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1 **Humus Forms affect soil susceptibility to water erosion in the Western Italian**

2 **Alps**

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9 10 **Abstract**

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

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

31

32 **1. Introduction**

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

42 The RUSLE equation (Revised Universal Soil Loss Equation; Renard et al., 1997), derived from USLE
43 (Wischmeier and Smith, 1978), is one of the most widely accepted empirical methods to estimate soil erosion
44 (e.g. Bazzoffi, 2006). It combines rainfall erosivity (R), soil erodibility (K), topography (LS), land cover (C),
45 and protection practices (P), to estimate soil water erosion rates (A). Soil erodibility (K) represents the intrinsic
46 susceptibility of soil particles to be detached and transported by surface runoff (Wischmeier and Smith, 1978).
47 It depends on soil texture, structure, permeability and organic matter contents, and it is closely related to soil
48 structure stability (e.g. Barthès et al., 1999; Tejada and Gonzalez, 2006). On the other hand, erosion is expected
49 to inhibit the development of soil structure (Poch and Antunez, 2010), as stable aggregates can build up only
50 if natural or anthropogenic disturbances are not too frequent (Six et al., 2000) and, consequently, when losses
51 of finer particles and cementing agents, such as soil organic matter (SOM) and inorganic binding agents, are
52 limited (Shi et al., 2010) Aggregation can, therefore, be considered a proxy for soil erosion (Moncada et al.,
53 2015; Stanchi et al., 2015b). Aggregate stability is also related to the processes of humus formation (Tisdall et
54 al., 1978). In fact, in surface mineral horizons, the interactions between clay particles and SOM are favoured
55 by the activity of organisms such as soil fauna, rootlets, fungi, and microorganisms, which mix decomposed
56 or fragmented litter materials with mineral particles (Schaetzl and Thompson, 2015). Because of earthworm
57 activity, Mull and Amphi A horizons tend to have high porosity and coarse granular aggregates (biomacro and
58 biomeso structure; Zanella et al., 2011), where organic matter is tightly bound to mineral particles. Moder

59 forms have biomicrostructured A horizons, where small organic pellets, produced by arthropods, are
60 juxtaposed to clean mineral grains. A much weaker organomineral interaction is thus typical of A horizons in
61 Moders. In AE and E horizons of Mors biological activity is inhibited by low pH value and strong leaching;
62 thus, their structure can be platy or single grained depending on soil texture and other abiotic factors, such as
63 wetting and drying and freezing and thawing cycles (Schaetzl and Thompson, 2015). These differences in
64 structure among humus forms involve differences in other soil physical properties that affect erosion (Sevink
65 et al., 1998). As soil susceptibility to erosion is largely determined by the occurrence of overland flows, Mor
66 humus forms are considered to be more susceptible to erosion than Moder and Mull ones because of low
67 infiltration capacity and high water repellence (Imeson et al., 1988; Sevink et al., 1989).
68 Although humus forms synthesize SOM contents and biological activity, only a few studies focused on the
69 effect of humus type on soil vulnerability to erosion in mountain ecosystems. We hypothesized that, by
70 combining soil biological activity, organic matter turnover and interaction with the mineral soil phases, humus
71 forms might help in the assessment of soil vulnerability to erosion and aggregates loss. Each humus form might
72 behave differently, not only because of differences in SOM content but also thanks to its intrinsic
73 characteristics. The aim of the present study was therefore to evaluate the influence of different humus forms
74 on soil erodibility and aggregate stability, and consequently on soil susceptibility to water erosion.

75

76 **2. Materials and Methods**

77 2.1. Study area

78 We selected 67 sites under widespread forest vegetation types in the Western Italian Alps; 11 sites were in the
79 Brienno municipality on the slopes around the Como Lake (CO, Lombardy), 26 in the Tanaro Valley (CN,
80 Piemonte), and 30 in Aosta Valley (AO). The climatic conditions widely differ across the sites (mean annual
81 precipitation ranging from ca. 500 to 2000 mm) and along the altitudinal range (range ca. 300-2200 m a.s.l.).
82 Lithological substrates range from fine textured, weakly metamorphosed flysch (n=5), to calcschists (n=6), to
83 silica-rich intrusive or metamorphic rocks (n=15), to limestones and dolomites (n=23), to ultramafic
84 serpentinites (n=8), to mixed glacial till or mafic amphibolites and gabbros (n=10), thus covering much of the
85 environmental variability characterizing the Western Alps (tab. 1). The forest vegetation is dominated by
86 *Castanea sativa* Mill. (n=15); *Fraxinus ornus* L. - *Ostrya carpinifolia* Scop. - *Quercus pubescens* Willd.

87 (n=15); *Taxus baccata* L.- *Laurus nobilis* L. (n=2), *Fagus sylvatica* L. (n=5), *Pinus sylvestris* L. (n=7), *Picea*
88 *abies* L. or *Larix decidua* Mill. without ericaceous understory (n=9), subalpine vegetation dominated by *Larix*
89 *decidua* Mill., *Pinus cembra* L. or *Pinus uncinata* Mill. with *Rhododendron ferrugineum* L. (n=14).

