European Humus Forms Reference Base

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ABSTRACT

In Europe an abundance of humus taxonomies exists starting with early approaches in the late 19th century. Frequently used in an international context, they do not cover all site conditions in the European area. Although having basic concepts and general lines, the European (and North American, Canadian) classification systems differ in important parameters used for the description and classification of humus forms. These discrepancies result in incongruities, so require adjustments when exchanging partially compatible soil data, even between nearby countries. In 2003, 26 European specialists in humus forms met in Trento (Italy) and decided to formulate rules of classification based on morphogenetic descriptions and diagnostic horizons, adapted to European ecological conditions. Taking into account old and new European and North American systems of humus forms classification, six main references (Anmoor, Mull, Moder, Mor, Amphi and Tangel) were defined, each of them further dividing into detailed categories. This inventory assigned a strong discriminatory power to the action of the pedofauna. Both semiterrestrial (anoxic) and terrestrial (aerated) topsoils were classified. The descriptors of the diagnostic horizons were conceived in accordance with the spirit of recent international soil classifications. Assigning an "ecological value" to each main humus form along a gradient dividing those characterized by accumulation of poorly transformed organic matter, from very biologically active forms degrading and incorporating all organic remains, this European system of classification avoids a hierarchical structure and allows an elastic approach open to additional ecological contributions and renditions.

Keywords*: humus, humus forms, European humus classification, humus functioning, litter, litter decomposition, litter biodegradation, soil animals, soil dynamic, soil carbon,*

SUMMARY

INTRODUCTION

WHAT'S A HUMUS FORM ?

The humus form is the part of the topsoil that is strongly influenced by organic matter and coincides with the sequence of organic (OL, OF, OH, H) and underlying organo-mineral horizons (A, AE, Aa). Plant remains like leaves, needles, wood, root exudates, etc., form a prominent part of the primary production of forest ecosystems. During the 19th century, scientists noticed that the type and rate of decomposition of these organic components, as well as the incorporation of organic matter (OM) in mineral horizons, vary according to forest type (review in Jabiol *et al.*, 2005). These observations led Müller (1879, 1884, also in German 1887 and French 1889) to define three "humus forms", named Muld (later becoming Mull), Mor and Mullartiger Torf, characterized by their climatic, geological and biological conditions of formation in Danish beech forests. From the outset it was evident to Müller that the humus form corresponds to the "expression of life" within the topsoil. Many authors contributed to the development of a classification system of humus forms based on the key role of living components of the topsoil. The most prominent contributions are those of Hesselman (1926), Hartmann (1944), Kubiëna (1953), Babel (1971) and Delecour (1983).

All these concepts still form the basis of modern classification (Green *et al.*, 1993; AFES, 1995; Baize & Girard, 1998; Nestroy *et al.*, 2000; Zanella *et al.,* 2001; Brunner *et al.*, 2002; Baritz, 2003; AK Humusformen, 2004; Zanella *et al.*, 2006; Jabiol *et al.,* 2007; Van Delft *et al.*, 2007; AFES, 2009; Jabiol *et al.,* 2009). Although Canadian (British Columbian) and French classification systems are frequently used in an international context, none of them covers site and climate conditions worldwide, not even all European forest ecosystems. Moreover, the new national classification systems differ according to the parameters used for describing and classifying humus forms as well as for scaling diagnostic parameters. Similar designations of humus forms often have different contents. With harmonization purposes in mind, a wide range of European specialists met in Trento (Italy) in 2003 and formed a European Humus Group with the aim of improving the compatibility of established national systems of classification and setting out a unified European reference for humus forms (http://humusresearchgroup.grenoble.cemagref.fr/principal.html). The present synthesis was elaborated during the course of four plenary field sessions held in Alpine (Trento 2003, San Vito 2004, Vienna 2005) and Mediterranean (Cagliari 2007) ecosystems. On these occasions, the place of lesser known terrestrial humus forms such as Tangel and Amphi and that of semi-terrestrial humus forms were discussed and included in a new classification (Zanella *et al.,* 2009). In the meantime the key of humus forms was also tested by non specialists in order to improve it and to discard interpretative drawbacks (see Annex). In the future, the proposed humus form classification will be included in a worldwide topsoil characterization that is currently being prepared (Broll *et al.*, 2006).

STRUCTURE OF THE CLASSIFICATION

The classification has been conceived for forest soils, for which more information and larger datasets are available, as well as for soils of grasslands, pastures and wetland areas, with a negligible to strong human impact. It is not suited to tilled agroecosystems, because tillage destroys the "natural" organization and radically alters the functioning of the surface horizons. The manuals of the FAO (2006), IUSS Working Group WRB (2007) or Soil Survey Staff (2010) are more appropriate for describing and classifying these soils. An ongoing Canadian-German project on topsoil characterization of arable soils will be presented at the IUSS conference 2010.

The humus form classification is based on the sequence and morphological characteristics, including morphological evidence of biological activity, of organic and/or organo-mineral horizons observed and described in the field. In some cases a few basic chemical data (pH, organic carbon content) are required. A complete set of diagnostic organic and organo-mineral horizons, which are mutually exclusive, is defined. The classification keys use diagnostic horizons and other complementary topsoil or environmental data.

Every mineral horizon cited in this paper has been classed and named using the manual of the IUSS Working Group (2007).

The first dichotomy of the classification separates never saturated and saturated (submerged) humus forms (Fig. 1):

- **Terrestrial humus forms**: these are never submerged and/or water-saturated, or only for a few days per year. A or AE (non hydromorphic) organo-mineral horizons characterize these forms. In a second and more detailed step of the classification, *Terroforms* (= typical) are separated from *Entiforms* (= directly on bedrock or parent material) and *Paraforms* (= atypical);

- **Semiterrestrial** humus forms: these are submerged and/or water-saturated. *Hydroforms* are submerged and/or water-saturated for relatively short periods (less than 6 months per year) and are characterized by Ag or AEg hydromorphic organo-mineral horizons; *Histoforms* and *Epihistoforms* are submerged and/or water-saturated for protracted periods (usually more than 6 months per year) and are characterized by organo-mineral Aa or organic H horizons.

Within each group of the Terrestrial compartment (Terroforms, Entiforms and Paraforms) and within the group of Hydroforms of the Semiterrestrial compartment, the same five "biological types" are identified on a morpho-functional basis: Mull, Amphi, Moder, Tangel and Mor (Fig. 2). Within Histoforms and Epihistoforms, the Tangel biological type is not present, but a characteristic "soil moisture regime" generates the Anmoor biological type. These "biological types" can be considered as the first taxonomic level of the classification (Fig. 2). For Terroforms and Histoforms, the most important and best-known groups of humus forms, a second level of classification has been created. Here, each unit of the first level (Mull, Moder, …) is split in two or more biological sub-types (i.e. Eumull, Mesomull; Hemimoder, Dysmoder…).

Specific vocabulary listed in the section "specific terms", and topsoil layers detailed under the heading "diagnostic horizons", furnish the potential user with the necessary information for his/her field investigation of all Terrestrial and Semiterrestrial humus forms.

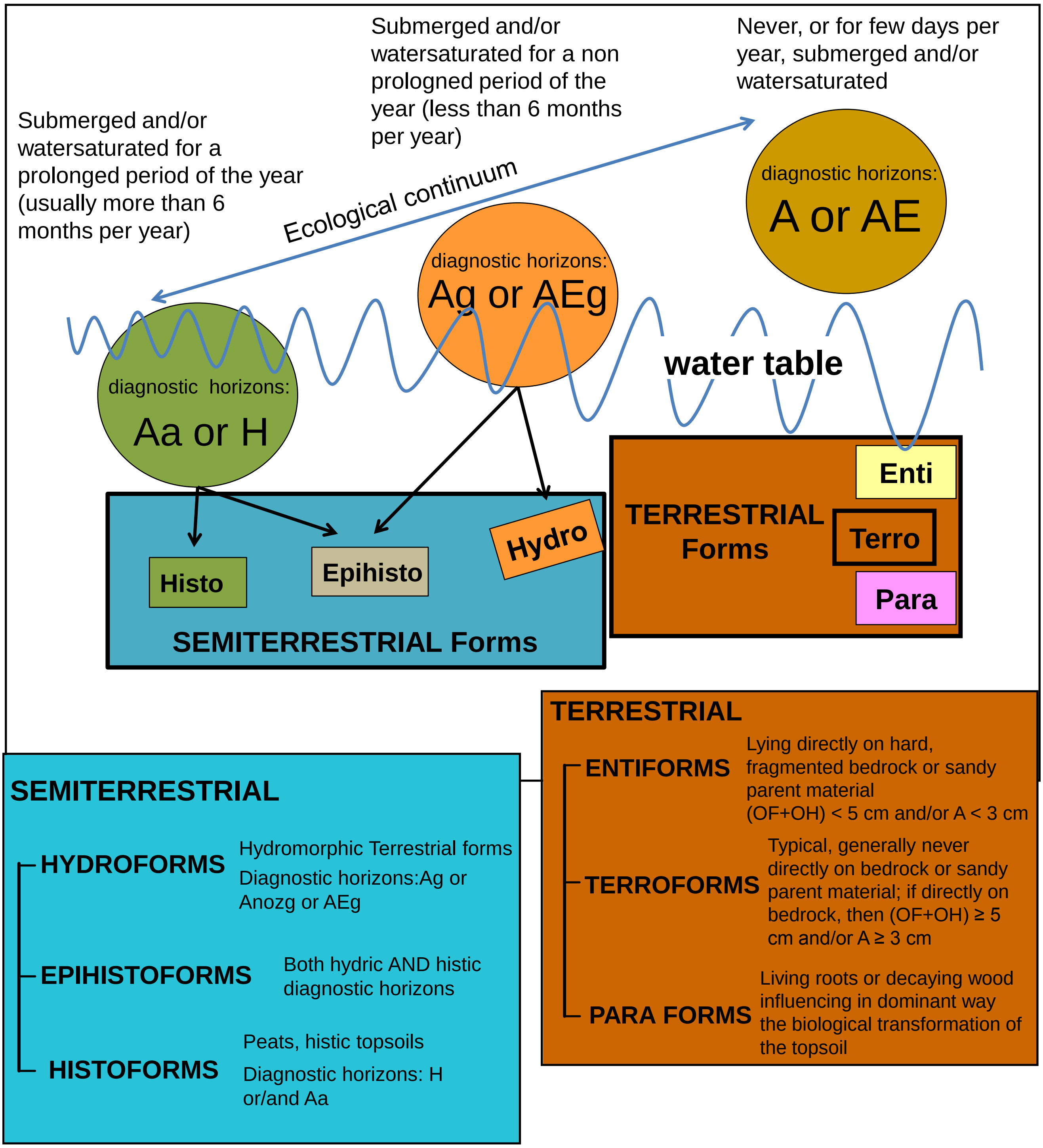


Fig. 1. *Semiterrestrial and terrestrial humus forms and their main subdivisions.*

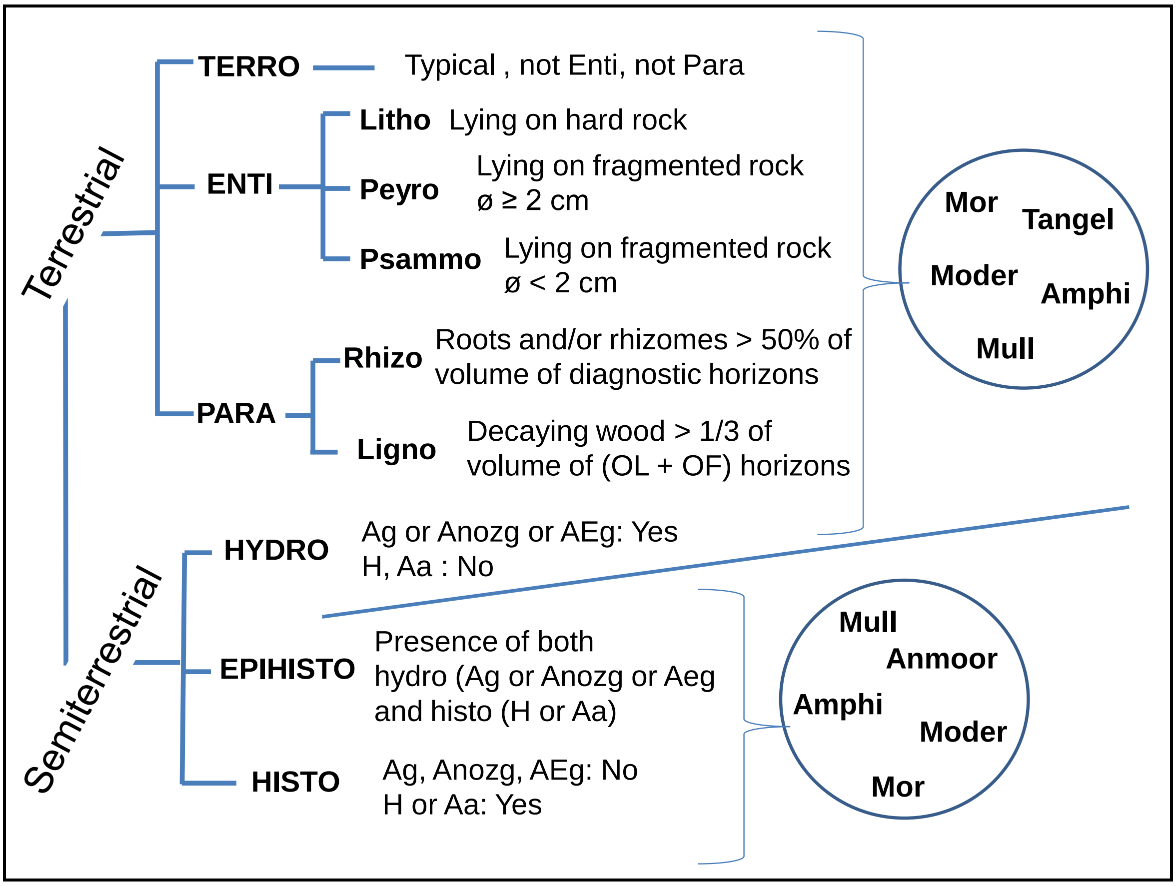


Fig. 2a. *The European tree of humus form classification. The first dichotomy separate Terrestrial humus forms, which are never waterlogged or only a few days per year, from Semiterrestrial humus forms which are seasonally waterlogged. Each of these main groups is subdivided in three secondary groups, one of them being typical of the main group (Terro for Terrestrial, Histo for Semiterrestrial humus forms), the other two being specialized or atypical forms. Among Terrestrial humus forms, Entiforms are initial forms, subdivided in turn according to substrate, and Paraforms are atypical, subdivided in turn according to the main agent of building. Among Semiterrestrial humus forms, Hydroforms are transitional to Terrestrial humus forms and Epihisto are atypical. On the right side two circles indicate main humus forms which can be found in both Terrestrial and Semiterrestrial groups. Note that these names correspond to morpho-functional types which can be found in both environments (Mull, Moder, Mor, Amphi) or not (Anmoor, Tangel) and are at least partly independent of the classification, as a reflectance of diagnostic features of biological activity.*

For Terrestrial and Hydro (transitional) Semiterrestrial humus forms, the 5 basic forms (Mull, Moder, Mor, Amphi, Tangel) are equilibrium points (ecological attractors) in a continuum running from a neutral and biologically active Mull (with rapid litter turnover) to either an acid pole with Mor (with nil or very slow litter turnover, due to low temperature or base-poor substrate), passing by Moder, with intermediate features, or a calcareous pole with Tangel (with slow litter turnover due to low temperature, summer drought or excess of carbonates), passing by Amphi (with litter seasonally unavailable to earthworms for climatic reasons). Most of these morpho-functional types may be found in Terro, Enti or Paraforms. For instance, a Mull, which can be recognized by the absence of an OH horizon and the presence of a A horizon processed by earthworms, is typically found lying on a B horizon (Terromull), but it can also be found lying directly on a still unweathered parent rock (Entimull) or modified by the dominance of roots or decaying wood (Paramull).

For both Histo and Epihisto Semiterrestrial humus forms, the 5 basic forms (Mor, Moder, Amphi, Mull, Anmoor) are equilibrium points in a continuum running from least biologically active and badly aerated (Mor) to more active and better aerated (either Mull or Anmoor) humus forms according to the water regime (fluctuating or stable, respectively). As an example a Mor, which is characterized by litter accumulation without any prominent faunal activity, can be either a Hydromor, an Epihistomor or a Histomor according to presence or absence of diagnostic submerged horizons.

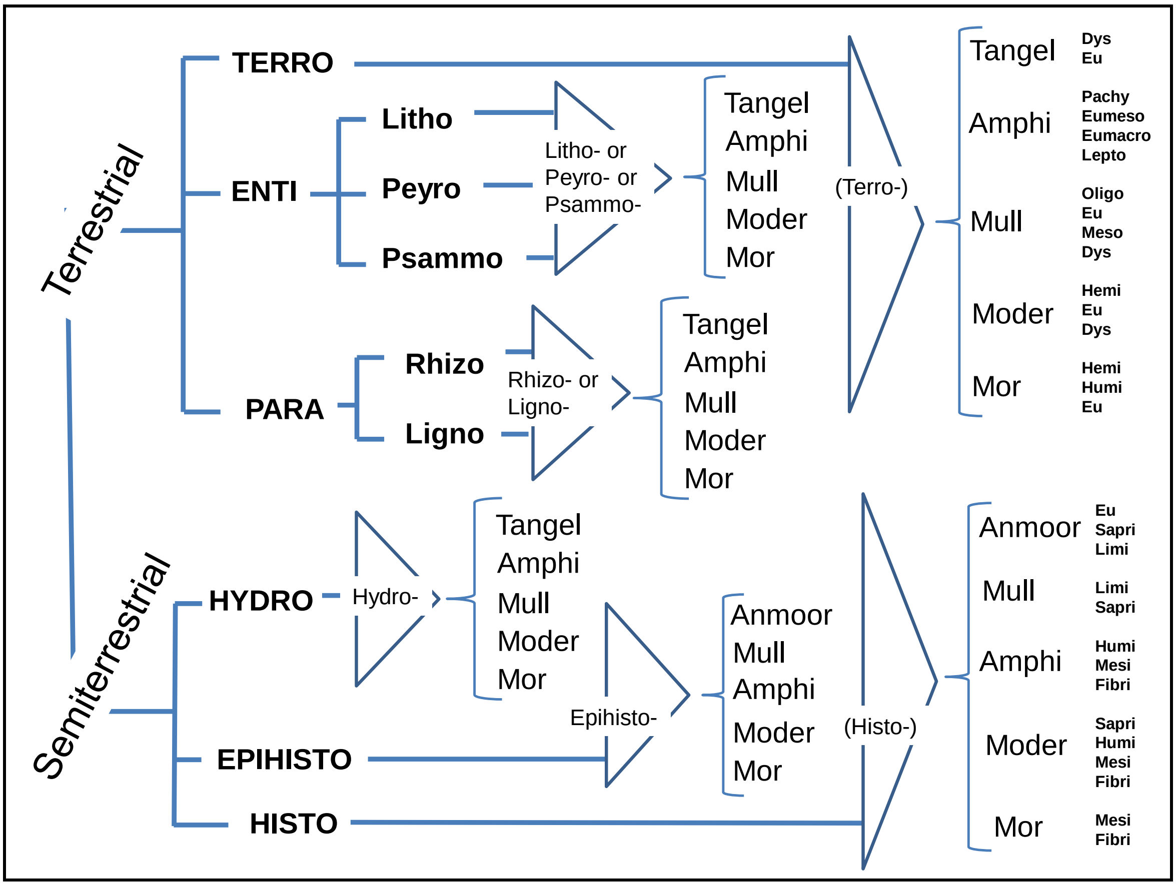


Fig. 2b. *The European tree of humus form classification. This figure displays a development of the tree at the second level of classification of morpho-functional types in typical representatives of Terrestrial and Semiterrestrial humus forms, i.e. Terroforms and Histoforms, respectively. As an example a Terrotangel can be either a Dysterrotangel or a Euterrotangel which, for the sake of simplification of the vocabulary, will be unambiguously named Dystangel and Eutangel. Thus, the facultative "(Terro.)" is enclosed in parenthesis, in the arrow on the right of the picture. In Semiterrestrial environments, a Tangel, which is present only in Hydroforms (transitional to Terrestrial forms), can only be a Hydrotangel. In Terrestrial environments, one can distinguish, in addition to abovementioned typical Terroforms of Tangel, Lithotangels, Peyrotangels, Psammotangel s (altogether Entitangels), Rhizotangels and Lignotangels (altogether Paratangels), which are classified only at the first level.*

TERRESTRIAL HUMUS FORMS

IDENTIFICATION AND SUBDIVISION

Terrestrial humus forms correspond to the topsoil never or for a few days per year submerged and/or water-saturated. Their investigation and description require a specific vocabulary; their classification rests on the knowledge of a few diagnostic layers used as references.

