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1 **A proposal for including humus forms in the World Reference Base for Soil**
2 **Resources (WRB-FAO)**

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18 ABSTRACT

19 The morpho-functional classification of humus forms proposed in a previous issue by Zanella and
 20 collaborators for Europe has been extended and modified, without any change in diagnostic horizons,
 21 in order to embrace a wide array of humus forms at worldwide level and to complete and make more
 22 effective the World Reference Base for Soil Resources. For that purpose 31 Humus Form Reference
 23 Groups (HFRGs) and a set of prefix and suffix qualifiers are proposed, following the rules erected for
 24 the WRB. An exhaustive classification key, respecting the principles of WRB, is suggested and
 25 examples of classification are given for some already well known humus forms.

26 *Keywords:* WRB; humus; humus classification; terrestrial humus forms; semi-terrestrial humus forms;
 27 humus diagnostic horizons; reference humus form groups; prefix and suffix qualifiers for humus forms

28

29 Highlights

30 A World Reference Base for Humus Forms consistent with WRB-FAO Soil Reference. > 31 Humus
 31 Form Reference Groups and a set of prefix and suffix qualifiers. > Exhaustive classification key and
 32 examples of classification.

33

34 **1. Introduction**

35 The last delivery of the World Reference Base for Soil Resources (IUSS Working Group
 36 WRB, 2006) updated previous texts adopted by the ISSS Council, and was proposed at the 18th World
 37 Congress of Soil Science as the official reference for soil nomenclature. As indicated in page 1 of the
 38 abovementioned document it was considered by the entire soil scientists community as the better
 39 framework “through which existing soil classification systems could be correlated and harmonized”.
 40 As in previous drafts, the humus form, i.e. the part of the topsoil which is strongly influenced by
 41 biological activities and organic matter (litter included), was only partially considered, taking into
 42 account organic layers only when their thickness was very high, and ignoring many fundamental
 43 evidences necessary for a sufficiently precise characterization of forest soils, as well as all soils not
 44 periodically ploughed. On the same year, a group of German experts proposed to adapt the most
 45 popular European and Canadian classifications of humus forms to a previous draft of WRB (Broll et
 46 al., 2006). Unfortunately this former attempt to include humus forms in the World Reference Base
 47 failed to cover the whole range of terrestrial and semiterrestrial humus forms.

48 Since that time, the importance given to soil/atmosphere exchanges and the carbon destocking
 49 influence of global warming raised the importance of carbon sinks, i.e. for their main part the organic
 50 component of the soil ecosystem (Harper et al., 2007). Soil changes occurred in the past through
 51 climate warming, e.g. podzols shifted to brown-earth, the driving force being the breakdown of
 52 organic layers (Willis et al., 1997), which means, from the point of view of humus form systematics,
 53 the evolution from a moder to a mull topsoil functioning (Paré et al., 2006). Climatewarming imposes
 54 a biological change to organic soil horizons, resulting in a modified carbon cycle: the carbon stocked
 55 in organic layers of moder becomes partly fixed to fine mineral particles in the newly generated
 56 organo-mineral mull structure, the remaining part being lost as CO₂. Neither the turnover rate of soil
 57 carbon nor the organic molecules in which carbon is stocked are the same when passing from moder to
 58 mull (Egli et al., 2009). While changes in soil development occur over millenaries, decrease or
 59 increase in thickness of the forest floor occurs within decades (Bernier and Ponge, 1994), the same in
 60 semi-terrestrial environments (Delarue et al., 2011). The thorough monitoring of humus forms might
 61 thus help to reveal and foresee the impact of global warming on surface-accumulated organic carbon
 62 (Paré et al., 2006; Egli et al., 2009; Ponge et al., 2011), to estimate the contribution of soil to
 63 atmospheric CO₂ increase on a worldwide scale (Thum et al., 2011), and to detect changes in
 64 hydrological environment (Bullinger-Weber et al., 2007; Sevink and de Waal, 2010), soil acidification

65 and eutrophication (Bernier and Ponge, 1994; Pinto et al., 2007), among many other environmental
66 threats leading to detectable changes of humus forms within a few years.

67 A modern, biologically meaningful classification of humus forms has been proposed at the
68 European level by Zanella et al. (2011a, b), encompassing a wide variety of humus forms, both in
69 terrestrial and semi-terrestrial environments. This morpho-functional classification, which has been
70 recently updated thanks to users' feedbacks, is the basis of our proposal to include humus form
71 characterization in the WRB, for the sake of completing and improving this soil classification system.

72

73 2. Architecture of the proposed classification

74 Following WRB specifications, two tiers of categorical detail have been performed: 31
75 Reference Humus Form Groups or RHFGs (tier 1), and the combination of RHFGs with prefixes and
76 suffixes, detailing the properties of RHFGs by adding a set of uniquely defined qualifiers (tier 2).

77 The architecture proposed for the RHFGs is based on the same principles as WRB:
78 “[RHFGs] are allocated to higher-level groups on the basis of diagnostic characters, i.e. factors or
79 processes that most clearly influence the biological formation of [humus forms]”. The last published
80 classification of humus forms elaborated by Zanella et al. (2011a, b) distinguishes 6 main morpho-
81 functional types: Mull, Moder, Mor, Amphi, Tangel and Anmoor. These main references can be scaled
82 along a gradient of decreasing biological activity, which is revealed by an increasing accumulation of
83 organic remains and/or a decrease in the abundance of living animals or pellets of them (Table 1).

