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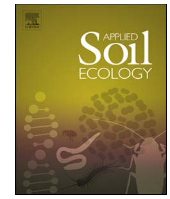

Review

Humusica 1, Article 6: Terrestrial humus systems and forms – Hydro intergrades☆

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ABSTRACT

In this article, we present the Terrestrial intergrades from never or only few days submersed humipedons, without permanent hydromorphic signs, until humipedons with presence of signs of partial asphyxia. Specific terms are defined and diagnostic horizons illustrated, both with the help of text explanations and photographs. The article ends with a table working as a classification field key.

1. Introduction

Soil pores may be filled with water, air and living organisms. Air carries into the soil oxygen and nitrogen, both very important elements for soil organisms (roots, bacteria, fungi and animals) (Gobat et al., 2004). When water replaces the air in the soil, soil organisms must face a period of anoxia and sometimes asphyxia (Hattori et al., 1976). Aerobic bacteria are most active in unsaturated moist soils, but anoxic hostile conditions will not completely kill bacteria, they will stop growing and get into a dormant stage (Bouthier et al., 2014). As for macro-organisms, earthworms without oxygen will suffocate and try to escape from their galleries. However, worm experts say that earthworms could survive for several weeks in water, providing there is sufficient oxygen in the water to support them. Earthworms do not surface to avoid drowning. We see them out of soil after rain because they can move around without dehydrating (Lee, 1985; Boyle et al., 1997; Edwards and Bater, 1992; Edwards, 2004) but also because the vibrations caused by raindrops mimic those emitted by predators as moles (Catania, 2008). For some species, growth and reproduction are maximal at a soil moisture of 80% (Hallatt et al., 1992). Anecic earthworms influence the soil porosity and have an impact on the soil water and mineral elements availability for plants (Andriuzzi et al., 2015; Bouché and Al-Addan, 1997; Le Bayon and Binet, 2006).

Concomitantly with soil organisms, specific plant communities grow on hydromorphic soils. Considering only Terrestrial ecosystems (not peat or always submersed soils, related to Histo humus forms and soils), plant phytosociologists list along a gradient from wet to fresh soils, forests belonging to Alnion glutinosae (dominant trees: *Alnus glutinosa*), Alno-Padion (*Alnus glutinosa*, *Fraxinus excelsior*, *Prunus padus*) and Carpinion (*Carpinus betulus*) phytosociological alliances (For the lists of plants refer to: Zanella, 1990; Géhu and Géhu, 1977; Noirfalaise, 1984; Oberdorfer, 1957). Rivers are also bordered by hydromorphic soils, which support linear plant formations assigned to Alnion incanae (rather mountain, rocky rivers) and Salicion albae (plain) phytosociological alliances. More complete data and geographical distribution in Europe of hydromorphic soil habitats are available on the website of the European Environment Agency (EEA, 2015). In the EUNIS habitat classification, the forests with hydromorphic soils are listed in Annexe 1 at levels G1.1 (Riparian and gallery woodland, with dominant [*Alnus*], [*Betula*], [*Populus*] or [*Salix*]), G1.2 (Mixed riparian floodplain and gallery woodland), G1.3 (Mediterranean riparian woodland) and G1.4 (Broadleaved swamp woodland not on acid peat). Broadleaved swamp woodland on acid peat Woodland (Histic humus forms or Histo soils)

☆ Background music while reading: Les feuilles mortes. La chanson de Prévert. Serge Gainsbourg: https://www.youtube.com/watch?v=YtBpBPvIHBs.

