Humusica 1, article 5: Terrestrial humus systems and forms — Keys of classification of humus systems and forms

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Foreword

Even if published as an independent article, if you are not accustomed to soil or humus field classification, this paper lacks of basic information you can find in: Humusica 1, Article 1: Essential bases – Vocabulary (Soil and humus profiles and horizons, Humus systems and forms classifications, historical overview…); Humusica 1, Article 3: Essential bases – Quick look at the classification (for beginners); Humusica 1, Article 4: Terrestrial humus systems and forms – Specific terms and diagnostic horizons.

Humusica recovers keys of classification published in preceding works (Zanella et al., 2011a,b; Jabiol et al., 2013), which are still valid but incomplete. Here an enlarged group of authors updated the old units, created few new references and better illustrated the whole.

1. Key of classification of humus SYSTEMS

On a morpho-functional basis, Terrestrial humipeds are subdivided in five systems (Mull, Moder, Amphi, Mor and Tangel), hereafter identified and described based on diagnostic features.

Essential legend (complete definition in Humusica 1, art. 4): biomacro A = biomacrostructured A horizon; biomeso A = biomesostructured A horizon; biomicro A = biomicrostructured A; zoOF or OF = zoogenic OF horizon; nozOF = non zoogenic OF horizon. OH = implied zoOH (zoogenic OH) and/or possible szoOH (slightly zoogenzic OH) horizons.

Caution: “and” written at the end of a phrase means that the exposed preceding diagnostic criteria are not sufficient and need to be completed with others; “or” reported between criteria allows to select among them. The sign “;” is used between two sentences and indicates that the process of classification is not finished.

1.1 Mull

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

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

or

2) Presence of biomeso A and at least two of the following:

• presence in the A horizon of living earthworms or their casts, except in frozen or desicated soil;
• presence of a very sharp transition (< 3 mm) between organic and organic-mineral horizons;
• pHwater of the A horizon ≥ 5.

Correct lecture/interpretation for Mull:

1) must be without OH horizon and
2) must show biomacro

or

2) biomeso A horizon and two of the listed three criteria.

1.2 Moder

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

1) presence of an OH horizon (even if sometimes discontinuous); and
2) absence of nozOF; and
3) absence of biomacro A; and one of the following:

• no sharp transition OH/A horizon (transition ≥ 5 mm);
• pHwater of the A horizon < 5;

or

3) presence of biomeso A or biomicro A, or A single-grain or (rare, in case of intergrades to Mor) A massive, and one of the following:

• no sharp transition OH/A horizon (transition ≥ 5 mm);
• pHwater of the A horizon < 5.

1.3 Amphi

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

1) simultaneous presence of OH and biomacro or biomeso A horizons; and
2) absence of nozOF; and
3) thickness of A horizon ≥ thickness of ½ OH horizon; and
4) absence of massive or single-grain A; and
5) presence of biomacro A and one of the following:
errors of classification. It allows beginners to avoid serious errors of classification. We reported main ecological conditions, dominant actors of biodegradation, actors’ actions, pHwater of A horizon, key diagnostic horizons and, sometimes, concise dynamic considerations. An entire paper (Humusica 1, article 8) has been written for describing/illustrating the humus systems biological activities.

2. General character and distribution of Mull

Ecological conditions: temperate or tropical climate and/or nutrient-rich 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 rapid disappearance of litter from the topsoil (≤ 3 years), carbon mainly allocated in the A horizon; pHwater of the A horizon: generally ≥ 4.5;

key diagnostic characters (morpho-functional result of specific biological activities): OH never present, biomacro or biomeso A, very sharp transition (< 3 mm) between organic and organic-mineral horizons.