84 The rationale for combining first and second levels of previous humus form classification is to raise
85 the scale of perception of the soil system, allowing to classify humus forms in a number of units
86 approaching the 32 Groups of References proposed in the last version of the FAO-WRB manual
87 (IUSS Working Group WRB, 2006).

88 Specific prefix and suffix qualifiers are then associated to RHFGs, allowing a wide variety of variants
89 (second-level classification) to be defined according to biological (vegetation) and environmental
90 (geology, climate) context. The sequence of higher-level groups of RHFGs (sets) corresponds to an
91 equal number of steps of the proposed key of classification, in the order of the sets reported in Table 2.
92 Previous Enti and Para humus forms (Zanella et al. 2011a, b) are now grouped in the single RHFG of
93 PARAHUMUS; specific qualifiers can be used for describing and classifying the numerous morpho-
94 functional variants of these initial and/or atypical humus forms.

95 The key of classification of the RHFGs is based on the identification of diagnostic horizons, which are
96 composed of basic components which are reported below.

97

98 3. Basic components of humus forms

99 **Recognizable remains** correspond to leaves, needles, roots, bark, twigs and wood pieces,
100 fragmented or not, whose original organs are recognizable to the naked eye or with a 5-10 X
101 magnifying hand lens. The **humic component** is formed by small and non-recognizable organic
102 remains and/or grains of organic or organo-mineral matter, mostly comprised of animal droppings of
103 different sizes. The humic component often takes the shape of **soil aggregates**, which are visible to the
104 naked eye or with a magnifying hand lens and are classified in three types, called **micro-** (< 1 mm),
105 **meso-** (1-4 mm) and **macroaggregates** (> 4 mm). Mineral particles bound to the humic component
106 are considered as part of the humic component. On the contrary, mineral particles of different sizes,
107 free or very weakly bound to the humic component and visible to the naked eye or with a 5-10 X
108 magnifying hand lens, form the **mineral component**.

109 **Zoogenically transformed component**(indicated by ‘zo’ after horizon name or not indicated
 110 when implicit) is made of recognizable remains and humic components processed by animals
 111 and transformed in animal droppings. Zoogenically transformed component may be active (currently
 112 processed by living animals) or inactive (without signs of recent animal activity). **Non-zoogenically**
 113 **transformed component**(indicated by ‘noz’ after horizon name) is made of recognizable remains and
 114 humic components processed by fungi or other non-faunal processes. Recognizable animal droppings
 115 are absent or not detectable in the mass by the naked eye. Fungal hyphae can be recognized as white,
 116 brown, black or yellow strands permeating the organic or organo-mineral substrates. Traces of animal
 117 activity may sometimes be detectable but are always marginal.

118 The structure of organo-mineral horizons can be **zoogenic**, being formed of micro-, meso- or
 119 macroaggregates (**micro-**, **meso-** or **macrostructure**, respectively) or **non-zoogenic**, being **massive** or
 120 **single-grained**.

121 The **fibric component** of peat is made of non-decomposed or very weakly decomposed
 122 remains of hygrophilous plants. The **sapric component** is made of homogeneous dark organic or
 123 organo-mineral matter comprised of well decomposed plant remains pure or partly mixed with mineral
 124 particles. Plant structures are not visible to the naked eye or with a 5-10 X magnifying hand lens.

125

126 4. Diagnostic horizons

127 As in the WRB, diagnostic horizons used for the definition of humus forms “are characterized
 128 by a combination of attributes that reflect widespread, common results of the processes of [humus
 129 form] formation or indicate specific conditions of their formation”.

130 In order to classify a humus form it is necessary: a) to dig a little cubic pit in the soil
 131 (dimensions: 50 cm at least); b) to observe one of the walls of the pit; c) to identify layers, varying in
 132 composition, colour, texture, structure and thickness; d) to assign each layer to a pre-defined
 133 diagnostic horizon; e) to associate each series of superposed diagnostic horizons to one or more
 134 references using a key of classification. The minimum thickness of diagnostic horizons has been
 135 established at 3 mm. Below this limit a horizon is considered **discontinuous** if clearly in patches or
 136 **absent** if indiscernible from other neighbouring horizons. Three types of transition between horizons
 137 are considered: **very sharp transition** within less than 3 mm, **sharp transition** between 3 and 5 mm
 138 and **diffuse transition** if over more than 5 mm. More detailed descriptions of diagnostic horizons and
 139 recognition criteria can be found in Zanella et al. (2011b).

140 4.1. Diagnostic horizons of waterlogged topsoils

141 **Histic organic horizons(H horizons)** are submerged and/or water-saturated for a prolonged
 142 period of the year (usually more than 6 months) or have been artificially drained (the groundwater
 143 level being kept a few decimetres under the surface level, i.e. peat meadows of the Netherlands,
 144 Belgium and northern Germany...); carbon content 20% or more (approximately 35-40% organic
 145 matter) by weight in dry samples, living roots excluded (Method: element analyzer, ISO 10694, 1995).

