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Short communication

Humus forms affect soil susceptibility to water erosion in the Western Italian Alps

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ABSTRACT

Soil erosion depends mainly on its intrinsic vulnerability (soil erodibility), which is represented by the K factor of the RUSLE equation. Soil erodibility is strictly related to soil structure, which depends mostly on soil particle-size distribution and organic and inorganic binding agents. Soil erodibility can be estimated through soil aggregate stability measurements. However, the effects of different humus forms on soil erodibility and aggregate stability are poorly understood. In this study, we evaluate the influence of different humus forms on these parameters, and consequently on soil susceptibility to erosion. In the Western Italian Alps, 67 sites were selected on different substrata under common forest vegetation types. In all sites, soil profiles and humus forms were described and classified. Soil samples from the upper mineral horizons (A or E) were analysed (SOM content, water aggregate stability that measures aggregates loss) and soil erodibility K factor was calculated. The results showed that surface mineral horizons in soils with Mor humus were the most susceptible to erosion because they had the greatest values of K and aggregates loss, and their surface mineral horizons were characterized by the lowest SOM content. Conversely, surface mineral horizons in soils with Amphi, which had the greatest SOM content, were the least susceptible to erosion, as demonstrated by the lowest K values and limited aggregates loss. Mull and Moder forms showed intermediate behaviours. Despite a similar SOM content as Mulls, Moders showed a slightly greater aggregates loss. At low SOM content, the aggregates loss increased but it varied significantly among the humus forms. In Moders, SOM variations induced large changes in aggregates losses while Amphi forms were the least influenced by SOM. These results show that the intrinsic characteristics of humus forms, derived from the biological factors to which they are associated, influence soil erodibility and aggregate stability and consequently soil susceptibility to water erosion.

1. Introduction

Soil is a limited resource essential for life on Earth because it controls biological, hydrological, erosional and geochemical cycles (Ochoa et al., 2016), therefore it plays a fundamental role in sustaining ecosystem services, human life and ensuring environmental stability (e.g. Mol and Keesstra, 2012). However, climate changes are affecting world's soils, in particular, mountain soils, which are especially vulnerable to extreme meteorological events (e.g. Giannecchini et al., 2007) and are often located at the interface with densely settled areas which may be affected by sediment release from upstream erosion (e.g. Ziadat and Taimeh, 2013). In particular, mountain soils are very sensitive to water erosion, which represents a crucial problem affecting the landscape at different scales, because they are often shallow and their fertility is concentrated in the uppermost layers (e.g. García-Ruiz and Lana-Renault, 2011; Angassa, 2014).

The RUSLE equation (Revised Universal Soil Loss Equation; Renard et al., 1997), derived from USLE (Wischmeier and Smith, 1978), is one of the most widely accepted empirical methods to estimate soil erosion (e.g. Bazzoffi, 2006). It combines rainfall erosivity (R), soil erodibility (K), topography (LS), land cover (C), and protection practices (P), to estimate soil water erosion rates (A). Soil erodibility (K) represents the intrinsic susceptibility of soil particles to be detached and transported by surface runoff (Wischmeier and Smith, 1978). It depends on soil texture, structure, permeability and organic matter contents, and it is closely related to soil structure stability (e.g. Barthès et al., 1999; Tejada and González, 2006). On the other hand, erosion is expected to inhibit the development of soil structure (Poch and Antunez, 2010), as stable aggregates can build up only if natural or anthropogenic disturbances are not too frequent (Six et al., 2000) and, consequently,

