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1 ***TerrHum: An iOS App for Classifying Terrestrial Humipedons and some Considerations about***
2 **Soil Classification**

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24

25 **Abstract**

26 The name *TerrHum* is an abbreviation of the words Terrestrial (not hydromorphic, not
27 submerged) and Humipedon (organic and organic-mineral humus horizons). With this
28 application, it is possible to describe and classify terrestrial forest and grassland topsoils in a
29 system published in Applied Soil Ecology, Special Issue 'Humusica 1 – Terrestrial Natural
30 Humipedons'. *TerrHum* allows the storage of the main content of Humusica 1 on a cellphone.
31 Images, diagrams and simplified tables of classification may be recalled with a few touches on
32 the screen. Humus forms, representing five humus systems, are classified based on the
33 vertical arrangement of diagnostic horizons and their attributes. *TerrHum* allows accessing
34 specific figures that are stored in a cloud and can be downloaded the first time the user recalls
35 them. Once all figures have been opened in the device, the application is ready to use, without
36 any further internet connection. The app is in continuous evolution.

37 Core Ideas

38 A common humus classification system improves communication among soil scientists

39 A cellphone application can be used for global soil mapping and monitoring purposes

40 The humus classification can be combined with different soil classification systems

41

42 **Introduction**

43 In 2003, 26 soil scientists gathered in Trento (Italy) to standardize methods and rules for
44 classifying the biologically most active upper part of the soil. For doing so, it was essential to
45 develop a common terminology and to exchange data on soil carbon dynamics and its relation
46 to morphological characteristics of organic and organic-mineral topsoil. The definitions of
47 organic and organic-mineral horizons of the soil, for example, diverged a lot. These scholars
48 came from 9 different European countries and immediately realized that the task was not an
49 easy one because each country had its own historical classification systems, often
50 incompatible in-between. It took more than 5 years of meetings and discussions to publish,
51 on behalf of a part of the members of the ‘European Humus Group’, then simply ‘Humus
52 Group’, a first synthesis (Zanella et al., 2009).

53 The main problem was not the existing classifications, but the fact that for bringing together
54 the existing pieces of knowledge to form a frame compatible with all points of view, it was
55 necessary to enlarge the picture, and also to understand what the different classifications had
56 not considered individually. As an example, there were some humus forms called ‘humus
57 gemellare’ (twin humus) by an Italian classification. In France, these forms were considered
58 as ‘double’ forms, but rather classified as Mulls (Amphimull) because of their thick and
59 impressive crumbly organic-mineral horizon (Jabiol et al., 1994). In other countries, these same
60 forms were classified as Moder, because of their very thick OH horizon (Broll et al., 2006).
61 Because of all these disparities, it was then proposed to bring all these ‘double’ forms
62 together into a new category called ‘Amphi’. This decision caused a rift between i) those who
63 had seen and supported the existence of such forms of humus, and ii) those who instead
64 preferred to stick to the current classification systems without considering such forms,

65 because they were not very common in their respective countries. The issue was solved only
66 after a workshop in San Vito (2005, Italy), with field trips to see ‘Amphi’ and comment on it.
67 Back home, a German member of the Humus Group published an article explaining to his
68 compatriots the existence of such forms in Germany, also highlighting that they could become
69 more frequent and therefore be used as indicators of ongoing global warming (Graefe, 2007).

70 However, the story went on. When members of the Humus Group came together to see these
71 Amphi forms in Austria (Vienna, 2004), other humus forms already described many years
72 before did not match this category, and then fell more or less in oblivion (Hartmann, 1952,
73 1965; Kubiëna, 1953). So are Tangel forms (sometimes called ‘Alpenmoder’ by local forest
74 managers), found at high altitude on calcareous substrates, while corresponding Mor humus
75 forms, with different morphological and chemical properties, are related to silicate bedrock
76 and acidic soils. The fact opened a diatribe concerning differences between Mor and Tangel
77 that lasted for years and was solved only recently (Kolb and Kohlpaintner, 2018; Meynier and
78 Brun, 2018). In order to clarify the situation, we decided to set up a classification linked to the
79 soil forming substrate (only if it influences the topsoil: Amphi and Tangel on calcareous
80 substrates, Moder and Mor on ‘acidic’ ones, with Mull in-between in neutral or nearly neutral
81 situations. All members of the Humus Group were then in agreement with this solution,
82 except supporters of ‘Mor rather without pedofauna’ (French point of view) and others who
83 wanted instead ‘Mor with rather relevant pedofauna’ (German supporters who described
84 Mor as extreme Moder forms).

