" ("OM bound to inorganic constituents"), characterized by a lower OM content (0.7-16g C/100g fraction), C/N ratios lower than 11, more "humified" than the light fractions and *(26) - "constituées en particulier du complexe argilo-humique".*

This densitometric approach has been essentially developed between 1950 and 1970 by French scientists (Monnier et al. 1962, Duchaufour & Jacquin 1966, Dabin 1971), as a preliminary step in humus fractionation. However, the use of heavy liquids, either inorganic or organic, involves a range of methodological problems: such as contamination and/or alteration of the fractions. This may explain why this approach was not widely adopted.

This approach was further advanced by Greenland & Ford (1964), and Ford et al. (1969) who improved the separation of "free OM" by combining ultrasonic dispersion (for disrupting aggregates) with densitometry (d = 2.0).

c) Particle-size fractionation

Edwards and Bremner in 1964 and 1967a, referred to and developed earlier works[13] in order to show the effectiveness of the ultrasonic method in dispersing the soil in water, with no need for a preliminary extraction of OM or the addition of a dispersing agent. Particle-size fractions can thus be separated together with the associated organic materials. This work is of cardinal importance as it provides a practical method for locating OM among particle-size fractions, with no interfering chemical reaction likely to alter the organic or inorganic constituents. At the same

[13] According to Watson (1971), the dispersing effect of ultrasounds on soil suspensions had been already demonstrated by Whittles in 1923.

time, the study of clay-organic fractions highlights the concept of "clay-humus complex" (Greenland 1965). Finally, depending on the energy level imparted, information can be obtained regarding OM associated with aggregates or microaggregates that have different stabilities (Edwards & Bremner 1967b). With regard to history, let us point out that Edwards & Bremner in their first publications (1965, 1967a, b) demonstrated that Na-resins could be as successful as ultrasounds in dispersing strongly aggregated samples. They also reported that shaking soils with beads may be used to disrupt aggregates. The fractionation schemes proposed by Feller et al. (1991a), and Bruckert et al. (1978), respectively, rely on these two former notions.

It then appeared very rapidly (Chichester 1969, McKeague 1971, Watson & Parsons 1974, Feller 1979, Tiessen et al. 1984) that OM associated with size fractions higher than 20 or 50 µm, consisted largely of plant debris in varying stages of decomposition, with C/N ratios often higher than 15, whereas OM associated with clays were characterized by C/N ratios generally lower than 10.

Generally, the turnover of OM associated with the different particle-size fractions strongly decreased from the coarse fractions (plant debris) to the fine fractions (organo-clay complexes) (Anderson & Paul 1984, Balesdent et al. 1987, 1988). In other words, it is possible by simple particle-size fractionation in water to easily separate forms of natural[14] OM very different from the point of view of their nature, properties and dynamics. In order to specify the nature of the fractions, densitometric separations can be applied to some or to the whole size-fractions (McKeague 1971, Turchenek & Oades 1974, 1979, Spycher & Young 1977).

Bruckert et al. (1978) and Bruckert (1979) have proposed particle-size fractionations of OM employing shaking of the soil in water with beads, instead of ultrasonics. Most of the works published actually use the ultrasonic method (Elliott & Cambardella 1991, Morra et al. 1991) but do not always take into account its modifying effect on soil plant debris (Balesdent et al. 1991).

Presently, numerous studies are being developed through the physical approach to analyze the role of SOM in biogeochemical cycles and macro- or microaggregations. Microscopic and ultramicroscopic techniques were used to establish the precise nature of SOM and its relationships with biological and mineral constituents in the particle-size fractions (Emerson et al. 1986, Tiessen & Stewart 1988, Santos et al. 1989, Feller et al. 1991b). Recently, Feller (1995) proposed a quantitative approach of functional organic compartments of the soil.

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[14]Adjective used occasionally when comparing this approach to the "humic" one (McKeague 1971, Turchenek & Oades 1974).

