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Humus Forms in the Forest-Alpine Tundra Ecotone at Stillberg (Dischmatal, Switzerland): Spatial Heterogeneity and Classification

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Abstract

In the forest-alpine ecotone at Stillberg (Dischmatal/Switzerland) the morphology of humus forms and the spatial variability of organic layer properties were investigated. At northeast-exposed gully sites mulls with high acidity in the A-horizon occur. They were classified after the Canadian classification of humus forms as Rhizomulls. Mors occur on ridges and on their east- and north-exposed aspects. They can be differentiated by the ratio between the thickness of the F-horizon and the combined thickness of the F- and H-horizon. The relative thickness of the F-horizon increases significantly in the order: east aspects < ridges < north aspect. The humus forms of the east aspects and the ridges were classified as Humimors and those of the north aspects as Hemimors. The Canadian classification was suitable to describe the properties of the horizons and to classify the humus forms. The results of a grid sampling at the study sites and the computation of nonergodic correlograms show that the spatial variability of organic-layer thickness, bulk density, and moisture is high (CV around 50%), with a pronounced small-scale heterogeneity (range usually below 2 m and more than 50% variability occurs within 0.3 m). Only 33% of the variance of organic-layer thickness were explained by site and vegetation structure, but in spite of the low percentage both proved to be a significant factor. In the forest-alpine tundra ecotone about 30 to 35 soil samples per site are needed for a reliable estimation of the mean of the organic-layer thickness.

Introduction

The forest-alpine tundra ecotone of the Central Alps is characterized by an extreme patchiness of both dwarf shrub-heath plant communities and humus forms. At Stillberg and at other comparable locations in the Alps the humus forms raw humus or moder are very common (Pallmann and Haffter, 1933; Neuwinger and Czell, 1959; Larcher, 1977; Blaser, 1980). For forest sites on limestone in the northern Alps, Bochter (1984) developed a classification of humus layers. Frequently, the description of the humus horizons, however, is not very detailed and there is not any specific classification for humus forms in high mountain soils (Beyer, 1996). The humus profile is a sensitive indicator for site conditions and microbial activity. Therefore, a more detailed description of humus horizons in the forest-alpine tundra ecotone is needed. Compared to our understanding of soils, investigations on the microscale spatial variability of humus horizons are lacking.

The aims of the present study are

(1) to determine the spatial variability of the thickness of the organic horizons at meso- and microscale (10–1000 m, 0.2–2 m, respectively);
(2) to determine the spatial variability of physical properties of the organic horizons and the sample size appropriate for a reliable estimation;
(3) to examine the influence of topography and plant cover on the thickness of the organic horizons;
(4) to give a detailed morphological description of typical humus forms by using the Canadian classification of forest humus forms (Green et al., 1993), which has been applied in a wide range of ecosystems.

Study Area and Sites

The research area, Stillberg Alp, is located in Switzerland on a northeast-exposed steep slope of the Dischmatal near Davos (09°52′E, 46°47′N; 2000–2200 m a.s.l.) (Fig. 1). The climate is characterized by an annual precipitation of 1047 mm with a maximum in summer (July: 131 mm) and a wide annual temperature amplitude (15.2°C). The mean annual temperature is 1.4°C (Schönenberger and Frey, 1988). Parent material of the research area is gneiss. The slope is characterized by ridges and gullies (Fig. 2). Microtopography is the main factor determining the microclimatic conditions and correspondingly the distribution of plant communities and humus forms (Kuoch, 1970; Blaser, 1980; Schönenberger and Frey, 1988). The relationship between the site conditions (microclimate, plant cover, and soils) are demonstrated by Table 1.

Methods

Investigations were made at three plots (9 m × 3 m) on each of the four study sites (gully, east aspect, ridge, north aspect) (Fig. 2) and at grid-cells on two plots each of the east aspects, ridges and north aspects in June 1996 (Fig 3).

The thickness of the organic layers (F- and H-horizons) was measured perpendicular to surface at 20 small pits (20 cm × 20 cm) randomly distributed on each plot. The distance between the pits was at least 1 m. Differences in organic layer thickness and the ratio F-/H-horizon thickness between the sites were tested by nonparametric one-way ANOVA (Kruskal-Wallis Test) (cf. Sachs, 1992). Humus forms were described and classified fol-

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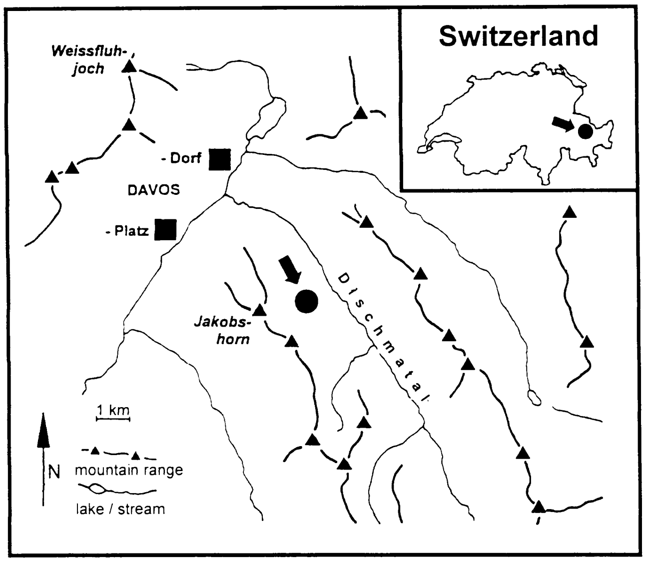


