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Micromorphology of organic matter and humus in Mediterranean mountain soils

Olena Zaiets, Rosa M. Poch *

Departament de Medi Ambient i Ciències del Sòl, Universitat de Lleida, Catalonia

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ABSTRACT

Humus classification is one of the most useful approaches when studying the dynamics of SOM in an ecosystem. Until now, soil micromorphology has seldom been applied to the determination of humus types, in spite of the close relationship between soil organic matter and soil structure. Micromorphological techniques were applied to the study of humus soils under forest and pasture in the Catalan Pre-Pyrenean region in order to characterize particulate organic matter, its degree of decomposition and its relationship with the physico-chemical and biotic properties of topsoil. Fourteen thin sections were studied from the humus profiles of 5 soils (2 Typic Ustifluvent, 2 Typic Calciustept and 1 Typic Ustorthent). Nine fabric units related to organic matter were identified and counted through a petrographic microscope and in scanned images of the thin sections. The results helped to classify two humus forms (Amphi and Mull) that had statistically different qualities and quantities of micromorphological features and assemblages. Amphi humus forms were characterized by a laminated fabric in the OL horizon and by a loose dropping fabric in the OF and OH horizons; with droppings of mesofauna (enchytraeids, springtails and mites), and fungal elements (sclerotia, hyphae). Mull humus forms had larger amounts of earthworm casts and feces of *Isopods*/*Arthropods*/*Diptera* together with faunal pores. The use of scanned thin sections proved to be useful for the general determination of the humus forms, although for a detailed organic matter study the use of the optical microscope is essential.

1. Introduction

The transformation and accumulation of soil organic matter (SOM) in terrestrial ecosystems occur mainly in the topsoil. The humus form is the part of the topsoil that is strongly influenced by organic matter and coincides with the sequence of organic and underlying organo-mineral horizons. The specific sequences and properties of these horizons, formed under given environmental factors, determine the type of humus form.

Humus as a decomposed organic matter was first described by Wallerius in 1761 (Senn and Kingman, 1973). However, the first one who defined humus forms in terms of the organization of soil organic matter in the horizons was P.E. Müller (1878). At the time, two main groups of humus – Mull and Mor – were identified. Mull humus appears in biologically active soils with well humified organic matter, while Mor humus develops in poorly active, acidic environments, with a slow humification. Moder forms represent an intermediate stage between them.

In the works of Zachariae (1964) and Bal (1970) the important role of soil fauna in soil organic matter disintegration was discussed. However, Babel (1975) described the most common humus components and fabric types of several topsoils found in Central Europe. Further work on humus forms led to their perception as indicators of ecosystem nutrient status through the reflection of SOM dynamics (Brethes et al., 1995; Ponge, 2003; Ponge et al., 1997; De Nicola et al., 2014). At the same time, field morphological studies and descriptions resulted in the revision of previous attempts at humus form classification and the development of several new ones, as the Amphi (Zanella et al., 2011), also called Amphimull (Brethes et al., 1995) humus type, appearing in Mediterranean, eutrophic environments where humification is not complete due to a seasonal water deficit or other factors. This type of humus forms corresponds to "Amphi humus" in the Référentiel Pédologique (Baize and Girard, 2008). According to some authors, Amphi is the result from the co-evolution of Mull and Moder, as a response to a periodically dry sub-Mediterranean climate (Zanella et al., 2001; Galvan et al., 2008; Ponge et al., 2014). Nevertheless, Bottner et al. (2000) indicate that it is common to find a "Xeromoder" overlying the A horizon of an earthworm Mull in Mediterranean forests, which is a typical feature of the Amphi humus type. Exhaustive characterization of Mediterranean humus forms including Amphis, related to the ecosystem functioning are given by Andreetta et al. (2011) and Andreetta et al. (2016).

All present-day classifications (North American, French, German, and European) are based on humus characterization in the field. Nevertheless, field observations cannot always give complete information on SOM dynamics, and additional analytical data is needed (Brethes et al., 1995). Although microscopy-assisted observations of disturbed humus

* Corresponding author.
E-mail address: rosa.poch@macs.udl.cat (R.M. Poch).

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have been applied to the quantification of some components (Galvan et al., 2008), the micromorphology of humus, through the study of thin sections of undisturbed samples is at present seldom applied.

The most comprehensive studies on the micromorphology of humus forms date from last century (Kubiëna, 1955; Zachariae, 1964; Babel, 1968; Babel, 1975; Pawluk, 1987). Mainly all of them are dedicated to Moders and Mors that are found in temperate climates and are based on their qualitative description, while little is known about humus micromorphology of Mediterranean region. Moreover, the micromorphology of SOM components is restricted to four basic forms depending on the degree of decomposition in the most recent guidelines for soil thin section description (Stoops, 2003). Thus, it would be necessary to enlarge and complete the methods of description and quantification of SOM forms through the microscope, so that they could be used to characterize the humus forms, as indicators of ecosystem health status, and help model the dynamics of soil organic matter and its turnover (Jeffery et al., 2010). Moreover, the interpretation of micromorphological features found in thin sections reflects the history of the site and its evolution (Bunting and Lundberg, 1987), which is essential in the evaluation of the management practices carried out on the soil (Pagliai, 1993).