Terrestrial forms are divided into Terroforms, Entiforms and Paraforms (Fig. 1):

- **Terroforms** correspond to typical terrestrial humus forms, never lying directly on bedrock or parent material (initial forms) and never influenced in a dominant way by roots or decaying wood;

- **Entiforms** are characterized by thin organic (OF + OH < 5 cm) and/or organo-mineral (A < 3 cm) horizons lying directly on hard, fragmented bedrocks or sandy parent material;

- **Paraforms** are atypical humus forms which result from control by living roots (Rhizoforms) or decaying wood (Lignoforms) on the biological transformation of the topsoil. Roots interact with soil microorganisms (Clarholm, 1985; Fitter and Garbaye, 1994) and wood structural polymers cannot be degraded in the same way as other components of litter (Marcuzzi, 1970; Edmonds, 1987; Aerts, 1997).

SPECIFIC TERMS

SOIL STRUCTURE. As every observable object, the soil is made of aggregate units themselves built up by small aggregate sub-units. A level of structure finer than 1 mm cannot be detected by the naked eye. Using a 10 X magnifying lens, the limit is 0.1 mm. Indeed, in forest and natural soils, a fine granular structure of the A horizon, or even a "single grain" structure, are often the result of the presence of small arthropod or enchytraeid droppings (purely organic or mixed organic and mineral matter), mixed with mineral particles. In our classification, the IUSS Working Group WRB (2007) procedure and vocabulary is adopted, re-elaborated from the Soil Survey Division Staff (1993) and Schoeneberger *et al.* (2002). Nevertheless, the "normal test" has to be coupled in some cases with a finer analysis in order to: 1) better define the finer structures, checking the presence of small animal droppings (see the "microstructured" diagnostic A horizon); 2) observe and quantify the presence of structures concerning only a fraction of the soil mass (secondary structures), which have a diagnostic character (e.g., the presence of larger peds, the result of worm activity, in the soil mass of A horizon with a very fine granular structure).

ORGANIC HORIZONS. Organic horizons (OL, OF, OH) are formed by dead organic matter (OM), mainly leaves, needles, twigs, roots and, under certain circumstances, dead plant materials such as mosses and lichens. This OM can be transformed in animal droppings following ingestion by soil/litter invertebrates and/or slowly decayed by microbial (bacterial and fungal) processes (Fig. 3). A limit of 20% organic carbon (OC) by mass was established to define O horizons (IUSS Working Group WRB 2007), also followed in this work, as weight % of OC in dry samples, without living roots (Method: element analyzer, ISO 10694, 1995).

ORGANO-MINERAL HORIZONS. The organo-mineral horizons (code: A) are formed near the soil surface, generally beneath organic horizons. Coloured by organic matter, these horizons are generally darker than the underlying mineral layer of the soil profile. In the soil fraction Ø < 2mm of the A horizon, the organic carbon has to be less than 20% by mass following the IUSS Working Group WRB (2007).

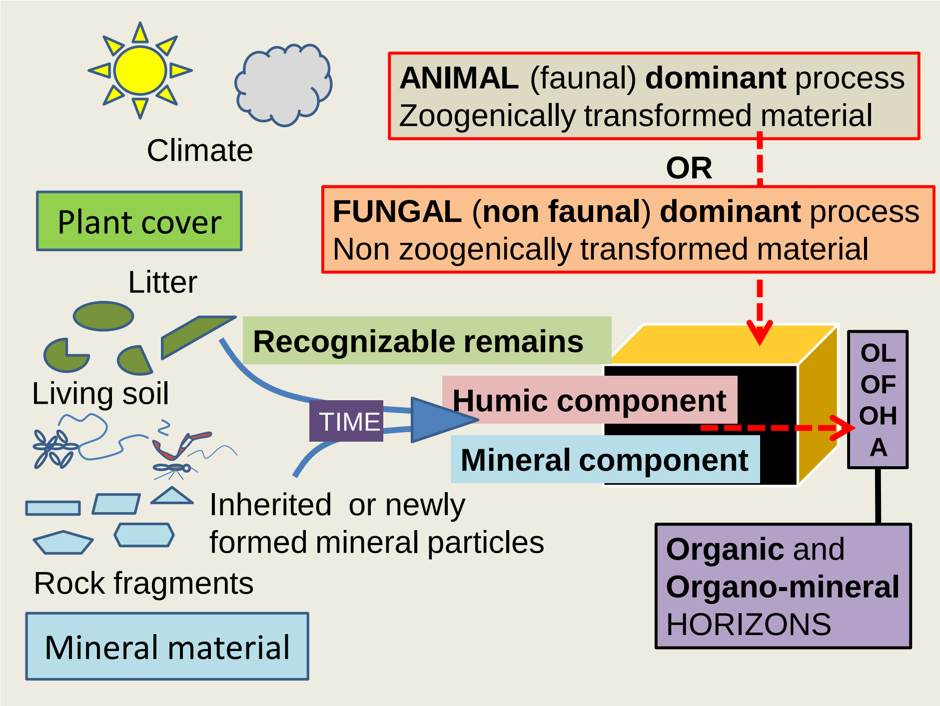


Fig. 3. *Vocabulary and dynamic formation of an example topsoil. Above- and below-ground processes are similar. On one side "decomposition" or "weathering" (from complex structures to their unit components), from leaves to molecules, from minerals to elements; on the other side "composition" (from atoms or molecules to new structures), from mineral elements, organic molecules and water to biological structures (trees, animals…), from minerals to new clay, humic component, soil sub-units (peds).*

RECOGNIZABLE REMAINS within an organic or organo-mineral horizon = organic remains like leaves, needles, roots, bark, twigs and wood, fragmented or not, whose original organs are recognizable to the naked eye or with a 5-10 X magnifying hand lens. Fresh litter is generally made up of 100% recognizable remains.

HUMIC COMPONENT of an organic or organo-mineral horizon = small and not recognizable particles of organic remains and/or grains of organic or organo-mineral matter mostly comprised of animal droppings of different sizes. The original plant/animal organs form the litter and generate the small particles (free or incorporated in animal droppings) are not recognizable to the naked eye or with a 5-10 X magnifying hand lens. Bound mineral particles can be visible within the humic component and so are parts of the humic component. Partially or totally, the humic component composes organo-mineral (A) and organic (OL, OF, OH) horizons indifferently. An A horizon mostly made of anecic and endogeic hemorganic (organo-mineral) earthworm droppings as well as a totally, finely humified and mostly organic OH horizon resulting from epigeic earthworm, enchytraeid and microarthropod activities, are both composed of humic component (100% or close to it, Fig. 4), despite differences in the animals responsible for the structure of the horizon.

Fig. 4. *Humic component on a palm hand. This scrap of OH horizon is mostly composed of minute animal (arthropod and enchytraeid) droppings. It also corresponds to a sample of zoogenically transformed material.*

MINERAL COMPONENT of an organic or organo-mineral horizon = mineral particles of different sizes, free or very weakly bound to humic component and visible to the naked eye or with a 5-10 X magnifying hand lens.

ZOOGENICALLY TRANSFORMED MATERIAL = RECOGNIZABLE REMAINS AND HUMIC COMPONENT PROCESSED BY ANIMALS = leaves, needles and other plant residues more or less degraded by soil animals, mixed with animal droppings (Fig. 4). A finely powdered and/or granular structure (less than 1 mm) is typical of the terminal stage of faunal attack in an organic horizon. At this last level of biotransformation, the substrate (OH horizon) is essentially comprised of organic animal droppings of varying size (droppings of epigeic earthworms, of macroarthropods such as millipedes, woodlice and insect larvae, of microarthropods such as mites and springtails and of enchytraeids dominate). Within organo-mineral horizons, animal activity leads to different types of A horizons, depending on the animals' ability to dig into the mineral soil and to thoroughly mix organic and mineral matter. Zoogenically transformed material may be active (currently inhabited by living animals, freshly transformed, with recent droppings, grazing marks or tunnels) or inactive (without living animals or recent signs of animal activity, aged 1-2 years or more). The massive and plastic organic endpoint of biological transformation in the sequence of organic horizons (OL→OF→OH) is classified as inactive zoogenically transformed material.

NON-ZOOGENICALLY TRANSFORMED MATERIAL = RECOGNIZABLE REMAINS AND HUMIC COMPONENT PROCESSED BY FUNGI OR OTHER NON-FAUNAL PROCESSES = leaves, needles and other plant residues more or less fragmented and transformed into fibrous matter by fungi (Fig. 5). Recognizable recent animal droppings are absent or not detectable by the naked eye in the mass; fungal hyphae can be recognized as white, brown, black or yellow strands permeating the organic or organo-mineral substrates; traces of animal activity (droppings, old bite marks, mucus) may sometimes be detectable but are always marginal. In the last stage of biodegradation of an organic horizon, non-zoogenic substances may essentially be composed of dry, brown plant residues more or less powdered or in tiny fragments. Non-zoogenically transformed material is in any case inactive material that exhibits low biological activity. It concerns organic horizons which show particular more or less fragmented/bleached complexion due to strong fungal attack, or not zoogenic organo-mineral horizons with massive or single-grain structure sometimes overrun by hyphae.

Fig. 5. *Non-zoogenically transformed material. Dry or cold climate, acidity, unpalatibility of the substrate, introduction of new and unadapted species (here the case of an organic topsoil in an artificial stand of Pinus radiata in substitution of a natural Quercus ilex forest) lags behind the arrival of pedofauna. The decomposition of the organic substrate is essentially due to fungal attack.*

DIAGNOSTIC HORIZONS

A minimum thickness of horizons for description, diagnosis and sampling purposes has been established at 3 mm. Below this threshold, the horizon is considered discontinuous if clearly in patches or absent if indiscernible from other neighbouring horizons.

The vagueness of transitions between organic and organo-mineral horizons (or mineral ones, in the absence of an organo-mineral horizon) is an important diagnostic character. Three scales of transition have been adopted: very sharp transition within less than 3 mm, sharp transition between 3 and 5 mm and diffuse transition if over more than 5 mm.

ORGANIC HORIZONS

Roots excluded, following the rate of recognizable remains and humic component, organic horizons have been grouped in three diagnostic horizons, OL, OF and OH (Fig. 6). Suffixes are used to designate specific kinds of organic matter horizons then detailed into types. At present, the names and suffixes of these organic horizons are not in line with IUSS Working Group WRB (2007) or Soil Survey Staff (2010) proposals. Historical discrepancies and habits prevent a common nomenclature. However, the following approximated correspondence may be established, considering the parity European (present paper) = IUSS Working Group WRB (2007) or Soil Survey Staff (2010) codes: OL = Oi; OF = Oe; OH = Oa. A general attempt to homogenize vocabulary and procedures for topsoil classification is in progress (Broll *et al.*, 2006).

OL (from Organic and Litter). Horizon characterized by the accumulation of mainly leaves/needles, twigs and woody materials. Most of the original plant organs are easily discernible to the naked eye. Leaves and/or needles may be discoloured and slightly fragmented. Humic component amounts to less than 10% by volume; recognizable remains 10% and more, up to 100% in non-decomposed litter (Fig. 6).

OL types (suffixes: n, v):

- OLn = new litter (age < 1 year), neither fragmented nor transformed/discoloured leaves and/or needles;
- OLv = old litter (aged more than 3 months, vetustus, verändert, verbleichert, vieillie), slightly altered, discoloured, bleached, softened up, glued, matted, skeletonized, sometimes only slightly fragmented leaves and/or needles;

Remarks:

- the passage from OLn to OLv can be very rapid (1 to 3 months) or very slow (more than a year) according to litter types (plant species composition), climate, season and level of soil biological activity;

a beech leaf may be spotted due to fungal infection, without losing its integrity, thus while still belonging to the OL horizon.

OF (from fragmented and inappropriately 'fermented'). Horizon characterized by the accumulation of partly decomposed (i.e. fragmented, bleached, spotted, skeletonized) litter, mainly from transformed leaves/needles, twigs and woody materials, but without any entire plant organ. The proportion of humic component is 10% to 70% by volume (Fig. 6a). Depending on humus form, decomposition is mainly accomplished by soil fauna (OFzo) or cellulose-lignin decomposing fungi (OFnoz). Slow decomposition is characterized by a partly decomposed matted layer, permeated by hyphae.

OF types (suffixes: zo, noz):

- OFzo= content in zoogenically transformed material: > 10% of the volume of the horizon, roots excluded (Fig. 6b);

- OFnoz = content in non-zoogenically transformed material: 90% or more of the volume of the horizon, roots excluded;

Remark: the ratio zo/noz in transformed material can exhibit relatively important seasonal variation.

OH (from humus, humification). Horizon characterized by an accumulation of zoogenically transformed material, i.e. black, grey-brown, brown, reddish-brown well-decomposed litter, mainly comprised of aged animal droppings. A large part of the original structures and materials are not discernible, the humic component amounting to more than 70% by volume. OH differs from OF horizon by a more advanced transformation (fragmentation, humification, …) due to the action of soil organisms (Fig. 4).

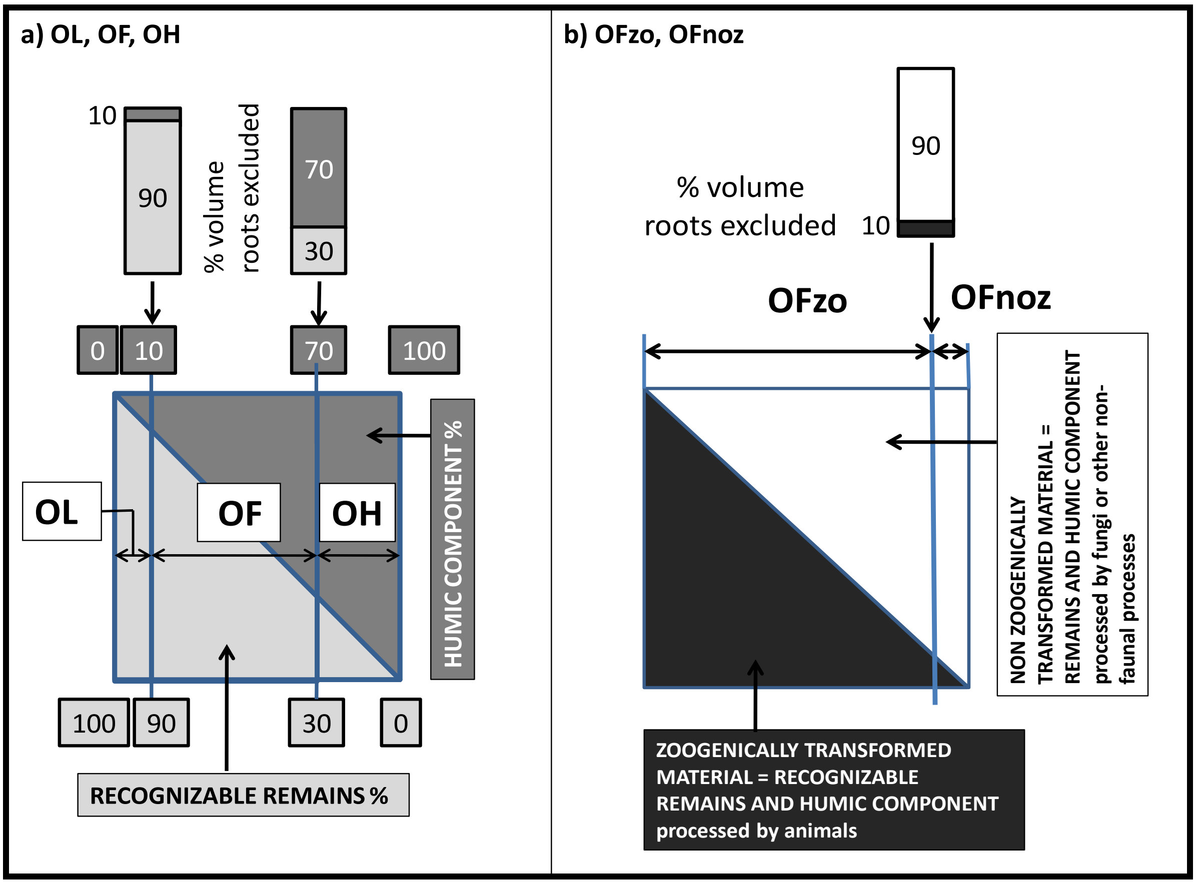


Fig. 6. a) *Humic component and recognizable remains in the main organic horizons. By moving a narrow vertical window across the squared graph, humic component and recognizable remains appear in their respective importance (percentage) in the composition of an observed horizon. Among fresh or still not degraded litter (OL horizon), the volume of humic component will be irrelevant (<10%) against recognizable remains; in a well-humified organic layer (OH horizon), the volume of humic component dominates (>70%) that of recognizable remains; OF horizon corresponds to intermediate situations.* ***b)*** *Zoogenically Transformed Material and Non-Zoogenically Transformed Material in zoogenic and non-zoogenic OF horizon types.*

ORGANO-MINERAL HORIZONS (A HORIZONS)

The different diagnostic A horizons are identified in the field by observing the soil mass by the naked eye or with a 5-10 X magnifying hand lens, assessing structure (Soil Survey Division Staff, 1993; Schoeneberger *et al.*, 2002; FAO, 2006) and consistence, and measuring the acidity (pH_{water}) according to ISO 10390 (1995). Easier to measure in the field, the pH_{water} is less stable than the $pHCaCl_2$, which is generally established in the laboratory and reveals values about 1 unit lower. Five diagnostic A horizons may be distinguished (Figs. 7a and 7b):

Zoogenic A horizons:

1) **Biomacrostructured A** (code: **maA**) = Aneci-endovermic;
2) **Biomesostructured A** (**meA**) = Endo-epivermic;
3) **Biomicrostructured A** (**miA**) = Enchy-arthropodic.

Non-Zoogenic A horizons:

4) **Single grain A (sgA);**
5) **Massive A (msA).**

A types (zo, noz and other suffixes):

- Azo = zoogenic A horizon. Azo = maA (implied maAzo) or meA (meAzo) or miA (miAzo).
- Anoz = A horizon considered as non-zoogenic. To the naked eye, or with the help of a hand lens, this horizon does not show relevant signs of animal activity (absence of burrows, droppings, mucus, animal remains etc… < 5% of the soil volume). Zoological agents are not involved in soil aggregation. Fungal structures can be visible. Anoz = sgA (implied sgAnoz) or msA (msAnoz).

Though not strictly necessary for classifying the humus forms, other important properties of the A horizon can be checked in the field using the Guideline for Soil Description (FAO, 2006) and/or in the laboratory. Texture, abundance of rock fragments, colour (matrix and mottles), redox potential and reducing conditions (semiterrestrial forms), carbonates (content and forms), organic matter content, porosity and size/abundance of roots are all recommended.

