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## **Terrestrial humus forms: ecological relevance and classification**

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The Humus form, i.e. the part of the soil which is influenced by organic matter (Brêthes et al., 1995), has been recognized for a long time as the seat of most biological and physico-chemical processes essential to soil development and terrestrial ecosystem functioning. This concept applies to every kind of soil the upper part of which (the topsoil) is not permanently disturbed by human activity, i.e. to all non-tilled soils. In his seminal work, Müller (1879, 1884, 1887, 1889) put the basis of a multifaceted assessment of humus forms, embracing pedology, silviculture, biology, geology and climate. More than half a century later, Kubiëna (1953) classified European soils, considering the interaction between soil animals and vegetation as the driving force of soil development, geology and climate being the context. However, it is only recently that the concept emerged of humus forms as a digest of major processes which shape and stabilize ecosystems, pointing to the need for a better and worldwide assessment of diagnostic characters of humus forms (Ponge, 2003; Graefe & Beylich, 2006).



**Fig. 1. The five main terrestrial humus forms prevailing in temperate ecosystems (bar = 10 cm)**

Ponge (2003) considered Mull, Moder and Mor (Fig. 1) as three strategies of terrestrial ecosystems. Mull is characterized by an intense mixing of organic matter with mineral matter (i.e. the result of earthworm activity), stemming in a crumbly and nutrient-rich organo-mineral horizon, Moder by a less rapid transformation of litter by litter-dwelling animals and fungi, resulting in the accumulation of organic humus, Mor by the slow transformation and accumulation of undecayed plant debris, with a sharp transition to the mineral soil. Mull, Moder then Mor correspond to a scale of decreasing nutrient availability and colder conditions, stemming in decreasing biological diversity and

activity on siliceous substrates. Animals, microbes and plants are involved in positive (building forces) and negative (stabilizing forces) feed-back relationships most of them taking place in the humus profile. Look at the example of a forest mull: if the parent rock is rich in easy weathering minerals and the climate is mesic (not too cold, not too dry), then plant growth is rapid, including trees (site quality and productivity is high) and more exacting plants are allowed to grow (i.e. flower plants, with nutrient-rich and lignin-poor foliage, renewed annually). In turn litter (trees + forest vegetation) is nutrient-rich and will favoured more exacting microbes (bacteria) and animals (earthworms) the activity of which will contribute to favour tree growth and a diverse vegetation, which is typical of multi-layered forests. The same ring of causes and consequences explains why Mor, on the reverse side, is poorer in microbial, faunal and plant species and characterizes less productive but more conservative ecosystems: in familiar words, mull is a waster (the cicada of the fable), while Mor is a hoarder (the ant of the fable), but each of them allows a safe use of resources offered by geology and climate. Hence, the indicator value of humus forms.

Based on the knowledge accumulated on the relationships between morphological, biological and physico-chemical features of humus forms, several attempts have been made to classify them on the base of characters discernable to the naked eye directly on the field, and to derive from them properties at the ecosystem level (site quality assessment). Among many others we want to cite Delecour (1980), Green *et al.* (1993) and Brêthes *et al.* (1995), the latter concept of humus forms and diagnostic horizons being included in the 'Référentiel Pédologique' (Baize & Girard, 1998). Since that time, the need emerged of a common classification system at the European level, which could be compatible with the World Reference Base for Soil Resources (FAO, 2006).

