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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.

Keywords: aggregates stability, forest soils, RUSLE, soil erodibility.

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 Gonzalez, 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, 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 (tab. 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).

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 minutes (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):

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

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 Saxton et al. (1986) and classifying them into the RUSLE intervals as done in Stanchi et al. (2015b), and

$$M = \big(\text{silt }(\%) + \text{very fine sand }(\%)\big)\big(100 - \text{clay }(\%)\big) \qquad (2)$$

Differences in soil properties among humus forms were evaluated through a one-way analysis of variance (ANOVA) after Levene's homoscedasticity test, using Tukey HSD post-hoc to test differences among humus forms at a significance level of $p < 0.05$. Data analyses were performed using R (R Core Team 2015) and boxplots were produced with the multcomp R package.

3. Results

Humus forms showed the expected distribution (tab. 1, fig. 1), with Mulls dominating soils under broadleaf montane forests (most common form in *Castanea sativa* Mill., *Ostrya carpinifolia* Scop. and *Quercus* ssp. stands) independently from the parent material, while Amphis were detected mostly under beech (*Fagus sylvatica* L.) or spruce (*Picea abies* L.). Moders and Mors were common on acidic parent materials, with Moders under mixed subalpine or montane conifers/broadleaves tree vegetation and Mors under subalpine forests (mostly conifers with ericaceous understory). Climatic and morphologic conditions modulated the effects of vegetation and parent material, and originated the variability depicted in Table 1.

The SOM content of the surface mineral horizons was significantly different among humus forms (fig. 2a), with the highest contents in Amphis and Mulls and the lowest in Mors. Mor forms had the thickest organic layers (fig. 2b). The M factor (particle size parameter in K, eq. 2) did not show significant differences among humus forms (fig. 2c). Despite the textural similarity, Mors had a significantly higher erodibility (K) than Amphis, while Mulls and Moders showed intermediate values (fig. 2d). The loss of aggregates after 10 minutes (WAS10) was higher in Mor surface mineral horizons than in those of other humus forms (fig, 2e), while after 60 minutes (WAS60) a more differentiated situation was found with greater losses in Mors than in Amphis, with Moders and Mulls behaving intermediately (fig. 2f).

Aggregate losses decreased with increasing SOM contents in Mull, Moder and Amphi forms, but with different trends (fig. 3a). In fact, the best fitting regression curves ($p < 0.01$) between SOM and WAS60 were logarithmic for Mulls and Moders, linear in Amphis. The regression curve for Moders was the steepest. Surface mineral horizons of Mor forms were characterized by low SOM contents (< 4% in E or EA horizons), and no correlation between WAS60 and SOM was observed. (fig. 3a).

The K factor was significantly correlated with SOM content; the regression lines between the two properties were similar in the different humus forms (fig 3b). WAS60 showed a significant positive linear correlation with K (fig. 3c) in Moders, while the regressions were less significant and the determination coefficients lower in Mulls and Amphis. In both cases, no significant correlation was found for Mors.

4. Discussion

Humus forms were characterized by a different SOM content, which was reflected in the K factor (eq. 1), despite the similarity of the texture (M) parameter. In fact, Amphis were characterized by the lowest intrinsic erodibility and Mulls and Moders showed intermediate values, lower than Mors. The relationships between SOM and K were however similar for all humus forms (fig. 3b), thus indicating no deviation from the expected quantitative relationship. Different humus forms have different C storage capacities (De Vos et al., 2015, Andreetta et al., 2011, Bonifacio et al., 2011) and are, therefore, related to varying soil erodibility, thus playing a key role in maintaining soil quality, biodiversity and ecosystem services (Brevik et al., 2015).

Amphis, Mulls and Moders were also characterized by a higher aggregate stability than Mors (fig. 2d), and again soil texture can be excluded as a relevant factor for the different aggregate stability. However, in this case, no general relationship between WAS and SOM could be found, suggesting that the observed differences among humus forms are not only related to differences in the amount of SOM. In particular, because of the slope of the logarithmic curves, at SOM contents greater than 5-6%, the overall aggregate loss was negligible (fig. 3a) while below this threshold it strongly increased. A similar threshold was reported by Boix-Fayos et al. (2001). At low SOM content, Moder humus lost more aggregates than Amphi and Mull, i.e., the structure of Moder was less resistant, as shown by the steeper regression curve (fig. 3a). The biomicrostructured A horizons in soils with Moder, created by small arthropods, were not able to resist water effects when the SOM content is insufficient. On the contrary, the less steep, linear regression line indicated that Amphi aggregates have a weaker dependence from SOM contents, likely because of the efficiency of earthworm activity in creating stable humus–clay–iron complexes (Sevink et al., 1998). Thus, besides SOM, biological processes typical of different humus forms likely influenced aggregates stabilization.