People accustomed to FAO manuals may use step-by-step references rigorously outlined in the following frame:

Biomacrostructured A horizon = *ANECI-ENDOVERMIC A HORIZON*

To be identified as a biomacrostructured A horizon (maA), a layer must display at least four of the following properties:

- *structure (FAO, 2006): never lack of structure, i.e. never lack of "built" structure;*
- *structure grade (FAO, 2006): moderate or strong; size if granular shape: medium (2-5 mm) and/or coarse; size if subangular blocky shape: fine (5-10 mm) or fine (5-10 mm) and very fine (< 5 mm);*
- *presence of peds, observable in place in undisturbed soil as well as after gently squeezing a sample of soil in the palm of the hand: all sizes of peds are present, but the volume of peds larger than 4 mm is greater than the volume of all other peds or units of soil;*
- *living earthworms, or earthworm burrows and/or casts;*
- *earthworm burrows within the underlying horizon;*
- *$pH_{water} > 5$.*

The whole horizon is made up of more or less aged anecic and endogeic earthworm droppings (the limit of 4 mm is rarely reached by droppings of arthropods and epigeic earthworms); roots and fungal hyphae (visible or not) also play an important role in the formation and stability of aggregates. Living earthworms or their burrows and casts are always present within the horizon. Earthworm middens (Hamilton & Sillman, 1989) can be present. In dry Mediterranean sites, a biomacrostructured A horizon from Coleoptera (Tenebrionidae) adult stages has also been observed (Peltier et al., 2001).

Biomesostructured A horizon = *ENDO-EPIVERMIC A HORIZON*

The biomesotructured A horizon (meA) displays all of the following properties:

- *structure (FAO, 2006), observable in place in undisturbed soil: never lack of structure;*
- *structure grade (FAO, 2006): moderate or strong (rarely weak); size if granular shape: fine (1-2 mm) and/or medium (2-5 mm); size if subangular blocky shape: very fine (<5 mm);*
- *presence of peds, observable in place in undisturbed soil as well as after gently squeezing a sample of soil in the palm of the hand: the volume of peds whose diameter is comprised between $1 < ø \leq 4$ mm is greater than the volume of all other peds or parts of soil;*
- *living earthworms, arthropods or enchytraeids or their droppings.*

Biological: earthworms (mostly epigeic and small endogeic), enchytraeids and arthropods are responsible for the structure; roots and fungal hyphae are also involved. Anecic and large endogeic earthworm droppings, classified typically as biomacro peds, are absent because they are generally larger than 4 mm.

Biomicrostructured A horizon = *ENCHY-ARTHROPODIC A HORIZON*

The biomicrostructured A horizon (miA) displays at least five of the following properties:

- *absence of peds > 4 mm; observable both in situ, in undisturbed soil, and after gently squeezing a sample of soil in the palm of the hand: peds of varying size can be present, but the volume of peds smaller than 1 mm is greater than the volume of all other peds or parts of the soil; gently squeezing the soil, almost all large peds easily reduce into smaller units;*
- *structure grade (FAO, 2006): moderate, strong; shape: granular; size: very fine (< 1 mm);*
- *presence of (generally uncoated) mineral grains (mineral components > 10%);*
- *> 10% organic particles and dark-coloured biogenic peds (holorganic or hemiorganic peds = humic components);*
- *living microarthropods, enchytraeids or their droppings;*
- *$pH_{water} < 5$.*

The horizon displays an important amount of faecal pellets, droppings of enchytraeids (potworms), microarthropods (tiny larval stages of insects, mites, springtails, …) and non-recognizable particles of organic matter (remains of decomposed litter). This horizon is observed on sandy loamy to sandy soils; the large amount of mineral grains (> 50%) seems to prevent the formation of a larger-size structure or a massive one. Hyphae and roots are also very common.

SINGLE GRAIN A HORIZON

To be identified as a single grain A horizon (sgA), a layer must display at least four of the following properties:

- *undisturbed soil mass: unbound loose consistence;*
- *structure (FAO, 2006): single grain;*
- *presence of clean (= uncoated) mineral grains;*
- *< 10% of fine organic particles and/or dark-coloured biogenic (holorganic or hemorganic) peds;*
- *$pH_{water} < 5$.*

Mineral grains coated with organic matter indicate a process of podzolization in place. Faecal pellets of micro-arthropods or enchytraeids are sometimes present but irrelevant (< 10%).

Because of observable processes of eluviation or podzolization, the horizon could be defined as sgAE (or sgEA) or sgAB following its similarity to mineral horizons. E horizons are mineral horizons in which the main feature is loss of silicate clay, iron, aluminium, or some combination of these, leaving a concentration of sand and silt particles, and in which all or much of the original rock structure has been obliterated (FAO, 2006). Transitional AE or EA horizons are possible.

MASSIVE A HORIZON

To be identified as a massive A horizon (msA), a layer must display at least three of the following properties:

- *undisturbed soil matrix: heterogeneous but one-piece, no planes or zones of weakness are detectable in the mass;*
- *structure (FAO, 2006): massive. If the soil is dry, when applying moderate to strong pressure with the fingers, the soil sample progressively breaks up into finer artificial units; these fine units have a varying mineral, organo-mineral or organic composition; if the soil is moist, the sample can be transformed into tender, plastic, non-elastic matter;*
- *presence of clean (= uncoated) mineral grains. A 5-10 X magnifying hand lens is necessary to detect the composition of the pellets or grains (animal droppings < 5% of the soil volume), the size of the most common biostructured units being < 1 mm;*
- *$pH_{water} < 5$.*

Cohesion forces among soil components appear equally distributed in the soil, as they depend mostly on physical or chemical conditions rather than biological aggregation. Past biological activity could also be involved in the process of formation of the horizon (incorporation of organic matter, peds originated by animals < 5%). Traces of current biological *activity are possible, organic or organo-mineral pellets generated by arthropods or enchytraeids, in any case < 5% of the soil volume.*

Remarks:

- *Because of observable processes of eluviation or initial podzolization, the horizon could be defined as msAE (or msEA), following its characteristics in common with the mineral E horizon;*
- *sometimes the A horizon shows a laminated and coherent structure, because infiltrating humic substances are permeating the mineral component of the horizon and make it appears massive; mechanically induced compaction can also be involved in other circumstances, such as heavy traffic. Anyway, only when these other types of "compact" A horizons are associated to a natural process of strong acidification in the topsoil, can they be considered as "massive A horizons".*

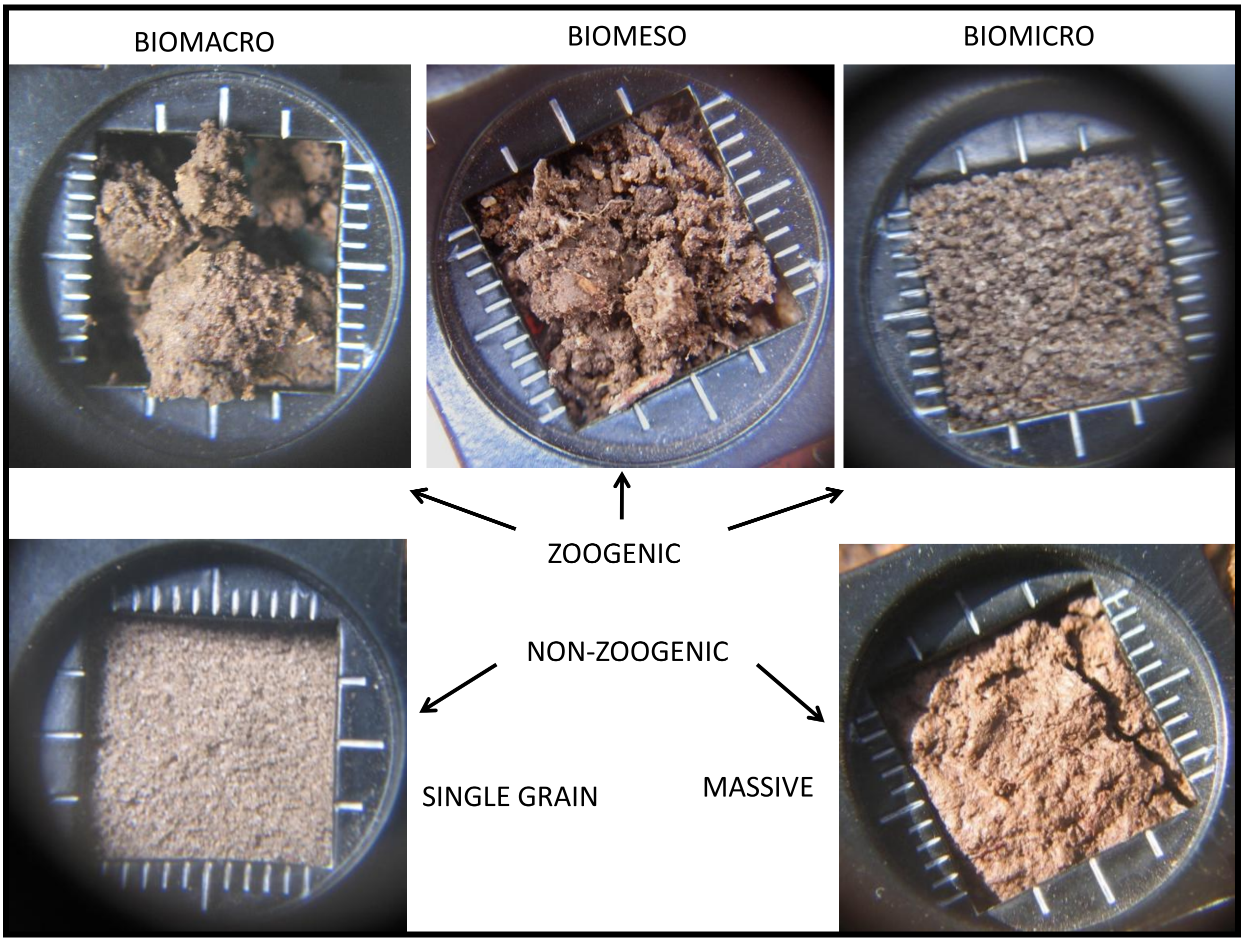


Fig. 7a) *Zoogenic and non-zoogenic organo-mineral horizons*

A HORIZON AND RATIO OF HUMIS/MINERAL COMPONENTS

The ratio of humic and mineral components of the A horizon, even if evaluated by the naked eye, might be a useful field characteristic for better identifying the different diagnostic horizons. Going from left to right across the square diagonally divided in two parts (Fig. 8), coloured in dark grey for humic component (above) and in light grey for mineral component (below), the horizons succeed in order from units very rich in humic component (and poor in mineral component) to those very poor in it.

The massive structure has also been detected in very organic and very mineral A horizons and the massive A covers the whole ratio range. Biomacro and biomesostructured A horizons have a rate of humic component (earthworm-made structures) from 30% until the entire volume of the horizon. If the rate of humic component is less than 30%, then the horizon can be massive, biomicro or single grain. A single grain structure has generally been found in horizons very poor in humic component (AE, EA), less than 10% of the volume of the horizon. If the humic component (microstructured) is more than 50% of the volume of the horizon, then the probability of it being an OH horizon instead of an A horizon is very high (OH = Organic Carbon > 20%, in weight). Humic component is not synonymous of organic matter, especially when droppings are organo-mineral and poor in organic matter.

Zoogenic A horizons	Structure (FAO, 2006)	Dominant engineering organisms	pH (water)
maA **Biomacrostructured A** **Aneci-endovermic A**	Never lack of structure Grade: moderate or strong Shape: granular and/or subangular blocky Size of dominant (in volume) peds: ø > 4 mm	The whole horizon is made of more or less aged anecic and endogeic earthworm droppings. Roots dominate in particular circumstances	More than 5 (rare exceptions lower but near 5 are possible)
meA **Biomesostructured A** **Endo-epivermic A**	Never lack of structure Grade: moderate or strong (rarely weak) Shape: granular and/or subangular blocky Size of dominant (in volume) peds: 1< ø ≤ 4 mm	The largest part of the horizon is made of epigeic and small endogeic earthworm, enchytraeid and arthropod droppings. Roots dominate in particular circumstances	A large range from acid to basic values has been observed
miA **Biomicrostructured A** **Enchy-arthropodic A**	Grade: moderate, strong Shape: granular Size of dominant (in volume) peds: ø ≤ 1 mm; peds > 4 mm never present	Enchytraeids (potworms) and microarthropods (tiny larval stages of insects, mites, springtails…). Roots dominate in particular circumstances	Less than 5 (rare exceptions higher but near 5 are possible)
Non zoogenic A horizons	**Structure (FAO, 2006)**	**Origin**	**pH (water)**
sgA **Single grain A**	Single grain. Unbound loose consistence. Presence of clean (=uncoated) mineral grains	Observable process of eluviation or podzolisation Fine organic particles and/or biogenic peds < 10 % in volume	Less than 5 (rare exceptions lower but near 5 are possible)
msA **Massive A**	Massive. If dry: the one-piece soil breaks up into finer artificial units; If moist: the one-piece soil can be transformed into tender, plastic, non-elastic matter	Cohesion forces among soil components appear equally distributed in the horizon, as they depend mostly on physical or chemical condition rather than biological aggregation	Less than 5 (exceptions are possible)

Fig. 7b. *Organo-mineral horizons classification. Zoogenic A horizons are divided into biomacro, biomeso or biomicrostructured horizons; non-zoogenic A horizons are divided into single grain or massive unstructured horizons.*

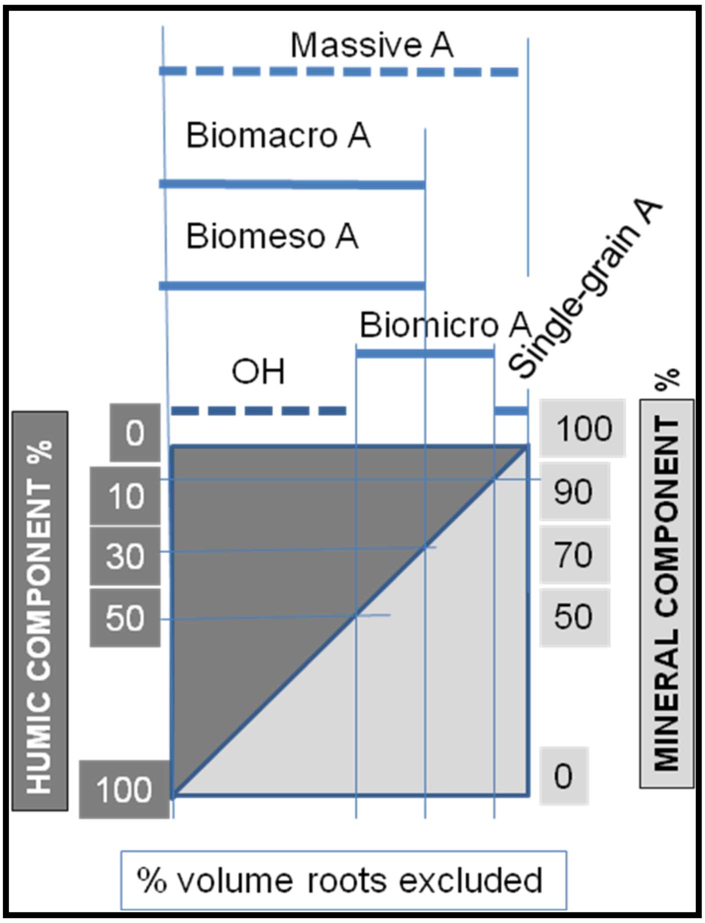


Fig. 8. *Range of the ratio of humic and mineral component in the different A horizons, distinguished by the naked eye or with the help of a 5-10 X magnifying hand lens. At this scale, mineral grains included in animal droppings are considered as humic component; only free or very weakly bound grains are considered as mineral component. Biomacro- and biomesostructures differ by the mean size of the peds but not by the HC/MC ratio, which is generally very high (often 100%). On the right side, the biomicrostructured A becomes single grain A when MC rises to more than 90% of the horizon volume; on the left side, biomicrostructured A becomes OH horizon when MC decreases until less than 50% of the horizon volume. The massive structure is independent of the HC/MC ratio.*

FUNCTIONAL AND MORPHOLOGICAL CLASSIFICATION OF TERROFORMS

On a morpho-functional basis, Terroforms are subdivided in five biological types (Mull, Moder, Amphi, Mor and Tangel), hereinafter identified and described thanks to diagnostic features (Fig. 9).

People accustomed to FAO manuals may use the following step-by-step references:

MULL

To be identified as Mull, a topsoil must display the following properties:

1. *absence of any OH horizon; and*
2. *presence of A biomacro;*

or

2. *presence of A biomeso and at least two of the following:*
    - *presence in the A horizon of living earthworms or their casts, except in frozen or desiccated soil;*
    - *presence of a very sharp transition (< 3 mm) between organic and organo-mineral horizons;*
    - *pH_{water} of the A horizon ≥ 5.*

MODER

To be identified as Moder, the topsoil must display the following properties:

1. *presence of OH horizon (even if sometimes discontinuous); and*
2. *absence of OFnoz; and*
3. *absence of A biomacro; and*
4. *absence of A biomeso and one of the following:*
    - *no sharp transition OH/A horizon (transition ≥ 5 mm);*
    - *pH_{water} of the A horizon < 5;*

or

4. *presence of A biomicro, or A massive, or A single grain, and one of the following:*
    - *no sharp transition OH/A horizon (transition ≥ 5 mm);*
    - *pH_{water} of the A horizon < 5.*

AMPHI

To be identified as Amphi, the topsoil must display the following properties:

1. *simultaneous presence of OH and A biomacro or A biomeso horizons; and*
2. *absence of OFnoz; and*
3. *thickness of A horizon ≥ thickness of ½ OH horizon; and*
4. *absence of A massive or single grain; and*
5. *presence of A biomacro and one of the following:*
    - *living earthworms in the A horizon;*
    - *sharp transition between A and OH;*
    - *pH_{water} of the A horizon ≥ 5,*

or

5. *presence of A biomeso and one of the following:*
    - *living earthworms in the A horizon;*
    - *no sharp transition between OH and A;*
    - *pH_{water} of the A horizon ≥ 5.*

MOR

To be identified as Mor, the topsoil must display the following properties:

1. *never A biomeso or biomacro; and*
2. *presence of OFnoz and one of the following:*
    - *pH_{water} of E or AE or A horizon < 4.5;*
    - *A absent, or A biomicro, or A massive, or A single grain,*

or

2. *presence of OH horizon in very sharp (< 3 mm) transition to A, AE or E horizon and one of the following:*
    - *pH_{water} of E or AE or A horizon < 4.5;*
    - *A absent, or A biomicro, or A massive, or A single grain.*

TANGEL

To be identified as Tangel, the topsoil must display the following properties:

1. *presence of thick organic zoogenic horizons (OFzo + OH > 5 cm); and*
2. *hard limestone and/or dolomite rock/rock fragments at the bottom of the humus profile; and*
3. *cold climate (subalpine or upper montane belts); and*
4. *absence of OFnoz; and*
5. *presence of a thin (thickness < ½ OH) A massive or single grain or biomeso; or*
5. *pH_{water} of the a thin (thickness < ½ OH) A horizon ≥ 5.*

Diagnostic horizons	MULL	MODER	AMPHI	MOR	TANGEL
OL	possible	present	present	present	present
OF	possible, zoogenically transformed	present, zoogenically transformed, active	present, zoogenically transformed, active	not zoogenically transformed always present even if sometimes discontinuous; zoogenically transformed possible (accompanied), inactive or partially active	present, zoogenically transformed, active
OH	absent	present, active, sometimes discontinuous	present, active, thick (but ≤ 2 times thickness of A)	present or absent, if present: inactive or partially active	present, inactive or partially active, thick (> 2 times thickness of A)
Transition O/A or O/AE or O/E	very sharp (< 3 mm)	not sharp (≥ 5 mm)	if A biomacro: sharp (< 5 mm) if A biomeso: not sharp (≥ 5 mm)	very sharp (< 3 mm)	if A massive: sharp (< 5 mm) if A biomeso: not sharp (≥ 5 mm)
A	biomacro or biomeso	biomicro or single grain or massive	biomacro or biomeso, biomeso accompanied by biomicro possible	absent (= E) or present, if present: not zoogenic or discontinuously biomicro.	massive or biomeso
Horizon of dominant faunal activity	A (anecic and endogeic earthworms)	OF (feeding) OH (accumul. droppings)	OF (feeding) OH (accumul. droppings) A (earthworms)	OH (weak or traces of old activity)	OF (feeding) OH (feeding and accumulated droppings)
Earthworms – Organic horizons	Epigeic and Anecic	Epigeic	Epigeic	Epigeic rarely present or absent	Epigeic possible
Earthworms – Organo-mineral horizon	Endogeic and Anecic	absent	Endogeic and/or Anecic	absent	Endogeic possible

Fig. 9. *Diagnostic horizons and features of five references (= biological activity types) of Terroforms.*

GENERAL CHARACTERS AND DISTRIBUTION OF MULL

- ecological conditions: temperate climate and/or non-acid siliceous, or calcareous parent material and/or easily biodegradable litter (C/N < 30) and/or no major environmental constraint;
- dominant actors of biodegradation: anecic and large endogeic earthworms, bacteria;
- actors' action: fast biodegradation and consequent disappearance of litter from the topsoil (≤ 3 years), carbon mainly stocked in the A horizon;
- pH_{water} of the A horizon: generally ≥ 5;
- chief characters (morpho-functional result of specific biological activities): OH never present, A biomacro or biomeso, very sharp transition (< 3 mm) between organic and organo-mineral horizons.