85 One day, inevitably, the classification bogged down on the definition of soil (Zanella et al.,
86 2018a; e; Zanella and Ascher-Jenuß, 2018) a point of contention for more than two years. For
87 some of us, abiotic factors predominate pedogenesis, while for others biotic factors outshine.

88 When the soil was proposed as a ‘digestion system”, a ‘belly”, with living organisms having it
89 inside (in their belly), the group started to crumble. And it spread to individual members when
90 the idea came out that soil binds life and death (for many soil scientists, philosophy should
91 remain separated from what they call ‘real science”, ‘numbers”, ‘mathematical evidence”,
92 even if all of us - as living beings - are destined to die an incalculable day coming). Against all
93 odds, however, the group remained united, but encountered very often many other
94 difficulties, for example when the various humus forms were arranged on a global scale
95 (Zanella et al., 2018f; d) . It was then necessary to introduce the concept of ‘humus system”,
96 comprising ecologically and functionally similar humus forms as well as creating new systems
97 for collecting strange, unusual or never surveyed humus forms (Zanella et al., 2018d) or for
98 those in water (Zanella et al., 2018l, k; b) and in anthropogenically strongly shaped
99 environments (Zanella et al., 2018j).

100 Nevertheless, there are still many questions that may be resolved in the near future. New
101 methods at the frontier of science in soil biology can answer issues linked to co-evolution of
102 soil and organisms, biogeography of soil organisms, soil biodiversity etc.. Anyway, all these
103 questions give a huge importance to the soil and may be reflected in its morphological
104 characteristics. Humans need to better know the soil, but what about ‘humus’? Recently it has
105 been suggested to abandon the use of this term, because ‘humus’ cannot be clearly
106 characterized from a chemical point of view (Lehmann and Kleber, 2015). We strongly suggest
107 to keep the term and to speak of ‘humus’ when organic particles and accompanying biota are
108 present.

109

110 **How does *TerrHum* work?**

111 Let us consider a user facing a soil profile to be classified. A cubic 50x50x50 cm hole dug into
112 the ground is generally sufficient for studying humus systems and forms in a forest
113 environment, while a larger hole or many well-distributed small holes are necessary for a
114 representative survey of a heterogeneous area (Zanella et al., 2018i). A detailed description
115 of the main actors of soil biodegradation and their relationships with the horizontal and
116 vertical distribution of humus horizons is reported in (Zanella et al., 2018c).

117 As a humus form is made of superposed humus horizons, the app asks the user to indicate
118 one by one which types of humus horizons are present in the observed profile. Organic
119 horizons (OL, OF and OH, corresponding to USDA Oi, Oe, Oa) were clearly distinguished from
120 organic-mineral ones (different types of A horizons) (Fig 1).

121 In general, when in the field a horizon appears totally consisting of organic remains, it is
122 classified as an organic horizon. It is well accepted that the organic matter (OM) composing
123 such horizons amounts to more than 1/3 of the total weight, which corresponds to 20 % or
124 more organic carbon (OC). That allows the separation of organic and organic-mineral horizons
125 in the field and the adjustment of the classification, if necessary, after laboratory analyses of
126 the OC concentration in a horizon sample. The organic horizons are divided into OL, OF and
127 OH following their decreasing content of “recognizable remains” (e.g. a leaf, a needle, a piece
128 of bark...): more than 90 % in OL, from 90 to 30% in OF, and less than 30% in OH.