Nota Bene: Even if a very low soil pH is observed (≤ 4.5) in the equatorial zone, temperature and moisture compensate for unfavourable soil conditions (Sanchez et al., 2003) and a very active Mull humus system occurs in all this area (Lavelle et al., 1993), except in white sand or inselberg sites (with very low base content), where Mor and Moder dominate, respectively (Hartmann, 1970; Klinka et al., 1981; Coomes and Grubb, 1996; Kounda-Kiki et al., 2008). The equatorial Mull shows a large number of roots at its surface (it is often a Rhizo Mull), which can absorb the nutrients thanks to mycorrhizal symbiotic partners (Nasto et al., 2014). Nitrogen fixing bacteria ensure a good amount of nitrogen in the soil and compensate for the leaching effect due to intense rainfall. On the contrary of temperate and boreal soils which often lack nitrogen, tropical soils are frequently poor in phosphorus. Despite their acidity, equatorial soils may be very fertile. Their fertility depends on a closed nutrient cycle between living biomass and topsoil. This biological phenomenon explains the relative fragility of the equatorial Mull systems when the growing biomass is exported by deforestation, letting a humus system that rapidly lacks essential nutrients and collapses...

2.2. General characters and distribution of Moder

Ecological conditions: mild to moderately cold climate, frequently on acidic substrate; dominant actors of biodegradation: arthropods, epigeic earthworms and enchytraeids; fungi; actors’ action: slow biodegradation (2–7 years), carbon stocked in both organic and organic-mineral horizons; pHwater of the A horizon: generally < 4.5;

key diagnostic characters: OH always present (presence includes discontinuous presence too), nozOF never present, biomacro A, massive or single grain A, gradual transition (≥ 5 mm) between organic and organic-mineral horizons.

Nota Bene: When erosion bring away organic horizons, or in case of evolution from Moder toward Mull and absence of OH horizon, it is necessary to focus on the structure of the A horizon and/or to observe equivalent humipedons in areas not altered by erosion.

2.3. General characters and distribution of Amphi

Ecological conditions: strongly seasonal climate conditions (dry
Table 1
Diagnostic horizons and features of the five Terrestrial humus systems (five references = biological activity types). In the table, the adjectives “active” or “inactive” refer to the presence or absence of living organisms in the diagnostic horizons.

<table>
<thead>
<tr>
<th>Diagnostic horizons</th>
<th>MULL</th>
<th>MODER</th>
<th>AMPHI</th>
<th>MOR</th>
<th>TANGEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>OL</td>
<td>possible</td>
<td>present</td>
<td>present</td>
<td>present</td>
<td>present</td>
</tr>
<tr>
<td>OF</td>
<td>possible, zoogenically transformed</td>
<td>present, zoogenically transformed, active, with living organisms</td>
<td>present, zoogenically transformed, active, with living organisms</td>
<td>not zoogenically transformed always present even if sometimes discontinuous; zoogenically transformed possible (accompanied), inactive or partially active</td>
<td>present, zoogenically transformed, active, with living organisms</td>
</tr>
<tr>
<td>OH</td>
<td>absent</td>
<td>present, active, sometimes discontinuous</td>
<td>present, active, thick (but ≤ 2 times thickness of A)</td>
<td>present or absent, if present: inactive or partially active</td>
<td>present, inactive or partially active, thick (&gt; 2 times thickness of A)</td>
</tr>
<tr>
<td>Transition O/A or O/ AE or O/E</td>
<td>very sharp</td>
<td>not sharp</td>
<td>if A biomacro: sharp (&lt; 5 mm)</td>
<td>very sharp (&lt; 3 mm)</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>biomacro or biomeso</td>
<td>biomeso or biomic or single grain or massive</td>
<td>biomacro or biomeso, biomeso accompanied by biomic possible</td>
<td>absent (= E) or present, if present: not zoogenic or discontinuously biomic.</td>
<td>absence or: present. If present: massive or biomeso</td>
</tr>
<tr>
<td>Horizon of dominant faunal activity</td>
<td>A (anecic and endogeic earthworms)</td>
<td>OF (feeding)</td>
<td>OF (feeding)</td>
<td>OH (weak or traces of old activity)</td>
<td>OF (feeding)</td>
</tr>
<tr>
<td>Earthworms</td>
<td>Organic horizons</td>
<td>Epigeic and Anecic Endogeic and Anecic</td>
<td>Epigeic</td>
<td>Epigeic absent or rarely present</td>
<td>Epigeic possible</td>
</tr>
<tr>
<td></td>
<td>Organic-mineral horizon</td>
<td>absent</td>
<td>Endogeic and/or Anecic</td>
<td>absent</td>
<td>Endogeic possible</td>
</tr>
</tbody>
</table>
summer or winter frost), generally on calcareous or dolomitic or nutrient-rich 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 acidic substrates or in cold climate conditions);