General characters and distribution of Moder

- ecological conditions: mild to moderately cold climate, generally on acid substrate
- dominant actors of biodegradation: arthropods, epigeic earthworms and enchytraeids; fungi;
- actors' action: slow biodegradation (2-7 years), carbon stocked in both organic and organo-mineral horizons;
- pHwater of the A horizon: generally < 5;
- chief characters: OH always present, OFnoz never present, A biomicro, massive or single grain, no sharp transition (≥ 5 mm) between organic and organo-mineral horizons.

General characters and distribution of Amphi

- ecological conditions: contrasting climate conditions (dry summer, rainy autumn), generally on calcareous and/or dolomitic substrate; an artificial substitution of vegetation, with a consequent shift from rich and palatable broad-leaf litter (C/N < 20) to recalcitrant coniferous litter (C/N > 40), leads generally to a transformation of the original mull into amphi (this dynamic process can also generate a moder on acid substrate or in cold climatic conditions).
- dominant actors of biodegradation: endogeic and anecic earthworms in the organo-mineral horizon; arthropods, enchytraeids and epigeic earthworms in the organic horizons; fungi;
- actors' action: slow biodegradation (2-7 years), high carbon content in both organic and organo-mineral horizons;
- pH_{water} of the A horizon: generally ≥ 5;
- chief diagnostic characters (morpho-functional result of specific biological activities): OH always present, OFnoz never present, thickness of A horizon ≥ ½ OH; A biomacro and sharp transition (< 5 mm) between organic and organo-mineral horizons, or A biomeso (biomicro possible, in addition to A biomeso) and no sharp transition (≥ 5 mm) between organic and organo-mineral horizons.

General characters and distribution of Mor

- ecological conditions: cold climate, and/or siliceous acid substrate, poorly degradable litter (richness in resins, cuticle, C/N > 40);
- dominant actors of biodegradation: fungi (mostly mycorrhizal) and other non-faunal processes;
- actors' action: very slow biodegradation (> 7 years), highest carbon content in organic horizons;
- pH_{water} of E or AE or A horizon: < 4.5;
- chief characters (morpho-functional result of specific biological activities): OFnoz (always present but sometimes difficult to recognize especially in wet conditions), E horizon or A biomicro, or A massive or single grain, very sharp transition (< 3 mm) between organic and organo-mineral (or mineral) horizons.

General characters and distribution of Tangel

- ecological conditions: mountain climate (subalpine or upper montane belts) on hard limestone and/or dolomite rock/rock fragments;
- dominant actors of biodegradation: epigeic earthworms, enchytraeids and arthropods within organic horizons; fungi;
- actors' action: very slow biodegradation (> 7 years), carbon stocked mainly in organic horizons;
- pH_{water} of the A horizon ≥ 5;
- chief characters (morpho-functional result of specific biological activities): OFnoz never present but thick organic horizons [(OFzo + OH) ≥ 7 cm], thickness of A horizon < ½ OH; A biomeso and no sharp transition (≥ 5 mm) to OH, or A massive and sharp transition (< 5 mm) to OH.

Presence-absence, thickness or distribution (discontinuous or in pockets) of the diagnostic horizons allow a more accurate second level of classification to be defined (Figs. 10a, 10b, 10c, 10d, 10e, 10f).

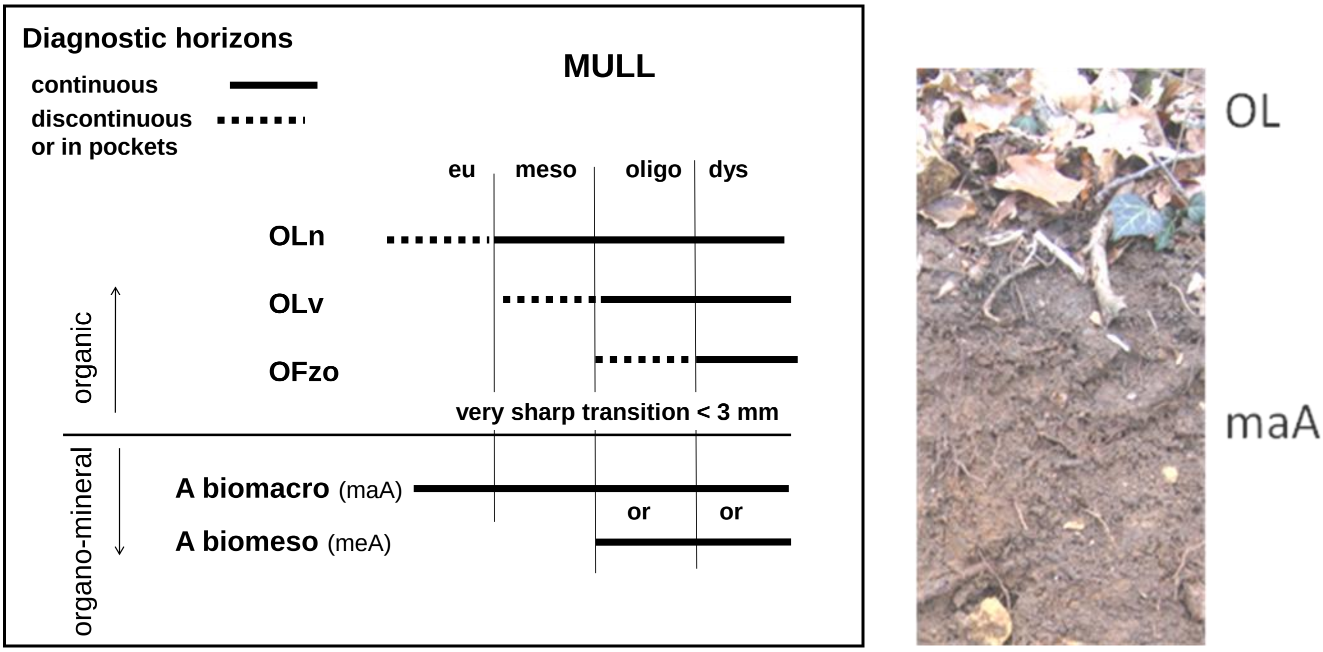


Fig. 10a. *Terroforms, second level of classification of Mull.* ***Lines****: diagnostic horizons, sequence as in real profile.* ***Columns****: second level of classification. Names of second level of Mull forms: eumull, mesomull, oligomull, dysmull.*

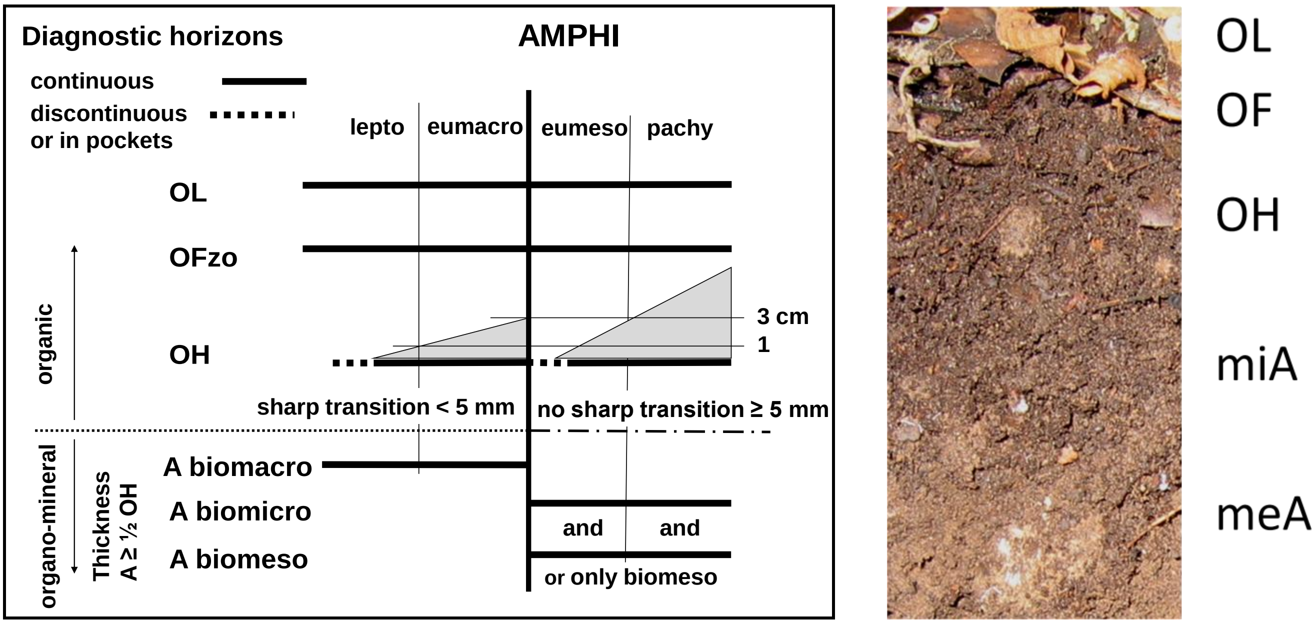


Fig. 10b. *Terroforms, second level of classification of Amphi. Lines: diagnostic horizons, sequence as in real profile. Columns: second level of classification. Names of second level of Amphi forms: leptoamphi, eumacroamphi, eumesoamphi, pachyamphi.*

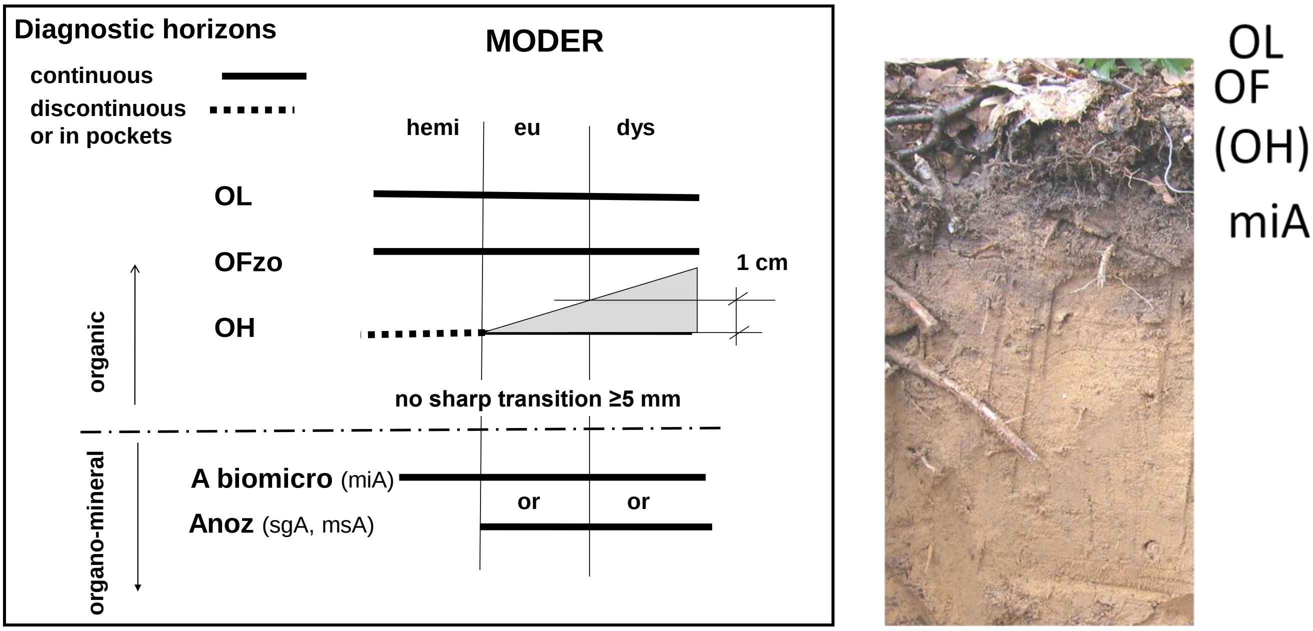


Fig. 10c. *Terroforms, second level of classification of Moder. Lines: diagnostic horizons, sequence as in real profile. Columns: second level of classification. Names of second level of Moder forms: hemimoder, eumoder, dysmoder*

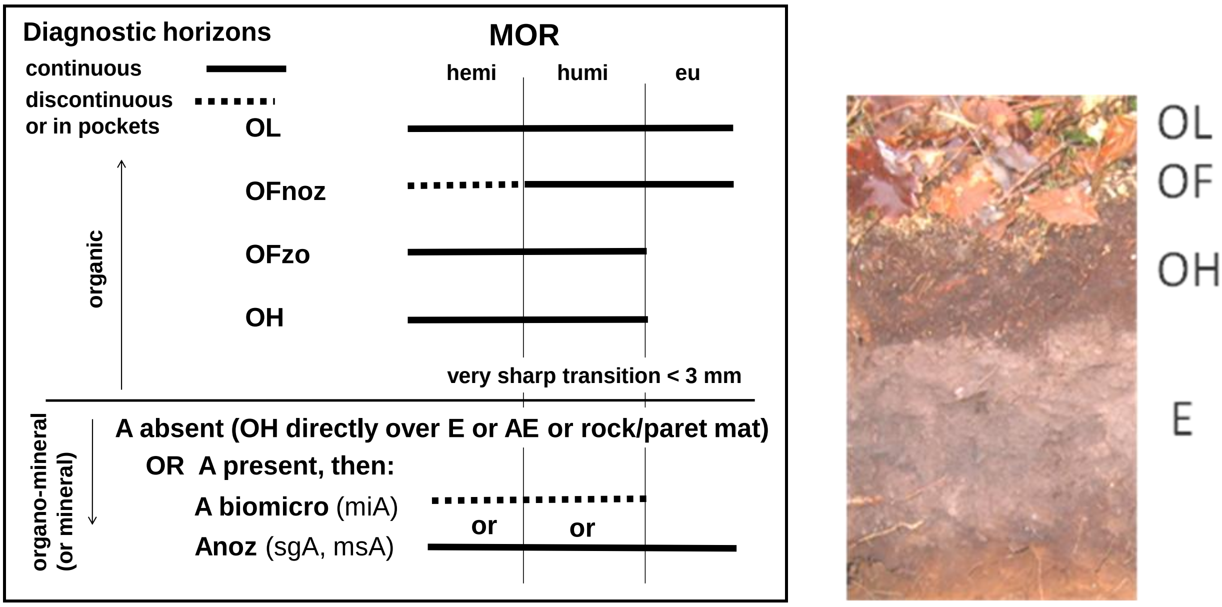
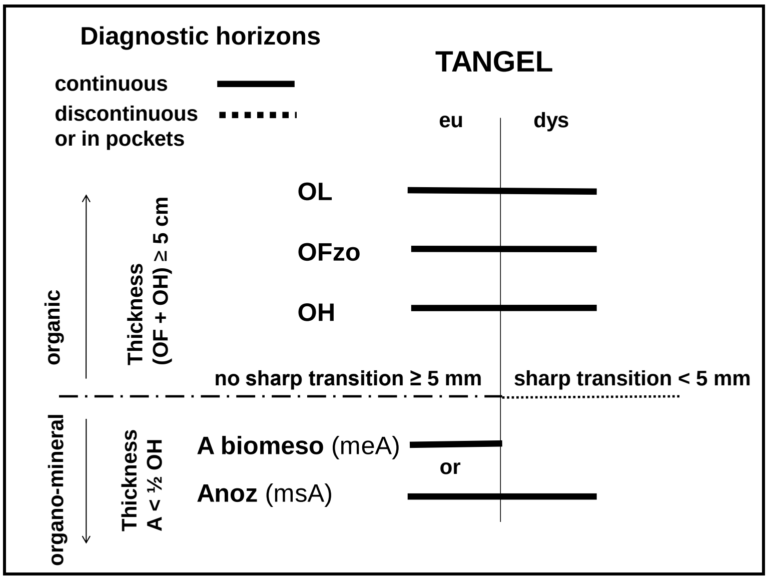


Fig. 10cd *Terroforms, second level of classification of Mor. Lines: diagnostic horizons, sequence as in real profile. Columns: second level of classification. Names of second level of Mor forms: hemimor, humimor, eumor.*



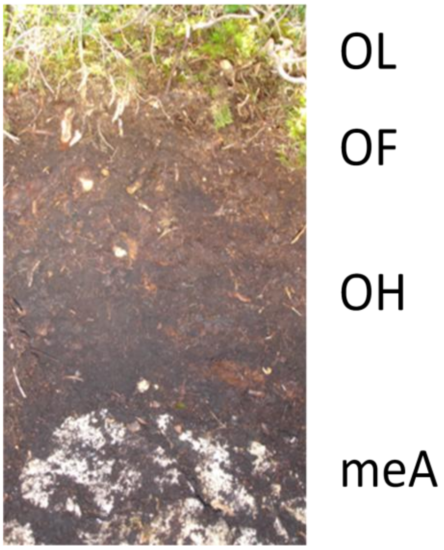


Fig. 10e. *Terroforms, second level of classification of Tangel. Lines: diagnostic horizons, sequence as in real profile. Columns: second level of classification. Names of second level of Tangel forms: eutangel, dystangel.*