129 Another diagnostic criterion is, if the process of litter transformation (decomposition) is
130 accomplished mainly by animals or by microbes. Respectively, the process generates zoogenic
131 zoOF or non-zoogenic nozOF horizons described in the app and recognizable in the field.
132 Accordingly to its structure and genesis, the organic-mineral A horizon is classified in zoogenic

133 biomacro, biomeso and biomicro A horizons (maA, meA, miA), and in non-zoogenic massive
134 and single-grain A horizons (msA and sgA). All these horizons are described and illustrated in
135 the app.

136 The user is asked to answer a series of YES/NO questions in a dichotomous key; an example:
137 'is OH horizon present?' (Fig. 2, 3a, 3b, 3c, 3d). Slightly differing from the App, the
138 simplified key (Fig. 2) requires some field experience, but allows a faster, equivalent,
139 correct classification. For detailed definitions of all diagnostic horizons and criteria of
140 classification, refer to Zanella et al. (2018l, 2018m).

141 A touch-button located at the bottom of the screen allows the user to recall at any time
142 definition and photographs of each diagnostic horizon, allowing users to more accurately
143 define the real horizon (Figs 4a, 4b, 4c, 4d).

144 Other keys at the bottom of the screen allow retrieving examples of humus systems and forms
145 (Fig. 5), as well as tables of composition/classification of humus horizons, or groups of animals
146 and their droppings (Fig. 6). At the end of the classification process, a photograph of the target
147 humus form appears, along with a list of the chosen horizons.

148 By touching the screen, each photograph may be magnified (Figs 3d, 4b, 5b, 6b). A caption at
149 the bottom of each picture provides access to the morpho-functional features of the soil
150 profile and leads finally to the classification of the humus system.

151 Many examples of soil horizon features are documented in the app. Future updates of the
152 app will include useful links to enriched external data banks. We are currently collecting

153 information and photographs to further improve the classification of charcoal, charred
154 mass and other dark-coloured sublayers that can interfere with the definitions of
155 standard diagnostic horizons (e.g. (Ponomarenko et al., 2018)). We also are
156 collecting new photographs and drawings of soil animals, related to the assessment
157 of soil biological quality.

158

159 **Is it possible to integrate TerrHum into different soil classification systems?**

160 The purpose of *TerrHum* is to share a morpho-functional classification of topsoils at global
161 level. All over the world, students, researchers, forest managers may recognize humus forms,
162 take a georeferenced photograph and send it to one of the authors of this article. Collected
163 and checked data may help to improve published maps (Zanella et al., 2018f) or to prepare
164 new soil and humus maps. The photographs being georeferenced, it is relatively easy to create
165 new maps if the number of points is sufficient.

166 Fire is an integral process of carbon transformation and pyrogenic features of humus horizons
167 are currently overlooked, and still have to be incorporated into the TerrHum system. Adding
168 these features to the Terrhum app may enable collecting an important layer of information
169 on past fire events at both local and global levels.

170 An Android version of *TerrHum* for smartphones will be available in the near future.

171 TerrHum (iOS) and/or the up-coming Android version or in general the concept of TerrHum
172 can be an example also for soil classification. For this purpose, it would be important to adopt

173 a soil model subdivided into Humipedon, Copedon and Lithopedon published in (Zanella et al.,
174 2018g; h) We programmed to work on apps like this for Copedons and Lithopedons. Histosols
175 are also considered as humus forms and will be later integrated in *TerrHum*. People interested
176 in the project are kindly asked to contact the authors of this paper. Given Humipedons,
177 Copedons and Lithopedons could then be associated to provide a full profile and name for
178 each type of soil.

179 This is the reason we would like to widen the concept of soil. We would like to divide the soil
180 profile into three parts, each of them being studied either separately or brought together to
181 better understand the overall soil functioning (Figs. 7 and 8). We know that this concept may
182 hurt some among the pedologists, however, it is crucial to understand that each humus form
183 functions relative to soil and vegetation but has also its own spatio-temporal scale of
184 formation, functioning and dynamics (Bernier and Ponge, 1994).