90

91 2.2. Soil sampling, analysis, and statistics

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

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

102 The soil erodibility of the RUSLE model ($K, t\ ha\ h\ ha^{-1}\ MJ^{-1}\ mm^{-1}$) was calculated according to Renard et al.
103 (1997):

$$104 K = 0.0013175 [2.1M^{1.14} \times 10^{-4}(12 - a) + 3.25(s - 2) + 2.5(p - 3)] \quad (1)$$

105 where a is SOM (%), s is the structure code, ranging from 1 to 4, based on aggregate shape and size assessed
106 in the field, p is the permeability code (ranging from 1 to 6), obtained by estimating K_s according to Saxton et
107 al. (1986) and classifying them into the RUSLE intervals as done in Stanchi et al. (2015b), and

$$108 M = (\text{silt (\%)} + \text{very fine sand (\%)})(100 - \text{clay (\%)}) \quad (2)$$

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

113

114 3. Results

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

122 The SOM content of the surface mineral horizons was significantly different among humus forms (fig. 2a),
123 with the highest contents in Amphis and Mulls and the lowest in Mors. Mor forms had the thickest organic
124 layers (fig. 2b). The M factor (particle size parameter in K, eq. 2) did not show significant differences among
125 humus forms (fig. 2c). Despite the textural similarity, Mors had a significantly higher erodibility (K) than
126 Amphis, while Mulls and Moders showed intermediate values (fig. 2d). The loss of aggregates after 10 minutes
127 (WAS10) was higher in Mor surface mineral horizons than in those of other humus forms (fig. 2e), while after
128 60 minutes (WAS60) a more differentiated situation was found with greater losses in Mors than in Amphis,
129 with Moders and Mulls behaving intermediately (fig. 2f).

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

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

139

140 **4. Discussion**

141 Humus forms were characterized by a different SOM content, which was reflected in the K factor (eq. 1),
142 despite the similarity of the texture (M) parameter. In fact, Amphis were characterized by the lowest intrinsic

143 erodibility and Mulls and Moders showed intermediate values, lower than Mors. The relationships between
144 SOM and K were however similar for all humus forms (fig. 3b), thus indicating no deviation from the expected
145 quantitative relationship. Different humus forms have different C storage capacities (De Vos et al., 2015,
146 Andreetta et al., 2011, Bonifacio et al., 2011) and are, therefore, related to varying soil erodibility, thus playing
147 a key role in maintaining soil quality, biodiversity and ecosystem services (Brevik et al., 2015).

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

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

166 The weaker aggregate stability and higher erodibility of surface mineral horizons of Mors were expected, as
167 this humus form is associated with eluvial E or transitional AE horizons immediately below the organic layers
168 (Zanella et al., 2011). These horizons have low organic matter (fig. 2a) and mineral binding agent contents,
169 such as Fe oxides and clays, and are, therefore, characterized by a greater erodibility (e.g. Stanchi et al., 2015a).
170 Soils with Mor humus are indeed often acknowledged as the most vulnerable to surface erosion (Imeson et al.,

171 1988, 1992; Sevink et al., 1989, 1992). However, Mor existence itself is a strong indicator of weak actual
172 erosion, because of the time required for the formation of podzolic E or AE horizons: in the Alpine range they
173 were found to develop in 70 years locally (D'Amico et al., 2014), but the full formation of Podzols requires
174 around 600-3000 years (Egli et al., 2006). It is thus possible that the great thickness of organic layers typical
175 of Mor forms mitigates its intrinsic vulnerability, thus permitting E or AE horizons development. Vegetation
176 litter layers are considered an effective cover above soil surface that prevent soil erosion, because they protect
177 soil from raindrop splash by intercepting rainfall, therefore reducing runoff and significantly decreasing soil
178 loss (Li et al., 2014). The thick organic layer of Mor humus could thus act through some physical protection
179 of the mineral surface horizon, a sort of “cushion” effect that prevents soil aggregate destruction by dissipation
180 of the kinetic energy of rainfall, despite the low structural stability.