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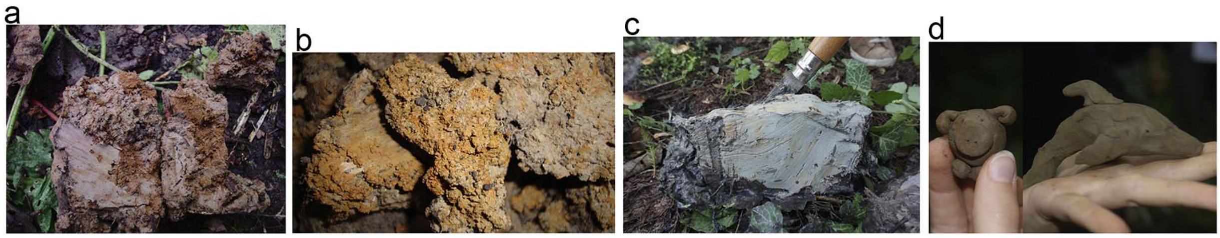

Fig. 1. Hydromorphic properties. a–c: orange: oximorphic; Bluish-green: reductimorphic; d: artistically sensible students always play with the clay consistence of this material: small curbed pig ears and dolphin thin crooked fins cannot be done with less than 35–40% of clay content. Even if this test is not very accurate, to combine science and art during teaching activities is always pleasant.

Fig. 2. Organic hydromorphic gOH horizon. This horizon resembles a very organic anA horizon, or a "more mineral than usual" and humid OH horizon.

Fig. 3. Organic hydromorphic gOF horizon. This horizon looks like a black fragmented litter within a watered brown mineral matrix.

are placed in a separate G1.5 section. Besides a gradient from semi-terrestrial forests to humid forests, there is also a gradient from quacking mires, reeds, sedges to half natural wet to humid grasslands and *Sphagnum* dominated bog-like short vegetation. A LIFE publication titled "LIFE and Europe's wetlands: Restoring a vital ecosystem" is also available (Silva et al., 2007) and furnishes very useful information about geographical distribution in Europe of these sites, as well as fauna (especially birds and amphibians), flora and human exploitation, with the aim to support their conservation.

2. Specific terms and diagnostic horizons

Specific terms and diagnostic horizons are equivalent to the ones presented in preceding publications (Zanella et al., 2011a, 2011b). In the current version, the "g" letter indicating the presence of hydromorphic features is set before the capital letter of each concerned horizon, avoiding confusion with the same letter used in other soil description guides (in the French Référentiel Pédologique, "g" is used as horizon letter for defining a group the Redoxisoils main reference) with different significance. Specific terms and diagnostic horizons are reported in a synthetic manner, as in a key of classification (as in Humusica 1, article 4, for Terrestrial humus systems and forms). In all humipedon investigations, a minimum horizon thickness for description, diagnosis and sampling purposes has been established at 3 mm. Below this threshold, the horizon is considered discontinuous if clearly in patches or absent if indiscernible from other neighbouring horizons. Only organic horizons OL, OF, OH, H (for Histic profiles) and upper organic-mineral A horizons are considered in Humipedon classification of Humusica articles. To identify mineral horizons, we followed the Guidelines of Soil Description FAO (2006) and preconize the use of WRB (IUSS Working Group WRB, 2015) to complement entire soil classifications. All lowercase letters used for humipedon horizons description precede the horizon capital letter as prefix, avoiding confusion with suffix soil lowercase letters use in "classical" soil description recommendation.

2.1. Hydromorphic properties

In the description of humipedon horizon, the letter "g" is used before the horizon letter as a prefix (a lower case letter for hydromorphic properties and a capital letter for horizon; example: gA). The prefix "g" is used for Terrestrial organic (O and H) as well as organic-mineral (A) horizons to highlight water influence on those horizons. However, recognizing criteria are different in these two categories of horizons. In O and H horizons, prefix "g" is used when the organic horizons are very dark, sign of a long period of water saturation; in organic-mineral A horizon, prefix 'g' designates those horizons in which a distinct pattern of mottling occurs and reflects alternating conditions of oxidation and reduction of iron oxides, caused by seasonal surface waterlogging. The mottling means that either reductimorphic and/or oxymorphic colours are present at the level of the cited horizon (gA). Reductimorphic colours reflects permanently wet (gley) conditions (colours indicating the presence of reduced iron, bluish-green grey or bright blue-green according to the presence/absence of organic matter and concentration of iron), while oximorphic reflects oxidizing conditions, as in the capillary fringe and in the surface horizons of soils with fluctuating groundwater levels (pseudogley). Availability of macronutrients like phosphate and nitrogen is also influenced by the aeration-water saturation of the root zone (redox-processes) (Abuarab et al., 2013; Dickson and Broyer, 1972). Oximorphic colours indicate the presence of precipitated oxidised iron: reddish brown, bright yellowish brown, orange, dark orange and pale yellow, according to the proportion of hematite (red) and goethite (yellow) and other ferric minerals (Torrent et al., 1983). Reductimorphic and oximorphic colours cover only some parts of the soil volume when the hydromorphic properties are weakly expressed. Bluish-green colours are usually unstable and often oxidize to a reddish brown within a few hours of exposure to air. Oximorphic colours inside