FIGURE 1. Location of the study area.

lowing the guidelines of the Canadian classification from Green et al. (1993). Colors were determined by the Revised Standard Soil Color Charts (Oyama and Takehara, 1970).

Two soil samples, each consisting of 10 randomly distributed subsamples, were taken from the A-horizons at the gully sites and the F- and H-horizons at the other sites. All chemical analyses refer to fine soil (<2 mm). The following methods were used: (1) Organic carbon and total nitrogen content by elemental analyzer (Carlo Erba NA 1500); and (2) pH by a 1:5 dilution of soil and 0.01 *M* $CaCl_2$, using a glass electrode (Sparks, 1996).

The organic layers were sampled on a regular 15 × 15 grid (225 grid points) with 0.2 m grid point distance (grid cell 0.2 × 0.2 m) on two of the three plots per study site (Fig. 3). The gully sites were excluded from grid sampling because they do not have much organic layer. The grid was positioned so that the middle columns of the grid were parallel to the slope of the plot. At each grid point the thickness of the organic layer was determined perpendicular to the surface. Vegetation at each grid cell was classified according to the number of strata (cover >50%), resulting in four structural vegetation types:

(1) two shrub strata (*Rhododendron ferrugineum* L., *Vaccinium* spp.);
(2) one shrub stratum (only *Vaccinium* spp.);
(3) only moss-layer (mainly *Hylocomium splendens*);
(4) only lichens or bare soil.

On the main diagonals, the middle row and the middle column of each one of the two grids per study site (Fig. 3) soil cores were taken from the organic layer (4 cm diameter) to determine bulk density (Doran and Mielke, 1984), dry mass per surface area and gravimetric water content.

The grid sampling results in 550 measurements of organic layer thickness (225/plot) and 114 measurements (57/plot) of the other variables per study site. Univariate statistics were computed with SPSS 6.1 program package. Coefficients of variation and median deviations were computed according to standard statistical formulae (cf. Sachs, 1992). A two-way ANOVA (site type × vegetation type) was executed for the variable "thickness of organic layer." Instead of using the significance value from this ANOVA the Friedmann-Test was applied for testing the factors effects, by putting the medians for each factor combination (site type × vegetation type) into the Friedmann-Scheme (Sachs, 1992). Thus the problem of pseudoreplication *sensu* Hurlbert (1984) was avoided.

Before geostatistical analysis the variables thickness, bulk-density, and dry mass per area were log-transformed $Y = \log_{10}(X + q)$, with the parameter q being estimated graphically (Kneese and Thews, 1960). The estimation of the parameter q has been accepted, if the skewness of the transformed variable was insignificant. The variable "vegetation type" was indicator-transformed to the variable X_V (Rossi et al., 1992; Smith et al., 1994), with "$X_V = 1$" meaning "vegetation type V present" and $X_V = 0$ meaning "Vegetation type V absent." Then standardized, nonergodic correlograms were computed for each variable and each grid, using the formula

$$\hat{\rho}(h) = \frac{1}{N(h)} \cdot \frac{\sum_{i=1}^{N(h)} \{[z(x_i) - m_{-h}] \cdot [z(x_i + h) - m_{+h}]\}}{s_{-h} \cdot s_{+h}} \quad (1)$$

FIGURE 2. Study sites (June 1996). 1: NE-exposed gully; 2: E-aspect of a ridge; 3: NE-exposed ridge; 4: N-aspect of a ridge.

TABLE 1

Vegetation, soil types and microclimate (during the growing season) of the study sites (data from: Kuoch (1970), Nägeli (1971), Turner et al. (1975), Blaser (1980); classification: Eidgenössische Forschungsanstalt für landwirtschaftlichen Pflanzenbau (1992), USDA Soil Survey Staff (1998))