dominant actors of biodegradation: endogeic and/or anecic earthworms in the organic-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 organic-mineral horizons; pHwater of the A horizon: generally ≥ 5;

key diagnostic characters (morpho-functional result of specific biological activities): OH always present, nozOF never present,
thickness of A horizon ≥ ½ OH; biomacro A and sharp transition (≤ 5 mm) between organic and organic-mineral horizons, or bio-mesos A (biomicro A possible in addition to biomeso A) and no sharp transition (≥ 5 mm) between organic and organic-mineral (or mineral) horizons.

2.4. General characters and distribution of Mor

Ecological conditions: cold climate, and/or very nutrient-poor siliceous substrate (most sand or sandstone), poorly degradable litter (rich in resins and/or phenols, thick 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; key diagnostic characters (morpho-functional result of specific biological activities): nozOF (always present but sometimes difficult to recognize especially in wet conditions), E horizon or massive A or single-grain A, very sharp transition (≤ 3 mm) between organic and organic-mineral (or mineral) horizons.

2.5. General characters and distribution of Tangel

Ecological conditions: mountain humid 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; If presence of A horizon: pH_{water} of the A horizon ≥ 5; key diagnostic characters (morpho-functional result of specific biological activities): nozOF never present but thick organic horizons ([zoOF + OH] > 10 cm), if presence of A horizon: thickness of A horizon < ½ OH; A biomeso or A massive.

In Table 1, the main diagnostic horizons and their specific features are synthetically associated to the main Terrestrial humus systems.

3. Key of classification of humus FORMS

In this new version of the key of classification of humus forms, we added a Tangel form and the names of the three Tangel forms were
changed in order to fit with the corresponding forms of an Amphi system. The prefix “Dys” (reminiscent of poor nutrient availability) was abandoned because not suited for a humus form that can be even calcareous.

Terrestrial humus forms correspond to the topsoil never submerged and/or water saturated, or only for a few days per year, having:

- **Step 1**
  1. Organic zoogenic horizons present and thick (zoOF + OH) > 10 cm; and
  2. nozoOF absent; and
  3. Hard limestone and/or dolomite rock fragments in or at the bottom of the humus profile; and

- **Step 2**
  a) **Dysmoder.** Alpine, between the dark brown OH and clear E horizons it is possible to notice the presence of a black organic-mineral A horizon, in gradual transition with the above OH horizon. b) Dysmoder. Brown organic OH horizon in gradual transition with a clearer organic-mineral A horizon in a Mediterranean forest ecosystem.

- **Step 3**
  a) Eumoder. Thin continuous OH horizon over a thin organic-mineral biomicrostructured A horizon, in a Mediterranean forest ecosystem.

- **Step 4**
  a) Hemimoder. Discontinuous OH horizon laying over an organic-mineral biomicrostructured A horizon. a) Earthworms can consume all the OH horizon which becomes discontinuous; b) two types of A horizons are often possible: dark and thin at the soil surface, clearer and thick in contact with the mineral part of the soil profile.

- **Step 5**
  a) A horizon absent or present. If present:

  1. Biomeso A; and A < 1/2 OH
  2. Massive A horizon and both the following:
     a) A < 1/2 OH;
     b) pH_{water} of A ≥ 5

  **TANGEL** (Fig. 1), and either:
a) thickness of organic horizons (zoOF + OH) > 50 cm: Pachytangel (Fig. 2);
b) thickness of organic horizons (zoOF + OH) comprised between 15 and 50 cm: Eutangel (Fig. 3a and 3b);
c) thickness of organic horizons (zoOF + OH) < 15 cm: Leptotangel (Fig. 4).

