Geoderma 264 (2016) 195–204

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Tree or soil? Factors influencing humus form differentiation in Italian forests

Anna Andreetta [a], Guia Cecchini [a], Eleonora Bonifacio [b], Roberto Comolli [c], Simona Vingiani [d], Stefano Carnicelli [a,*]

[a] Department of Earth Sciences, University of Florence, Piazzale Cascine 15, 50144 Firenze, Italy
[b] Dipartimento di Scienze Agrarie Forestali e Alimentari, Largo Paolo Braccini 2, 10095 Grugliasco, Torino, Italy
[c] Department of Agricultural Sciences, University of Naples Federico II, Portici, Napoli, Italy
[d] Department of Earth and Environmental Sciences, Milano Bicocca University, Piazza della Scienza, 1, 20123 Milano, Italy

ARTICLE INFO

Article history:
Received 21 July 2015
Received in revised form 26 October 2015
Accepted 1 November 2015
Available online 12 November 2015

Keywords:
Humus forms
Forest soils
Boosted regression trees

ABSTRACT

We aim to investigate the occurrence of forest humus forms (Moder, Amphi and Mull) in relation to environmental factors describing parent material, climate and tree species. Boosted regression trees (BRTs) were applied as modeling tool to analyze data of 238 plots of the BioSoil database covering the whole Italian forest territory. Though predictive ability was not very high, especially for the Amphi form, we could gain significant insight into factors controlling humus form differentiation. In the BRT analysis, the diversity of tree species was the most important predictor for Moder and Mull models and specific plant effects were evidenced. However, our results showed that the geographic distribution of Italian forest species was influenced by soil and climate conditions, partly explaining the high weight of tree species as factor. The importance of the soil nutritional status, due to parent material properties, in driving humus form differentiation was stated, highlighting the key role played by pH and calcium content, with the hitherto understated importance of phosphorus. This study further clarified the functioning of the still poorly understood Amphi form. Reduced effective soil volume (EfVol) combined with seasonality appeared to constrain pedofauna activity in otherwise favorable and nutrient rich systems, favoring the evolution of Amphi instead of Mull forms.

1. Introduction

Humus forms are the morphological expression of the pathways through which organic debris is either incorporated within the mineral topsoil or accumulated on top of it, to form ectorganic horizons (Ponge, 2003; Zanella et al., 2011). Numerous studies (see Ponge, 2003, 2013 for reviews) have established that humus forms result from composition, biomass, activity and behavior of soil meso- and micro-fauna; in turn, these biotic factors are controlled by nutrient availability and pedoclimate conditions (Wall et al., 2008). Nutrient availability is conditioned by soil fertility, but also by complex feedbacks involving soil microbiota, climate (Aerts, 2006) and plants (Hooper et al., 2000), through litter quality and quantity. Further feedbacks were identified in relation to forest stand life cycle and development (Mulder et al., 2013; Ponge and Chevalier, 2006; Schaefer and Schauermann, 1990; Scheu and Falca, 2000), influencing sign and magnitude of soil–plant nutrient transfers and, also, pedoclimate, through control on soil insolation and temperature exerted by stand density, LAI, continuity, etc. Extensive knowledge of these relationships brought Ponge (2003) to point to humus forms as keys to soil biodiversity and as indicators of ecosystem nutrient management strategies. More recently, humus forms have been found to be significant indicators of soil organic carbon storage (Andreetta et al., 2011; De Vos et al., 2015).

Existing data demonstrate how humus forms react punctually and rapidly to even small changes in soil nature, forest life cycle and forest management (Ponge et al., 2014) and this, given their easy experimental access, leads them to be proposed as practically useful keys to forest ecosystem surveys (Andreetta et al., 2011; Ponge et al., 2014). In more general terms, humus forms might have a potential to represent what soils, in their entirety, were expected to represent at the dawn of Pedology, i.e., a faithful "impression" of the environment (climate, biota, drainage) on a portion of the Earth's crust, and are responsive enough to change accordingly to environmental changes, thus offering an "integrating" view of ongoing environmental processes and their results.

Recently, analysis of the factors driving humus form differentiation has received increasing attention (Labaz et al., 2014; Ponge et al., 2011, 2014), but a basic issue in these analysis still requires more investigation. This is the relative weight of different kinds of factors, which may be alternately defined as "distal" (geology, climate, main tree species) vs. "proximal" (topsoil conditions, litter quality, microbiota) or as "truly independent" vs. "co-varying with humus". Ponge et al. (2011) showed that, for the

* Corresponding author.
E-mail address: stefano.carnicelli@unifi.it (S. Carnicelli).

http://dx.doi.org/10.1016/j.geoderma.2015.11.002
0016-7061/

French territory, geology and climate were the major determinants of humus forms, while the influence of forest canopies was negligible. Labaz et al. (2014) found that bedrock geology was the least influencing factor on humus forms, though they pointed out that this result was possibly influenced by relatively homogeneous geology in their sample. In Veneto (Northern Italy), Ponge et al. (2014) showed that the first canonical component of the projection of environmental variables could be interpreted as a composite factor embracing both geological, climate and soil gradients. They also showed that geology, climate, soil and vegetation exert a prominent influence on the distribution of humus forms.

This study takes advantage of the existence of a database covering the entirety of Italy as produced by the BioSoil project, to identify the environmental factors that mostly influence the occurrence of Moder, Amphi and Mull forms, treated in three separated models, at national level. Differently from comparable studies (Cools et al., 2014; Ponge et al., 2011; Ponge, 2013) the central aim of this study is not to select covariates for upscaling humus form observations at national or continental scale, but rather to get deeper into elucidating factors controlling humus form development, involved processes, and soil-humus feedbacks.