Fig. 4. Organic hydromorphic gOL horizon. In water (anoxic conditions), litter becomes black or dark brown.

superficially grey soil aggregates mean a recent and unstable submersion of the aggregate. A horizon showing hydromorphic properties may be all grey in case of permanent submersion or more or less finely mottled grey and orange if phases of submersion/emersion (Fig. 1).

2.2. Terrestrial hydromorphic organic horizons

ORGANIC HORIZONS (gOL, gOF, gOH): organic horizons submersed and/or water-saturated for a non-protracted period of the year (less than 6 months per year) and showing the effects of temporary anoxia; carbon content reaches 20% or more (approximately 40% of total organic matter) by weight, in dried samples sieved at 1 mm thus removing living roots (Method: element analyser, ISO 10694, 1995). Horizons are still under saturated circumstances or drained.

gOL, gOF, gOH (from hydromorphic Terrestrial horizons, Figs. 2–4). Hydric organic horizons formed under non-prolonged water saturation (less than 6 months), periodically water-saturated and showing the effects of temporary anoxia. A prefix letter "g", preceding the code of Terrestrial horizons, indicates the presence of hydromorphic features: plant remains becoming dark, glued together and often coloured (more evident than usual) along the venation of the leaves by black particles of humic component deposited here by water during the period of immersion; humic component often dark grey or black, massive and plastic, may be structured in faunal faecal pellets during aerated periods. Carbon content is ≥20% by weight. Humic component is less than 10% in volume (roots excluded) in gOL, between 10 and 70% in gOF and more than 70% in gOH.

2.3. Terrestrial hydromorphic organic-mineral horizons

ORGANIC-MINERAL HORIZON (gA): submersed and/or water-saturated for a non-protracted period of the year (less than 6 months per year); carbon content is generally less than 7% by weight, in dry

Fig. 6. Hydro Mull. OL and gmaA horizons, in humid grassland in Parisian region.

Fig. 7. Hydro Mor. OL, gOF, gOH horizons lying on a grey gley mineral horizon.

samples without living roots (Method: element analyser, ISO 10694, 1995).

gA (from Terrestrial A horizon and "g" hydromorphic properties, Fig. 5). Hydric organic-mineral horizons show evidence of temporary anoxia such as oxidation/reduction Fe-mottling colours (orange-red spots within grey to bluish-grey matrix) covering at least 1/3 of the surface of the horizon profile; the carbon content is generally less than 7% by weight. All Terrestrial A horizons can show hydromorphic properties (examples: gzoA = hydromorphic zoogenic A horizon, gnozA = hydromorphic non zoogenic A, gmaA = hydromorphic biomacrostructured A, gmeA = hydromorphic biomesostructured A, gmiA = hydromorphic biomicrostructured A, gmsA = hydromorphic massive A, gsgA = hydromorphic single grained A, gamsA = hydromorphic anthropogenic massive A, gamaA = hydromorphic biomacrostructured A, gszoA = hydromorphic slightly zoogenic A, etc.). Sometimes these properties are only traces of past events and are not in accordance with the current hydrological situation. If carbon content is higher than 7% by weight, similarities with mrA or HS are possible.