185 The soil may be divided into three layers which may be described and classified relatively
186 independent each from each other: Humipedon, Copedon and Lithopedon. The first depends
187 mainly on the source of organic matter and animals and microorganisms that live in the soil:
188 they generate the Humipedon composed of organic (OL, OF and OH) and organic-mineral (A)
189 horizons (Hole, 1981).

190 Beyond these, in the most evolved soils, different mineral horizons like E and B can be
191 distinguished. Their development, though linked to root dynamics and turnover of organic
192 matter is strongly dependent on physical and chemical soil processes. As for those belonging
193 to the Humipedon, there are different types of Copedon horizons, according to climate and
194 parent material (Muhs et al., 2001).

195 The bottom of the profile completely depends on the original rock. These are the fragmented
196 C horizons and the hard R rock layer. There are different types of Lithopedon (e.g. carbonatic,
197 silicatic; all possible morpho-functional types or more or less transformed initial rocky
198 basements). The Lithopedon is not always at the bottom of a well-differentiated soil profile.
199 A very young soil is just a thin ‘biofilm’ laying on a Lithopedon, like in deglaciated
200 environments (Wynn-Williams, 1996). Then Humipedon and Lithopedon are built-up, the soil
201 profile evolving toward a complete sequence of Humipedon, Copedon and Lithopedon (Fig.
202 5). Occasionally the soil can either lose some of its more superficial parts by erosion (truncated
203 soils; (Desmet and Govers, 1995)) or one part grows till taking all the place (e.g. Humipedon
204 in submerged soils - Histosols, or Copedon in tropical Vertisols).

205 Once mastered this classification, things become simpler and easier to understand; and the
206 definitive/detailed name of the soil could arise from combining the names given separately to
207 the humipedon and the classification of the soil profile in any system.

208

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291

292

293 **List of Figures:**

294 **Figure 1.** *The basic concept of humus classification and the designation of organic layers on*
295 *forest floors (O-horizons) and organic-mineral soil horizons in the European classification of*
296 *humus systems (TerrHum).*

297

298 **Figure 2.** *Dichotomous key for identifying Terrestrial Humus systems and Forms. The*
299 *first bifurcation divides 3. Terrestrial (described in TerrHum) from 1. Histic and*
300 *Aqueous or 2. Para systems (2 and 3 are described in Zanella et al. 2018k).*

301

302 **Figure 3.** *TerrHum screens. a) Initial screen. The main key of classification is accessible by*
303 *touching the red button (Yes/No Key). In addition, four options allow accessing to illustrations*
304 *of humus horizons, forms, systems and types of transition between organic and organic-*
305 *mineral horizons. The third option ("Systems and Forms") allows opening specific tables*
306 *containing helpful specific information for the classification (e.g. % of recognizable remains in*
307 *different diagnostic horizons). The last option ("About TerrHum") corresponds to a link to an*
308 *external site, where the user may find a complete manual of the app; b) A single click on the*
309 *"Yes/No Key" (red button) opens a new window where a Yes/No question is proposed to the*
310 *user; touching the screen on either "Yes" or "No" and subsequently on the "Next" red button*
311 *activates a series of further Yes/No questions; c) At the end of the series of Yes/No answers, a*
312 *humus form is proposed as solution, along with the list of horizons chosen during the*
313 *run/classification process; d) By clicking on the proposed image it is possible to magnify the*

314 *photograph and, in addition, to see other examples of the same humus form, in different*
315 *environments.*

316

317 **Figure 4.** *TerrHum screens. a) Clicking on the first touch-button ‘Horizons’ (Fig. 3a) allows to*
318 *see examples of diagnostic horizons; b) Example of the result of clicking on ‘zoOH horizon’; c)*
319 *By clicking on the touch-button named ‘O/A transitions’, the user may display examples of*
320 *passages between O and A horizons; d) An example of a very sharp O/A transition.*