No. (Fig. 1) site	1 Gully NE—exposed	2 East aspect E—exposed	3 Ridge NE—exposed	4 North aspect N—exposed
Plant community	*Calamagrostis villosae*	*Junipero-Arctostaphyletum juniperetosum*	*Empetro-Vaccinietum cladonietosum*	*Empetro-Vaccinietum hylocomietosum*
Average wind speed ([m/s]) (1 m above surface, daily mean between 6.00 h–18.00 h)	1.6	1.7	2.1	1.9
Irradiation ([kcal/m²]) (sum within the growing season)	58	67	58	48
Soil temperature [°C] (depth: 8 cm, mean of the growing season)	7.0	9.3	6.8	6.1
Soil types:				
a) Swiss classification	Podsol	Rohhumoser Podsol	Rohhumoser Podsol	Rohhumoser Podsol
b) US Soil Taxonomy	Entic Haplocryod	Typic Haplocryod	Lithic Humicryod	Typic Haplocryod

of Rossi et al. (1992), where $z(x_i)$ and $z(x_i + h)$ are two data points separated by the lag-vector *h*, $N(h)$ is the number of points separated by lag *h*, and m_{-h} and m_{+h} are the mean of the points that correspond to the tail and the head of the lag-vector *h*, respectively. s_{-h} and s_{+h} are defined accordingly, with '*s*' having the meaning of standard deviation instead of the mean. Then $\hat{\rho}(h)$ is the empirical, nonergodic correlogram, and $1 - \hat{\rho}(h)$ is the nonergodic correlogram expressed as variogram (Rossi et al., 1992). The difference between the nonergodic correlogram and the usual variogram is that the correlogram accounts for any differences (e.g., trends) of local means and standard deviations. For the variables 'thickness' of organic layer and 'indicator-transformed vegetation type' correlogram values were computed for the *h*-vector angles 0°, 45°, 90°, and 135° (expressed counter-clockwise from isohypse) and the lag distances 0.2 m, $\sqrt{2}$ 0.2 m, 0.4 m, $\sqrt{2}$ 0.4 m, etc. No tolerance for lag distance and angle was accepted (Isaaks and Srivastava, 1989). The spatial distribution of the other variables (bulk density, dry mass per area, and water content) was analyzed by means of omnidirectional correlograms with lag distance increments of 0.2 m and 0.1 m tolerances. The number of data pairs per lag vector always was

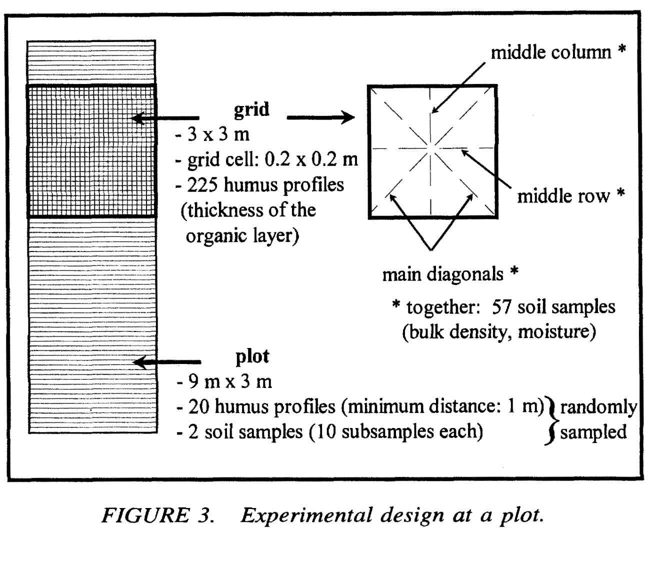


FIGURE 3. Experimental design at a plot.

between 64 and 210 and thus exceeded the generally claimed 30 to 50 pairs per lag vector (Rossi et al., 1992). In order to obtain an overview about the overall spatial heterogeneity of the vegetation structure we summarized the correlograms of the four indicator-transformed vegetation-type variables by calculating the arithmetic mean of the four $\hat{\rho}(h)$-values per lag vector *h*, i.e.

$$\hat{\hat{\rho}}(h) = \frac{1}{M} \cdot \sum_{1}^{M} \hat{\rho}_i(h) \qquad (2)$$

where $\hat{\rho}_i(h)$ is the empirical correlogram value for the vegetation-type variable *i* and the lag vector *h*, and *M* is the number of vegetation types present in the corresponding grid.

After computation of the empirical correlograms (expressed as variograms) two authorized, omnidirectional variogram models were fitted to the data: the often utilized spherical model (e.g. Isaaks and Srivastava, 1989; Munoz-Pardo et al., 1990; Rossi et al., 1992; Jackson and Caldwell, 1993; Robertson et al., 1993),

$$[1 - \rho(h)] = \begin{cases} C_0 + C_1 \cdot \left[1.5 \cdot \frac{h}{a} - 0.5 \cdot \left(\frac{h}{a}\right)^3\right] & \text{for } h \leq a \\ C_0 + C_1 & \text{for } h > a \end{cases} \qquad (3)$$

and the unbounded linear model (Webster and Oliver, 1990),

$$(1 - \rho(h)) = C_0 + b \cdot h \qquad (4)$$

In the spherical model, C_0 is the nugget effect, C_1 is the structural variance, $C_0 + C_1$ is the sill and *a* is the range of spatial autocorrelation. The linear model does not assume any sill, but the nugget effect also is C_0. The fitting procedure was performed by nonlinear regression (*proc* NLIN, SAS Institute 1982), using the method of weighed least squares (Cressie, 1985). The model which reached the higher coefficient of determination was then considered to be the "valid" one.