146 Following the rate of fibric and sapric components, they have been divided in three diagnostic
 147 horizons: Hf, Hm and Hs. The **Hf horizon** consists near entirely of almost practically unchanged plant
 148 remains (fibric component $\geq 90\%$, sapric component $< 10\%$ horizon volume). The **Hm horizon**
 149 consists of moderately decomposed organic component (fibric component 10% to 70%, sapric
 150 component 30% to 90% in volume). The **Hs horizon** is an organic horizon in an advanced stage of
 151 decomposition, with only few recognizable plant remains (sapric component $\geq 70\%$, fibric component
 152 less than 30% horizon volume). For the sake of RHFG identification, several sub-types must be
 153 distinguished within Hs horizons: **Hszo** (meso- or macrostructured, with a high activity of soil animals,
 154 especially earthworms, mineral component less than 50%), **Hsnoz** (massive, with a low activity of soil
 155 animals, humification resulting mainly from the activity of microorganisms, typical of oligotrophic
 156 environments), and **Hsl** (with more than 50% clay, silt or sand mineral particles).

157 **Histic organo-mineral horizons** are called **Aa** (as “Anmoor”). They are dark coloured, with
 158 plastic and massive structure, either high or low base-saturated; carbon content between 7 and 20% by
 159 weight, in dry samples, living roots excluded (Method: element analyser, ISO 10694, 1995).

160 **Hydromorphic horizons** are submerged and/or water-saturated for more than a few days but
 161 less than 6 months per year. **Hydromorphic organic horizons** are periodically water-saturated and
 162 show the effects of temporary anoxia; carbon content 20% or more (approximately 40% organic
 163 matter) by weight, in dry samples, living roots excluded (Method: element analyzer, ISO 10694,
 164 1995). They are named **OLg**, **OFg** and **OHg**: the humic component is less than 10% in volume (roots
 165 excluded) in **OLg**, between 10 and 70% in **OFg** and more than 70% in **OHg**. **Hydromorphic organo-**
 166 **mineral horizons** show effects of temporary anoxia such as iron-mottling and oxidation/reduction
 167 colours, which cover at least 1/3 of horizon depth; the carbon content being generally less than 7% by
 168 weight (Method: element analyser, ISO 10694, 1995).

169 4.2. Diagnostic horizons of aerated topsoils

170 Two main types of diagnostic horizons (O for organic and A for organo-mineral) have been
 171 distinguished in aerated soils.

172 The **OL horizon** is characterized by the accumulation of leaves, needles, twigs and woody
 173 materials, most original plant organs being easily discernible to the naked eye (humic component less
 174 than 10 %, recognizable remains 10 % or more). Suffix letters distinguish between neither fragmented
 175 nor transformed/dicoloured leaves and/or needles (**OLn**) and slightly altered, sometimes only slightly
 176 fragmented leaves and/or needles (**OLv**).

177 The **OF horizon** is characterized by the accumulation of partly decomposed litter, mainly
 178 from transformed leaves/needles, twigs and woody materials, but without any entire plant organ
 179 (humic component from 10 to 70%). Decomposition is mainly accomplished by soil fauna (**OFzo**) or
 180 cellulose-lignin decomposing fungi (**OFnoz**).

181 The **OH horizon** is characterized by an accumulation of zoogenically transformed material,
 182 mainly comprised of aged animal droppings. A large part of the original structures and materials are
 183 not discernible (humic component more than 70%).

184 In some cases, above defined O horizons cannot be identified because of the specificity of
 185 their components, hence the need for defining more specific diagnostic horizons: **lignic**, **rhizic** and
 186 **bryoid diagnostic O horizons (OW, OR, and OM horizons, respectively)**, are comprised of more
 187 than 75% in volume of wood remains, dead or living roots, and dead or senescent moss parts,
 188 respectively.

189 Different **organo-mineral A horizons** are identified in the field by observing the soil mass
 190 with the naked eye or with a 5-10X magnifying hand lens. Five diagnostic A horizons may be
 191 distinguished according to their structure: three zoogenic or root-structured (biomacro-, biomeso-, and
 192 biomicrostructured) according to abovementioned sizes of aggregates and two non-zoogenic or non-
 193 root-structured (single grain, massive). Topsoil horizons weakly expressed and impossible to define
 194 (e.g. recent alluvial or aeolian deposits, horizons very poor in organic matter) are not considered to be
 195 A horizons.

196

197 5. Key to Reference Humus Form Groups

198 **Step 1:** Humus forms in which predominance of parent or plant material arrests or masks incipient
 199 animal activity in terrestrial or semi-terrestrial ecosystems, i.e. topsoils whose O (to the exception of
 200 **OLn**), H and A diagnostic horizons either:

201 • are absent; or

- 202 • are weakly expressed and impossible to define; or
- 203 • have a total thickness < 2 cm; or
- 204 • are lignic, rhizic or bryoc horizons over more than 75% of their total thickness:
- 205 **PARAHUMUS,**
- 206 **OR** other humus forms in which faunal activities and decomposition of organic matter are well visible
- 207 but are or have been strongly limited and/or influenced by anaerobic conditions
- 208 **Step 2:**Topsoils (organic and organo-mineral horizons) submerged and/or water saturated for more
- 209 than a few months per year, of wet very base-poor soils in brook valley systems and fens and bogs,
- 210 and characterized by the presence of H horizon AND:
- 211 1. Hf horizon present and thick; and
- 212 2. Hs absent
- 213 AND either
- 214 • Hm absent: **FIBRIMOR,**
- 215 • OR: Hm present but never thicker than Hf: **MESIMOR,**
- 216 **OR**
- 217 **Step 3:**Other topsoils (organic and organo-mineral horizons) submerged and/or water saturated for
- 218 more than a few months per year, of wet moderately base-poor soils in brook valley systems, or base-
- 219 enriched soils of drained previously base-poor fens and bogs,and characterized by the presence of H
- 220 horizon AND:
- 221 1. Hsnoz and Hm always present; Hf possible but never thicker than Hm
- 222 AND either
- 223 • Hf present; thickness: Hm> Hf >Hsnoz: **FIBRIMODER,**
- 224 • OR:Hf present; thickness: Hm>Hsnoz>Hf: **MESIMODER,**
- 225 • OR:Hf absent, thickness: Hm>Hsnoz: **HUMIMODER,**
- 226 • OR:• Hf absent, thickness: Hsnoz>Hm: **SAPRIMODER,**
- 227 **OR**
- 228 **Step 4:**Other topsoils (organic and organo-mineral horizons) submerged and/or water saturated for
- 229 more than a few months per year, of moderately moist base-poor soils in brook valley systems or base-
- 230 rich soils in half-drained fens and bogs,and characterized by the presence of an H horizon AND:
- 231 1. Hszo horizon presentand dominant in thickness; and
- 232 2. Hf and Hm thinner than Hszo within the control section (first 40 cm below the surface), Hsl
- 233 possible
- 234 AND either
- 235 • Hf absent, Hm possible: **HUMIAMPHI,**
- 236 • OR:Hf present, Hm possible; thickness: Hszo>Hf>Hm: **MESIAMPHI,**

- 237 • OR:Hf present, Hm absent; thickness: Hszo>Hf: **FIBRIAMPHI**,

238 **OR**

239 **Step 5:**Other topsoils (organic and organo-mineral horizons) submerged and/or water saturated for
 240 more than a few months per year, or organic and drained,of moist base-rich soils in brook valley
 241 systems or fens and bogs (large extended systems characterized by a dominant process of
 242 sedimentation, large floodplains), and characterized by the presence of Aa or H horizon(s) AND:

243 1. Hf or Hm never present within the control section; and

244 2. Hszo or Hsl present at the top of the profile; and

245 3. Hsnoz possible but thinner than Hszo

246 AND either

- 247 • Hsl present and thicker than Aa: **LIMIMULL**,

- 248 • OR:Hszo present and thicker than Hsnoz: **SAPRIMULL**,

249 **OR**

250 **Step 6:**Other topsoils (organic and organo-mineral horizons) submerged and/or water saturated for
 251 more than a few months per year, of wet base-rich soils or soils enriched by base-rich groundwater in
 252 brook valley systems (small rivers, brooks, small streams and floodplains, not in dynamic floods or
 253 inundations with fast currents),and characterized by the presence of Aa or H horizon(s) AND:

254 1. Aa organo-mineral horizon present and dominant;and

255 2. HszoandHsl possible but never thicker than Aa

256 AND either

- 257 • H absent: **EUANMOOR**,

- 258 • OR: Hszo present and thinner than Aa: **SAPRIANMOOR**,

- 259 • OR: Hsl present and thinner than Aa: **LIMIANMOOR**,

260 **OR**

261 **Step 7:**Other topsoils, never submerged and/or water saturated, or only a few weeks per year,in which
 262 faunal activities and decomposition of organic matter are strongly limited by mountain climate (low
 263 temperature, continental distribution of rainfall, higher in summer) on calcareous hard substrate and
 264 warmer aspect, AND having:

265 1. Organic zoogenic horizons present and thick (OFzo + OH > 5 cm); and

266 2. Hard limestone and/or dolomite rock fragments at the bottom of the humus profile; and

267 3. Cold climate (subalpine or upper mountain belts); and

268 4. OFnoz absent; and

269 5. A massive or single grain or biomesostructured present and thin (thickness < 1/2 OH), with
 270 $\text{pH}_{\text{water}} \geq 5$

271 AND either

272 • Sharp transition between OH horizon and Anoz horizon, **DYSTANGEL**,

273 • OR: no sharp transition between OH and A horizons, **EUTANGEL**,

274 **OR**

275 **Step 8:**Other topsoils, never submerged and/or water saturated, or only for a few days per year, in
276 which faunal activities and decomposition of organic matter are strongly limited by cold and/or acid
277 conditions,AND having:

278 1. never A biomeso or biomacro;

279 AND three of the following:

- 280 ○ presence of OFnoz
- 281 ○ very sharp (< 3 mm) transition of O to A, AE or E horizons
- 282 ○ pHwater of E or AE or A horizon < 4.5;
- 283 ○ A absent, or A biomicro, or A massive, or A single grain,

284 AND either:

285 • OFnoz continuous, OH absent,A biomicro absent, **EUMOR**,

286 • OR: OFnoz continuous, OH present and continuous, A biomicro possible, **HUMIMOR**,

287 • OR: OFnoz discontinuous and OH present and continuous, A biomicro possible **HEMIMOR**