181

182 **5. Conclusions**

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

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

194

195 **6. References**

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285

286 **Figures**

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



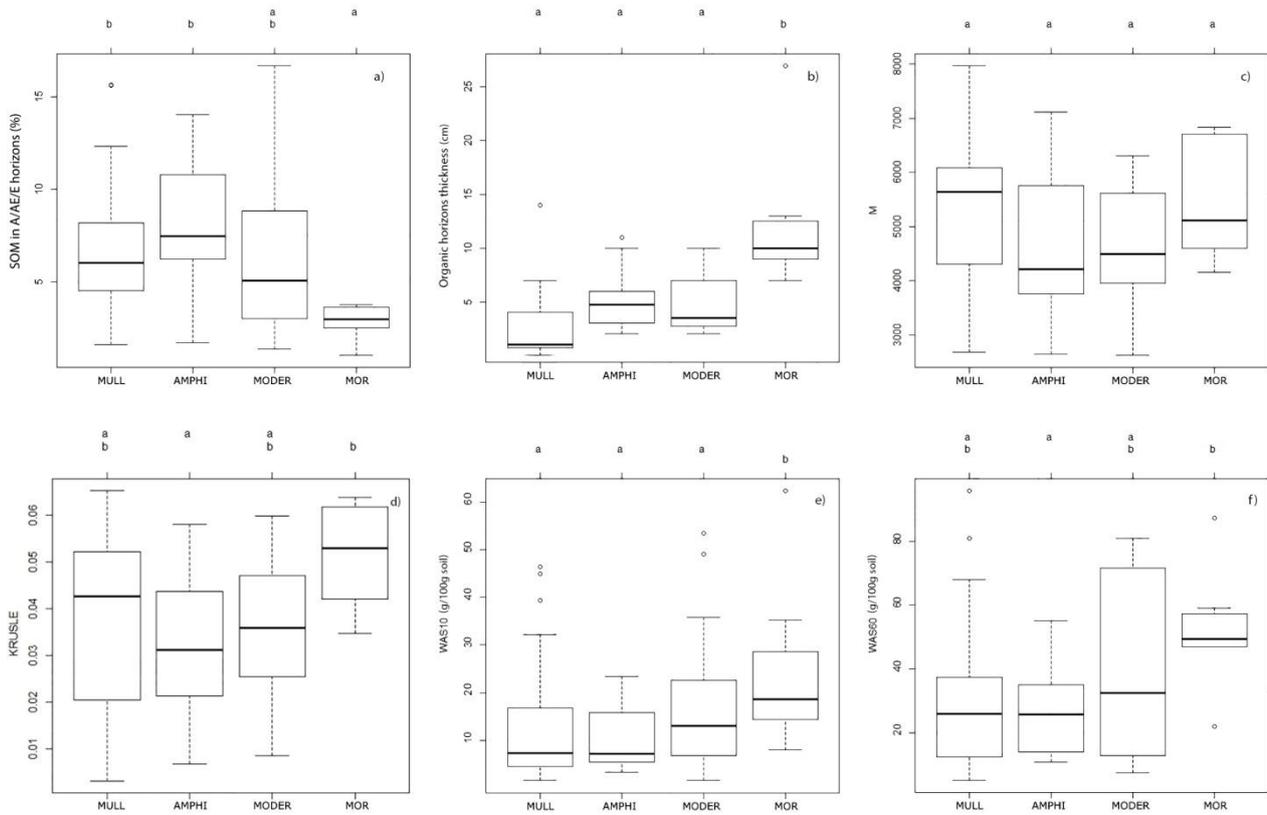
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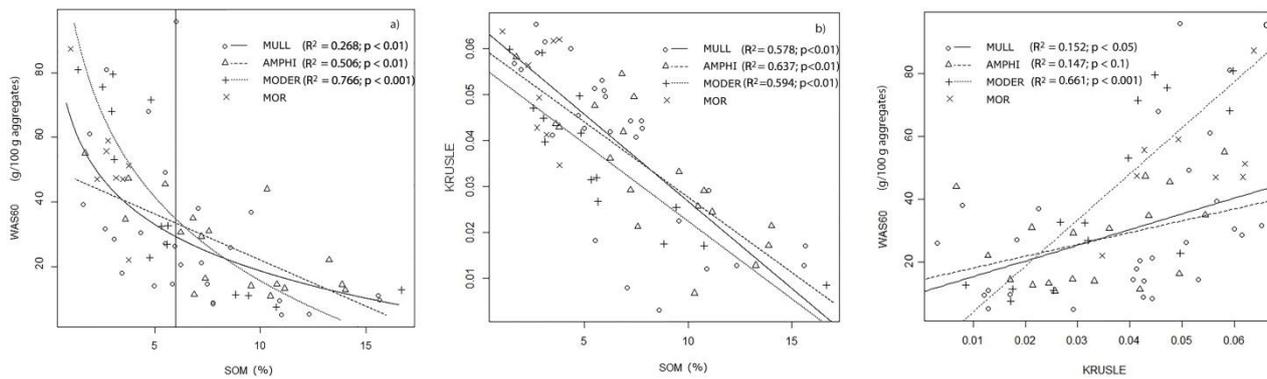
295 Fig. 2. Boxplots (n=67) of SOM content (a), O thickness (b) and M factor (c), K RUSLE factor (d), WAS 10 (e), WAS 60 (f) values in the mineral horizon of humus forms. Letters indicate statistically significant differences.



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299 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.

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307 **Table**

308 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)

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

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

316 ^c Soil type code according to IUSS Working Group (2015).

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