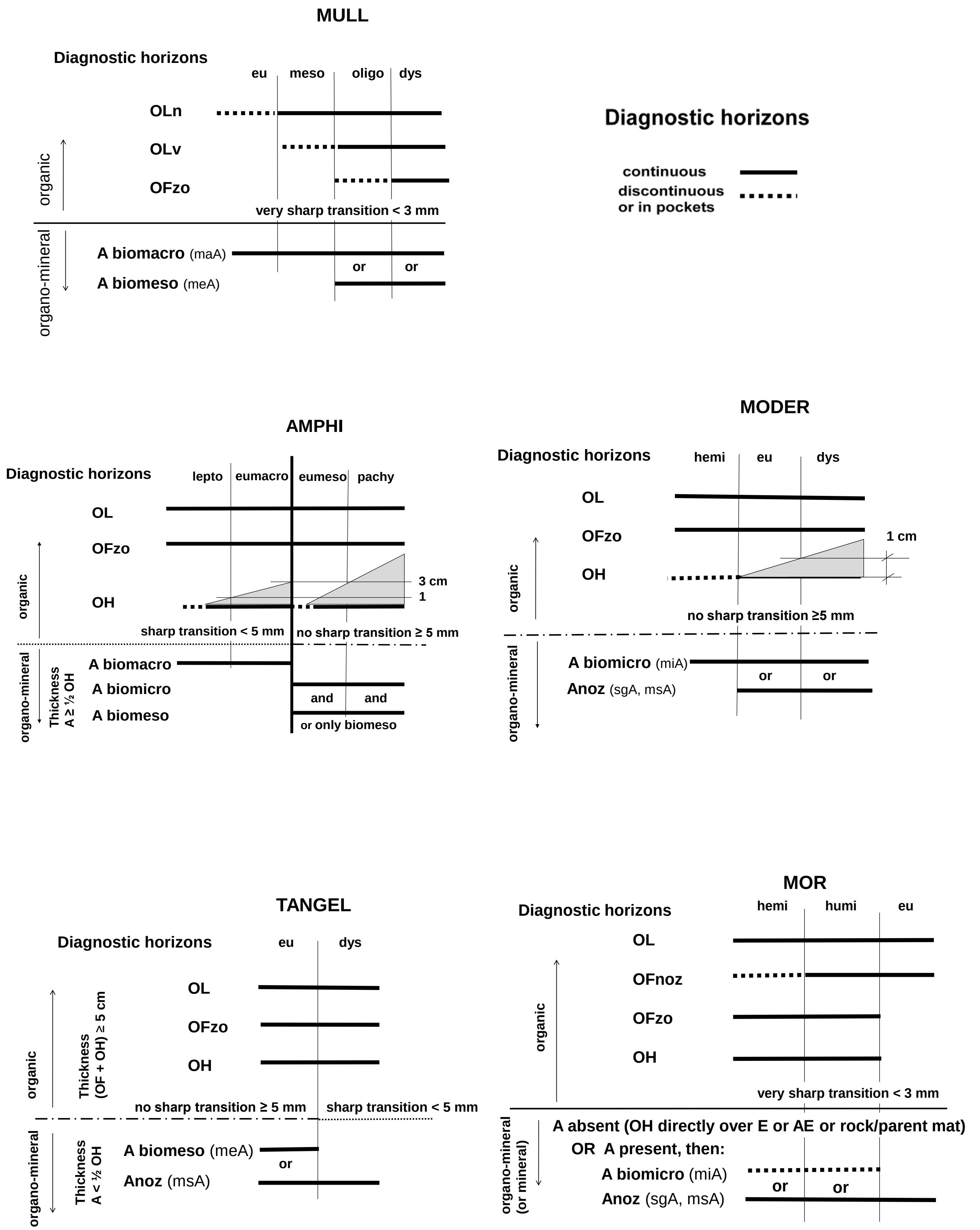


Fig. 10f. *Terroforms, all second level classification. Lines: diagnostic horizons, sequence as in real profile. Columns: second level of classification.*

FUNCTIONAL AND MORPHOLOGICAL CLASSIFICATION OF ENTIFORMS

Entiforms are divided into Lithoforms, Peyroforms and Psammoforms (Figs. 1 and 2):

- **Lithoforms** correspond to humus forms lying directly over consolidated, continuous, hard rock; thickness of organo-mineral (A or AE) horizons < 3 cm;
- **Peyroforms** are humus forms lying directly over/among rock fragments (Ø > 2 cm). Thickness of organo-mineral (A or AE) horizons < 3 cm (without considering narrow pockets often present deeper in the profile); thicker pockets can be present between boulders;
- **Psammoforms** are humus forms lying directly over sandy, loamy-sand or sandy-skeletal parent material (rock fragments, Ø ≤ 2 cm); thickness of organo-mineral (A or AE) horizons < 3 cm.

According to the sequence of diagnostic horizons, Lithoforms, Peyroforms and Psammoforms are subdivided on a morpho-functional basis into five biological types (Tangel, Amphi, Mull, Moder and Mor), corresponding to the first level of morphological and functional classification of Entiforms (Fig. 11).

Diagnostic horizons	LITHO or PEYRO or PSAMMO				
	TANGEL	AMPHI	MULL	MODER	MOR
OL					
OFzo			disc. or pock.		
OFnoz					
OH	OH > 2xA	OH ≤ 2xA			
E					possible
miA, Anoz		discontinuous or in pockets			
meA	AND/OR	AND/OR	AND/OR	disc. or pock.	
$pH(A)_{water}$	pH ≥ 5			pH < 5	

Fig. 11. *First level of classification of Entiforms: Lithoforms, Peyroforms and Psammoforms. Syntax rules: Lithoforms, Peyroforms and Psammoforms only display a single second level of classification. At present the term Lithomull, for example, means every kind of Lithomull.*

GENERAL CHARACTERS AND DISTRIBUTION OF ENTIFORMS

- Substrate or parent material: calcareous or non-acid siliceous for Tangel, Amphi and Mull; acid siliceous for Moder and Mor;
- pH_{water} of the A horizon (never biomacro) ≥ 5 for Tangel, Amphi and Mull; < 5 for Moder and Mor;
- vegetation: pioneer grasses, lichens and mosses;
- dominant actors of biodegradation: epigeic earthworms, enchytraeids and arthropods within organic horizons; fungi; bacteria.
- chief characters (morpho-functional result of specific biological activities): see Figure 9. This first draft of classification allows the inventory of still unknown Entiforms. New data are necessary for better circumscribing and classifying these initial phases of topsoil developement.

FUNCTIONAL AND MORPHOLOGICAL CLASSIFICATION OF PARAFORMS

Paraforms are divided into Rhizoforms and Lignoforms (Figs. 1 and 2):

- **Rhizoforms** correspond to humus forms under dominant influence of roots and/or rhizomes. Roots and/or rhizomes (> 50% of the volume of the horizon) confer a particular structure and a characteristic aspect to diagnostic horizons;
- **Lignoforms** are humus forms in which decaying wood comprises more than 1/3 of the volume of added OL and OF horizons. The wood-rich topsoil assumes the characteristic red-brown aspect of degraded wood, quite different from typical Terroforms evolving in similar environmental conditions but without such a mass of decaying wood.

According to the sequence of diagnostic horizons, Rhizoforms and Lignoforms are subdivided on a morpho-functional basis into five biological types (Tangel, Amphi, Mull, Moder and Mor), corresponding to the first level of morphological and functional classification of these Paraforms (Fig. 12).

Diagnostic horizons	RHIZO or LIGNO				
	TANGEL	AMPHI	MULL	MODER	MOR
OL					
OF and OH	OH > 2xA	OH ≤ 2xA			
AE, EA					possible
miA, Anoz					
meA	possible				
maA		AND	AND		
pH(A) $_{water}$	pH ≥ 5			pH < 5	

Fig. 12. *First level of classification of Paraforms: Rhizoforms and Lignoforms. They develop under the dominant influence of roots (>50% of the bulk volume of OF and OH horizons of Tangel, Amphi, Moder and Mor and the A horizon of Mull) or decaying wood (at least 1/3 of the bulk volume of OL and OF horizons). Syntax rules: Rhizoforms and Lignoforms only display a single second level of classification, thus, at present, the term Rhizomull, for example, means every kind of Rhizomull.*

GENERAL CHARACTERS AND DISTRIBUTION OF PARAFORMS

- Substrate or parent material: calcareous or non-acid siliceous for Tangel, Amphi and Mull; acid siliceous for Moder and Mor;
- pH_{water} of the A horizon ≥ 5 for Tangel, Amphi and Mull; < 5 for Moder and Mor;
- vegetation while Rhizoforms:
    - grasses (pasture, especially at high altitude/latitude), or open forest (regeneration phases in a sylvogenetic cycle, mostly beneath coniferous species). The topsoil is often without organic horizons and the structure of the A horizon assumes a light consistency and a well-aerated strong structure composed of relatively small aggregates (Ø < 3 mm);
    - ericaceous vegetation (*Erica*, *Vaccinium* or *Rhododendron*) in calcareous or acid soils, or in areas under Mediterranean influence with shrubby, dense vegetation composed of evergreen shrubs and bushes over dry soils. The topsoil has deep organic horizons structured by a thick mat of roots, fragmented dead organic remains leaving voids among roots. Animals are present but seem to be only in transit in this system of galleries (as ants in their nests). The process has been observed in mountain regions.

- vegetation while Lignoforms: forest ecosystems, especially old phases of unmanaged ecosystems.
- dominant actors of biodegradation while Rhizoforms:
    - under grasses: endogeic, anecic earthworms, bacteria;
    - under ericaceous species: epigeic earthworms, enchytraeids, arthropods, fungi;
- dominant actors of biodegradation while Lignoforms: in the first phase of the process of biodegradation of wood, fungi and insects play a major role. Fungi produce hyphae and different enzymes that deteriorate the cell wall and cause partial wood degradation, whereas insects chew and feed on sapwood and thereafter on heartwood and transform wood into humus (insect frass). A wood-decaying fungus has the ability to digest wood causing it to rot. Brown, white and soft rots are involved, which are able to remove carbohydrates, and further metabolize major structural components of wood. Insects destroy the wood by fragmenting it, burrowing in it and are responsible for its final disappearance, epigeic earthworms and woodlice also being active in the last stages of wood degradation (Schwarze *et al.*, 2004; De Long *et al.*, 2005). Although fungal spores are common in the air, fungi cannot develop and attack wood unless conditions are favourable (adequate oxygen supply, moisture, temperature, antagonistic influence of other fungi), which occurs in accumulated or buried wood under forest cover, within buffered organic soil horizons. The process is often localized around dead, more or less buried stems, logs, large branches or roots (Sippola & Renvall, 1999). The process of decomposition of a large wood mass depends on whether it is a standing or fallen dead tree or a stump. In each of these cases, the rapidity of the organic matter transformation, as well as the succeeding phases and corresponding involved biological actors, are very different (Gobat *et al.*, 2003, 2004).
- chief characters (morpho-functional result of specific biological activities): see Figure 10. This first draft of classification allows the inventory of still unknown Paraforms. New data are necessary for better circumscribing and classifying these atypical topsoils.

BIOLOGICAL APPROACHES TO TERROFORMS

Wallwork (1970) considered seven groups of animals correlated with humus forms: mites, Collembola, Myriapoda, Isopoda, Annelida (in the sense of earthworms only), termites and insect larvae. According to him, six groups are always active in every main humus form, their relative importance changing according to humus form. Mites and Collembola dominate in Mor, mites, Collembola and insect larvae dominate in Moder, Myriapoda and Isopoda dominate in Mull-like Moder and Annelida (and termites) dominate in Mull. Summarizing Wallwork's thinking, humus forms can be split into two main categories on biological bases: 1) Mull-like Moder and Mull, mainly inhabited by Annelida and bacteria and with organo-mineral complexes in the neutral or slightly alkaline A horizon; 2) Mor and Moder, mainly inhabited by mites, Collembola and fungi and without organo-mineral complexes in the acid A horizon.

Wallwork's scheme has been contradicted by Ponge (1999, 2003) and Graefe (2005), who elected potworms (Enchytraeidae) as the dominant faunal group in Mor, and a companion of mites and Collembola in Moder. In fact, Enchytraeidae and Lumbricidae (European earthworms) seem to live in different ecological conditions (Galvan *et al.*, 2008) and were shown by Haukka (1987) to exhibit some antagonism, at least when placed in experiment al conditions.

The Lumbricidae family has been split by Bouché (1977) into three ecological subcategories: epigeic, endogeic and anecic earthworms. More recently, epigeic earthworms have been divided in two subcategories (epigeic, epi-endogeic/epi-anecic) and endogeic in four subcategories (polyhumic, mesohumic, endo-anecic, oligohumic) as proposed by Lavelle (1981) and Coleman *et al.* (2004). The relationships between soil moisture, pH of the topsoil and earthworm life forms are well-known (Sømmer *et al.*, 2002; Römbke *et al.*, 2005). The largest ecological range for ecological factors is assigned to epigeic earthworms, which prefer organic layers, move only seasonally deeper in the mineral soil (in some Amphi humus forms) and can also be found at low pH values ($pH_{water} < 5$). Instead, endogeic and anecic earthworms avoid acid topsoils, preferring sub-alkaline, neutral or slightly acid conditions ($pH_{water} > 5$). The definition of diagnostic horizons in our classification system is also based on these biological features. We separated Anecic/Endogeic A horizons (Mull and some Amphi A horizons) from Epigeic/Enchytraeid/Arthropod A horizons (Moder and some Amphi A horizons).

Microorganisms play a major role in the process of litter biodegradation. It is well-known that fungi are more tolerant of low pH in the topsoil than bacteria (Matthies *et al.*, 1997), the activity of which increases with pH. Therefore, acid Mor/Moder topsoils are dominated by fungi and are characterized by slow litter biotransformation and consequent accumulation of not or imperfectly humified organic remains. On the contrary, Mull-like Moder/Mull topsoils are dominated by bacteria, which can rapidly mineralize the organic substrate, leading to a fast disappearance of litter and advanced humification of soil organic matter (Eskelinen *et al.*, 2009; Van der Heijden *et al.*, 2008).

However, a bipolar model of the natural fate of litter cannot be exhaustive. In sub-acid to sub-alkaline soils, fungi are known to rapidly transform stable phenolic components of litter (lignin, tannins) into soluble organic compounds (Toutain, 1981), which can move downwards and be integrated into underlying organo-mineral horizons. In any case, bacteria (Scotti *et al.*, 2008) and fungi (Ponge, 2003) are genetically and functionally different according to the humus form.

The concept of "twin humus" was originally developed by Hartmann (1952, 1970) and thereafter elaborated by Brêthes *et al.* (1995) for the French classification system as Amphimull. This form can be related to Wallwork's and Kubiena's Mull-like Moder. In this humus form, a zoogenic A horizon (from anecic or endogeic earthworms) and an OH horizon (from epigeic worms and/or arthropods and/or enchytraeids) are both present and probably reflect a dominant zoogenic litter turnover in periodically milder (warmer and moister) soil-climate conditions. This form can be observed in many Alpine calcareous areas (Hartmann, 1970; Zanella *et al.*, 2001; Sartori *et al.*, 2005; Galvan *et al.*, 2008) where it is the dominant humus form in subalpine beech and spruce forests. Recently Graefe (2007) proposed using this same humus form to better classify some atypical Moders relatively frequent in warm/dry German forest areas.

Mull humus forms are typical of a mild climate (Fig. 13) and nutrient-rich substrates (Ponge, 2003). When the climate becomes harsher, the depth of organic horizons increases considerably (seasonal impediment of litter biodegradation) and earthworm activity concentrates in the A horizon. On the contrary, going towards a milder climate Amphi progressively gives rise to Mull, losing the OH horizon by the incorporation of holorganic droppings in the underlying A horizon (Sartori *et al.*, 2004; Visintainer, 2008). This interesting shift has also been described by Bernier & Ponge (1994) and Bernier (1995) on siliceous substrates, as a dynamic phenomenon associated to the forest cycle: mature and juvenile phases are characterized by Amphi and Mull, respectively, while growth phases are characterized by Moder. This transformation of humus forms can be explained by the intervention of different groups of animals along the space/time dimension of the forest ecosystem, earthworms succeeding arthropods at the end of a forest cycle when selective cutting (as opposed to clear cutting) has been the dominant sylvicultural practice for centuries.

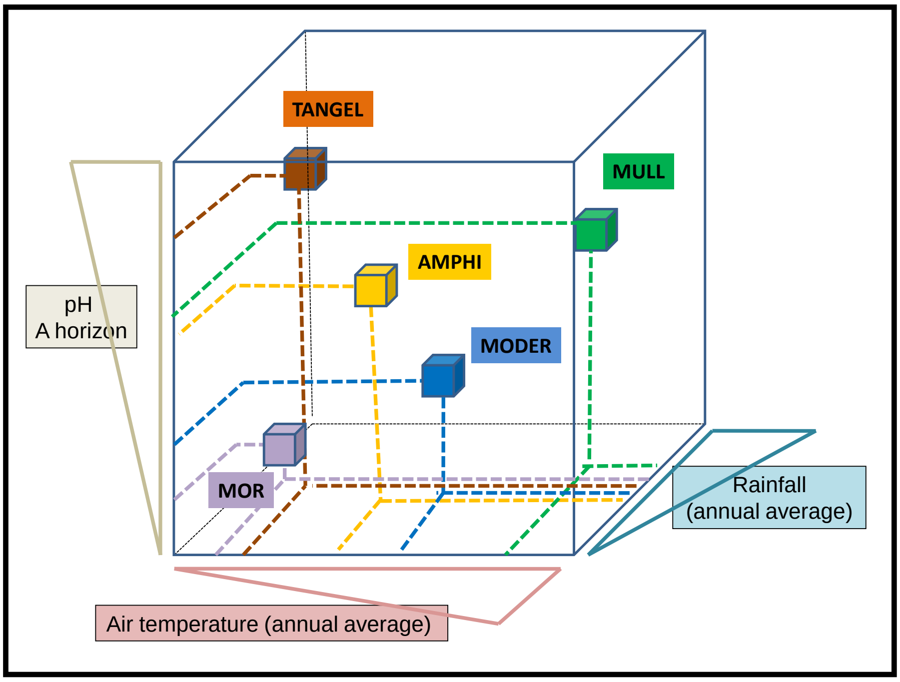


Fig. 13. *First attempt at an ecological framework for Terroforms. The gravity centres of the different Terroforms have been positioned in the space of three main factors, temperature, annual rainfall and soil pH, known to influence litter biodegradation. The scheme aims to show the relative position of the main humus forms in a hypothetical three-dimensional space of potential development.*

A rough recognition key has been created for droppings of the more common soil animals, based on a first version by Galvan *et al.* (2005, 2006). In this field key (Fig. 14) excrements are classified in three categories according to their size and are correlated with the three types of biostructured A horizons of our humus form classification.

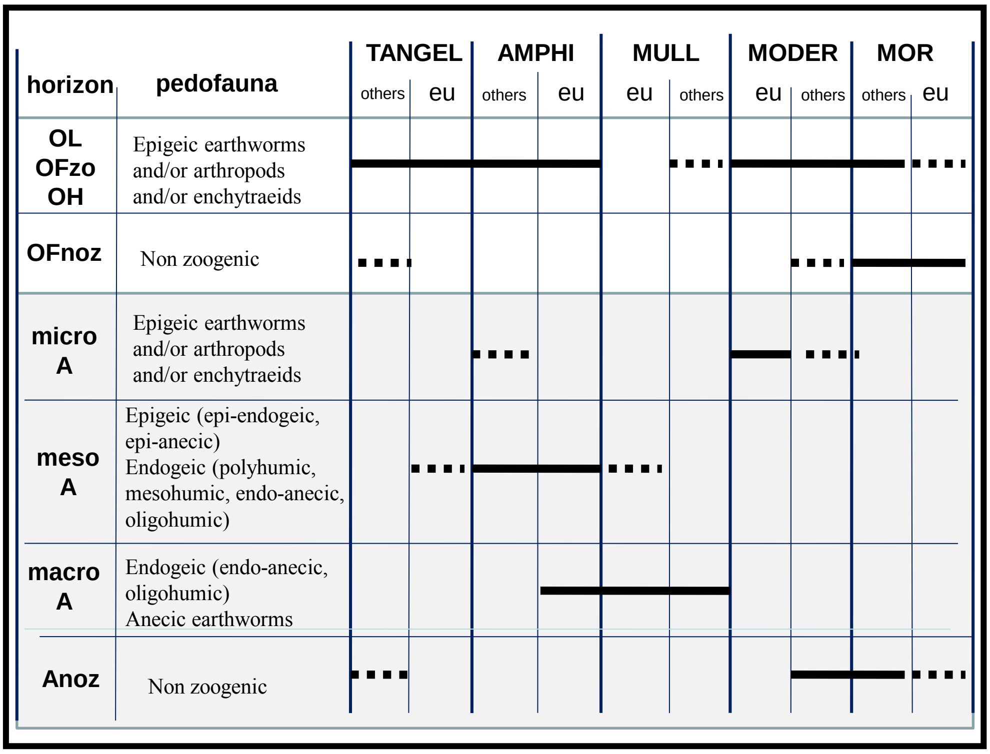


Fig. 14. First level of classification of Terroforms, diagnostic horizons and their pedofauna. For each main humus form typical central forms (eu) and other forms (others) have been separated.