OR

Step 2

1) never A biomeso or biomacro or biomicro; and
2) presence of nozOF and one of the following:

- possible and not discriminant
- possible

Fig. 13. Amphi system and forms. Table: diagnostic horizons in line, sequence as in real profile; humus forms in columns: Leptoamphi, Eumacroamphi, Eumesoaamphi, Pachyamphi. Profile: Typic Amphi diagnostic horizons with biological organic OH and organic-mineral A horizons.

Fig. 14. Pachyamphi. Thick brown zoOH horizon in gradual transition to an organic-mineral biomesostructured A horizon, (unfortunately the structure is not visible on the picture) in a Mediterranean forest ecosystem.

Fig. 15. Eumesoaamphi. Thick but < 3 cm black organic zoOH horizon in gradual transition to a brown-grey thick organic-mineral biomesostructured A horizon; In an Alpine pure spruce forest, on calcareous lithopedon.

Fig. 16. Eumacroamphi. Large aggregates in a grey organic-mineral biomacrostructured A horizon, overlaid by a black OH horizon. a) In a broadleaf and coniferous forest, b) in a beech forest, both in the Alps on calcareous lithopedon.

Fig. 17. Leptoamphi. Like a Mull, but with a thin OH horizon covering the biomacrostructured A horizon. In an Alpine beech forest.
pHwater of E or AE or A horizon < 4.5;
A absent, 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:

- pHwater of E or AE or A horizon < 4.5;
- A absent, or A massive, or A single grain.

**MOR** (Fig. 5) and either:
- nozOF continuous, OH absent: Eumor (Fig. 6),
- nozOF continuous, OH present and continuous: Humimor (Fig. 7),
- nozOF discontinuous and OH present and continuous: Hemimor (Fig. 8).

**OR**

**Step 3**

Other topsoils, never submerged and/or water saturated, or only for a few days per year, having:
1) OH horizon present (even if sometimes discontinuous); and
2) nozOF absent; and
3) Biomacro A horizons absent; and
4) Biomeso or biomicrostructured, or massive, or single grain A horizon present, and one of the following:

- Gradual transition OH/A horizon (transition ≥ 5 mm); or
- pHwater of the A horizon < 5

**MODER** (Fig. 9) and either:
- Biomeso A absent, OH horizon continuous and ≥ 1 cm, Dysmoder (Fig. 10),
- Biomeso A absent, OH horizon continuous and < 1 cm, Eumoder (Fig. 11),
- Massive or single grain A absent, OH horizon discontinuous or in pocket, Hemimoder (Fig. 12).

**OR**

**Step 4**

Other topsoils, never submerged and/or water saturated, or only a few days per year, having:
1) nozOF horizon absent; and
2) Thickness of A horizon > ½ that of OH horizon; and either:
3) OH and biomeso A horizons present; and one of the following:

- Living earthworms (or freshly deposited earthworm faeces) in the A horizon; or
- Gradual transition (≥ 5 mm) between A and OH horizons; or
pH_{water} of the A horizon $\geq 5$;

**AMPHI** (Fig. 13) and either:
- OH horizon $\geq 3$ cm, Pachyamphi (Fig. 14),
- OH horizon $< 3$ cm, Eumesoamphi (Fig. 15),

3) OH and biomacro A horizons present; and one of the following:

- Living earthworms (or freshly deposited earthworm faeces) in the A horizon;
- Sharp ($< 5$ mm) transition between OH and A horizons; or
- pH_{water} of the A horizon $\geq 5$

**AMPHI** and either:
- OH horizon $\geq 1$ cm, Eumacroamphi (Fig. 16a and 16b),
- OH horizon $< 1$ cm, Leptoamphi (Fig. 17),

OR

Step 5
Other topsoils, never submerged and/or water saturated, or only a few days per year, having:
- 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 $> 5$

**MULL** (Fig. 18) and either:
- OF horizon present and continuous, Dysmull (Fig. 19),
- OF horizon missing or discontinuous and vOL horizon continuous and thick, Oligomull (Fig. 20a, 20b),
- OF horizon missing and vOL horizon present but discontinuous, Mesomull (Fig. 21),
- OF and vOL horizons missing, Eumull (Fig. 22a, 22b)

The name of a humus forms is written in a single word, beginning with a capital letter. Example: Eumull, not Eu Mull, not Eu-Mull, not Eu-mull, not eumull.