288 **OR**

289 **Step 9:**Other topsoils, never submerged and/or water saturated, or only for a few days per year, in
290 which biological activities and decomposition of organic matter are moderately limited by low
291 temperature and/or acidity of the parent material, ANDhaving:

292 1. OH horizon present (even if sometimes discontinuous); and

293 2. OFnoz absent; and

294 3. Biomacro- and biomesostructured A horizons absent; and

295 4. Biomicrostructured, or massive, or single grain A horizon present, and one of the following:

296 • No sharp transition OH/A horizon (transition < 3 mm); or

297 • pHwater of the A horizon < 5

298 AND either:

299 • OH horizon continuous and ≥ 1 cm, **DYSMODER**,

300 • OR: OH horizon continuous and < 1 cm, **EUMODER**,

301 • OR: OH horizon discontinuous or in pocket, **HEMIMODER**,

302 **OR**

303 **Step 10:**Other topsoils, never submerged and/or water saturated, or only a few days per year, in which
304 faunal activities and decomposition of organic matter are strongly influenced by seasonally contrasted
305 climate conditions (Mediterranean or sub-Mediterranean distribution of rainfall, i.e. higher in spring
306 and autumn, very low during summer,causing drought stress especially in the topsoil) AND having:

- 307 1. OFnoz horizon absent; and
- 308 2. Thickness of A horizon > ½ that of OH horizon;
- 309 AND either
- 310 3. OH and biomesostructured A horizons present; and one of the following:
- 311 • Living earthworms (or freshly deposited earthworm faeces) in the A horizon; or
- 312 • Diffuse transition between A and OH horizons; or
- 313 • pH_{water} of the A horizon ≥ 5;
- 314 4. AND either:
- 315 • OH horizon ≥ 3 cm, **PACHYAMPHI**,
- 316 • OR: OH horizon < 3 cm, **EUMESOAMPHI**,
- 317 OR
- 318 3. OH and biomacrostructured A horizons present; and one of the following:
- 319 • Living earthworms (or freshly deposited earthworm faeces) in the A horizon; or
- 320 • Sharp transition between OH and A horizons; or
- 321 • pH_{water} of the A horizon ≥ 5
- 322 4. AND either:
- 323 • OH horizon < 1 cm, **LEPTOAMPHI**,
- 324 • OR: OH horizon ≥ 1 cm, **EUMACROAMPHI**,
- 325 **OR**
- 326 **Step 11:** Other topsoils, never submerged and/or water saturated, or only a few days per year, in which
- 327 faunal activities and decomposition of organic matter are weakly or not limited by harsh
- 328 environmental conditions, AND having:
- 329 1. OH horizon absent; and
- 330 2. Biomacrostructured A horizon present; or
- 331 2. Biomesostructured A horizon present and at least two of the following:
- 332 • Presence in the A horizon of living earthworms or their casts, except in frozen or desiccated
- 333 soil;
- 334 • Presence of a very sharp transition (< 3 mm) between organic and organo-mineral horizons;
- 335 • pH_{water} of the A horizon > 5
- 336 AND either:
- 337 • OF horizon present and continuous, **DYSMULL**,
- 338 • OF horizon missing or discontinuous and OL_v horizon continuous and thick, **OLIGOMULL**,

- 339 • OF horizon missing and OL_v horizon present but discontinuous, **MESOMULL**,
- 340 • OF and OL_v horizons missing, **EUMULL**

341

342 6. Prefix and suffix qualifiers

343 Qualifiers are used for the second level of humus form classification, exactly in the same
 344 manner as for soils (IUSS Working Group WRB, 2006). Many prefix and suffix qualifiers used for
 345 soil classification are also used for humus form classification (Table 3). However, most of them are
 346 here attributed to the “A horizon” instead to a defined part of the soil profile (ex. calcaric, dystric,
 347 clayic, skeletal...). Other qualifiers are specific to particular humus forms (ex. hyperrhizic,
 348 hyperbryotic...).

349

350 7. Some examples

351 Loranger (2001) and Loranger et al. (2003) described a humus form, called amphimull
 352 according to classification by Brêthes et al. (1995), in Caribbean semi-evergreen secondary forests on
 353 pure hard calcareous substrate (tropical rendzina). This humus form was characterized by the presence
 354 of O horizons (OL 4 cm, OF 2 cm, OH 1.5 cm) overlying a biomacrostructured A horizon. According
 355 to our proposal it can be called EUMACROAMPHI, with the prefix haplic indicating that
 356 neithertypically associated nor intergrade qualifiers apply, and the suffix rendzic indicating the
 357 pedogenetic context, hence haplic EUMACROAMPHI (rendzic). In a nearby forest plantation on deep
 358 vertisol a humus form with contrasting characters was called Eumull according to abovementioned
 359 literature. It was characterized by a thin (1 cm) OL_n horizon overlying directly a deep
 360 biomacrostructured A horizon. According to our proposal this is a EUMULL (name unchanged) with
 361 the suffix eutric acknowledging for the base-saturated A horizon (IUSS Working Group WRB, 2006),
 362 hence haplic EUMULL (eutric).