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when losses of finer particles and cementing agents, such as soil organic matter (SOM) and inorganic binding agents, are limited (Shi et al., 2010) Aggregation can, therefore, be considered a proxy for soil erosion (Moncada et al., 2015; Stanchi et al., 2015b). Aggregate stability is also related to the processes of humus formation (Tisdall et al., 1978). In fact, in surface mineral horizons, the interactions between clay particles and SOM are favoured by the activity of organisms such as soil fauna, rootlets, fungi, and microorganisms, which mix decomposed or fragmented litter materials with mineral particles (Schaetzl and Thompson, 2015). Because of earthworm activity, Mull and Amphi A horizons tend to have high porosity and coarse granular aggregates (biomacro and biomeso structure; Zanella et al., 2011), where organic matter is tightly bound to mineral particles. Moder forms have biomicrostructured A horizons, where small organic pellets, produced by arthropods, are juxtaposed to clean mineral grains. A much weaker organomineral interaction is thus typical of A horizons in Moders. In AE and E horizons of Mors biological activity is inhibited by low pH value and strong leaching; thus, their structure can be platy or single grained depending on soil texture and other abiotic factors, such as wetting and drying and freezing and thawing cycles (Schaetzl and Thompson, 2015). These differences in structure among humus forms involve differences in other soil physical properties that affect erosion (Sevink et al., 1998). As soil susceptibility to erosion is largely determined by the occurrence of overland flows, Mor humus forms are considered to be more susceptible to erosion than Moder and Mull ones because of low infiltration capacity and high water repellence (Imeson et al., 1988; Sevink et al., 1989).

Although humus forms synthesize SOM contents and biological activity, only a few studies focused on the effect of humus type on soil vulnerability to erosion in mountain ecosystems. We hypothesized that, by combining soil biological activity, organic matter turnover and interaction with the mineral soil phases, humus forms might help in the assessment of soil vulnerability to erosion and aggregates loss. Each humus form might behave differently, not only because of differences in SOM content but also thanks to its intrinsic characteristics. The aim of the present study was therefore to evaluate the influence of different humus forms on soil erodibility and aggregate stability, and consequently on soil susceptibility to water erosion.

2. Materials and methods

2.1. Study area

We selected 67 sites under widespread forest vegetation types in the Western Italian Alps; 11 sites were in the Brienno municipality on the slopes around the Como Lake (CO, Lombardy), 26 in the Tanaro Valley (CN, Piemonte), and 30 in Aosta Valley (AO). The climatic conditions widely differ across the sites (mean annual precipitation ranging from ca. 500 to 2000 mm) and along the altitudinal range (range ca. 300–2200 m a.s.l.). Lithological substrates range from fine textured, weakly metamorphosed flysch (n = 5), to calcschists (n = 6), to silica-rich intrusive or metamorphic rocks (n = 15), to limestones and dolomites (n = 23), to ultramafic serpentinites (n = 8), to mixed glacial till or mafic amphibolites and gabbros (n = 10), thus covering much of the environmental variability characterizing the Western Alps (Table 1). The forest vegetation is dominated by *Castanea sativa* Mill. (n = 15); *Fraxinus ornus* L. – *Ostrya carpinifolia* Scop. – *Quercus pubescens* Willd. (n = 15); *Taxus baccata* L. – *Laurus nobilis* L. (n = 2), *Fagus sylvatica* L. (n = 5), *Pinus sylvestris* L. (n = 7), *Picea abies* L. or *Larix decidua* Mill. without ericaceous understory (n = 9), subalpine vegetation dominated by *Larix decidua* Mill., *Pinus cembra* L. or *Pinus uncinata* Mill. with *Rhododendron ferrugineum* L. (n = 14).

Table 1
Humus forms distribution in the selected soil profiles.