These results are further reinforced by the observation of the relationship between WAS60 and K (fig. 3c). The highest regression coefficient between the two parameters was found in Moders, showing therefore a good agreement between actual structure stability and calculated erodibility. The low regression coefficients for Mulls and Amphis suggest a relative uncoupling of K and WAS60, likely related to an effective resistance improvement in earthworm-affected soil materials.

The weaker aggregate stability and higher erodibility of surface mineral horizons of Mors were expected, as this humus form is associated with eluvial E or transitional AE horizons immediately below the organic layers (Zanella et al., 2011). These horizons have low organic matter (fig. 2a) and mineral binding agent contents, such as Fe oxides and clays, and are, therefore, characterized by a greater erodibility (e.g. Stanchi et al., 2015a). Soils with Mor humus are indeed often acknowledged as the most vulnerable to surface erosion (Imeson et al., 1988, 1992; Sevink et al., 1989, 1992). However, Mor existence itself is a strong indicator of weak actual erosion, because of the time required for the formation of podzolic E or AE horizons: in the Alpine range they were found to develop in 70 years locally (D'Amico et al., 2014), but the full formation of Podzols requires around 600-3000 years (Egli et al., 2006). It is thus possible that the great thickness of organic layers typical of Mor forms mitigates its intrinsic vulnerability, thus permitting E or AE horizons development. Vegetation litter layers are considered an effective cover above soil surface that prevent soil erosion, because they protect soil from raindrop splash by intercepting rainfall, therefore reducing runoff and significantly decreasing soil loss (Li et al., 2014). The thick organic layer of Mor humus could thus act through some physical protection of the mineral surface horizon, a sort of "cushion" effect that prevents soil aggregate destruction by dissipation of the kinetic energy of rainfall, despite the low structural stability.

5. Conclusions

Results deriving from field description, soil analysis and statistical elaborations showed that aggregate stability and soil susceptibility to water erosion varied with humus forms. However, while soil erodibility is strictly linked to SOM contents, the differences in aggregate stability were also related to other intrinsic properties. The surface mineral horizons of soils with Amphis were the most stable, while Moders had a much lower aggregate stability than Mulls, despite the similar SOM contents. The specificity of humus forms was particularly visible below a SOM content threshold of 5-6%, when the differences in biological activity likely became more important.

Humus forms may be viewed as a synthetic index combining soil biological activity and interaction between organic matter and mineral phases. Therefore, they can give important information on soil vulnerability to losses of aggregates and erosion. However, in order to improve the obtained results, further field investigations and measurements are necessary.

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Figures

Fig. 1. Humus form profiles: Mull (a) under spruce (*Picea abies* L.) on calcschists (CLS in table 1) in Aosta Valley (AO), Amphi (b) under beech (*Fagus sylvatica* L.) forest on dolomite (CRB) in the Tanaro Valley (CN), Moder (c) under Scots pine (*Pinus sylvestris* L.) on quartzite (GNS) in the Tanaro Valley (CN), Mor (d) under subalpine Stone pine (*Pinus cembra* L.) forest on gneiss (GNS) in the Aosta Valley (AO).

Fig. 2. Boxplots (n=67) of SOM content (a), O thickness (b) and M factor (c), K RUSLE factor (d), WAS 10 (e), WAS 60 (f) values in the mineral horizon of humus forms. Letters indicate statistically significant differences.