Results

The humus profiles of the east aspects of the ridges are characterized by a predominant H-horizon which comprises usually more than 75% of the combined thickness of the F- and H-horizons (F-horizon: partly decomposed plant residues predom-

TABLE 2

Chemical characteristics of the study sites

Parameter	Gully (A-horizon)	East aspect (F-horizon and H-horizon)	Ridge (F-horizon and H-horizon)	North aspect (F-horizon and H-horizon)
pH ($CaCl_2$)	3.6	3.0	3.0	3.1
C_{org} [%]	5.65	45.26	40.31	43.55
N_t [%]	0.37	1.71	1.36	1.59
C/N	15	26	30	28
C_{org} [kg m^{-2}]	1.25	6.75	5.82	4.05

inate over fine substances; H-horizon: fine substances predominate, plant structures are generally not recognizable). At the ridges the relative thickness of the F-horizon is greater but in the most cases below 50%. Some humus profiles of the ridges and most of the humus profiles of the north aspects of the ridges exhibit F-horizons with a relative thickness above 50%. Additionally, at the north aspect the thickest moss layer was found. The means of the combined thickness of the F- and H-horizons of the sites are very similar (east aspect: 9.6 cm, ridge: 11.2 cm, north aspect: 11.7 cm). The mean relative thickness of the F-horizons is highly significant for each site type, while the combined thickness is not.

The C/N ratios of the organic layers of the east aspects, the ridges and the north aspects are wider than the C/N ratios of the A-horizons of the gully sites (Table 2). Organic carbon content and storage is lower at the gully site and higher in the organic horizons of the other sites. The A-horizons are very strongly acid and the organic layers are extremly acid (acidity classes after Schoeneberger et al., 1998).

The results of the grid point sampling give evidence that the properties of the organic layers exhibit high spatial variability with coefficients of variation between 39 and 72% (Fig. 4). The organic-layer thickness within the grid point sampling plot ranges from 0–40 cm, the bulk density from 0.03 to 0.6 g cm^{-3}, except for the north aspect of the ridges where bulk density does not exceed 0.2 g cm^{-3}. The dry mass per area ranges from 0 to 30 kg m^{-2} on the ridges and the east slope of the ridges and from 0 to 15 kg m^{-2} at the northern exposure. Generally, variability is lowest on the north aspect.

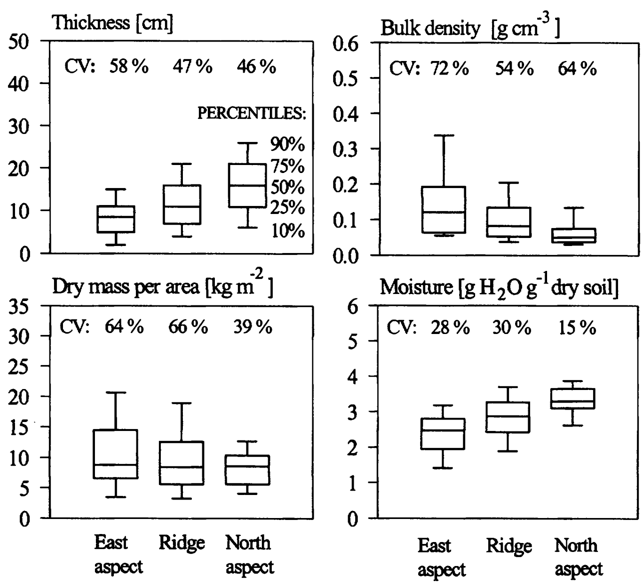


FIGURE 4. Organic layer properties with coefficients of variation (CV) within the grids of the different study sites.

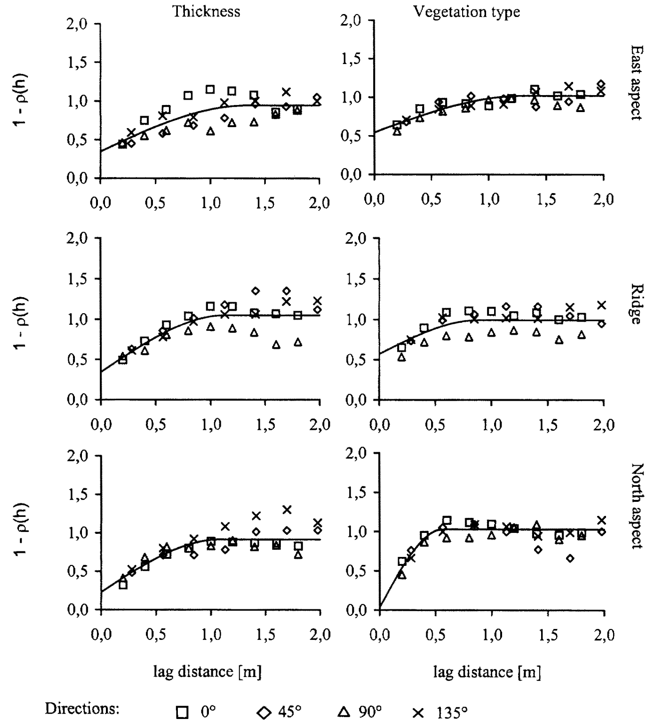


FIGURE 5. Nonergodic directional standardized correlograms in variogram form for the variables thickness of organic layer and vegetation type (indicator correlograms averaged over all vegetation types). Directions are expressed counter-clockwise from the isohypses (0° = right hand parallel to isohypse).