The aim of the present paper is to propose a qualitative and quantitative method of studying soil organic matter in thin sections and its contribution to humus classification, in particular to Amphi humus forms, through its application to selected humus profiles with known chemical and physical properties from a Pre-Pyrenean region in the NE Iberian Peninsula.

2. Materials and methods

2.1. Study sites

The study area is situated in the northeastern Iberian Peninsula, in the Pre-Pyrenean mountain region within the Ribera Salada river basin, belonging to the Ebro river basin. The area is covered mainly by pine and oak forests.

The relief is tabular, sometimes with steep slopes over 20%. The altitude is between 800 and 1100 m with peaks reaching 2500 m asl. The substrate is made of massive calcareous conglomerates. The climate is typical Mediterranean with a transition to subalpine at higher altitudes. The average temperature during winter is 5.1 °C and average summer temperature is 20 °C. The annual precipitation is 731 mm, with two peaks in spring and autumn. The soils in the region are stony and calcareous. Topsoils from 5 sites (CAN: Canalda, T: Torra, CS: Cogulers sunny, CO: Cogulers shaded and P: Prat) classified as Typic Ustifluvent/Orthofluvic Fluvisol (CAN); Typic Calciustept/Leptic Calcisol (T, CS); Typic Ustorthent/Calcaric Regosol (CO) and Typic Haplustept/Leptic Calcaric Cambisol (P) (SSS, 2014/IUSS, 2014), under three different natural forests and one meadow (Table 1) were studied and sampled for humus form determination. Cogulers sunny (CS) and shaded (CO) refer to the slope aspect.

The soil moisture, physical and soil-water characteristics of the soil profiles were previously studied by Loaiza-Usuga and Poch (2009), from which the main soil properties and information were obtained (Table 1).

2.2. Chemical analysis

The organic, organo-mineral and mineral horizons of the profiles were analyzed following the methods described by Porta et al. (1986). Seventeen soil samples (one per horizon, taking composite samples for OF and OH, see Table 1) were oven dried at 40 °C for 48 h prior to analyses. Samples from OL horizons were crushed in a mortar into thin powder, whereas the others were sieved through a 2 mm sieve following grinding. Carbonates were determined by the Bernard calcimeter. SOM in the OL horizons was analyzed by combustion, and in the rest of the samples it was analyzed by the Walkley-Black method (wet oxidation).

2.3. Humus sampling and classification

Observation and sampling of humus were conducted at the beginning of May 2015 in all selected study sites through the opening of a topsoil profile. Humus forms were classified following the European Humus Forms Reference Base (Zanella et al., 2011). During the process of classifying the sequence of organic horizons (OL, OF, OH), their continuity or discontinuity was taken into account as well as the macrostructure of the organo-mineral horizon (A) and the traces and types of soil faunal activity. At some points the litter horizon was not present or poorly developed, thus it was not sampled. Moreover, the sampling of OH horizons was done together with OF due to their thinness and gradual boundary with the overlying OF horizon.

2.4. SOM micromorphology

Micromorphological observations were conducted on 14 horizontal thin sections, 5 × 13 cm in size, following the methods of Benyarku and Stoops (2005). They were distributed as follows: 3 CS, 2 CO, 3 P, 2

Table 1
Characteristics of the sampled soils.

Site name and code	Canalda (CAN)				Cogulers shady (CO)				Cogulers sunny (CS)				Torra (T)			Prat (P)	
Vegetation	Natural riparian *Pinus nigra* forest				Natural not managed *Pinus nigra* and *Pinus sylvestris* mixed forest				Natural not managed *Pinus nigra* and *Pinus sylvestris* mixed forest				Natural not managed *Quercus ilex* forest			*Thymus vulgaris* high meadow	
Altitude, m asl	800				800				800				900			1100	
Soil type (SSS, 2014/IUSS 2014)	Typic Ustifluvent/Orthofluvic Fluvisol				Typic Ustorthent/Calcaric Regosol				Typic Calciustept/Leptic Calcisol				Typic Calciustept/Leptic Calcisol			Typic Haplustept/Leptic Calcaric Cambisol	
Humus form (Zanella et al., 2011)	Pachyamphi				Eumacroamphi				Eumesoamphi				Oligomull			Eumull	
Horizon	OL	OF + OH	A	Bw	OL	OF + OH	A	Bw	OL	OF + OH	A	Bw	OF	A	Bw	A	Bw
SOM (%) (1)	69.6	39.6	6.4	5	62.7	22.3	8.4	4.2	39.3	9.4	8.2	3.3	19.4	4.8	2.4	6.1	4.3
Carbonates (%)	—	32	32.5	34.1	—	32.6	36.4	40.6	—	33.4	30.8	38	5.3	6	8.3	6.3	7.4
pH (1:5, H_2O)		7.5	8	8.1		7.9	8.1	8.5		8	7.9	8.4	7.3	7.5	8	7.8	8.2
Bulk density (kg/m^3) (1)			1200				1100				1300			1300		1400	
Infiltration rate (mm/min) (2)			6				3.8				8.8			6.5		10.8	
Sand (%) (3)			45	50			43	33			55			58	53	53	53
Silt (%) (3)			45	37			44	44			32			27	29	37	34
Clay (%) (3)			10	13			13	23			13			15	18	10	13
Coarse fragments (weight %)			36				45.2				37.2			39.9		27.8	

1. Cylinder method, 2. Double ring infiltrometer, 3. Pipette method