The main humus forms in our classification and the corresponding diagnostic horizons can be related with the pedofauna responsible for their genesis (Fig. 15). Mull occupies a peculiar position, being influenced by ecological factors that allow an optimum pedofaunal development (Fig. 13).

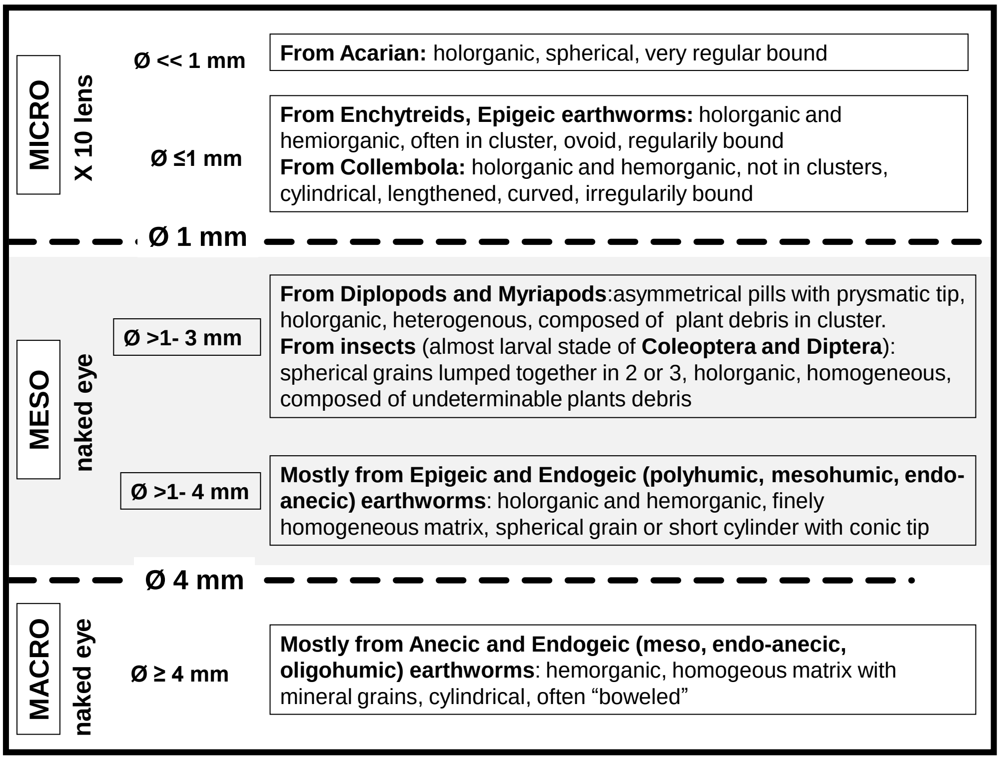


Fig. 15. Field classification of droppings of the most common groups of pedofauna (modified from Galvan et al., 2005). Droppings are divided into three categories, named micro (<=1 mm), meso (1-4 mm) and macro (>4 mm), corresponding to the abovementioned zoogenic A horizons (miA, meA and maA).

Variations in environmental conditions (climate, vegetation, human activities...) induce unfavourable niches for large soil earthworms, which are replaced by smaller species. The result is a reduction in the average size of droppings (Secco, 2004; Zanella *et al.,* 2008), switching the soil structure from biomacro to biomeso (Amphi) or biomicro (Moder). In the first case, summer dryness (Mediterranean areas) or winter frost and snow (subalpine areas) seasonally force earthworms to go deeper within the soil to find more acceptable water or heat conditions, respectively. In the organic horizons, there are epigeic earthworms, enchytraeids, arthropods (mites, spiders, springtails, insects, woodlice, millipedes, centipedes…) and small gastropods. The organo-mineral horizon can be biomeso- or biomacro-structured, according to the presence of endogeic earthworms (meso) or endogeic and anecic earthworms (macro), respectively.

DYNAMIC ASPECTS OF TERROFORMS

Humus forms cover the forest floor of natural or semi-natural forests as pieces of a mosaic corresponding to phases of the forest cycle (Bernier & Ponge, 1994; Bernier 1995, 1997). Their distribution is also well-correlated to other ecological factors like climate and parent material (Slompo, 2004) and involves chemical changes in the soil (Pizzeghello *et al.*, 2006; Salmon *et al.*, 2006; Galvan *et al.*, 2008; Cason *et al.,* 2008) which can also affect microbial populations (Carletti *et al.*, 2009). On each point of the forest floor, the ratio between the holorganic and the organo-mineral humic component changes over time (Fig. 16). Droppings of animals with a holorganic diet, living in litter, are progressively substituted by animals living in contact with the underlying organo-mineral soil and ingesting holorganic remains and/or droppings and mineral fine grains. The improvement in light and nutrient conditions associated with stand maturation influences pedoclimatic conditions and creates an environment favourable to the development of anecic and endogeic earthworm populations. This biological improvement is followed by an important incorporation of organic horizons in new organo-mineral layers and a consequent shift of the humus form. The process stops when the canopy closes again and the population of actively growing trees extracts the necessary mineral elements from the soil, thus impoverishing the topsoil. The humus form switches again, the organo-mineral horizon becoming poorer in bases and deprived of anecic and endogeic earthworms. In a mountain spruce forest over siliceous parent material in the Alps, the phenomenon is related to the altitude (Fig. 16), which interferes with faunal vitality, low temperatures restricting the time of favourable living conditions. The sequence of humus forms throughout a complete forest cycle revolves around a central Mull under 950 m, Amphi at 1550 m and Moder at 1800 m.

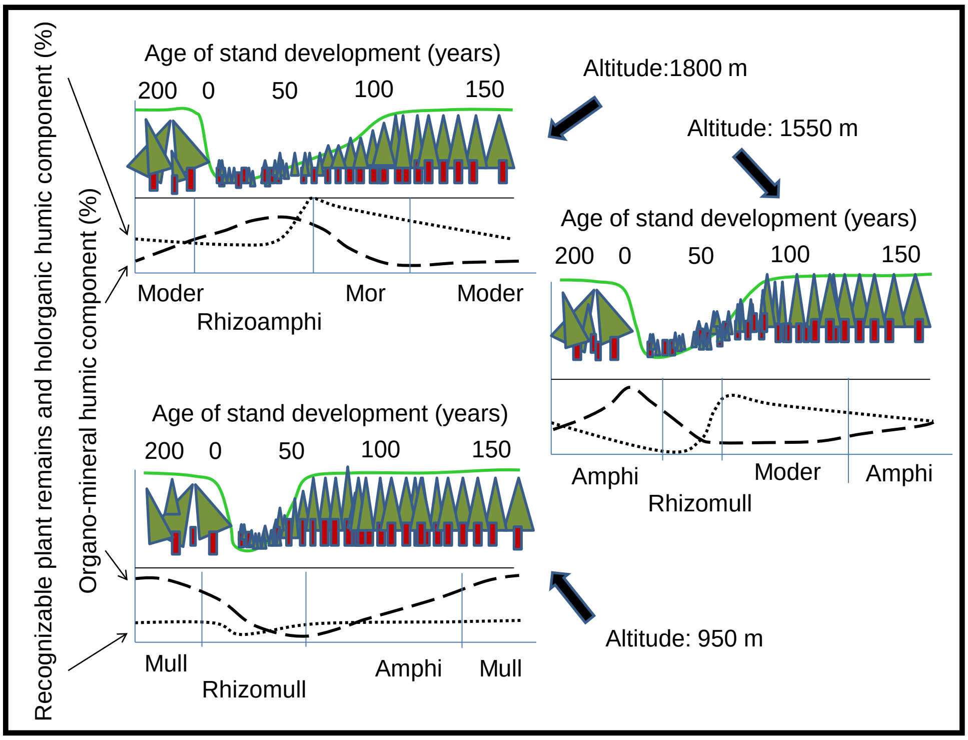


***Fig. 16.** Humus form dynamics during the sylvogenetic cycle in a mountain spruce forest at three altitudes. After Bernier (1997), modified according to the present classification of humus forms.*

SEMITERRESTRIAL HUMUS FORMS

IDENTIFICATION AND SUBDIVISION

Semiterrestrial humus forms correspond to the topsoil (organic and organo-mineral horizons) submerged and/or water saturated for more than a few days per year. These conditions of anoxia delay the process of biodegradation and the thickness of organic layers may even increase to several metres. Only the first 40 cm of the topsoil are observed and analyzed in order to classify semiterrestrial humus forms, the underlying part of the profile corresponding to well-detected and described Histosols following methods proposed by the main international soil classifications (FAO, 2006; AFES, 2009; Soil Survey Staff, 2010).

Bearing in mind the classification of terrestrial humus forms, a similar scheme has been elaborated for semiterrestrial categories, using as close as possible conceptual bases. Even if slowed down by anoxia, the process of biodegradation of plant remains can be perceived in the soil profile as a series of overlapping horizons. Nevertheless, there are major differences with terrestrial humus forms. In semiterrestrial circumstances the zone of biological change is to be found in the aerated zone, the top horizons of the humus profile. Lower organic layers are water-saturated and therefore subject to a much slower degradation than surface layers.

As a consequence, a terrestrial OH layer cannot be fully compared with a semiterrestrial Hs horizon. For that reason, definitions of semiterrestrial Mull, Moder and Mor differ from terrestrial definitions. The unaltered organic layers act as a kind of parent material, while in terrestrial humus forms parent materials are strictly mineral.

The most typical semiterrestrial forms are the Histoforms, They are submerged and/or water saturated for a prolonged period of the year (usually more than 6 months). Peat appears at the top of the humus profile because of anaerobic conditions which slow down the biological transformation of organic matter.

In Hydroforms organic horizons are rarely submerged and the biotransformation of organic matter is relatively close to aerated conditions, with the same animals and products of their activities. However, organo-mineral horizons always show signs of periodic anoxia.

Epihistoforms are introduced for classifying initial or transitional semiterrestrial humus forms with both organic horizons of Histoforms and Hydroforms. Specific vocabulary and diagnostic layers used as references are necessary for the description and classification of semiterrestrial humus forms and are introduced below.

SPECIFIC TERMS

FIBRIC COMPONENT. Non-decomposed or very weakly decomposed hygrophilous plant remains like *Sphagnum* species (Fig. 17, left), sedges, rushes, reeds... Whole plants, parts of them and/or free plant organs (leaves, needles, twigs, wood, roots...).

SAPRIC COMPONENT. Homogeneous dark organic and organo-mineral matter comprised of well decomposed plant remains partly mixed with mineral particles (Fig. 17, right). Plant structures are not visible to the naked eye or with a 5-10 X magnifying hand lens. Animal droppings are possible in periodically drained horizons and can be abundant in drained peats.

ORGANIC HORIZONS. Two groups of organic horizons have been distinguished:

- *HISTIC ORGANIC HORIZONS* (Hf, Hm, Hs): organic horizons submerged and/or water-saturated for a protracted period of the year (usually more than 6 months per year); carbon content

20% or more (approximately 35-40% organic matter) by weight in dry samples, without living roots (Method: element analyzer, ISO 10694, 1995). Horizons still under saturated circumstances or drained;

- *HYDRIC ORGANIC HORIZONS* (OLg, OFg, OHg): organic horizons submerged and/or water-saturated for a non-protracted period of the year (less than 6 months per year) and showing the effects of temporary anoxia; carbon content 20% or more (approximately 40% organic matter) by weight, in dry samples without living roots (Method: element analyzer, ISO 10694, 1995). Horizons still under saturated circumstances or drained.

ORGANO-MINERAL HORIZONS. Two kinds of organo-mineral horizons have been distinguished:

- *HISTIC ORGANO-MINERAL HORIZON* (Aa): submerged and/or water-saturated for a protracted period of the year (usually more than 6 months per year); carbon content between 7 and 20% by weight, in dry samples without living roots (Method: element analyser, ISO 10694, 1995);
- *HYDRIC ORGANO-MINERAL* (Ag): submerged and/or water-saturated for a non-protracted period of the year (less than 6 months per year); carbon content generally less than 7% by weight, in dry samples without living roots (Method: element analyser, ISO 10694, 1995).

Fig. 17*. Fibric (left) and sapric (right) components of histic organic horizons*

DIAGNOSTIC HORIZONS

ORGANIC HORIZONS

A minimum thickness of horizons for description, diagnosis and sampling purposes has been established at 3 mm. Below this threshold, the horizon is considered discontinuous if clearly in patches or absent if indiscernible from surrounding horizons. Following the rate of fibric and sapric components, histic organic horizons have been divided in three diagnostic horizons, Hf, Hm and Hs (Fig. 18). Though named differently (Hf=Hi or Oi; Hm=He or Oe; Hs=Ha or Oa or L), these horizons are the same as those used in the main international soil taxonomies (IUSS Working Group WRB, 2007; AFES, 2009; Soil Survey Staff, 2010) for describing peat soils.

HF (from Histic and fibric). Histic organic horizon consisting almost entirely of practically unchanged plant remains. Fibric component ≥ 90%, sapric component < 10% of horizon volume (Fig. 18). Content of rubbed fibres (Levesque & Dinel, 1977; Levesque *et al.*, 1980; Green *et al.*, 1993) ≥ 40% of soil by dry weight (105 °C). Von Post scale of decomposition: 1 to 3 (4, 5 possible). Close to the Soil Survey Staff (2010) definition of Fibric Soil Material. Plant remains from mosses like Sphagnum species, sedges, rushes and reeds are recognizable. Fibric horizons are quite common in bogs and oligotrophic parts of isolated fens. These horizons are mainly composed of remains of Sphagnum and Eriophorum species. In mesotrophic fens, the Hf-horizon is mainly composed of remains of sedges and rushes. Fibric horizons in eutrophic fens are less common because of the fast decomposition in those environments.

HM (from Histic, mesic). Histic organic horizon consisting of half decomposed organic material not fitting the definition of fibric (Hf) or sapric (Hs). Fibric component 10% to 70%, sapric component 90% to 30% by volume (Fig. 18). Content of rubbed fibres (Levesque & Dinel, 1977; Levesque *et al.*, 1980; Green *et al.* 1993): 10 to 40% of soil by dry weight (soil dried at 105 °C), Von Post scale of decomposition: 4 to 7 (8 possible). Close to the Soil Survey Staff (2010) definition of Hemic Soil Material.

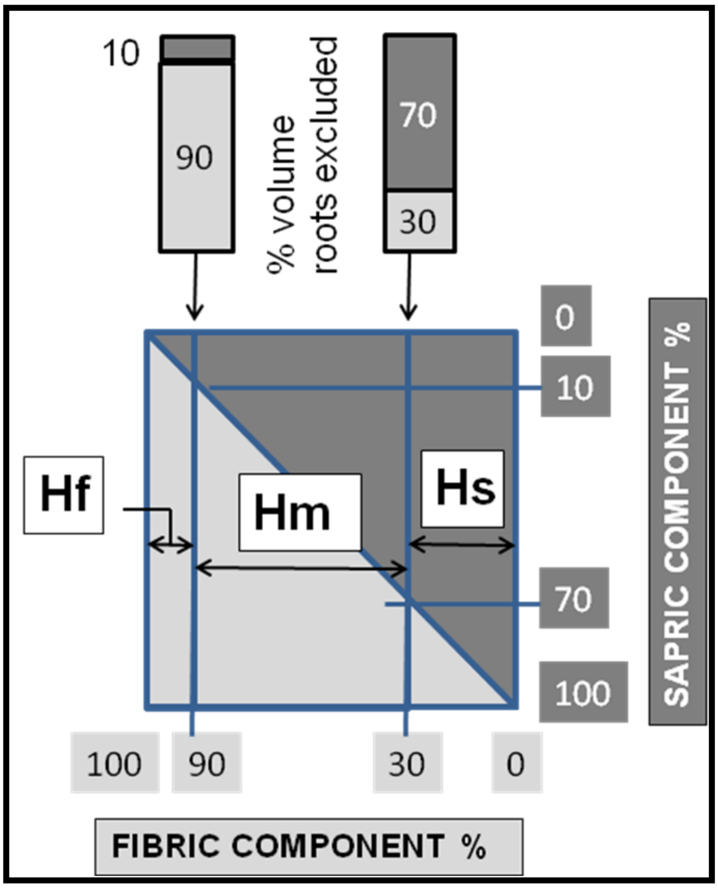
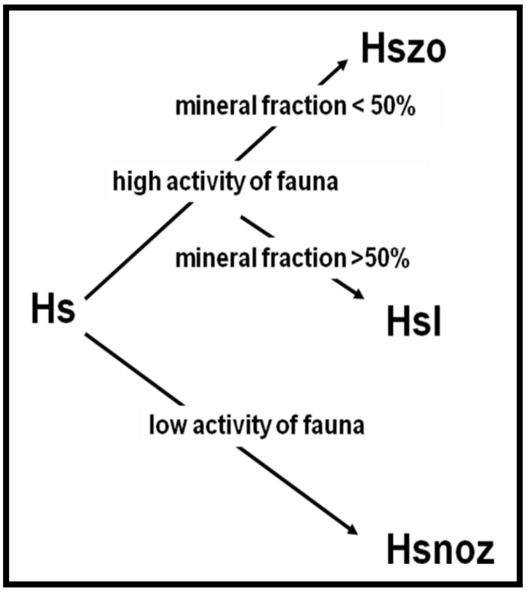


Fig. 18. *Horizons Hf, Hm and Hs in graphical definition.*

Fig. 19. *The different sapric horizons*



HS (from Histic and sapric). Histic organic horizon in advanced stage of decomposition. Sapric content ≥ 70% of the horizon volume; fibric component less than 30% (Fig. 18). Content of rubbed fibres (Levesque & Dinel, 1977; Levesque *et al.*, 1980; Green *et al.*, 1993) < 10% of soil by dry weight (soil dried at 105 °C). Von Post scale of decomposition: 8 to 10. Close to the Soil Survey Staff (2010) definition of Sapric Soil Material. Sapric horizons of brook valley systems and around wells have mostly a higher amount of mineral fraction than those in fens or bogs. Although at first sight quite similar, the horizons can differ in structure, pH, nutrient content and base saturation due to differences in water quality, vegetation and soil organisms.

Hs types (suffixes: zo, noz, l):

- Hszo = Meso or macrostructured Hs horizon with a high activity of soil animals, especially earthworms. The mineral fraction is less than 50% (Fig. 19). Typically present in drained semiterrestrial humus forms (both naturally and artificially drained). Activity of earthworms is high. The mineral fraction (clay, loam and/or sand) is commonly high compared to that of fibric horizons;
- Hsnoz = Massive Hs horizon with low activity of soil animals. Common around bogs and rain-fed ponds. Humification mainly results from the activity of microorganisms, which is typical of oligotrophic environments. Complexes of humic substances are acid and relatively poor in nutrients and bases and subject to eluviation when drained. The mineral fraction is variable;

- Hsl = Hs horizon with a high percentage of mineral particles (clay, silt and sand). The mineral fraction is more than 50%. The mineral component may occur in the form of thin layers. The bioactivity is comparable to Hszo.