3.4 Modelling of SOM dynamics and integrative approach

Following Jenny's model (1941) of soil nitrogen dynamics, different types of models have been used to represent medium to long term changes in SOM. That model is a single-state variable one. In 1945, Henin and Dupuis presented a model with two compartments: annual organic inputs to soil and humified SOM. Different models including two or more different compartments of organic inputs or SOM were proposed later. Campbell (1978) distinguished between "stable" and "labile" organic matter while Balesdent & Guillet (1982) recognized "young" and "ancient" organic matter. Van Veen & Paul (1981) considered "recalcitrant" and "decomposable" fractions of plant residues and introduced the notion of "physically-protected SOM". Jenkinson & Rayner (1977) considered five compartments including soil microbial biomass. Finally, the "Century Model" of Parton et al. (1987) integrates some of the previous quoted models and takes into consideration two plant material compartments ("Structural" and "Metabolic") and three soil compartments (Active, Slow, Passive).

The actual necessity of simulating SOM dynamics, either at the local scale in relation to soil management practices, or on a global scale in relation to climate, pollution, erosion-sedimentation cycle, led to the development of more and more research on modelling. In this way, an integrative approach will be developed in the future between the conceptual model compartments and the natural chemical, biological or physical SOM fractions.

In conclusion, three main partly overlapping approaches about the humus-constituent concept during the two last centuries, have been developed to characterize SOM. The "humic approach", the oldest one, emphasized the constituents representing the most stable and most transformed fraction of SOM. It provided criteria for comparing the main soil types of the world and testing the effect of environmental factors on SOM. However, it provided little information on soil functioning especially in agricultural ecosystems. Since the 1960s, the "microbiological" approach (i) led to quantitative measurements of the microbial biomass, which plays a major role in the whole bio- and geochemical processes, and is considered as being the most "active" organic pool in the soil with a high turnover rate, and (ii) through electron microscopic studies, the nature of microbial habitats in the soil were revealed. The "particle-size" approach, also recently developed, takes into consideration, like the "humic" approach, the whole SOM. However, it stresses the separation and the study of the various natural pools of the soil, either organic or organo-mineral, which differ from one another in their morphology, chemical and biochemical characteristics, and turnover rates. The methodological works in progress will lead to an integration of the "microbial/ particle-size" approaches through global conceptual models of SOM dynamics.

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Notes

(Translations of the French quotations)

(1) - ... "stricto sensu, "humus" refers to the fraction of SOM which has undergone a more or less rapid transformation of biological as well as physicochemical origin ... lato sensu, "... (the humus) ..." designates the ensemble of organic horizons ..."

(2) - "Humus, natural history, this latin word is often borrowed by naturalists (even into French) and denotes the mould, the earth of the garden, the earth formed by plant decomposition. It refers to the brown or darkish earth on the surface of the ground. Refer to the mould or vegetable mould"

(3) - ... "to produce mould or humus, the only vegetable mould" (vol. 1, 506),
- ... "a soil which lacks only humus, mould or soluble earth, ... is the only vegetative earth. The other earths serve solely as matrices for plants" (vol .1, 568),
- ... "the calcareous earth is thus the only vegetable mould, the perfect humus soluble in water, and the only one establishing and constituting the "frame" of the plants ... if plants are piled up ... undergoing decomposition ... we will end up with a pure calcareous earth, the perfect humus. Farmers, keep on producing this precious humus which is a real "animal earth", the only one to be present in their composition ..." (the plants) (vol. 9, 390-401, 1796).

(4) - "it is the outermost layer of the earth ... from which the soil is formed when the rock is not uncovered ... its depth varies from two or three inches to several feet ..."

(5) - "the black substance the plants get imbedded in"

(6) - "the thick humus composed of plant debris"

(7) - "the increase in plant carbon by the action of vegetation"

(8) - "the dissolution in water of coal, thus sucked up by the roots and deposited into the plants ... the dissolved coal is one of the plant nutrients"

(9) - "The usual name of this substance is mould. This designation has been widely misunderstood as it referred to the layer of vegetable earth rather than the special part of the substances forming it. This mistake has been repeated even in the writings of eminent agronomists, which led to increasing misconception of this part of science. This is the reason why I adopted the term humus which is unequivocal. Generally, the scientific designation of earth is not appropriate; properly speaking, it is

not earth; it was only designated so for its powdery form ...". "Humus is the residue of animal and plant putrefaction, it is a black body ..."