321

322 **Figure 5.** *TerrHum screens. a) Clicking on the third touch-button ‘Systems and Forms’ (Fig. 1a)*
323 *opens a list of the latter categories; b) By selecting one of the definitions listed in the rubric*
324 *‘Humus Forms’, e.g. ‘Leptoamphi’, a photograph of this humus form appears on the screen;*
325 *which can be magnified by clicking on it; two other photographs are accessible by sweeping*
326 *the screen with a finger; c) By clicking on the fourth touch-button called ‘Tables’ (Fig. 3a), the*
327 *user can display information (Help) concerning groups of animals c) and produced soil*
328 *aggregates d).*

329

330 **Figure 6.** *TerrHum screens. a) Selecting the fourth touch-button ‘Tables’ (Fig. 3a) opens the*
331 *related ‘Help’ info; b) By selecting ‘Pedofauna and droppings’ and then e.g. ‘Arthropods’, two*
332 *photographs of these animals collected in Petri dishes may be recalled and magnified. In*
333 *addition, schemes with info about the composition of humus horizons (c), or tables of humus*
334 *systems and forms (d) are available.*

335

336 **Figure 7.** *The subdivision into strata of the soil profile. The biodiversity maximum is not realized*
337 *at the surface, but in the layer that separates the horizons OL and OF or in the horizon OF. The*
338 *latter is a very protected horizon (in particular desiccation but also rain), which contains a large*
339 *number of trophic resources (very transformed dead leaves, but also fungi and bacteria) and*
340 *which, by its fragmentation, constitutes many refuges for species that would otherwise be in*
341 *strong competition, all that is needed to have maximum biodiversity.*

342

343 **Figure 8.** *Pedon sub-units: Humipedon, Copedon and Lithopedon in a theoretical series of soil*
344 *development. From (Zanella et al., 2018e; a), slightly modified.*

345

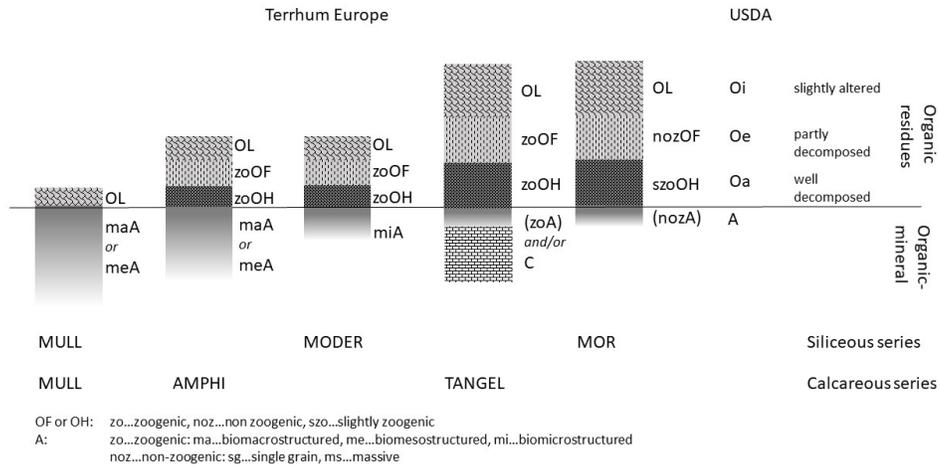


Figure 1. The basic concept of humus classification and the designation of organic layers on forest floors (O-horizons) and organic-mineral soil horizons in the European classification of humus systems (TerrHum).

338x190mm (96 x 96 DPI)