OLg, OFg, OHg (from hydromorphic terrestrial horizons). Hydric organic horizons formed under non-prolonged water saturation (less than 6 months), periodically water-saturated and showing the effects of temporary anoxia. A suffix letter "g", written after the code of terrestrial horizons, indicates the presence of hydromorphic properties: plant remains becoming dark, glued together and often coloured along the venation (more evident than usual) of the leaves by black particles of humic component deposited here by water during the period of immersion; humic component often dark grey or black, massive and plastic, may be structured in faunal droppings during aerated periods. Carbon content ≥ 20% by weight. Humic component less than 10% in volume (roots excluded) in OLg, between 10 and 70% in OFg and more than 70% in OHg.

ORGANO-MINERAL HORIZONS

Aa (from A horizon and anmoor). Histic organo-mineral horizon mostly formed by microorganisms (actinomycetes), dark coloured, with plastic and massive structure, both high and low base-saturated. Earthworms may be abundant in better aerated periods, but the typical structure of their droppings is rapidly destroyed by water immersion and permanence, which allows this horizon to be distinguished from Ag in case of similitude in carbon content. Because of long periods of immersion, the oxidation of organic matter is slow, conferring a dark colour of partially oxidized organic matter on the soil. When needed, a subdivision could be made under local circumstances (Van Delft *et al.*, 2002).

Ag (from terrestrial A horizon and hydromorphic properties). Hydric organo-mineral horizons showing evident effects of temporary anoxia such as Fe-mottling and oxidation/reduction colours (orange-red splashes within grey to bluish-grey mass) covering at least 1/3 of the surface of the horizon profile; carbon content generally less than 7% by weight. All terrestrial A horizons can show hydromorphic properties (maAg, meAg, miAg, msAg, sgAg). Sometimes these properties are only traces of past events and are not in accordance with the current hydrological situation.

If carbon content is higher than 7% by weight, similarities with Aa or Hs are possible. However, the structure of maAg or meAg horizons, mostly due to anecic and endogeic earthworms, and although partially destroyed by water, never becomes completely plastic and massive as in the Aa horizon; carbon content of miAg, msAg and sgAg never reaches 20%, which is the case in every kind of Hs horizon.

FUNCTIONAL AND MORPHOLOGICAL CLASSIFICATION OF HISTOFORMS

The classification of Histoforms closely resembles that of peat soils in main soil taxonomies (IUSS Working Group WRB, 2007; AFES, 2009; Soil Survey Staff, 2010). This is not surprising given the fact that a peat soil is nothing more than a humus form in which the impeded decomposition of organic matter is the dominant feature of soil development. The classification of peat soils is in that sense a humus form classification "avant la lettre". Selecting the right master diagnostic horizons, a few main references are distinguished in order to separate Histoforms along a gradient of increasing biodegradation rate (Fig. 20)

Diagnostic horizons	ANMOOR	MULL	AMPHI	MODER	MOR
Hf	absent	absent	present but thinner than Hszo	possible but never dominant	dominant
Hm	absent	absent	possible but never dominant over Hszo	present	possible
Hsnoz	absent	possible but thinner than Hszo	absent	present	absent
Hszo	possible but never thicker than Aa	present or absent if Hsl present	dominant	absent	absent
Hsl	possible but never thicker than Aa	present or absent if Hszo present	absent	absent	absent
Aa	dominant	possible but never dominant	absent	absent	absent

Fig. 20. *Diagnostic horizons and features of five biological activity types of Histoforms.*

A second level of classification is shown on Fig. 21. People accustomed to FAO manuals may use the following step-by-step references:

ANMOOR

To be identified as Anmoor, the topsoil must display the following properties:

1. *presence of a dominant Aa organo-mineral horizon;and*
2. *Hszo, Hsl possible but never thicker than Aa.*

HISTOMULL

To be identified as Histomull, the topsoil must display the following properties:

1. *Hf or Hm never present within the control section; and*
2. *presence of Hszo or Hsl at the top of the profile; and*
3. *Hsnoz possible but thinner than Hszo; and*
4. *very active biodegradation of plant remains and their complete integration in an organo-mineral horizon.*

HISTOAMPHI

To be identified as Histoamphi, the topsoil must display the following properties:

1. *Hszo horizon dominant in thickness and present with Hf or Hfs or Hf and Hm; and*
2. *Hf and Hfs thinner than Hszo within the control section (first 40 cm below the surface); and*
3. *active to very active biodegradation of organic matter and mixing with organo-mineral matter.*

HISTOMODER

To be identified as Histomoder, the topsoil must display the following properties:

1. *Hf possible but never dominant; and*
2. *Hm or Hsnoz present and thicker than other horizons; and*
3. *organic matter degradation more active than in a Histomor.*

HISTOMOR

To be identified as Histomor, the topsoil must display the following properties:

1. *presence of a thick Hf horizon; and*
2. *Hm possible but never thicker than Hf; and*
3. *degradation of organic matter slow or inhibited.*

Each main Histoform has been subdivided in 2, 3 or 4 second level units, according to the ratio of thickness of the composing diagnostic horizons and using the following prefixes:

- fibri, mesi, humi and sapri along a gradient of increasing biological activity and consequent transformation of the Hf (fibric) horizon in an Hs (sapric) horizon;
- limi indicates the units of Mull and Anmoor with Hsl (limic) horizon;
- eu indicates the typical Anmoor expressed by the Aa horizon only.

All second level names of Histoforms are unambiguous and the prefix "histo" can be omitted (ex. Fibrimor instead of Fibrihistomor).

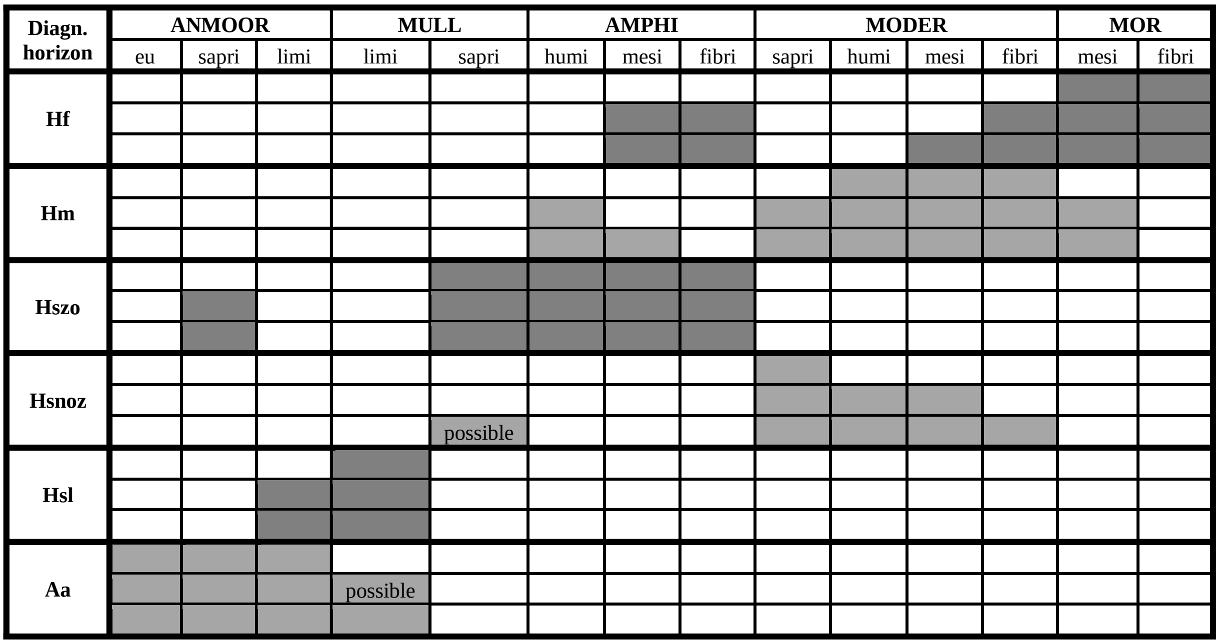


Fig. 21. *Second level of classification of Histoforms. Columns: second level (example, second level forms of Anmoor: euanmoor, saprianmoor, limianmoor); lines: diagnostic horizons superposed as in a real profile. Both presence/absence and relative thickness (dominance) of each diagnostic horizon are important for classifying Histoforms.*

FUNCTIONAL AND MORPHOLOGICAL CLASSIFICATION OF EPIHISTOFORMS

The Epihistoforms can be grouped according to the process of formation in three categories:

- stationary thin Histoforms in which decomposition matches accumulation of organic matter. They develop in mesotrophic environments such as groundwater fed areas, brookvalleys and wet depressions (rather common);

- real initial forms generated as a consequence of a dynamic evolution from hydro into histo soil-conditions in different ways:
    - brookvalley example: change of a dynamic (erosive) wet environment (Hydromull fed by mesotrophic or eutrophic water) into a wet, non dynamic, rainwater fed situation (Histoform), isolated from the streamchannel. This could be caused by a change in the course of the streamchannel;
    - moist depressions (especially on sandy areas) example: depression becoming wet because of an increasing stagnation of rainwater on an old terrestrial humus profile;
- peat remnant-forms (change from histo into hydro):
    - brookvalleys and wet depressions after drainage (natural or artificial): development of Hydroforms from Histoforms;
    - wet areas in which the toplayer is removed without drainage;
    - remnants of Histoform because of peat-mining;
    - brackish situations: when the influence of fresh groundwater becomes more important, the peaty toplayer disappears. The process is typical for polders and other reclamations of tidal flats and grassland estuaries.

Selecting the right master diagnostic horizons, a few main references have been distinguished in order to separate humus forms along a gradient of increasing biodegradation (Fig. 22).

Diagnostic horizons	EPIHISTO				
	ANMOOR	MULL	AMPHI	MODER	MOR
Hf					
Hm					possible
Hs					possible
Hsl					
Aa	dominant	possible			
Ag		dominant			
Anozg					possible
AEg					possible
pH(A) $_{water}$	pH ≥ 5			pH < 5	

Fig. 22. *Synoptic table of classification of Epihistoforms. Syntax rules: Epihistoforms only display a single second level of classification, thus, at present, the term Epihistomull, for example, means every kind of Epihistomull. All names of Epihistoforms are unambiguous and the prefix "histo" can be omitted (e.g. Epianmoor instead of Epihistoanmoor).*

People accustomed to FAO manuals may use the following step-by-step references:

EPIHISTOANMOOR

To be identified as Epihistoanmoor, the topsoil must display the following properties:

1. *presence of Hls; and*
2. *Aa always present and thicker than Hsl and Ag; and*
3. *presence of Ag (from earthworms) never thicker than Aa; and*
4. *pH$_{water}$ (A) ≥ 5.*

EPIHISTOMULL

To be identified as Epihistomull, the topsoil must display the following properties:

1. *presence of Hls; and*
2. *presence of Aa possible but never thicker than Ag; or*
3. *presence of Ag (from earthworms) thicker than Aa if Aa present; and*
4. *pH$_{water}$ (A) ≥5.*

EPIHISTOAMPHI

To be identified as Epihistoamphi, the topsoil must display the following properties:

1. *presence of Hf, Hm and Hs; and*
2. *presence of Ag (from earthworms); and*
3. *pH_{water} (A) ≥ 5.*

EPIHISTOMODER

To be identified as Epihistomoder, the topsoil must display the following properties:

1. *Hs always present; and*
2. *presence of Anozg; and*
3. *pH_{water} (A) < 5.*

EPIHISTOMOR

To be identified as Epihistomor, the topsoil must display the following properties:

1. *Hf always present, Hm and/or Hs possible; and*
2. *presence of Anozg and/or AEg; and*
3. *pH_{water} (A) < 5.*

FUNCTIONAL AND MORPHOLOGICAL CLASSIFICATION OF HYDROFORMS

In this first attempt at classifying Hydroforms, five main categories have been defined without any second level of classification (Fig. 23).

Diagnostic horizons	HYDRO				
	TANGEL	AMPHI	MULL	MODER	MOR
OL(g)			possible		
OFnoz (g)					
OFzo(g)			disc. or pock.		
OH(g)					
Ag					
Anozg					possible
AEg					
$pH(A)_{water}$	pH ≥ 5			pH < 5	

Fig. 23. *Synoptic table of classification of Hydroforms. Legend: (g) = g possible, i.e. hydromorphic properties of the horizon can be present or not; g = presence of hydromorphic properties. Syntax rules: Hydroforms only display a single second level of classification, thus, at present, the term Hydromull, for example, means every kind of hydromorphic Mull.*

People accustomed to FAO manuals may use the following step-by-step references:

HYDROTANGEL

To be identified as Hydrotangel, the topsoil must display the following properties:

1. *presence of OL(g), OFzo(g), OHzo(g), Ag horizons; and*
2. *pH_{water} (A) ≥ 5; and*
3. *OHzo(g) always thicker than twice the thickness of the A horizon.*

HYDROAMPHI

To be identified as Hydroamphi, the topsoil must display the following properties:

1. *presence of OL(g), OFzo(g), OHzo(g), Ag horizons; and*

2. *pH_{water} (A) ≥ 5; and*
3. *OHzo(g) never thicker than twice the thickness of the A horizon.*

Hydromull

To be identified as Hydromull, the topsoil must display the following properties:

1. *presence of OL(g), Ag horizons; OFzo(g) possible, discontinuous or in pockets; and*
2. *pH_{water} (A) ≥ 5; and*
3. *OH never present.*

The transition between organic and organo-mineral horizons is often sharp; water table rises thanks to capillarity are responsible for local anoxia within the horizons; periodic immersion for short periods is also possible, but less important than in other Hydroforms.

Hydromoder

To be identified as Hydromoder, the topsoil must display the following properties:

1. *presence of OL(g), OFzo(g), OHzo(g), Anozg horizons; and*
2. *pH_{water} (A) < 5; and*
3. *Ag never present.*

Hydromor

To be identified as Hydromor, the topsoil must display the following properties:

1. *presence of OL(g), OFnoz(g), OHnoz(g), (Anozg), AEg horizons; and*
2. *pH_{water} (A) < 5; and*
3. *OFnoz (g) always present.*

All Hydroforms except Hydromull are often submerged up to the base of the OH horizon and the transition between organic and organo-mineral horizons is often no sharp (> 5 mm); tongues of coloured organic matter can dip within the soil from the top organic horizons. Investigations into Hydrotangel and Hydroamphi forms have never been published. They develop on calcareous soils or similar parent materials, unlike Hydromoder and Hydromor which are formed on acid substrates.

Biological and dynamic aspects of semiterrestrial forms

In water-saturated systems, the bioactivity, and with it the decomposition of organic plant residues, depend on water quantity, oxygen availability, water quality (pH, nutrients and bases) and quality of the peat itself, mineral content included. All these factors are closely related and form the complex which describes the main peat-forming systems (Stortelder *et al.*, 1998).

The water quantity can be described in terms of water level and oxygen availability, which vary with the frequency and duration of inundation events and flooding and with the fluctuation of the water level (Wolf *et al.*, 2001). Main peat-forming systems are bogs, springs and brook valleys. Within these systems, conditions can vary within a rather short period. The peat-forming system can be described as a complex of nested cycles (Fig. 24).

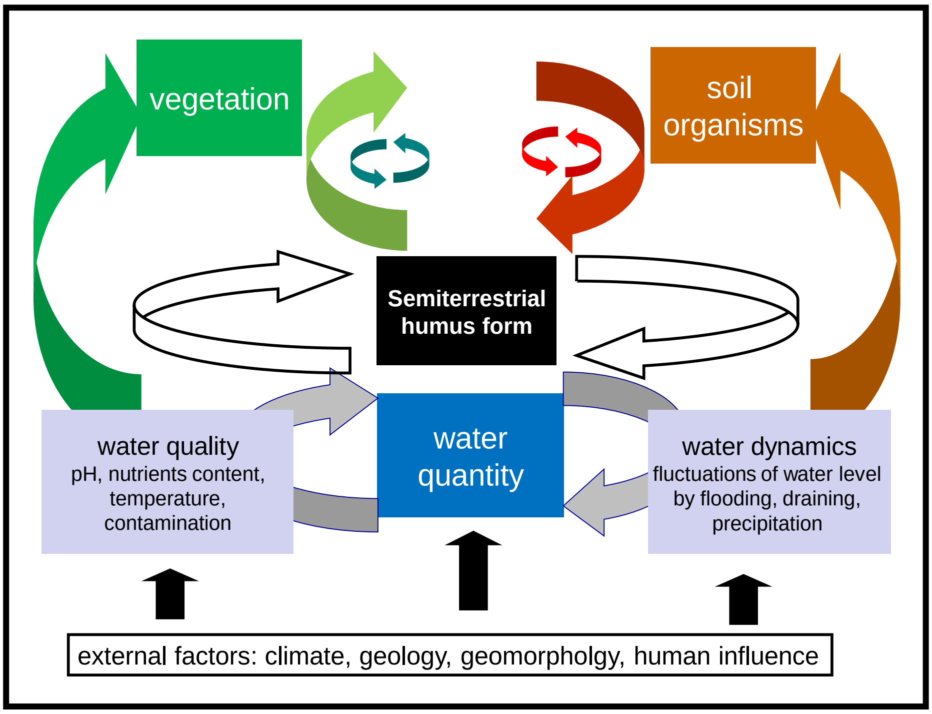


Fig. 24. *Interacting ecological factors in semiterrestrial humus forms.*

BIOACTIVITY IN BOGS AND RAIN-FED FLOATING FENS

In fens, bogs and springs the fluctuation of the water table is rather small. Decomposition in oxygen-poor circumstances (a constant state of water saturation) is mainly directed by anaerobic microorganisms (Scheffer *et al.*, 1982). As a result, the level of mineralization, humification and mixing of the organic material is very low (Fig. 25). Accumulation of almost unaltered plant remains is the main humus forming process here. The humus form in this kind of environment is mainly a Histomor. After a sudden desiccation caused by peat mining activities the biological activity stays low and a "fossilic" Histomor persists (Stortelder *et al.*, 1998).

Histomors can also exist for a rather short period in eutrophic peaty environments like floating fens composed of reeds and sedges. Most typical Histomors of the more durable kind evolve in rain-fed bogs and rain-fed isolated areas of floating fens. In these fully water-saturated humus forms, without large seasonal fluctuations, earthworm and enchytraeid activity is almost nil, because of lack of oxygen. In addition, the pH in some acid parts of fens and in bogs is too low to sustain a population of earth- and potworms (Graefe & Beylich, 2003). In these acid and water-saturated environments *Sphagnum* mosses dominate all types of chemical and physical processes. Slight drainage leads to some increased bioactivity (Fig. 25). In these drained acid circumstances, enchytraeids like *Cognettia sphagnetorum* will colonize and become active (Beylich & Graefe, 2002). Only after a long time, poor and acid amorphic Saprimoders will develop (Jongerius & Pons, 1962). A poor Histomoder acts as an intermediate phase (Fig. 26). Going toward less acid areas, a condition of slight drainage allows the arrival of animal populations in the organic topsoil, leading to the formation of a Histoamphi, which evolves into a Histomull in the case of a base-rich environment.