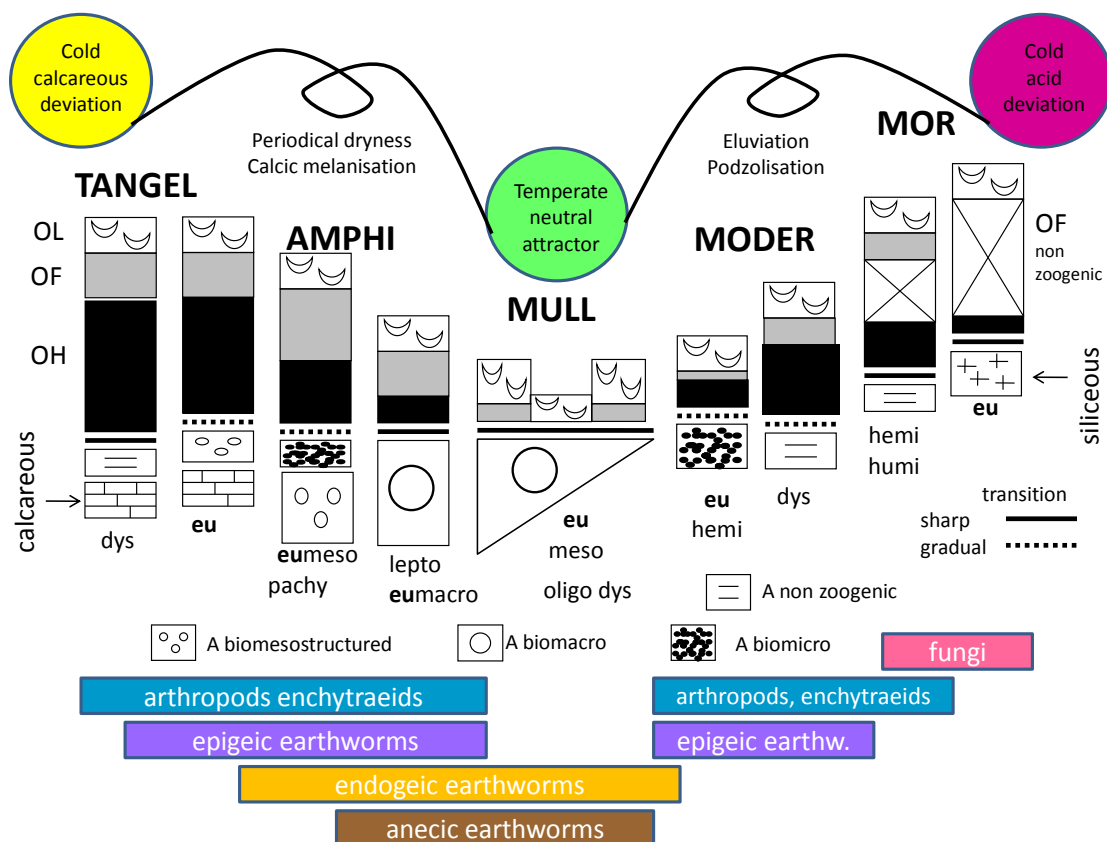


Fig. 2. Mull as an attractor for humus forms in terrestrial environments

A network of European humus researchers was founded in Trento (Italy) in 2003, gathering 25 specialists coming from eight European countries. Since this date, the Humus Group met each year in different countries, to exchange knowledge, discover humus forms in new ecological conditions and to progress in harmonizing humus form concepts. New terrestrial humus forms were given names, such as Amphi (Graefe, 2007; Galvan *et al.*, 2008), others were redescribed, such as Mor and Tangel (Fig. 1), and soil organisms were recognized as main agents of soil structure (Graefe & Beylich, 2006). The widest possible array of humus forms was covered, from southern to northern Europe, from seashore to high mountains, from dry to damp environments (Zanella *et al.*, 2009; Zanella *et al.*, in prep.). Figure 2 exemplifies the concept of Mull as an attractor for terrestrial humus forms in forest environments, and its deviation under harsher environmental conditions.

On calcareous substrates Amphi is a twin humus form showing both characters of Mull (crumby organo-mineral horizon) and Moder (accumulated organic humus), due to a seasonal alternation between phases of high and low biological activity in strongly seasonal Alpine and Mediterranean environments. Tangel, still badly known from a biological point of view, expresses particular characters at high elevation and on hard calcareous rocks, where litter is out of reach of soil decomposer activity for most of the year and invertebrates cannot dig through the parent rock.