The correlograms of the variable "organic layer thickness" reveal that there is a distinct spatial structure on all plots (Fig. 5). The structural variance computed by the spherical model always exceeds 50% of the sample variance, and reaches 70% on the north aspects of the ridges. The range of autocorrelation lies between 1 and 2 m, and generally more than 50% of the sample variance occurs even below 0.3 m. Furthermore, the empirical correlograms show a slight zonal anisotropy with on average 10% less variability upwards/downwards the slope (90°-direction).

Part of the spatial variability of the organic layer thickness is explained by the vegetation structure (Fig. 6). Lichen-domi-

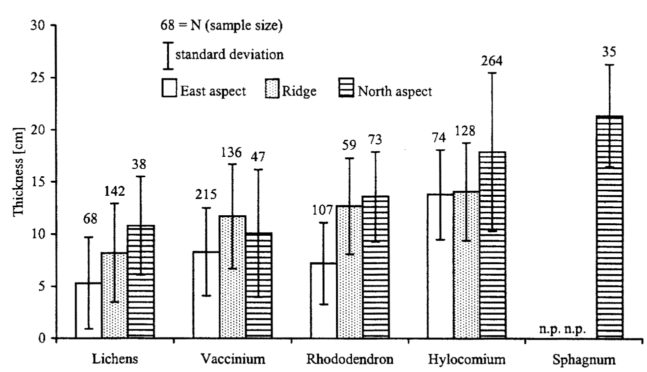


FIGURE 6. Organic-layer thickness by the two factors site and vegetation type.

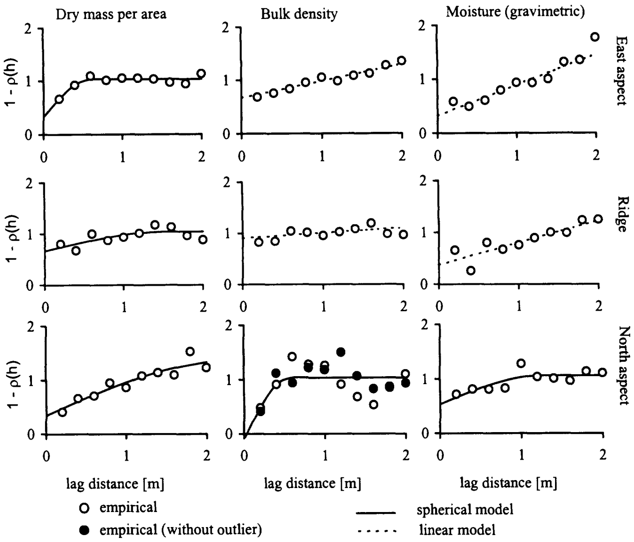


FIGURE 7. Nonergodic omnidirectional standardized correlograms expressed in variogram form at three sites for the variables dry mass per area, bulk density, and moisture.

nated grid cells tend to have the thinnest organic layers, while moss-dominated cells (*Hylocomium, Sphagnum*) have the thickest. The effect of the vegetation structure on organic layer is significant (Friedman-Test, $\alpha = 0.05$). However, only 33% of the overall variability of the organic-layer thickness is accounted for by the two factors vegetation type and site, with unique sum of squares of 6.1% for the vegetation type, 3.7% for the site type, and 3.8% for the interaction vegetation type × site type. The indicator correlograms for the vegetation types are similar to those of the organic layer thickness (Fig. 5). On all plots the structural variance is above 40%. As to the organic layer thickness the north aspects of the ridges exhibit the highest structural variance. Spatial autocorrelation for the vegetation type extends to maximally 1.3 m. The zonal anisotropy is less pronounced than for the variable organic layer thickness.

The correlogams for the other variables (bulk density, dry mass per area, water content per dry mass) do not provide such a uniform picture as with organic layer thickness and vegetation type (Fig. 7). The spherical model fits best to the omnidirectional correlograms for the variable "dry mass per area" at all sites. Yet the spherical model fits well for bulk density and water content only on the north aspect of the ridges. At the ridges and the east aspect the linear model fits better, indicating that the range of autocorrelation is beyond the 2 m evaluated in this study. The nugget effects among variables and site types are ranging from less than 30% to more than 90% of the sample variance. Nevertheless, one general feature is that spatial variability at lag distance of 0.3 m is nearly always higher than 50% of the sample variance, i.e. more than 50% of the spatial variability in the plots is expressed within 0.3 m.