Vegetation[a]	Litology[b]	Soil type[c]	Humus forms
CS (15)	CRB	PH (1), UM (1), CM (1), LV (1), RG (1), AL (1);	Mull (5), Amphi (1)
	CLS	RG (1)	Mull (1)
	GNS	LV (1), CM (2)	Moder (3)
	MIX	CM (2)	Mull (1), Moder (1)
	PEL	CM (1), RG (1)	Amphi (1), Mull (1)
	SRP	CL (1)	Mull (1)
FO (15)	CRB	PH (7), RG (1), LP (1), CL (1);	Mull (8), Amphi (2)
	GNS	RG (2);	Mull (1), Amphi (1)
	MIX	RG (1), CM (1);	Mull (1), Amphi (1)
	SRP	RG (1)	Amphi (1)
LN (2)	CRB	LV (2)	Mull (1), Amphi (1)
FS (5)	CRB	LV (1), CH (1);	Amphi (2)
	GNS	LV (1), PZ (1);	Amphi (1), Mor (1)
	PEL	CM (1)	Amphi (1)
PS (7)	CLS	CL (1);	Mull (1)
	CRB	CM (1), PH (1), UM (1);	Amphi (3)
	GNS	CM (1);	Moder (1)
	PEL	AL (1);	Moder (1)
	SRP	CM (1)	Mull (1)
PL (9)	CLS	PH (1), CM (2);	Amphi (2), Mull (1)
	GNS	RG (3)	Mull (1), Amphi (1), Moder (1)
	MIX	PH (1), RG (2)	Mull (2). Moder (1)
SU (14)	CLS	CM (1)	Mor (1)
	GNS	PZ (4);	Moder (1), Mor (3)
	MIX	UM (1), CM (1), RG (1);	Moder (2), Mor (1)
	PEL	RG (1);	Mull (1)
	SRP	RG (1), CM (1), PZ (3)	Amphi (1), Moder (2), Mor (2)

[a] CS: *Castanea sativa* Mill.; FO: *Fraxinus ornus* L., *Ostrya carpinifolia* Scop. and *Quercus pubescens* Willd. association; LN: *Laurus nobilis* L. and/or *Taxus baccata* L.; FS: *Fagus sylvatica* L.; PS: *Pinus sylvestris* L.; PL: *Picea abies* L. and *Larix decidua* Mill. montane forests without Ericaceae; SU (subalpine vegetation): *Larix decidua* Mill., *Pinus Cembra* L. or *Pinus uncinata* Mill. with *Rhododendron ferrugineum* L. Values in brackets are the number of soil profiles.

[b] GNS: gneiss and silica-rich intrusive or metamorphic rocks; CRB: carbonates; MIX: moraine or mixed debris including portions of mafic materials; PEL: weakly metamorphosed pelitic rocks; SRP: serpentine; CLS: calcschists.

[c] Soil type code according to IUSS Working Group (2015).

2.2. Soil sampling, analysis, and statistics

A representative soil profile was described at all sites (n = 67), following the FAO guidelines (FAO, 2006) and the upper mineral horizons (A or E) were sampled. The soils were classified according to the WRB classification system (IUSS Working Group WRB, 2015), and humus forms following the morpho-functional criterion, based on holorganic layers thickness and A horizon properties (Zanella et al., 2011).

The soil samples were air-dried and sieved to < 2 mm. Total carbon (C) was measured using an elemental analyzer (CE instruments NA2100, Rodano, Italy). The carbonate content was evaluated by volumetric analysis of the carbon dioxide liberated by a 6 M HCl solution. The organic carbon (OC) was then calculated as the difference between total C measured by dry combustion and carbonate-C; SOM was calculated by multiplying the OC content by 1.72. WAS (Wet aggregate stability) was measured after 10 (WAS10) and 60 min (WAS60) using the method described by Zanini et al. (1998), and reported as% loss of aggregates.

The soil erodibility of the RUSLE model (K, $t\,ha\,h\,ha^{-1}\,MJ^{-1}\,mm^{-1}$) was calculated according to Renard et al. (1997):

$$K = 0.0013175\,[2.1\,M^{1.14} \times 10^{-4}(12-a) + 3.25(s-2) + 2.5(p-3)] \quad (1)$$

where *a* is SOM (%), *s* is the structure code, ranging from 1 to 4, based on aggregate shape and size assessed in the field, *p* is the permeability code (ranging from 1 to 6), obtained by estimating Ks according to

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