363 In a quite climatic (temperate) and geographic context (western Europe), Gillet and Ponge
 364 (2002) described a humus form, which they called mor, in a poplar plantation strongly polluted by
 365 heavy metals (Zn up to 40,000 mg.kg⁻¹) where poplar failed and was replaced by thrift (*Armeria*
 366 *maritima*) vegetation. Plant remains accumulate in a context from which faunal and bacterial activities
 367 were excluded, resulting in thick O horizons (OL, 1 cm, OF_{noz}, 9 cm) lying directly on industrial
 368 waste products. Such a humus form can be called haplic EUMOR (spolic).

369 Bullinger-Weber et al. (2007) described several types of humus forms in alluvial soils of the
 370 Swiss Alps, with strong changes in thickness and nature of diagnostic horizons according to riverbank
 371 successional status. The youngest profile (under willow) was described as a Eumull, according the
 372 abovementioned French classification. It exhibited characteristic features on initial soils in an
 373 otherwise calcareous context. It was characterized by the scarce presence of a very thin (when present)
 374 OL_v horizon, overlying a thin (1 cm) weakly differentiated organo-mineral horizon without any traces
 375 of animal activity visible to the naked eye and with a very poor content in organic matter, overlying in
 376 turn on sandy alluvial deposits. Given the impossibility to discern trends in the formation of diagnostic
 377 horizons (although faunal investigations on earthworms and enchytraeids testimony for incipient mull
 378 formation), such a humus form, without any structured O and A horizons, could be called
 379 PARAHUMUS, with hyperskeletal, hyperarenic as prefixes and fluvic and calcaric as suffixes, hence
 380 hyperskeletal hyperarenic PARAHUMUS (fluvic, calcaric).

381 Hiller et al. (2005) described soils and humus forms in Swiss alpine tundra ecosystems,
 382 following for humus forms the British Colombian classification by Green et al. (1993). Outside snow
 383 beds, at alpine elevation (2800 m) they found a humus form they called Rhizic Mullmoder. It was
 384 characterized by the following sequence from surface to depth according to the here presented
 385 nomenclature of diagnostic horizons: an OL_v horizon (5-6 cm), then an OF_{zo} horizon with abundant

386 roots (3-5 cm), then when present an OH horizon (0-3 cm) overlying with a wavy transition a single-
 387 grain A horizon. According to the present classification, such a humus form could be named
 388 HEMIMODER (because of the discontinuous OH horizon and the gradual transition from O horizons
 389 to a single-grain A horizon), with rhizic as suffix, hence haplic HEMIMODER (rhizic).

390 Fons et al. (1998) described a new humus form, called ‘Lamimoder’, which was observed to
 391 occur in trembling aspen boreal forests and more generally in circumboreal broadleaf forests. It was
 392 characterized by a thick OF horizon in which nonzoogenic (OFnoz) horizons, with a dense root mat of
 393 aspen, were thicker than zoogenic (OFzo) horizons, overlying a continuous OH horizon.
 394 Unfortunately, no details were given of the transition of O to A (or E) horizons. According to our
 395 proposal, and supposing that the transition was abrupt (< 3 mm), this humus form could be called
 396 haplic HUMIMOR (rhizic).

397 To the date of our proposal to include humus forms in the FAO-WRB soil classification, we suggest
 398 assigning to a “pedon” two names, corresponding to a humus profile established on a soil profile.
 399 Examples (using some just reported humus forms on a most probable soil reference) are given below:

400 haplicEUMACROAMPHI (rendzic) on rendzic LEPTOSOL

401 haplicEUMACROAMPHI (rendzic) on VERTISOL

402 haplicEUMOR (spolic) on TECHNOSOLL

403 hyperskeletal hyperarenic PARAHUMUS (fluvic, calcaric) on FLUVISOL

404 haplicHEMIMODER (rhizic) on folic UMBRISOL

405 haplicHUMIMOR (rhizic) on enticPODZOL

406

407 **8. Conclusion and perspectives**

408 Including the European morpho-functional classification of humus forms (Zanella et al.,
 409 2011a, b) in the World Reference Base for Soil Resources would allow to profitably identify and
 410 characterize forest and other unploughed soils, embracing a wide variety of terrestrial and semi-
 411 terrestrial humus forms (Dudal, 2003). This integration, that reflects the present state of our
 412 knowledge (Blum and Laker, 2003), is based on the flexibility given by the adjunction of prefix and
 413 suffix qualifiers to a set of 31 reference groups. Tests made with a large array of humus forms
 414 described in Europe as well as in tropical, temperate, mountain and boreal biomes showed that the
 415 proposed classification is able to be used worldwide. However, it remains to check its applicability
 416 where estimating the nature and the thickness of diagnostic horizons and of basic components in the
 417 field is tricky. Since some time is necessary for a given biological process to result in the formation of
 418 a given horizon (for instance the formation of a biomacrostructured A horizon needs the existence of a
 419 stable population of soil-dwelling earthworms, i.e. at least several consecutive years without
 420 population collapse), cases where this requirement cannot be fulfilled will make the identification of
 421 diagnostic horizons rather difficult if even impossible. This is what is currently happening due to the
 422 expansion of earthworm populations for several causes such as global warming, forecast by Ponge et
 423 al. (2011) and confirmed by personal observations (J.F. Ponge), or the invasion of North-American
 424 terrestrial ecosystems by earthworm species of European origin (Frelich et al., 2006). In both cases
 425 profound changes in humus forms occur, increasing vertical and horizontal heterogeneity: horizons are
 426 perturbed in the topsoil and abrupt changes may appear in the forest floor at the scale of a few meters
 427 without any link to litterfall amount and quality (Hale et al., 2005). Diagnostic features of directional
 428 changes in humus forms (whether passing from mull-forming to moder-forming processes or the
 429 reverse, as an example) would be welcome, if we want not only to describe but also to forecast humus
 430 form dynamics. Other difficulties may lie in the temporary (or incipient) nature of some environments,
 431 such as glacier moraines, river banks, seashore dunes and many others. In this case, and for the same