According to properties and the mean relative thickness of the organic horizons within the plots the typical humus forms of the east aspects of the ridges and the ridges are Humimors (raw humus after Blaser, 1980) (Figs. 8, 9). At the north aspects of the ridges Hemimors are present (extreme raw humus after Blaser, 1980) (Fig. 10). Some Hemimors are characterized by a relatively thick organic layer. They were classified as Pachic Hemimors. The gully site mineral humus forms were classified as Rhizomulls (acid mull after Blaser, 1980) (Fig. 11). The mean thickness of the A-horizon is 10 cm (spatial variability was not investigated).

Discussion

Morphological descriptions of humus horizons from Stillberg (Blaser, 1980) and other comparable sites in the Alps (Pallmann and Haffter, 1933; Neuwinger and Czell, 1959; Larcher, 1977) correspond with our observations. According to the results from Blaser (1980) the relative thickness of the F-horizon and the occurrence of mosses are indicators for the microclimatic conditions of the study sites. The great variability of the thickness of organic layers is typical for forest-tundra ecotone sites (e.g. Neuwinger and Czell, 1959; Larcher, 1977; Holtmeier and Broll, 1992).

Beside this mesoscale spatial variability there is an important microscale variability on our sites. The CV of the mor layer thickness investigated by Bringmark and Bringmark (1998) at a forest site in southern Norway was comparable to our results. In a similar study, at a boreal forest site, Liski (1995) computed a spatial CV of 25% for the thickness of organic layer and concluded 15 samples are necessary to estimate that variable. Applying the same rationale as Liski (1995) we conclude at least 30–35 samples from each site to be appropriate for the estimation of the organic layer thickness. Furthermore, the general claim to take statistically independent samples would lead to the conclusion that the distance between sampling points should be 2 m or more, because our geostatistical analysis revealed spatial dependence reaching 2 m in some cases. However, that would lead to plots of at least 30×4 m^2 = 120 m^2, which are hardly to find in our timberline terrain. For the variable thickness, however, spatial autocorrelation ceased soon after 1 m. So the distance chosen in our study between the sampling points for the estimation of F- and H-horizon thickness within the plots should be sufficient. Also the sample size in our investigation (60 per study site) should be enough to estimate the mean thickness of the organic layer (Fig. 12).

The analysis revealed, that on the study sites all parameters exhibit great spatial variability with coefficients of variation up to 75%. The spatial variability of the physical parameters exceeds by far that of lowland agricultural and forest sites (Ernst et al., 1995; Liski, 1995) and reaches values usually known for soil biological variables (e.g., Robertson et al., 1993; Smith et al., 1994; Ernst et al., 1995).

In addition to the overall relief position the microscale heterogeneity of plant cover proves to be one significant source of the microscale variability of the organic layer thickness. However, only 33% of the variance can be explained by relief position (site type) and plant cover. The residual variability is not a "white noise," but the parameters exhibit spatial structure usually expressed within the short range of 2 m. Still in most cases more than half of the spatial variability occurs within 30 cm. This underlines the high degree of microscale heterogeneity of the sites (Robertson et al., 1993). Indicator correlograms for plant cover and for the organic layer thickness are quite similar, as nugget effect, range and anisotropy are regarded. The spatial distribution of plant cover influences the spatial continuity of organic-layer thickness (and vice versa).

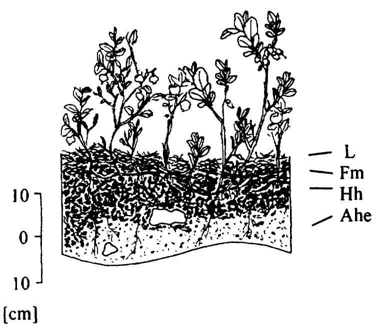
The directional correlograms revealed zonal anisotropy with lowest variability downwards/upwards the slope. The anisotropy might be caused by directional climatic factors such as wind and solar radiation combined with snow cover and mass translocation processes along the slope, which could enlarge variability rectangular to the slope, although difficult to evidence.

The correlation between study site, humus form and moss occurrence was described by Neuwinger and Czell (1959) and Blaser (1980), and the distribution of mosses appeared to be a

site: *E*-slope of a ridge (sunny lee)
(altitude: 2104 m a.s.l.; exposition: 80°; inclination: 40°)

vegetation: *Vaccinium myrtillus, Vaccinium gaultherioides*

humus form: **Humimor**



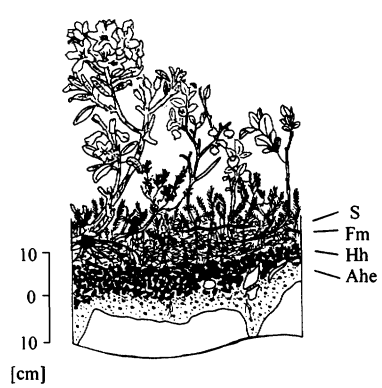
depth [cm]	horizon	description
11 - 10	**L**	discontinuously covered by leaves and stems from shrubs; single particle, loose; no roots. Boundary: clear, wavy.
10 - 8	**Fm**	strong non-compact matted, tenacious, fibrous; roots Ø < 2 mm: abundant, roots Ø > 2 mm: abundant; no visible faunal droppings; Boundary: clear, wavy.
8 - 0	**Hh**	black (7.5 YR 1.7/1); strong massiv, pliable and greasy when moist; roots Ø < 2mm: abundant, roots Ø > 2mm: abundant. Boundary: abrupt, wavy.
0 - 10	**Ahe**	brownish black (5 YR 2/2), single particle, loose, gritty; roots Ø < 2 mm: plentiful, roots Ø > 2 mm: very few.