(10)- Garden black earth (*Humus extra*)
- Red earth (*Humus rubra*).
- Dark earth (*Umbra*)
- Black earth (*Attramentum scissele*).
- Loam or peaty loam (*Humus palustris*)
- Peat (*Coespes*).
- Animal earth (*Humus animalis*).

(11) - "They are mineral substances composed of particles ... they can be considered as the primitive material of stones ..."

(12) - "They (the loams), serve as an envelope to the globe which they cover on its surface".

(13) - "In order to study the physical properties of a forest soil ... the soil has been prepared as it is usually done when research is carried out on the structure of an organism, with the same dissection and microscopy techniques. The separate parts of the soil have been examined "in situ", in the natural conditions of deposit, before calling up the chemical analysis to explain whenever possible what the eye could not elucidate.
... At first sight, it looks irrational to study a complex mixture such as an alluvial soil, as if it were a whole, organized and homogeneous ... But the study reveals that the various conflicting actions did not lead to any chaotic but fixed forms, ... but varied types of forest soil ... considered as an organized entity."

(14) - I propose to name the two principal types ... of humus ... from beech forest "Mull" (mould)* and "Torf" (peat)*

* - In Danish, "muld" and "mor" for Mull and Torf, respectively.

(15) - "Soil aspects. The soil ... is covered by a more or less thick layer of isolated (plant) remains cattered on the soil. When the cover is taken apart, the darkish brown surface ... of the soil has a gravelly and granular aspect. The line between the cover and the soil ... is quite marked ... This earth is as completely loose as ... tilled ... garden earth".

(16) - "If the soil is dug with a spade, ... a layer of tenacious black-brown humus, is found: the peat (mor); then, beneath, a grey-white, grey or black-grey sand ... the sand is clearer, the farther from the peaty layer ... (then, is found) ... a layer of earth having a red-brown or brown color ... and under it, some sandy clay, some sand". The grey sand is denominated "plumb sand" (bleichsand) and the brown-red layer, "Ortstein".

(17) - "Echter (Genuine) Mull. Perfectly divided, loose without cohesion. Does not contain more than 10 % organic substance, with no free humic acids ... well mixed with the mineral earth ... through the work of animals ... and the action of water".

(18) - "Mullartiger Torf. Perfectly divided, loose without cohesion". (Afterwards, idem to Echter Torf).

(19) - "Echter Torf. (Real mor) Imperfectly divided, firm, tenacious, coherent. Contains 30 to 60 % organic substance with free and soluble humic acids; imperfectly mixed with the mineral earth, owing, almost solely due to the action of water."

(20) - "on the contrary, nitrogen is the primary factor of natural humification which would not take place without it".

(21) - "the formation of humic materials results from an automatic chemical reaction where microorganisms do not have to play any role ... It is an aseptic phenomenon ... and ... anaerobic".

(22) - "the dead bodies, remains, moulds and ferments which pullulate in the arable soil ... They give rise to the active humic compounds and the nitrifying nitrogenous matter. In my mind, I venture to say so, it is the microbial humus above all which concerns agricultural chemistry".

(23) - "in order to study mould, one must attempt to separate it from mineral materials but ... mechanical separation is almost impossible to do. ... Eller obtains it" (mould) "by boiling water with potash ... The resulting mould ... cannot be studied with certainty as being identical to the mould contained in the soil. Probably, it has been modified ... It is a new body".

(24) - "clay contains 69 % organic matter; it is enough to be actually modified in the way it acts as a cement".

(25) - "trituration of the earth with 50 % Ca $(NO_3)_2$".

(26) - "constituted in particular by the clay-humus complex".

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The references ending with the sign *, have not been read directly by the author. Most of them have been borrowed from Grandeau (1879), Maillard (1913), Waksman (1936), Kononova (1961), Vaughan & Ord (1985).

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