432 reasons, time needed for the formation of horizons is lacking. The creation of reference groups without
 433 any definite horizons such as PARAHUMUS, may contribute to solve this problem, but incipient
 434 biological processes which may (or not) be conducive to the formation of identifiable horizons are not
 435 sufficiently known.

436

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 439 to the construction of the morpho-functional classification of humus form at the European level.

440

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- 508

509 Table 1: Humus forms in different ecosystems and along a gradient of decreasing biological activity. The well-
 510 known terrestrial gradient “Mull-Moder-Mor” is visible on the row “Terrestrial on acid substrate”. Notice that
 511 four main morpho-functional types (Mull, Moder, Amphi and Mor) can be Terrestrial and Semi-terrestrial as
 512 well, contrary to Tangel and Anmoor which are only Terrestrial and Semi-terrestrial, respectively. On the other
 513 hand, detailed morpho-functional types (second level of classification) have different names even if they belong
 514 to the same main morpho-functional type. According to this principle, Eumull, Mesomull, Oligomull and
 515 Dysmull are Terrestrial humus forms, while Limimull and Saprimull are Semi-terrestrial humus forms.
 516 Information about biodegradation rates is maintained in the name of second level units.

517

Ecosystem	Biological activity					
	High		Moderate		Low	
	Main morpho-functional type	Detailed morpho-functional types	Main morpho-functional type	Detailed morpho-functional types	Main morpho-functional type	Detailed morpho-functional types
Terrestrial: on calcareous substrate	Mull	Eumull Mesomull Oligomull Dysmull	Amphi	Leptoamphi Eumacroamphi Eumesoamphi Pachyamphi	Tangel	Eutangel Dystangel
Terrestrial: on acid substrate			Moder	Hemimoder Eumoder Dysmoder		Mor
Small Semi-terrestrial: brook valleys, little rivers...	Anmoor	Euanmoor Saprianmoor Limianmoor	Amphi or Moder	Humiamphi Mesiamphi Fibriamphi or Saprimoder Humimoder Mesimoder Fibrimoder	Mor	Mesimor Fibrimor
Large Semi-terrestrial: floodplains, fens and bogs...				Mull		

518

519 Table 2. Factors or processes that most clearly influence the biological formation of the main Sets of Humus
 520 Form Reference Groups.

521

Factors or processes that most clearly influence the biological formation of humus forms		Humus Form Reference Groups	SET
Humus forms in which the predominance of parent or plant material arrests or masks incipient animal activity in terrestrial and semi-terrestrial ecosystems		PARAHUMUS	1
Humus forms in which faunal activities and decomposition of organic remains are well visible but are or have been strongly limited and/or influenced by anaerobic conditions	wet very base-poor soils in brook valley systems, fens and bogs	MESIMOR, FIBRIMOR	2
	wet moderately base-poor soils in brook valley systems, or base-enriched soils of drained, previously base-poor fens and bogs	SAPRIMODER, HUMIMODER, MESIMODER, FIBRIMODER	3
	moderately moist base-poor soils in brook valley systems or base-rich soils in half-drained fens and bogs	HUMIAMPHI, MESIAMPHI, FIBRIAMPHI	4
	moist base-rich soils in brook valley systems, fens and bogs (large extended systems characterized by a dominant process of sedimentation, large floodplains)	LIMIMULL, SAPRIMULL	5
	wet base-rich soils or soils enriched by base-rich groundwater in brook valley systems (small rivers, brooks, small streams and floodplains, not in dynamic floods or inundations with fast currents)	EUANMOOR, SAPRIANMOOR, LIMIANMOOR	6
Humus forms in which faunal activities and decomposition of organic matter are well visible and occur in aerated conditions	faunal activities and decomposition of organic matter strongly limited by mountain climate (low temperature, continental distribution of rainfall, higher in summer period) on calcareous hard substrate and warmer aspect	EUTANGEL, DYSTANGEL	7
	faunal activities and decomposition of organic matter strongly limited by cold and/or acid conditions	HEMIMOR, HUMIMOR, EUMOR	8
	biological activities and decomposition of organic matter moderately limited by low temperature and/or acidity of parent material	HEMIMODER, EUMODER, DYSMODER	9
	contrasted climate conditions (Mediterranean or sub-Mediterranean distribution of rainfall, higher in spring and autumn, very low during summer, causing drought stress especially in the topsoil)	LEPTOAMPHI, EUMACROAMPHI, EUMESOAMPHI, PACHYAMPHI	10
	faunal activities and decomposition of organic matter weakly or not limited by harsh environmental conditions:	EUMULL, MESOMULL, OLIGOMULL, DYSMULL	11

522

523 Table 3. Prefix and suffix qualifiers used for the definition of humus forms. Qualifiers already used for the
 524 definition of soils (IUSS Working Group WRB, 2006) are indicated. Vocabulary refers to the present article or
 525 (*) to IUSS Working Group WRB (2006).