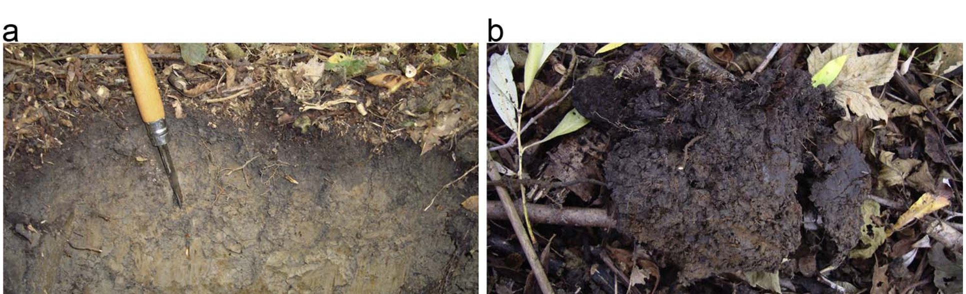

Fig. 5. Organic-mineral hydromorphic gmaA horizon. a) the whole profile. Due to periodical asphyxia, the litter biodegradation can't run as fast as in a non-hydromorphic humus Mull system. Grey traces of earthworm's galleries are visible in the orange/grey mass of the horizon; b) magnifying a piece of a biomacrostructured A horizon, it is possible to individuate the typical large organic-mineral soil aggregates of a Mull system.

DIAGNOSTIC HORIZONS Trans: O-A		TANGEL			AMPHI				MULL				MODER			MOR			DIAGNOSTIC HORIZONS Trans: O-A	
HYDRO	(typical)	Pachytangel	Eutangel	Leptotangel	Pachyamphi	Eumesoamphi	Eumacroamphi	Leptoamphi	Oligomull	Eumull	Mesomull	Dysmull	Hemimoder	Eumoder	Dysmoder	Hemimor	Humimor	Eumor	(typical)	HYDRO
gOL, gOF posble not sufficient, gOH sufficient for Hydro prefix	nOL	possible and not discriminant			possible and not discriminant					disc pock (a)			possible and not discriminant			possible and not discriminant			nOL	gOL, gOF posble not sufficient, gOH sufficient for Hydro prefix
	vOL										disc pock								vOL	
	nozOF															disc pock			nozOF	
	zoOF	OF+OH > 30 cm OH > 2A	OF+OH 15-30 OH > 2A	OF+OH < 15 cm OH > 2A					disc pock							possible			zoOF	
	szoOH				possible										possible			possible	szoOH	
	zoOH					< 3 cm	≥ 1 cm	< 1 cm or disc					disc pock	≤ 1 cm	> 1 cm	possible			zoOH	
Transition O-A (mm)		not discriminant			≥ 5 (b)		< 5 (c)		< 3 (d)				≥ 5 (e)			< 3 (mandatory)			Transition O-A (mm)	
gAE, gnozA, gzoA (gmaA, gmeA, gmiA) sufficient for Hydro prefix	AE, EA														OR	OR			AE, EA	gAE, gnozA, gzoA (gmaA, gmeA, gmiA) sufficient for Hydro prefix
	nozA	possible msA < OH/2												sgA, msA		A absent OR sgA, OR msA			nozA	
	miA				miA AND meA ≥ OH/2								OR						miA	
	meA	OR possible meA < OH/2			OR ONLY meA ≥ OH/2				OR			OR							meA	
	maA						A ≥ OH/2												maA	

MANDATORY in Tangel: pHwater of msA ≥ 4.5

MANDATORY in Amphi, one of the following:
living eartworms or freshly deposed earthworm feaces in A;
diffuse transition A/O; pHwater of A ≥ 5

MANDATORY in Mull, one of the following:
presence of living earthworm or their casts in A; transition O/A <3 mm; pHwater > 5

MANDATORY in Moder, one of the following: transition O/A ≥ 5mm; pHwaterof A < 5

MANDATORY in Mor, three of the following:
presence of OFnoz; transition O/A-E < 3mm; pHwater of E or A <4.5;
A absent or presence of msA or sgA or E