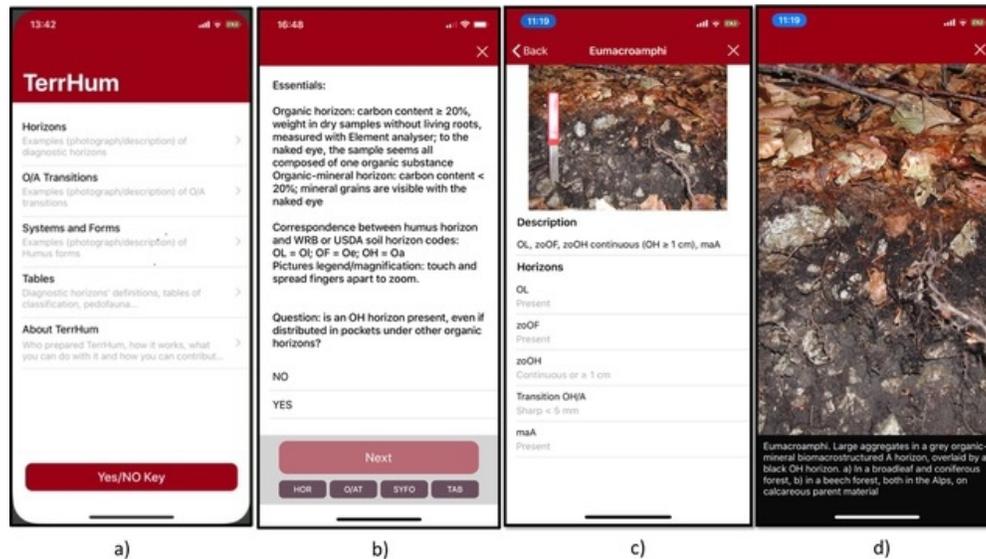


Figure 3. TerrHum screens. a) Initial screen. The main key of classification is accessible by touching the red button (Yes/No Key). In addition, four options allow accessing to illustrations of humus horizons, forms, systems and types of transition between organic and organic-mineral horizons. The third option ('Systems and Forms') allows opening specific tables containing helpful specific information for the classification (e.g. % of recognizable remains in different diagnostic horizons). The last option ('About TerrHum') corresponds to a link to an external site, where the user may find a complete manual of the app; b) A single click on the 'Yes/No Key' (red button) opens a new window where a Yes/No question is proposed to the user; touching the screen on either 'Yes' or 'No' and subsequently on the 'Next' red button activates a series of further Yes/No questions; c) At the end of the series of Yes/No answers, a humus form is proposed as solution, along with the list of horizons chosen during the run/classification process; d) By clicking on the proposed image it is possible to magnify the photograph and, in addition, to see other examples of the same humus form, in different environments.

108x60mm (150 x 150 DPI)

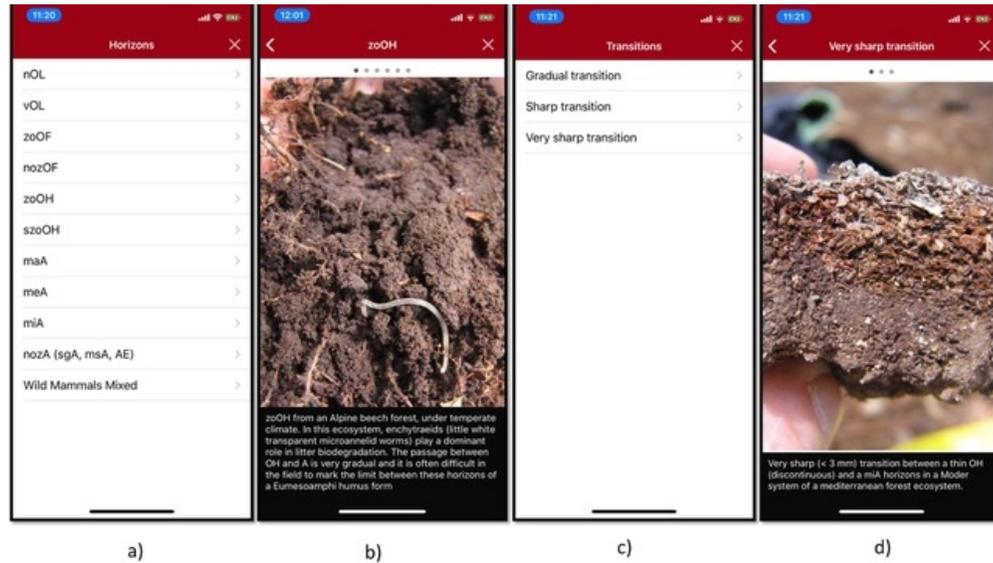


Figure 4. TerrHum screens. a) Clicking on the first touch-button 'Horizons" (Fig. 3a) allows to see examples of diagnostic horizons; b) Example of the result of clicking on 'zoOH horizon"; c) By clicking on the touch-button named 'O/A transitions", the user may display examples of passages between O and A horizons; d) An example of a very sharp O/A transition.

