ORGANIC MATTER IN ALPINE GRASSLAND SOILS AND ITS IMPORTANCE TO SITE QUALITY

Andreas Bohner
Agricultural Research & Education Centre Raumberg-Gumpenstein

SUMMARY

The importance of soil organic matter (SOM) to soil fertility and soil quality in alpine regions was investigated. Alpine soils are commonly humus-rich in topsoil primarily because of the slow rate of SOM mineralization and secondarily because of the high below-ground phytomass which is concentrated in the top 10 cm of the soil. Some favourable and unfavourable properties of SOM concerning soil fertility and soil quality will be discussed.

KEY WORDS

Soil organic matter, alpine grassland soils, below-ground phytomass, water-holding capacity, effective cation exchange capacity, aluminum solubility, nitrogen and sulfur content

INTRODUCTION

Soil organic matter (SOM) is an indicator of soil quality as it interacts with other numerous soil components, affecting water retention, aggregate formation, bulk density, pH, buffer capacity, cation exchange properties, mineralization, sorption of pesticides and other agrochemicals, color (facilitate warming), infiltration, aeration, and activity of soil organisms. In addition to the amount of SOM, its quality is also an important indicator of soil quality and soil fertility (Seybold et al., 1998). The quantity and quality of SOM depend on many state factors such as time, parent material, topography, climate, plants, and animals (Jenny, 1980). Generally, it is assumed that SOM increases with elevation (Birch & Friend, 1956; Körner, 2003); this fact enhances its relative importance to site quality at higher altitudes. Furthermore, human influence on alpine soils is commonly negligible compared to soils at lower altitudes, thereby minimizing the effect of management practices on the quantity and quality of SOM. These are the main reasons why these investigations were carried out in alpine soils. The objectives of this study were (1) to provide data on the quantity and quality of SOM in alpine grassland soils, (2) to analyse its dependence on some state factors, (3) to investigate its interaction with other soil properties, (4) to demonstrate its importance to site quality, and (5) to give some arguments concerning assessment of an optimal humus content in soil.

MATERIAL AND METHODS

This investigation was conducted in the montane, subalpine, and alpine zone of the Austrian Alps in Carinthia. The altitude was ranging from 1340 to 2160 m. Only soils of unfertilized and extensively managed grassland communities were selected for study. Soils were mainly Mollic Leptosols, Rendzic Leptosols, Calcaric Regosols, Mollic Cambisols, Cambic Umbrisols, and alpine forms of Stagnosols. Typical humus forms of the sandy and silty alpine soils were mull, mull-like moder, wet mull, and mull-like wet moder. Soil samples were taken exclusively from the A horizon from 0 to 10 cm depth. Visible roots were removed before the soil samples were air-dried at room temperature and sieved (< 2 mm). Soil analyses have been conducted according to the ÖNORM methods. Because no volumetric soil samples were taken, only concentrations can be mentioned. Relationships between organic carbon content and soil properties were determined by regression analyses.

RESULTS AND DISCUSSION

Table 1 shows the mean organic carbon and total nitrogen content, as well as the organic carbon to total nitrogen ratio in the topsoil (0-10 cm depth) of important grassland communities. Generally, soils under permanent grassland are characterized by a relatively high SOM content in topsoil.

Soils of unfertilized alpine pastures and meadows have on an average the highest concentration of organic carbon and the widest C_{org}:N_{tot} ratio in the A horizon compared to soils of grassland communities at lower altitudes. However, total nitrogen shows no such altitudinal trend. Also, moist grassland communities on hydric soils (*Cirsium oleraceum-Persicaria bistorta*-community, *Iridetum sibiricae*) and plant associations from higher elevations on finer-textured soils (e.g. *Geranio sylvatici-Trisetetum flavescentis*) have a comparatively high SOM content in topsoil. More detailed soil-chemical properties of unfertilized alpine grassland soils are listed in Table 2.

Table 1. Intensity of grassland management, soil water regime, and selected soil-chemical properties (0-10 cm of soil depth) of important grassland communities

Plant community	n	lgm	swr	% C_{org}	% N_{tot}	C_{org}:N_{tot}
Alpine pastures and meadows**	42	1,egr	b-pm	9.9*	0.7*	14.0
Cirsium oleraceum-Persicaria bistorta-community	19	2	mw-mm	9.8*	1.1*	10.6
Iridetum sibiricae	28	1	mw-mm	9.7*	0.8*	11.8
Geranio sylvatici-Trisetetum flavescentis	46	2-3	b	7.9*	0.8*	9.8
Festuca rubra-Agrostis capillaris-community	45	1-2,egr	b-pm	7.7*	0,6	12.0
Alchemillo monticolae-Arrhenatheretum elatioris	45	3-4	b	6.7*	1.0*	9.5
Alchemillo monticolae-Cynosuretum cristati	24	4-5	pm	5.5*	0.6*	9.0
Narcissus radiiflorus-community	41	1-2,egr	mm-sd	7.1	0.6	11.2
Trifolium repens-Poa trivialis-community	52	4-5	pm	6.5*	0.7	9.3
Mesobrometum erecti	22	1-2,egr	sd	5.8	0.6	10.5
Cardaminopsido halleri-Trisetetum flavescentis	30	2-3	b	5.7	0.7	10.1
Festuco commutatae-Cynosuretum cristati	13	egr	b-pm	4.4	0.5	9.4