Studies that have previously applied the same model tool of the present work to determine the main factors explaining forest floor parameters such as C/N ratio (Cools et al., 2014) and C stock (De Vos et al., 2015), found that the diversity of tree species was clearly the most important predictor. Due to the close link between humus forms and carbon-related parameters (Andreetta et al., 2011, 2013a, 2013b; Bonifacio et al., 2011; De Nicola et al., 2014), we hypothesized that tree species were also associated with humus forms with high relative influence score. A specific objective was then to deeply analyze interactions between tree species and other environmental factors.

2. Materials and methods

2.1. Study area

Studied sites were made up by the Level I sites of the European ICP-Forests network, based on a 16 km × 16 km grid (Van Ranst et al., 1998), modified to 15 by 18 km in Italy. Sites are located across the whole Italian territory. Sampling was carried out according to standard ICP-Forests protocols (FSCC, 2006). At each site, composite samples were made from samples collected at five different points. Organic horizons OF and OH were sampled together by a 25 × 25 cm frame, as OFH layer, due to their inconsistent and, in some cases, small thickness. Mineral soil was sampled to represent fixed soil depth intervals (0–10 cm; 10–20 cm; 20–40 cm; 40–80 cm).

2.2. Humus form classification

Humus forms were classified according to the structure (IUSS Working Group WRB, 2006) of the first mineral horizon (Fao, 2006) and the presence/absence of the OH horizon. Classification corresponds to the higher hierarchical level of the European Humus Group proposal (Zanella et al., 2011), namely:

- Moder, with massive E-AE or bio-microstructured (peds Ø ≤ 1 mm) A horizon and organic horizons (OL, OF and OH) present;
- Amphi, with either bio-mesostructured (1 mm < Ø ≤ 5 mm) or bio-macrostructured (Ø > 5 mm) A horizon and the presence of organic horizons (OL, OF and OH);
- Mull, with bio-mesostructured (1 mm < Ø ≤ 5 mm) or bio-macrostructured (Ø > 5 mm) A horizon and OH horizon absent.

Due to their rare occurrence in Italy, Mor forms were not considered in this study.

2.3. Soil analysis

Analytical methods followed the ICP Forests Manual on sampling and analysis of soil (FSCC, 2006; ICP Forest, 2010). Specifically, soil pH was measured in the supernatant suspension of a 1:2.5 soil:water mixture, exchangeable cations were determined after exchange with an unbuffered 0.1 M $BaCl_2$ solution, while extractable elements were determined in *aqua regia* extracts.

2.4. Statistical analyses

In order to evaluate differences in all parameters between humus forms and tree species populations, a non-parametric statistical test (Kruskal–Wallis) was applied due to non-normal distribution of some properties.

2.4.1. Predictor variables

Selection of predictor variables was derived from the aforementioned main objectives. Environmental factors such as climate/pedoclimate, parent material and vegetation were selected as primary predictor variables as they have a one-way relation to humus forms, i.e. they are true “independent” variables. Tree species has been considered as partially dependent (Ponge et al., 2011) but there is a shortage of physical hypotheses on such dependence.

Climatic data were obtained from the WorldClim database (http://www.worldclim.org/current), a gridded climate database with the very high resolution of 30 arc sec (≈1 km^2 or ~0.09°). Data layers are generated through interpolation of average monthly climate measurements from 1950 to 1990, using thin plate splines with climate data from meteorological stations and a digital elevation model to spatially model various climatic variables (Hijmans et al., 2005). For our models, we selected those variables that may affect biological activities, such as the mean temperature of warmest quarter seen as climatic limiting factor, and the range between the precipitation of the wettest quarter and the precipitation of the driest quarter, to represent seasonality.

Data from the ICP Forests database do not allow full model estimates of soil water availability; as a proxy data, we used effective soil volume, i.e. the plant- (and earthworm-) available soil volume, in $m^3 \cdot m^{-2}$ of surface area, obtained by subtracting coarse fragment percent volume from soil depth. This parameter is referred to as EfVol.

Parent material (p.m.) was recorded according to FSCC (2006); this is a simplified way, often derived from available geological maps. As such, it is equivalent to “Geology” as in Ponge et al. (2011) and De Vos et al. (2015); it is one of the most useful variables for upscaling geographical distribution of humus forms and carbon stocks, but not as much to understand relationships between p.m. and humus forms. In the models, we included subsoil extractable Ca (sub.Ca), subsoil total P (sub.P) and pH (sub.pH) as properties indicative of p.m. These parameters were those obtained from the deepest samples. Sub.Ca and sub.P were included in the model after being log transformed to improve readability of the partial dependence plots.

The ‘Tree’ variable was taken from the dominant tree species recorded in ICP Forests crown condition survey (Lorenz et al., 2004). Frequency of individual tree species was quite variable. According to Cools et al. (2014), species were grouped to obtain groups of no less than 20 sites (Table 1). The most frequent species (Norway spruce, *Picea abies* (Pabi), European beech, *Fagus sylvatica* (Fsyl), sweet chestnut, *Castanea sativa* (Csat), Turkey oak, *Quercus cerris* (Qcer)) were analyzed as pure groups. Other species were grouped according to physiological and ecological similarities, as follows: Conif included all conifers except *P. abies*; this group is dominated by black pine (*Pinus nigra*) and European larch (*Larix decidua*). “Other” grouped all broadleaved trees except *F. sylvatica*, *C. sativa* and oaks. Qpub included all strictly deciduous oaks, i.e. excluding *Q. cerris*; this group is dominated by downy oak (*Quercus pubescens*). Med grouped all sclerophyll oaks, mostly holm oak (*Quercus ilex*); in this group we also included other Mediterranean species such as *Pinus halepensis* and *Eucalyptus* spp.