(a) disc pock = discontinuous or in pockets
(b) or living earthworms (or freshly deposited earthworm faeces) in the A horizon; or pHwater of the A horizon ≥ 5.
(c) or living earthworms (or freshly deposited earthworm faeces) in the A horizon; or pHwater of the A horizon ≥ 5.
(d) at least two of the following:
d1: Presence of a very sharp transition (< 3 mm) between organic and organo-mineral horizons;
d2: Presence in the A horizon of living earthworms or their casts, except in frozen or desiccated soil;
3d: pHwater of the A horizon > 5
(e) or pH of A < 5

Possible hydromorphic (g) terrestrial diagnostic horizons

Terrestrial diagnostic horizons

Fig. 8. Simplified table of classification of Terrestrial humus systems, forms and Hydro intergrades.
Legend figure:
Hydro = prefix to utilize if presence of hydromorphic (horizons periodically water-saturated, for a period of less than a few months per year), examples: OL + maA = Mesomull; OL + Ag or OLg + Ag = Hydro Mesomull;
(typical) = tacit, without hydromorphic horizons = in typical terrestrial condition (horizons water-saturated less than a few days per year);
possible = horizon present or absent or thickness < 2 mm; the presence of hydromorphic organic gOL and gOF horizons is not sufficient for using the Hydro prefix for a humipedon when all other horizons are not hydromorphic.
possible and mandatory = horizon present or absent or thickness < 2 mm, but mandatory for using the Sagnic prefix;
OH > 2A = thickness of OH horizon > 2 times thickness of A horizon;
A ≥ OH/2 = thickness of A horizon ≥ half the thickness of OH horizon;
disc pock = horizon discontinuous or in pockets;
≥ 3 cm = thickness of indicated horizon ≥ 3 cm;
or = the indicated horizon could be present instead of another indicated horizon;
and/or = the indicated horizon could be present with or instead of another indicated horizon.

However, the structure of gmaA or gmeA horizons, mostly due to anecic and endogeic earthworms (faeces = macro- or meso-aggregates), and although partially destroyed by water, never becomes completely plastic and massive as in the mrA horizon. The carbon content of gzoA, gnozA, gmaA, gmeA, gmiA, gmsA, gsgA, gamaA, gameA, gszoA never reaches 20%, which is the case in every kind of HS horizon.

3. Names of Hydro intergrades

When gOH or gA hydromorphic horizons are present, the prefix "Hydro" (from Hydros, water) is set before the name of the corresponding Terrestrial forms, without hyphenation. The presence of gOL or gOF in Terrestrial humus forms is possible but not sufficient for using the prefix Hydro. The reason is that wet black gOL and gOF horizons can be present in a humipedon that does not show hydromorphic properties in its other horizons. In this case, it is preferable to assign the humipedon to a "normal", not hydromorphic Terrestrial form.

Example of names (case of hydromorphic Mull):

Hydro Mull: OL, OF, gmaA (Figs. 5 and 6) or gOL, gOF, gA or OL, gA, or…

Examples of names (cases of hydromorphic Mor):

Hydro Mor = Hydro Eumor: OL or gOL/gOF and/or gnozOF/gnozOH and/or gzoOH and/or gnozA or gAE or A absent (Fig. 7).

Hydro Hemimor; OL or gOL/nozOF discontinuous or in pockets or gzoOF or zoOF/OH or gOH/gnozA or gAE or A absent.

Hydro Humimor: OL or gOL/nozOF continuous/zoOH or gOH possible/nozOH or gnozOH/gnozA or gAE or A absent.

Hydro Eumor: OL or gOL/nozOF continuous/nozOH or gnozOH possible/gnozA or gAE or A absent (Fig. 7).

4. Simplified table of classification of Terrestrial humus systems, forms and Hydro intergrades

All Terrestrial humus systems and forms have been set in a single table (Fig. 8).

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