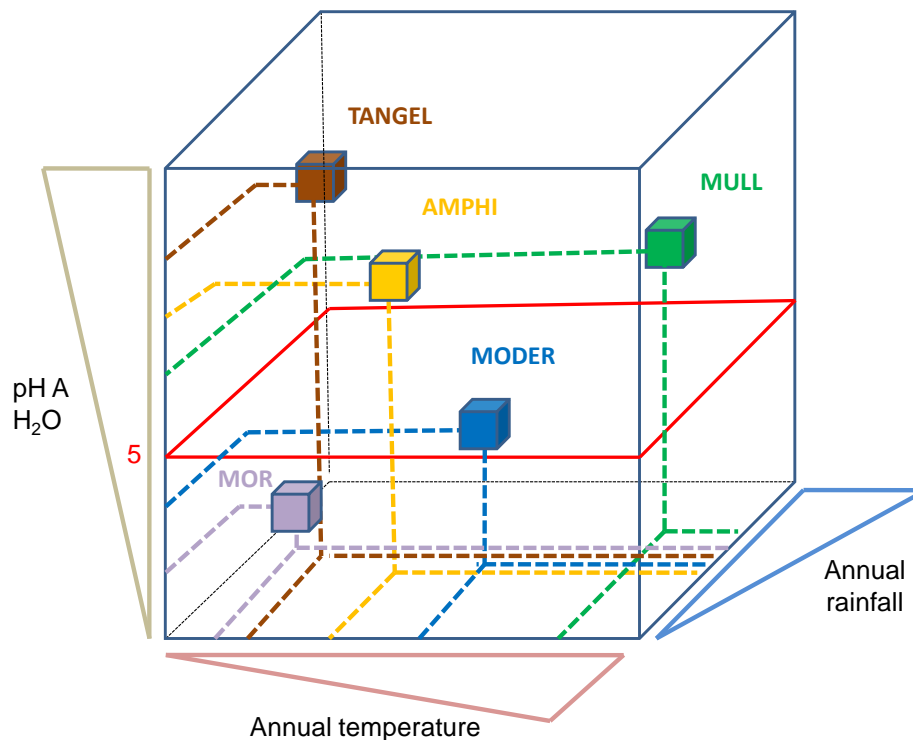
horizon	pedofauna	TANGEL		AMPHI		MULL		MODER		MOR		
		others	eu	others	eu	eu	others	eu	others	others	eu	
OL OFzo OHzo	Epigeic earthworms and/or arthropods and/or enchytraeids	—————					.....	—————				.....
OFnoz OHnoz	Non zoogenic	.....						.....		—————		
micro A	Epigeic earthworms and/or arthropods and/or enchytraeids			.....				—————	.....			
meso A	Epigeic (epi-endogetic, epi-aneic) Endogetic (polyhumic, mesohumic, endo-aneic, oligohumic)		.....	—————	.....							
macro A	Endogetic (endo-aneic, oligohumic) Aneic earthworms				—————							
Anoz	Non zoogenic	.....						—————		.....		

**Fig. 3. Morphological and biological characters of the five main terrestrial humus forms prevailing in Europe**

Main morphological and biological characters of Tangel, Amphi, Mull, Moder and Mor are summarized in Figure 3, which shows that the variety of humus forms known in Europe can be ascribed to several possible combinations of annelid oligochetes (earthworms, enchytraeids) the activity of which is of paramount importance for the building of soil structure (Brown, 1995). Undecayed litter, fragmented litter, humified litter and the underlying mixture of organic and mineral matter are currently called OL, OF, OH and A, respectively. Prefixes such as 'eu' (normal, perfect) or 'dys' (atypic, degraded) are used to characterize humus forms at a subordinate level of classification once characters of main humus forms have been defined. The size of aggregates (invertebrate faeces)

is indicated by prefixes ‘micro’ (<1 mm), ‘meso’ (1-4 mm) and ‘macro’ (>4 mm). The presence or absence of traces of faunal activity in horizons is described by suffixes ‘zo’ and ‘noz’, respectively. This flexible classification of horizons and profiles allows a wide variety of humus forms to be described and labelled, even when new to science.

The combination of geology (here expressed by pH) and climate (here expressed by rainfall and temperature) may help to explain the variety of humus forms found in European terrestrial environments (Fig. 4).



**Fig. 4. The five main terrestrial humus forms in a 3D frame of environmental conditions prevailing in Europe**

Beside being a need for those people who want to describe the topsoil in terms clearly undestandable by everybody, the classification of humus forms may also help to put a diagnostic to the welfare of ecosystems. In this direction, the Humus Index, obtained by scaling humus forms of acid soils from Mull to Mor (see upper row of Figure 1), proved to be correlated with soil physico-chemical variables, stand properties and floristic composition of various temperate forest ecosystems (Ponge et al., 2002; Ponge & Chevalier, 2006; Lalanne et al., 2008). Humus forms have been shown to be good indicators of present and past climate conditions and thus could be used for predicting future trends of global climate change (Egli et al., 2009, 2010). Hence the need for more expert tools based on a finer characterization of humus forms.

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