FIGURE 8. Humus profile of the east aspect of a ridge.

site: *NE*-facing ridge (moderatly irradiated windward)
(altitude: 2142 m a.s.l.; exposition: 34°; inclination: 32°)

vegetation: *Hylocomium splendens, Empetrum nigrum ssp. hermaphroditum, Vaccinium myrtillus, Vaccinium gaultherioides, Rhododendron ferrugineum*

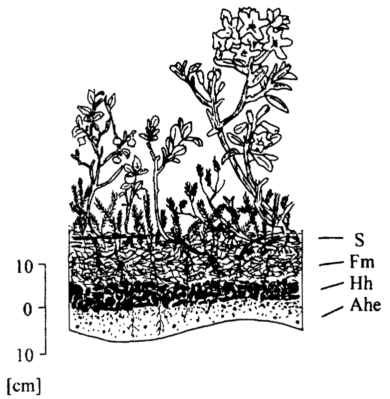
humus form: **Humimor**



depth [cm]	horizon	description
16 - 11	**S**	continuously covered by a layer of living bryophytes intermixed with suspended litter from shrubs. Boundary: clear, wavy.
11 - 6	**Fm**	strong non-compact matted, tenacious, fibrous; roots Ø < 2 mm: abundant, roots Ø > 2 mm: abundant; no visible faunal droppings. Boundary: abrupt, wavy.
6 - 0	**Hh**	reddish black (2.5 YR 2/1); strong massiv, pliable and greasy when moist; roots Ø < 2 mm: abundant, roots Ø > 2 mm: common. Boundary: abrupt, wavy.
0 - 5	**Ahe**	discontinuous, brownish black (7.5 YR 2/2), single particle, loose, gritty; roots Ø < 2 mm: abundant, roots Ø > 2 mm: very few. The Hh horizon can also lie on consolidated bedrock (**R**).

FIGURE 9. Humus profile of a ridge site.

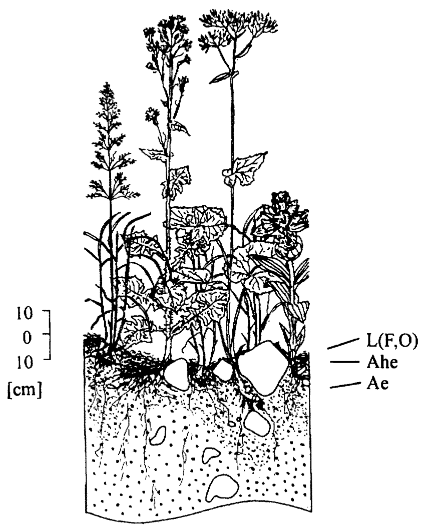
site:	*N*-slope of a ridge (shaded lee) (altitude: 2104 m a.s.l.; exposition: 2°; inclination: 38°)
vegetation:	*Hylocomium splendens, Pleurocium schreberi, Vaccinium myrtillus, Vaccinium gaultherioides, Rhododendron ferrugineum*
humus form:	**Hemimor**



depth [cm]	horizon	description
19 - 14	**S**	continuously covered by a layer of living bryophytes intermixed with suspended litter from shrubs. Boundary: clear, wavy.
14 - 5	**Fm**	strong non-compact matted, tenacious, fibrous; roots Ø < 2 mm: abundant, roots Ø > 2 mm: abundant; no visible faunal droppings. Boundary: clear, wavy.
5 - 0	**Hh**	reddish black (2.5 YR 2/1); strong massiv, pliable and greasy when moist; roots Ø < 2 mm: abundant, roots Ø > 2 mm: common. Boundary: abrupt, wavy.
0 - 5	**Ahe**	brownish black (7.5 YR 3/2), single particle, loose, gritty; roots Ø < 2 mm: abundant, roots Ø > 2 mm: very few.

FIGURE 10. Humus profile of the north aspect of a ridge.

site:	*NNE*-facing gully (moderately irradiated lee) (altitude: 2102 m a.s.l.; exposition: 36°; inclination: 32°)
vegetation:	*Calamagrostis villosa, Cicerbita alpina, Adenostyles alliariae, Gentiana punctata*
humus form:	**Rhizomull**



depth [cm]	horizon	description
1-0	**L** (F) (O)	discontinuously covered by leaves and stems from grasses and herbs; single particle, loose; no roots; in part intermixed with some partly and/or well decomposed organic matter. Boundary: clear, wavy.
0-10	**Ahe**	brownish black (10 YR 3/2); single particle, loose, gritty: sandy loam; roots Ø < 2mm: abundant (dense network of fine roots), roots Ø > 2mm: abundant; Boundary: gradual, wavy.
10-30	**Ae**	grayish brown (7.5 YR 4/2); single particle, loose, gritty: sandy loam; roots Ø < 2mm: common, roots Ø > 2mm: plentiful. Boundary: abrupt, wavy.