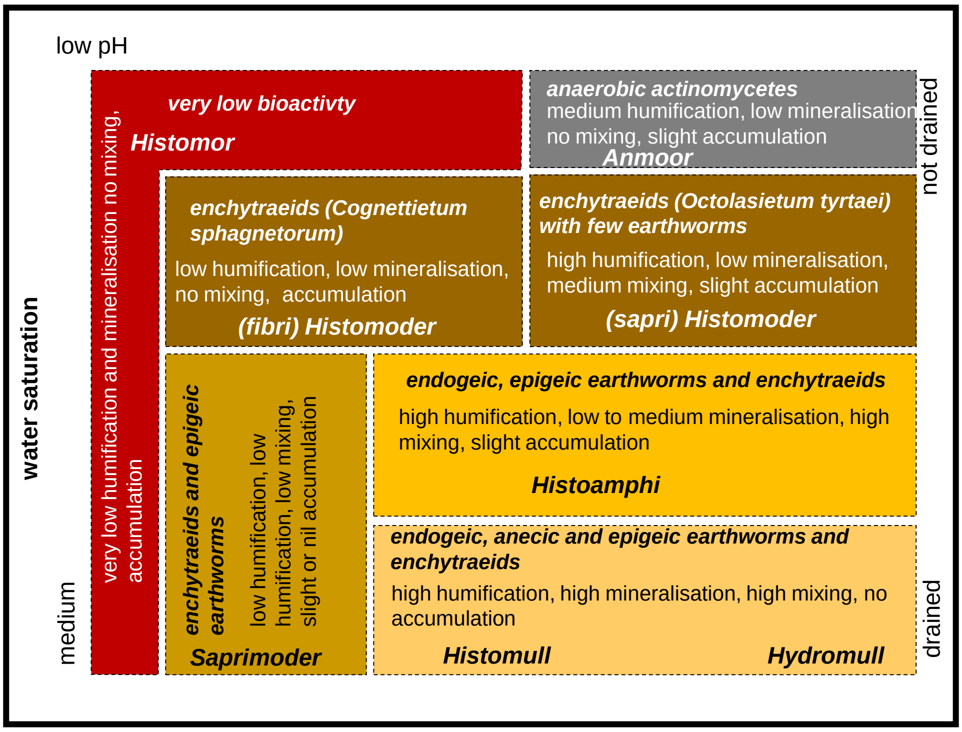


Fig. 25. *Relationship between pH and water saturation and bioactivity. Slightly modified after Beylich & Graefe (2002).*

FENS

In mesotrophic and slightly eutrophic environments with small water table fluctuations, Histomors are formed of more readily decomposable plant residues like sedges, often in combination with reeds, wood remnants and sometimes with a content of mineral soil particles. After only slight drainage (a few cm), enchytraeids may become active (Healy, 1987; Cole *et al.*, 2002; Laiho, 2006) and the Histomor develop into a Histomoder (Fig. 26). If the average water level is lowered by more than 10 cm, lumbricids may also become active if they are present in the immediate environment. Mainly endogeic and epigeic earthworms are active in the range of Histomoders (Fig. 25). The result is a growing, initially thin, black bed of well-decomposed and structured fine humus. In the event of further drainage, this will transform Histomoders into Histoamphis and Histomulls in which even anecic earthworms can become active (Fig. 25).

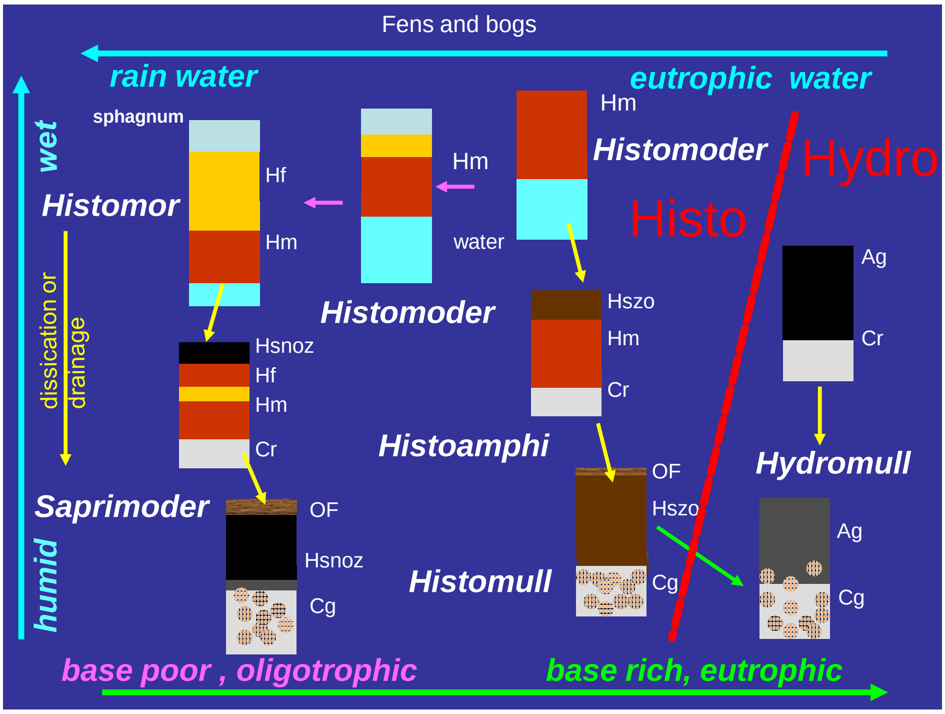


Fig. 26. *Development of humus forms in fens and bogs (large extended systems characterized by a dominant process of sedimentation, large floodplains) according to water quality and quantity. The profiles shown are just an indication and also include layers below the control section (first 40 cm). Modified after Stortelder et al. (1998) and Van Delf et al., (2002).*

In vast areas of reclaimed fens and mires in lowland parts of northern Germany and in the Netherlands, Histoamphis and Histomulls are the dominant humus forms. Although the groundwater fluctuations are larger in drained fens of meadows and woods than in untouched fens, moisture regimes are never entirely dry. Such an environment remains favourable for enchytraeids and earthworms. On the other hand, periods of high water levels (above ground level) can be temporarily unfavourable for enchytraeids and earthworms. However, earthworms can survive these anaerobic periods by migration, diapausing cocoons and other strategies (Plum, 2005).

Lowering of the water table does not always lead to a much higher activity of soil organisms. Especially in peaty humus forms which are originally influenced by nutrient- and calcium-rich water as at the shores of lakes, pH can drop due to the increasing influence of infiltrating rainwater. On some less eutrophic sites, a rainwater lens can even develop which favours the growth of *Sphagnum* species. These layers of living and decayed *Sphagnum* mosses act as a sponge which promotes the development of a thin water-saturated oligotrophic humus layer with low bioactivity. Although for a short time, layers with low and medium bioactivity can coexist (Amphi).

SPRINGS AND BROOK VALLEYS

At the more base-rich and more mineral end of the semiterrestrial spectrum, such as springs and groundwater-fed wet brook valleys, the accumulation of organic matter is not spectacular and most bioactivity is due to actinomycetes (Scheffer *et al.*, 1982). In these circumstances, rather rich Anmoor humus forms will develop. Under the influence of lower pH and lower calcium availability, a much poorer Anmoor will form, the activity of actinomycetes being decreased (Figs. 22 and 24).

In wet brook valleys, fluctuations are somewhat wider, which enables some annelids to be active in periods of lower water levels. Normally in brook valley systems the water level fluctuations enable enchytraeids and earthworms to transform the Histomoder into a Histomull. Earthworms have different strategies to cope with anaerobic periods during flooding (diapause, migration). Enchytraeids are less adapted to prolonged periods of inundation (Healy, 1987; Plum, 2005). Due to a larger content of mineral component (thin layers of sandy sediments as well as clay) in drained brook systems, Histomoders can develop into Hydromulls by way of oxidation and mineralization of the organic fraction (Stortelder *et al.*, 1998). Like in fens, drainage does not always lead to better circumstances for decomposing organisms (Oliver *et al.*, 1999; Van Diggelen *et al.*, 2006). Isolation from the rather rich brook water can lead to a growing influence of rainwater, especially when it stagnates on a loamy layer with low permeability, which occurs quite often in these systems. The development of Histoamphi humus forms is also a possibility here. In extreme circumstances, Histomoders and Histomulls can even develop into acid Histomors in the long-term, forming a small-scale bog system within the brook valley (Fig. 27).

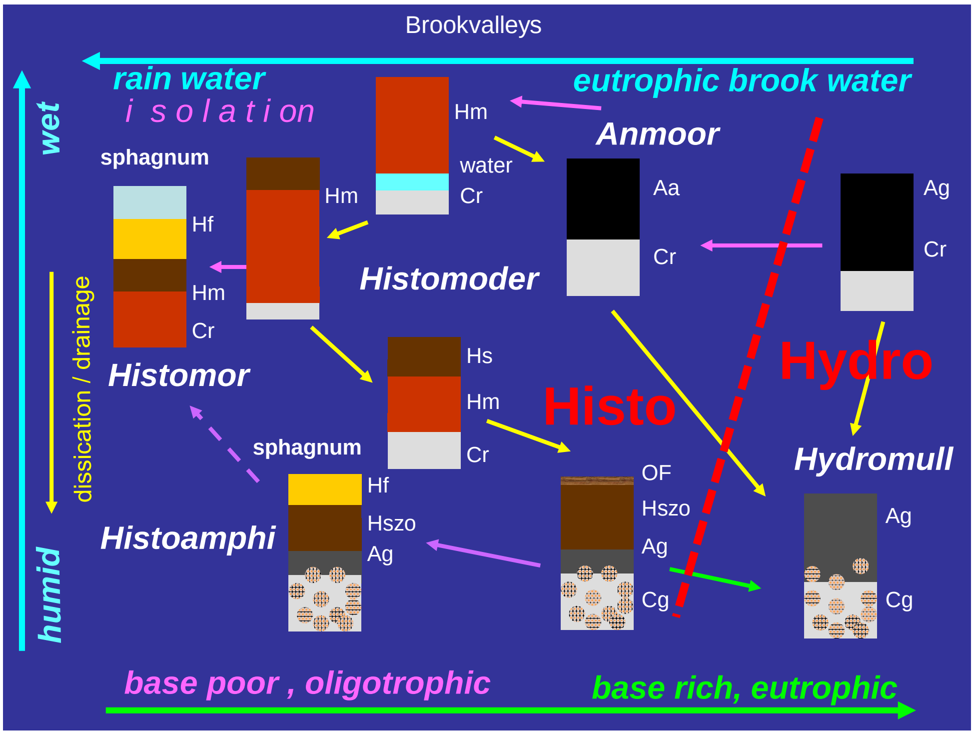


Fig. 27. Development of humus forms in brook valley systems (small systems, like small rivers, brooks, streams and floodplains). The profiles are just an indication and also show layers beneath the control section (first 40 cm).

CONCLUSION

SOIL ORGANIC CARBON AND TOPSOIL SAMPLING PANELS

The humus forms contain the largest part of soil organic carbon (in the case of Histosol, the humus form just coincides with the soil) in living structures (roots, fauna and microorganisms, virus), plant and animal dead remains (entire, fragmented, more or less biodegraded bodies or organs) and organic molecules (exudates, humic acids, proteins,….) within organic (OL, OF, OH, H) and/or organo-mineral horizons (A, Aa). The humus form is the result of interactions, within the topsoil of a given local ecosystem, among roots, animals and associated biodegrader communities. Changing the ecological frame (climate, parent material, anthropic pressure, history…), the system evolves consequently in new biocenoses characterized by adapted humus forms. The organic carbon content differs in each horizon of the humus forms as well in quantity as in quality. In terrestrial humus forms, for instance, the content of organic carbon generally decreases with soil depth (indicatively, OL: 30-45 %; OF: 25-40 %; OH: 20-35 %; A: 1-20 %); the C/N ratio also decreases of half his value from organic to organo–mineral horizons (indicatively, from 30 in organic horizons to 15 in A horizons); the carbon of fresh organic matter (OL and OF horizons) is still incorporated in structural molecules inherited from living organisms, while in zoogenically elaborated horizons (OH and A) it composes old transformed or newly synthesized organic molecules, partly or mostly bound to mineral particles. The organic molecules comprised in biological organo-mineral aggregates could be very resistant to biodegradation (Martin *et al.*, 1993; Balesdent *et al.*, 1998, 2005; Virto *et al*., 2010). Finally, soil carbon turnover and dissipation of this element in the air depend of the type of biodegradation acting in the topsoil, i. e. of the humus form.

The soil as carbon sink will be better understood if the spatial distribution of humus forms is taken in consideration while sampling the area. To survey and sample thickness and composition of diagnostic horizons of each different humus form is strongly recommended.

NEW HORIZONS

Protocols have been set up for the assessment and sampling of organic or organo-mineral horizons, as well as definitions for specific diagnostic horizons and their designation. Humic and mineral components have been distinguished within recognizable remains. Definitions of zoogenic and non-zoogenic materials have been introduced to better differentiate some crucial diagnostic horizons. Agreement has been reached regarding international references to characterize five diagnostic A horizons. For peat forms, fibric and sapric components of horizons have been described.

With the aim of completing the humus form classification, definitions of terrestrial and semiterrestrial forms have been established. The first group has been split into initial, typical and atypical forms. Amphi and Tangel humus forms have been admitted at the first level of classification, beside Mull, Moder and Mor. A second level of classification has been conceived for Amphi, which also includes some Mediterranean humus forms. Semiterrestrial forms have been separated according to the length of submerged or water-saturated periods and a second level of references has been established for each group.

Numerous doubts still remain. Dear reader, please use this classification system, evaluate it using your datasets, compare its efficiency with that of national taxonomies, forge new tools for better understanding humus forms and communicate the results of your experiences to the Humus Group. It will only be possible to extend the classification over the whole of Europe (and to other Continents?) with your collaboration.

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ANNEX

FIRST STEPS OF VALIDATION OF THE CLASSIFICATION KEY

In spring 2007, the Forest Soil Co-ordinating Centre of ICP Forests (FSCC) conducted a field survey on 34 Flemish forest experimental plots in order to test the draft key to the European humus forms of 2006 (Jabiol *et al*., 2004; Zanella *et al*. 2006). The French (Brêthes *et al.,*1995; Jabiol *et al.,* 1995) and a Belgian (Delecour, 1983) classification systems were also compared. Both Green *et al.* (1993) guidelines, developed for North American forest soils, and Jabiol *et al*. (2004) reference were used for field description of humus forms and identification of diagnostic horizons.

Based on this experience, some bottlenecks were identified, discussed and recommendations formulated. Most of them were taken on board in the updated classification key, after a meeting of the Humus group in Cagliari in 2007 and a workshop in Vienna, during the EuroSoil Congress 2008 (Fig. 28).

Bottlenecks in draft key (2006)	**Solutions to the problem and/or amendments to the present European Reference Base for Humus Forms**
The measure of horizon thickness or boundaries with a precision of 1 mm was impracticable.	A minimum thickness of horizons for description, diagnosis and sampling purposes is established at 3 mm. Below this threshold, the horizon is considered discontinuous if clearly in patches or absent if indiscernible from adjoining horizons.
The first definition of "organic horizon" (organic carbon > 17% ≈ 33% organic matter = 1/3 of horizon mass) differe from the definition reported in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2006), where an organic horizon contains 20% or more of organic carbon in the fine earth. Difficulties arise when comparing data gathered with both methods.	Agreement is reached for a minimum content (20%) of organic carbon in an organic horizon.
The first definitions of OL types (OLn and OLv) were not clear enough, especially concerning age and morphology of constituting materials and the altered nature of OLv.	The definitions are updated, some remarks are added. Leaves of previous autumn, for instance, become part of OLv only when they display the altered characters of old litter.
Jabiol *et al.* (2004) did not very clearly define the distinction between non-zoogenic and zoogenic horizons. Subjective interpretations were possible (how much is "mainly effected by soil fauna"?). In several plots, both faunal and fungal activities were observed. Furthermore, non-specialists did not find easy to define in the field whether the horizon was decomposed by soil fauna or by fungi.	New definitions of "zoogenically transformed material" and "non-zoogenically transformed material" are established. The estimation of the ratio of both components in the horizon allows identification of the correct horizon-type according to Zanella *et al.* (2009). The concept of "non-zoogenic OH horizon" has been abandoned: when fungi dominate in the process of litter biodegradation, the biological transformation of an OL horizon leads to a "non-zoogenic OF horizon", never to an OH horizon. A secondary faunal attack is possible and generally occurs in old OFnoz horizons, which become zoogenic OH horizons when the faunal-transformed material rises above 10% of horizon volume.
The definition of "fine organic matter" in Jabiol *et al.* (2004) was not clear enough about dimensions of organic particles and their carbon content. Small animal droppings (i.e. enchytraeid faeces), which look organic to the naked eye, are generally considered as "fine organic matter" even if in reality often organo-mineral. On the other hand, large earthworm droppings, which generate biomacro- and/or biomeso-structured organo-mineral A horizons, contain invisible fine organic matter of relevant functional importance.	The new specific term of "humic component" is defined: small and not recognizable particles of organic remains and/or grains of organic or organo-mineral matter mostly comprised of animal droppings of different sizes. Partially or totally, the "humic component" composes organo-mineral (A) and organic (OL, OF, OH) horizons indifferently. Organo-mineral A horizons, mostly made of anecic and endogeic earthworm droppings as well as totally, finely humified and mostly organic OH horizons resulting from epigeic earthworm, enchytraeid and microarthropod activities, are both composed of humic component (100% or close to it), despite differences in animal communities, horizon structure and organic carbon content.
The parameter "structure" is surveyed in a different way by soil or	Three zoogenic A horizons (microstructured, mesostructured and

humus scientists. The structure of the A horizon being of great interest in order to understand the biological functioning of the topsoil, prompted complementary methods. In the field, the volume of micro (≤ 1 mm), meso (1-4 mm) and macro (> 4 mm) aggregates can be estimated with appropriate sieves. The apparent absence of structure can also be linked to non-zoogenic A horizons.	macrostructured) and two non-zoogenic A horizons (massive, single grain) are defined approaching USDA-FAO references.
In the field, it was sometimes very hard to divide A and OH horizons, or zoogenic and non-zoogenic A horizons.	Figs. 6 and 16 are prompted in the aim of solving eventual conflicts of diagnosis.
Sometimes the morphology of organic layers fitted the requirements of a Mull humus form, although the structural characteristics of the A horizon fulfilled the requirements of a Moder humus form. Disturbance (human) = disequilibrium.	The present reference base does not take into account ecosystems with a strong human impact (agricultural crops, industrial and urban wastes,…).
In contrast to Delecour (1983), the first proposal of a European humus forms classification did not consider the pH(H_2O) of the A horizon as a discriminating diagnostic character. So, similar designations of humus forms referring to national or European systems could have different contents.	The pH(H_2O) of A horizons is taken into account in the proposed definition of humus forms.
Detailed morphogenic features of Rhizo and Lignoforms were never described. So the decision whether to apply these forms was subjective.	Specific features of Rhizo and Lignoforms are now defined as well as some morpho-functional types.
The concept of Mor humus form was unclear, particularly at its contact with Moder and Tangel forms.	The dominant character of Mor is the presence of a non-zoogenic OFnoz horizon, even if discontinuous or in pockets. When the identification of the OFnoz horizon is not easy, the transition between organic and organo-mineral or mineral horizons can be observed for reinforcing the diagnosis: in Mor humus forms the transition is generally very sharp (< 3 mm).
Initial humus forms and/or directly lying on bedrock differ from any other group of humus forms.	Entiforms are defined and shared from "mature" humus forms thanks to some specific characters and limits in thickness of diagnostic horizons.
The classification of Semiterrestrial topsoils was lacking.	A new tree of classification is proposed with three important branches: peat forms (Histoforms); forms in transition to terrestrial sites (Hydroforms); initial/atypical histoforms (Epihistoforms).
Animal droppings are key diagnostic characters. Non-specialized scientists often found them confusing.	A classification key (Galvan *et al.*, 2005) of animal droppings has been adapted and tested (Fig. 14). A table linking diagnostic horizons and animal communities has also been drawn up (Fig. 15).

Fig. 28. *Bottlenecks in draft key (in Jabiol et al., 2004; Zanella et al. 2006) and resulting solutions and/or amendments to the current European Reference Base for Humus Forms (2010).*

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