We strongly suggest adding survey date and geographic coordinates to the name as minimum information in a dataset.

Example July 2016 – Eumull – long +44.28.59; lat +09.41.25.

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**Fig. 21.** Mesomull. Absence of any OH and OF horizons. Presence of a continuous OL horizon (grass leaves in this case) and a discontinuous vOL horizon.

**Fig. 22.** Eumull. a) absence of OH, OF and vOL horizons, presence of a discontinuous nOL and a crumbly maA horizon visible even at the surface. b. Eumull. Presence of a biomaicrostructured maA horizon. The horizon is generally darker at the surface because the numerous anecic earthworms living in this humipedon progressively integrate the litter in the underlying soil by moving vertically through the soil profile. c) typical biomacrostructure of a Mull A horizon.

**Fig. 23.** Amphi and Tangel. Amphi and Tangel can be distinguished considering the relative thickness of A and OH horizons. Amphi = thickness A $\geq$ OH/2; Tangel = thickness OH $> 2x$A. Tangel can also be without an A horizon.
3.1. Tangel status and comparison with thickness of Amphi diagnostic horizons

It is sometimes difficult to distinguish Amphi and Tangel. They gradually pass the one into the other. Subjectively, it was decided to consider the relative thicknesses of A and OH horizons (Fig. 23) for distinguishing a system (Amphi) with strong biological activity in both organic-mineral (A) and organic (OH, OF, OL) horizons, from another system (Tangel) with strong activity only in the organic horizons. Amphi is generated even at low altitude, in Mediterranean climates; Tangel develops only at high altitude, in alpine or subalpine climates. We think that the low temperatures of these mountain climates (and the consequent low rate of rock weathering) does not allow the formation of mineral soil, resulting in a lack of habitat for large anecic earthworms (which live in depth during the bad season) and the evolution of the Tangel toward an Amphi humus form. Considering that temperature could be of minor importance in soil development with respect to rainfall, an alternative explanation could be that Tangels develop on carbonates and therefore on parent material that are easily dissolved, but because of their chemical composition (no Si and Al theoretically), soil minerals can only form from the impurities contained in calcite or dolomite.

3.2. Field dichotomic key of classification

This field key (Fig. 24) is elaborated starting from a French classification (Jabiol et al., 2007), completed with Amphi and Tangel forms (Zanella et al., 2011a, 2011b), updated with new codes horizons and slightly modifications (Le Bayon R.-C., unpublished), completed in September 2016 by Zanella A., Ponge J.F, Jabiol B. and Auber M. considering Histo and Para systems, pedofauna features and presence/absence of A diagnostic horizons.

In general, the criteria for humus system classification are assimilated by heart after few utilizations of the indications reported in Section 1. It is a good habitude to control whether the detected systems fit the main criteria reported in Section 2. If incoherence between classified with Section 1 and described in Section 2 systems, a second attempt of classification may be necessary. Each humus system is parted in few humus forms which range in intergrades and create bridges between systems. A doubtful situation can be solved using two names of humus forms and evaluating the surface occupied by each of them. The faster way for recognizing a humus form is to pass through the key of Section 3, at the level of the right humus system, or to go straight to the tables with annexed photographs (Sections 3).

The dichotomic field key (Fig. 24) is built considering even essential biological data. It is cautious to use biological criteria after acquiring some experience in the field, following the instructions of an expert. In Humusica 1, article 8, curious autodidacts may find supplementary information about pedofauna, droppings and other biological features related to each terrestrial humus system. The dichotomic field key is a very efficacious mean for a rapid and sure field classification of humus systems and forms.
Authors’ contributions


Other authors: re-lecture and correction of the text, participation to researches and meetings, field investigations, discussions for improvements of the content of key and article.

Not cited author of photographs: Zanella A.

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