FIGURE 11. Humus profile of a gully site.

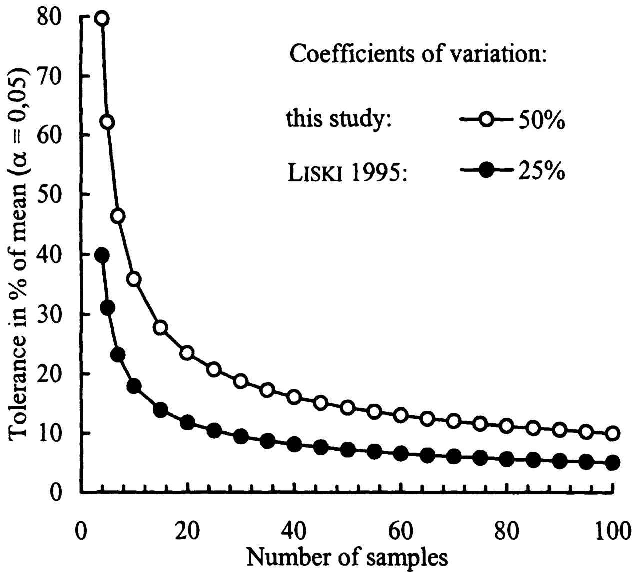


FIGURE 12. Inexactitude of parameter estimation of mean, as influenced by sample size and variability, under assumption of normal distribution according to Liski (1995) (half length of 95% confidence interval in % of mean).

sensible site indicator. The possibility of designating the layer of living mosses in the humus form description according to Green et al. (1993) takes this into consideration, although in the classification the designation of S-horizons is mainly applied to ground water influenced humus profiles.

At the gully sites, no accumulation of organic matter is evident above the mineral soil surface. Beside microclimatic conditions erosion may have an influence on the development of the humus form. Description of similar humus forms under comparable site conditions from other regions of the Alps are not available. The humus form is classified as a Rhizomull. According to Green et al. (1993) it is not typically developed because the associated soil is not rich in bases and the A-horizon has a single particle structure. In contrast to the recent version of the Canadian classification in the first approximation from Klinka et al. (1981) the phase name "acidic" could be used for humus forms with a high acidity. To show the specific properties of the investigated Rhizomull we proposed to adopt "acidic" as an adjective used in naming phases of the mull order (acidic Rhizomull). The concept of the Rhizomull cannot be applied to high mountain regions only but also to grassland humus forms of mountain regions and lowlands of Central Europe for example (Broll and Brauckmann, 1994).

Conclusions

The quantification of the spatial variability of humus layer properties gives useful information for sampling strategies in arctic and alpine ecosystems exhibiting highly varying site conditions. One practical consequence of the high spatial variability on our sites is that the amount of samples for a sufficiently exact estimation of the organic-layer thickness should be at least 30 samples. For the other soil parameters—partly showing higher variability—even more samples would be necessary. Investigations in other regions should prove whether these considerations are generally valid for the forest-alpine tundra ecotone.

The Canadian classification of humus forms (Green et al., 1993) is suitable for describing the horizons and the humus forms of the forest-tundra ecotone. One main advantage is that the relative thickness of the organic horizons is an important criterion to distinguish different humus forms of the mor order. Furthermore, the master organic horizons, which are adopted from Babel (1975), correspond to the humus horizons of the Swiss, French, and German humus form classifications (Eidgenössische Forschungsanstalt für landwirtschaftlichen Pflanzenbau, 1992; Brethes et al., 1995; AK Standortskartierung, 1996) and to the O-horizons of the US soil taxonomy (USDA Soil Survey Staff, 1998). This is important for the comparability of humus profile descriptions.

The individual humus form is characterized by varying thickness of the diagnostic horizons. As a result of our study the question arises, if, from the ecological viewpoint, the designation of humus forms should include the spatial variability of their typical properties (e.g., relative thickness of the F-horizon of Hemimors). If spatial variability is adopted into classification then certainly on a very low hierarchical level (e.g., phase name in Green et al., 1993). This topic may become important discussing the interdependencies between ecosystem spatial heterogeneity, biodiversity, and biogeochemical cycles (e.g., Chapin and Körner, 1995). In our study spatial distribution of plant cover and organic layers were clearly interrelated. Investigations of well-drained forest tundra ecotone sites in the European Subarctic (Broll, 1994) for example also showed the small scale (0–1 m) patchiness of vegetation and organic layers. This patchiness may have effects on biodiversity of soil organisms (Keplin, 1994). Certainly further investigations should be started to quantify the influence of the spatial variability on biodiversity and biogeochemical cycling.

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