108x60mm (150 x 150 DPI)

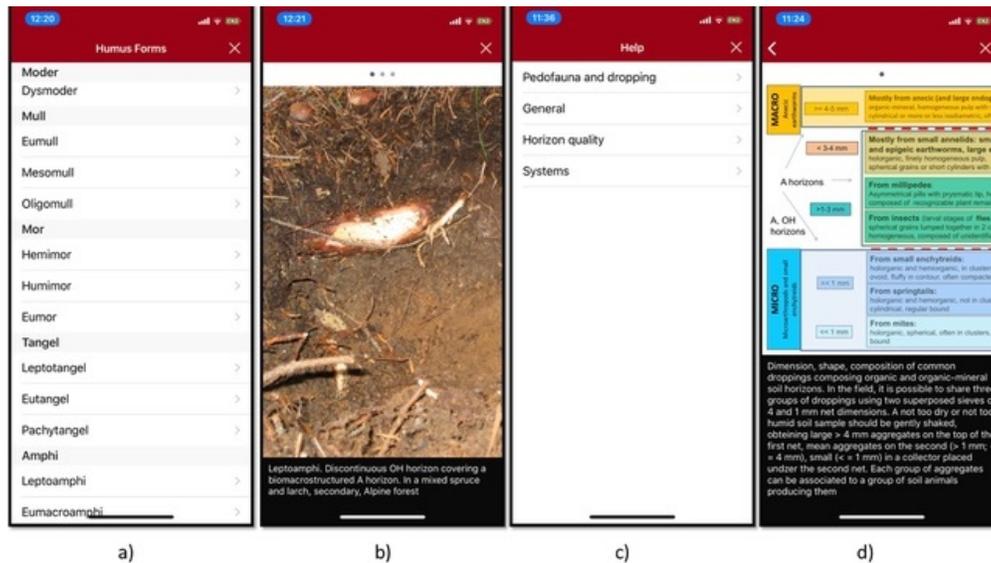


Figure 5. TerrHum screens. a) Clicking on the third touch-button 'Systems and Forms' (Fig. 1a) opens a list of the latter categories; b) By selecting one of the definitions listed in the rubric 'Humus Forms', e.g. 'Leptoamphi', a photograph of this humus form appears on the screen; which can be magnified by clicking on it; two other photographs are accessible by sweeping the screen with a finger; c) By clicking on the fourth touch-button called 'Tables'(Fig. 3a), the user can display information (Help) concerning groups of animals c) and produced soil aggregates d).

108x60mm (150 x 150 DPI)



Figure 6. TerrHum screens. a) Selecting the fourth touch-button "Tables" (Fig. 3a) opens the related "Help" info; b) By selecting "Pedofauna and droppings" and then e.g. "Arthropods", two photographs of these animals collected in Petri dishes may be recalled and magnified. In addition, schemes with info about the composition of humus horizons (c), or tables of humus systems and forms (d) are available.

108x60mm (150 x 150 DPI)