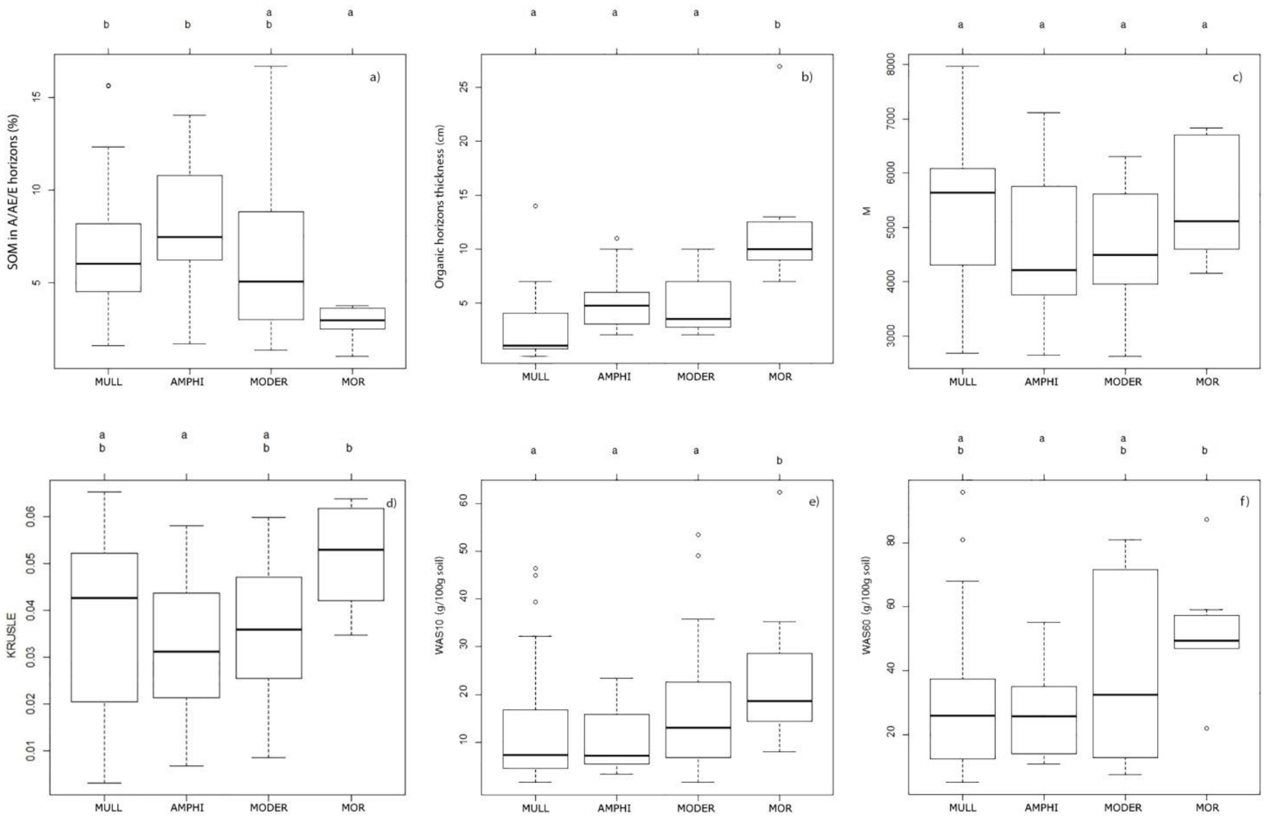
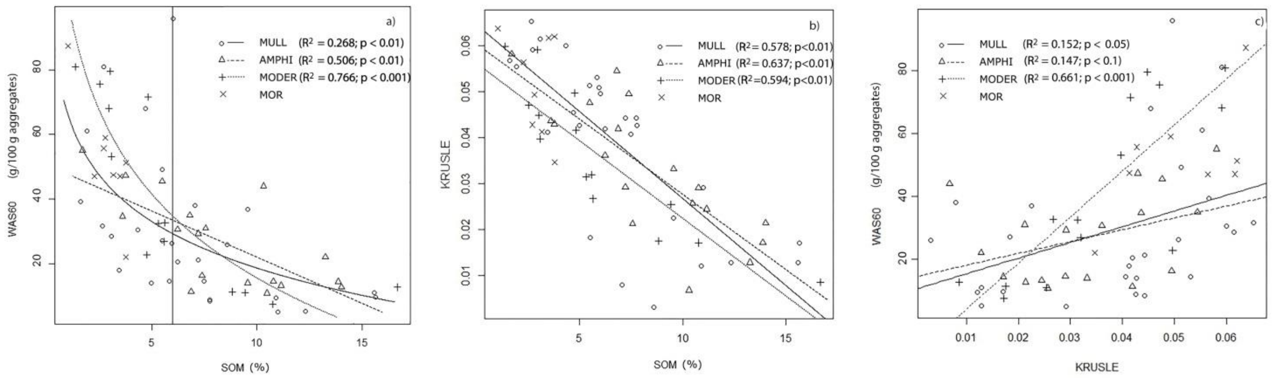


Fig. 3. Correlation and regression curves between SOM and WAS 60 (a), SOM and K RUSLE (b), K RUSLE and WAS 60 (c) of the different humus forms; regression lines for Mor forms are not shown.



Table

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).