526

PREFIX	SUFFIX	WRB 2006	DEFINITION, new or adapted for humus forms
hyperlignic		no	having an OW horizon of more than 75% of the thickness of combined diagnostic horizons (Parahumus only)
hyperrhizic		no	having an OR horizon of more than 75% of the thickness of combined diagnostic horizons (Parahumus only)
hyperbryoic		no	having an OM horizon of more than 75% of the thickness of combined diagnostic horizons (Parahumus only)
	lignic	yes (modified)	having an OW horizon between 25 and 75% of the thickness of combined diagnostic horizons or having more than 25% of wood remains in the total volume
	rhizic	no	having an OR horizon between 25 and 75% of the thickness of combined diagnostic horizons or having more than 25% of dead or living roots in the total volume
	bryoic	no	having an OM horizon between 25 and 75% of the thickness of combined diagnostic horizons or having more than 25% of dead or senescent moss parts in the total volume
	follic	yes	whose OH or H horizon is > 10 cm
	ombric	yes	having a histic* horizon saturated predominantly with rainwater
stagnic		yes	having reducing conditions and OLg, OFg, OHg and/or Ag horizon with stagnic* colour patterns
	gleyic	yes	lying directly on a horizon with gleyic* colour patterns
floatic		yes	having organic material floating on water
epihistic		no	having both [(OL, OF, OH)g and/or Ag] and histic (H or Aa) horizons
fluvic (also for lakes)		yes	whose A horizon or first mineral horizon comes with evidence from fluvic* material
	novic	yes	having above the O horizon, a layer with recent sediments (new material < 1y.), 3 mm or more and less than 2 cm thick
	sodic	yes	having 15 % or more exchangeable Na plus Mg on the exchange complex in the A horizon
	alcalic	yes	having a pH (1:1 in water) of 8.5 in the A horizon
	calcaric	yes	whose A horizon is calcaric* material
	hypereutric	yes	having a base saturation (by 1 M NH ₄ OAc) of 80 % or more in the A horizon
	eutric	yes	having a base saturation (by 1 M NH ₄ OAc) of 50 % or more in the A horizon
	dystric	yes	having a base saturation (by 1 M NH ₄ OAc) of less than 50 % in the A horizon
	hyperdystric	yes	having a base saturation (by 1 M NH ₄ OAc) of less than 20 % in the A horizon
	clayic	yes	having a texture of clay in the A horizon
	arenic	yes	having a loamy fine sand or coarser texture in the A horizon
hyperarenic		no	having a loamy fine sand or coarser texture within 2 cm of the soil surface without an A horizon under OLn (Parahumus only)
	lithic	yes	having continuous rock directly under the A horizon and within 10 cm of the soil surface
hyperlithic		no	having continuous rock under OLn and within 2 cm of the soil surface (Parahumus only)
	skeletal	yes	having 40 % by volume or more of gravel or other coarse fragments in the A horizon and within 10 cm of the soil surface
hyperskeletal		yes	containing less than 20 % by volume of fine earth within 2 cm of the soil surface
	hyperhumic	yes	having an organic carbon content of 5 % or more in the fine earth fraction to a depth of 20 cm or more
	rendzic	yes	whose A horizon is a mollic* horizon that contains 40 % or more calcium carbonate equivalent
	andic	yes	whose A horizon has andic* properties
	salic	yes (prefix)	whose A horizon is a salic* horizon
	albic	yes	with O horizons lying directly on an albic* horizon
	hortic	yes	whose A horizon is an hortic* horizon
	terric	yes	whose A horizon is a terric* horizon
	technic	yes	having 10 % or more artefacts in combined diagnostic horizons
	urbic	yes	having 25 % or more artefacts, containing 35 % or more of rubble and refuse of human settlements, in combined diagnostic horizons
hyperurbic		no	having 75 % or more artefacts, containing 35 % or more of rubble and refuse of human settlements, in combined diagnostic horizons

	spolic	yes	having 25 % or more artefacts, containing 35 % or more industrial waste, in combined diagnostic horizons
hyperspolic		no	having 75 % or more artefacts, containing 35 % or more industrial waste, in combined diagnostic horizons
	garbic	yes	having 25 % or more artefacts, containing 35 % or more organic waste materials, in combined diagnostic horizons
hypergarbic		no	having 75 % or more artefacts, containing 35 % or more organic waste materials, in combined diagnostic horizons
	erodic	no	having only remnants of diagnostic horizons, due to mechanical perturbation (erosion, waterlogging, action of boars or other macro mammals ...)
	plaggic	no	having 25 % or more artefacts, containing 35 % or more "plaggen" (Dutch name for a mixture of heather humus, manure and sand used for raising sandy soils around settlements), in combined diagnostic horizons
hyperplaggic		no	having 75 % or more artefacts, containing 35 % or more "plaggen" (see plaggic), in combined diagnostic horizons
haplic		yes	closes the prefix qualifier list indicating that neither typically associated nor intergrade qualifiers apply

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