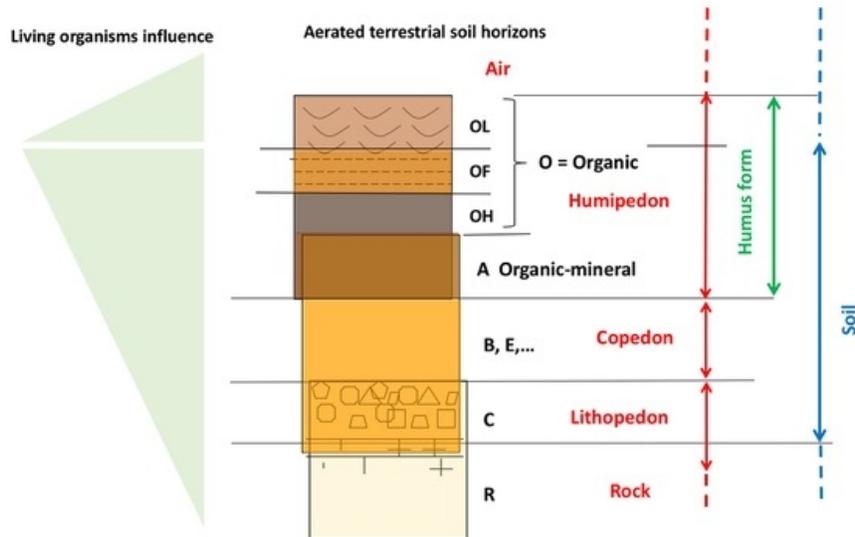


Figure 7. The subdivision into strata of the soil profile. The biodiversity maximum is not realized at the surface, but in the layer that separates the horizons OL and OF or in the horizon OF. The latter is a very protected horizon (in particular desiccation but also rain), which contains a large number of trophic resources (very transformed dead leaves, but also fungi and bacteria) and which, by its fragmentation, constitutes many refuges for species that would otherwise be in strong competition, all that is needed to have maximum biodiversity.

108x60mm (150 x 150 DPI)

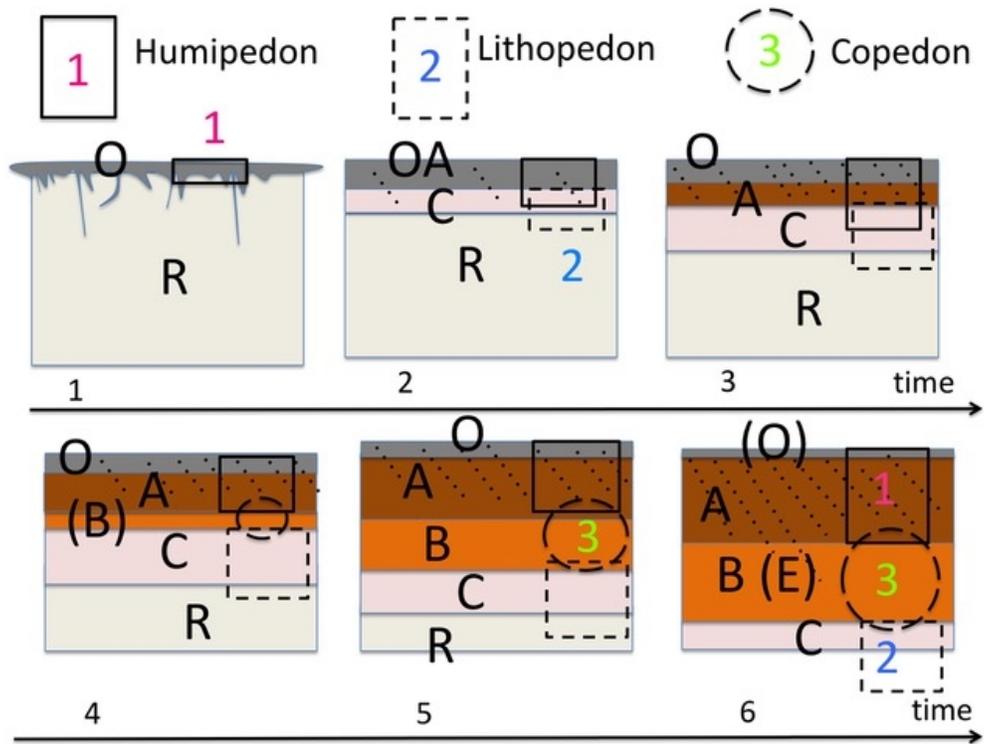


Figure 8. Pedon sub-units: Humipedon, Copedon and Lithopedon in a theoretical series of soil development. From (Zanella et al., 2018e; a), slightly modified.

81x60mm (200 x 200 DPI)