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Humus forms in a Mediterranean area (Castelporziano Reserve, Rome, Italy): classification, functioning and organic carbon storage

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ABSTRACT

This work reports the results of an investigation on humus forms in a Mediterranean LTER (Long-Term Ecosystem Research) site. The study tests the effectiveness of the recent European humus forms classification (Zanella et al. 2011b), based on morpho-genetic characteristics of diagnostic organic and organo-mineral horizons. Furthermore it reveals how humus forms, at the level of diagnostic horizons, are related to vegetation/soil type and carbon storage capacity of the soil.

The humus forms were surveyed in different substrates, soil types, and vegetation units of a Mediterranean forest ecosystem in Central Italy (Castelporziano Reserve). Thickness, organic carbon (OC) and total nitrogen (Ntot) contents in organic and organo-mineral horizons, pH and texture in the organo-mineral horizon were measured and statistically analysed.

The three main humus forms (Mull, Moder and Amphi) covering the soil of the Reserve appeared well separated on the PCA diagram. Thickness, OC and Ntot showed a high correlation with axes of PCA. Kruskal–Wallis tests revealed differences between Mull, Moder and Amphi: 1) the thickness of the A horizon was larger in Amphi; 2) OC in the A horizon was less in Moder; 3) Mull had less OC in organic horizons than Moder and Amphi; and 4) Mull and Amphi had twice OC of Moder in bulked organic and organo-mineral horizons.

Two main ecological gradients, from neutral/aerated Mull to acid/anaerobic-water saturated logged Moder on one side and from fresh Mull to dry Amphi on the other, explain the distribution of humus forms in the Reserve. The first gradient concerns circular belts around periodically filled small basins and is peculiar to the more or less impermeable plain of Castelporziano; on the contrary, the second progressive transition is very common in Mediterranean forests.

The European humus forms classification allows to better understand the organic matter cycle at the level of soil bio-structures even in this relatively small Mediterranean forest. New diagnostic horizons are proposed and necessary for surveying humus forms perturbed by wild boars. The crucial role played by the here investigated Amphi forms could increase with the prospect of climate change.

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1. Introduction

Humus forms are the fraction of the topsoil strongly influenced by organic matter composed of a sequence of organic and underlying organo-mineral horizons (Brêthes et al., 1995; Green et al., 1993). Humus forms are indicators of the conservation status of an ecosystem (Topoliantz and Ponge, 2000), particularly for sites subjected to a long-term disturbance affecting the herbaceous layer (Klinka et al., 1990).

Humus forms are influenced by biotic (litter amount and quality, soil-dwelling microbial and animal communities) and abiotic factors (climate, bedrock, soil type) according to a variety of key processes. While abiotic factors such as regional climate and geology cannot be back-influenced by humus forms, at least in the short-term (Marland et al., 2003), biotic factors are tightly linked to humus forms according to feedback loops (Ponge et al., 1999), making distal and proximal causes hard to discern and thus any predictions questionable.

Description and study of humus forms allow to follow short term climate changes since humus forms are more sensitive than soils to variations in plant growth, cover and species and to management (Gobat et al., 2010; Ponge, 2003; Zanella et al., 2001).

The humus form plays different roles in ecosystems:

- it is an important factor for the recruitment of species – i.e. nutrients, refuge or hiding-place, water content, permanent seed soil bank, edaphic mesofauna, symbiotic organisms etc. – and consequently for plant communities (Aubert et al., 2005; Mobaied et al., 2012; Morris and Blackwood, 2007; Ponge 2009, Ponge et al., 2010);

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- it forms part of the forest memory since it conserves the information for a long time in respect to field layer (Bardgett et al., 2005; Galvan et al., 2008; Ponge et al., 1999);
- it contributes to organic matter turn-over (Horwath, 2007; Ponge et al., 2006; Stevenson, 1994).

It has been shown that the thickness of the forest floor and the structure of organo-mineral horizons, which are under the paramount influence of ecosystem engineers such as earthworms (Bossuyt et al., 2005; Wironen and Moore, 2006), can vary according to plant species, age of tree species (Bernier and Ponge, 1994; Chauvat et al., 2007; Godefroid et al., 2005), and vegetation successional processes (Scheu and Schulz, 1996) and undergo cycles at the scale of centuries in naturally regenerating late-successional forests (Salmon et al., 2008). Litter quality, resulting from the species composition of forest vegetation (Loranger et al., 2002) and conditions of tree growth (Hättenschwiler et al., 2003; Northup et al., 1995), influences and is influenced by humus forms and associated soil trophic networks (Davies et al., 1964; Nicolai, 1988; Ponge et al., 1999). At last, forest vegetation is locally selected (filtered out from regional pools of species) by forest floor and topsoil properties, combined with plant species interactions (Daniel and Schmidt, 1972; Falkengren-Grerup and Tyler, 1993). In turn plant species influence activity of soil organisms, and thus the development of humus forms, through litter and rhizosphere effects (Bradley and Fyles, 1996; Emmer and Sevink, 1994; Miller et al., 2009).

Due to the importance of humus forms (De Nicola et al., 2013) in the ecosystems, a new proposal for including these living parts of the soil in the World Reference Base for Soil Resources has recently been published (Jabiol et al., 2013). We aimed here to test the effectiveness of the proposed classification based on morpho-genetic characteristics of diagnostic organic and organo-mineral horizons illustrated and depicted in the *European Humus Forms Reference Base 2011* (Zanella et al., 2011b).

Furthermore, we wanted to know how soil data are of interest for investigating carbon and nitrogen cycles in Mediterranean forest ecosystems at the level of the organic and organo-mineral horizons. In particular, classical parameters were measured [thickness, organic carbon (OC) and total nitrogen (Ntot) contents of organic and organo-mineral horizons, pH and texture of organo-mineral horizons] in humus forms generated in phytosociologically and pedologically circumscribed Mediterranean forest ecosystems.

2. Materials and methods

2.1. Study area

The study area is located in the evergreen and deciduous Mediterranean lowland oak forest of Castelporziano Presidential Reserve (Latium), a LTER – Long-Term Ecosystem Research – Italy site. Located at 25 km from Rome, the Reserve (http://www.quirinale.it/qrnw/statico/residenze/castelporziano/castelporziano-a.htm) covers 5892 ha and connects the suburb of the capital to the Tyrrhenian coast, which includes about 3.1 km of protected natural beach ecosystem. In relation to high plant species and community diversity, represented by 970 species of vascular plants and 45 plant communities, Castelporziano Reserve corresponds to a "hotspot" of biodiversity in the Mediterranean basin (Pignatti et al., 2001).

The area is mostly flat, and rises gently up to 80 m a.s.l. at about 4 km from the coast. Recent Dune, Ancient Dune, Tuffs and Alluvial deposits represent the different geomorphological units. The Recent Dune occupies a narrow belt along the coast, and consists of Holocene calcareous sands. The Ancient Dune, characterised by highly pedogenized Wurmian acidic aeolian sands, occupies 4/5 of the Reserve area. Slight depressions, called "pools", where water stagnates permanently or seasonally, are spread in the Reserve. In the northernmost sites, pyroclastic materials coming from the Latium Volcano overtop the sands. A network of small gorges crosses this layer of Tuff. A small river, the "Fosso di Malafede", with recent Alluvial material, marks the northern border of the Reserve.

The soils have been classified and mapped in the Reserve according to USDA Soil Taxonomy (Dowgiallo and Biondi, 2001). The consociations of soil correspond to belts more or less parallel to the coast. The soil types range from Entisols (corresponding to Arenosols, IUSS Working Group WRB, 2007) mainly on the Recent Dune, to Inceptisols (Cambisols) and to highly evolved Alfisols (Luvisols) with a xeric moisture regime on the Ancient Dune; soils with aquic regime are present in substrate depressions and show hydromorphic features. In relation to the high geomorphological and lithological diversity, a large variety of landscapes and plant associations occur, representative of four biomes coexisting at short distance (Table 1):

1) Relict of *Laurisilva*, in northeastern gorges, represented by *Laurus nobilis* and *Carpinus betulus* woodlands (*Lauro-Carpinetum* — code 1);
2) Deciduous temperate forest with *Quercus cerris* and *Quercus frainetto* on the Ancient Dune, dating back to 100,000 years (*Echinopo-Quercetum frainetto* with *Erica arborea* — code 2 and *Echinopo-Quercetum frainetto* with *Carpinus orientalis*/*C. betulus* — code 3);
3) Sclerophyllous evergreen forest, dating back to 1000 years represented by *Quercus suber* (*Viburno-Quercetum ilicis suberetosum* — code 4) and *Quercus ilex* (*Viburno-Quercetum ilicis* — code 5) woodlands;
4) Azonal humid forest spread in the Recent Dune slack dominated by *Fraxinus oxycarpa* and *Populus alba* (*Carici remotae-Fraxinetum oxycarpae* — code 6).

The plant associations were classified by Pignatti et al. (2001).

2.2. Humus form sampling and diagnostic horizons

The study of humus forms was carried out in the whole forested area, using sampling plots representative of the six different plant associations associated with six geomorphological units (Table 1). In the course of phytosociological investigations, a total of 60 soil/humus profiles were surveyed in December 2011. Among them, 32 profiles were analysed more carefully taking samples of each horizon, then submitted to detailed laboratory observations and measurements (see below). The subset of 32 sites covered the whole range of vegetation units and humus form sub-types of the Reserve.

Humus forms were classified according to the *European Humus Forms Reference Base 2011* (Zanella et al., 2011a), recently slightly modified for including humus forms in the World Reference Base for Soil Resources (Jabiol et al., 2013). The process of classification is realised considering the sequence and morphological characteristics of organic (OL, OF, OH) and/or organo-mineral (A) horizons, including morphological evidence of biological activity and structures. The procedure stops at the level of "biological sub-types" of terrestrial humus forms, holding the same names in European (current classification, Zanella et al. 2011b) and World (as proposed, Jabiol et al. 2013) References. Chemical [pH, organic carbon (OC) and total nitrogen (Ntot) contents] was measured to support field observations.

2.3. Diagnostic horizons and classification

2.3.1. Organic horizons

The OL horizon is characterised by the accumulation of mainly leaves/needles, twigs and woody materials, most of the original plant parts being easily discernible to the naked eye. The humic component amounts to less than 10% by volume, recognizable remains 90% and more, up to 100% in non-decomposed litter.

The OF horizon is characterised by the accumulation of partly decomposed litter, mainly from transformed leaves/needles, twigs and

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