** soil samples without roots; n = number of soil analyses; lgm = intensity of grassland management (number of cuts/grazings; egr = extensive grazing); swr = soil water regime (mw = moderate wet, mm = moderate moist, pm = periodically moist in topsoil, b = balanced, sd = semi-dry); * = coefficient of variability > 30 %

Table 2. Selected soil-chemical properties (A horizon, 0-10 cm) of alpine grassland soils

	%					
n = 42	C_{org}	N_{tot}	S_{tot}	C_{org} : N_{tot}	C_{org} : S_{tot}	N_{tot} : S_{tot}
Minimum	2,71	0,21	0,02	9,57	63,22	4,19
Maximum	19,67	1,63	0,27	20,36	195,75	12,00
Arithmetic mean	9,93	0,72	0,09	14,03	114,30	8,23
Median	8,50	0,61	0,08	13,32	110,50	7,86

Alpine grassland soils vary greatly in their organic carbon, total nitrogen, and total sulfur content. Mean C:N, C:S, and N:S ratios in the A horizon of unfertilized alpine soils are 14, 114, and 8, respectively. C:N ratios around 14 are typical of less productive alpine soils (Körner, 2003). A high C:N ratio indicates unfavourable conditions for the decomposition of SOM and poor humus quality. The relatively high concentration of organic carbon in the A horizon of many alpine grassland soils is mainly the result of unfavourable climatic and site conditions, such as low mean soil temperatures and long water-saturation of the alpine soils especially during the snowmelt period. These circumstances reduce the microbial activity and hence decrease the rate of SOM mineralization more rapidly than the annual net primary production of alpine plants (Franz, 1979). In addition, the temperature-dependent reduced rooting depth of plants in higher altitudes and the accumulation of a high below-ground phytomass in the top 10 cm of alpine soils are responsible for the high SOM concentration in the A horizon of many alpine grassland soils (Lichtenegger, 1997). At lower altitudes, SOM is usually diluted over a larger soil profil (Körner, 2003) mainly because of an enhanced rooting depth of plants. In alpine grassland soils, 80 to 93 % of the below-ground phytomass are concentrated in the uppermost 10 cm of the soil (Bohner, 1998). In higher altitudes, the below-ground phytomass is of eminent importance with respect to carbon input into the topsoil (Hitz et al., 2001). The amount of below-ground phytomass in alpine grassland soils ranges from 150 to 360 dt ha^{-1} (Bohner, 1998). Assuming the mean carbon content of roots of 46 %, the carbon storage will be of 6900 to 16560 kg C per ha in the below-ground phytomass. The distribution of carbon and phytomass in an alpine grassland community (*Sieversio-Nardetum strictae*) at an altitude of 1890 m at peak season is given in Table 3.

Table 3. Phytomass and carbon distribution in an alpine grassland community (*Sieversio-Nardetum strictae*) at an altitude of 1890 m at peak season (Bohner, 1998)

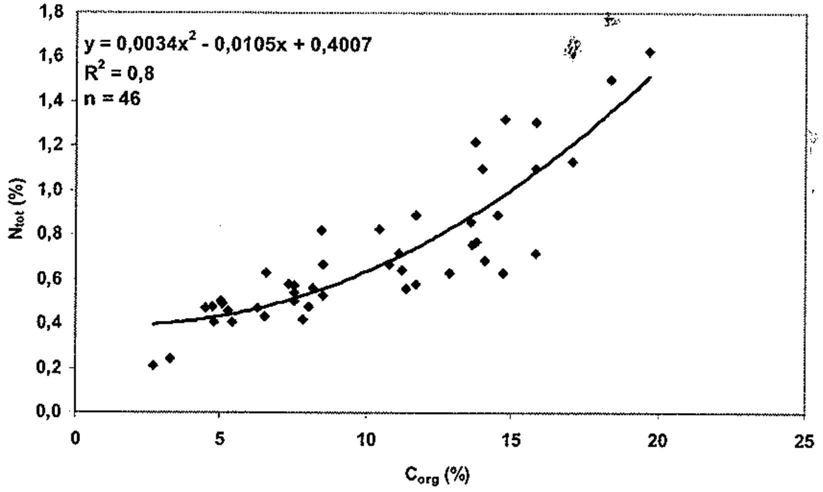
	dt ha^{-1}	%	kg ha^{-1}
above-ground phytomass (growing height > 3/5 cm)	21	9	935*
above-ground phytomass (growing height 0-3/5 cm)	40	16	1780*
below-ground phytomass (0-40 cm of soil depth)	185	75	8510**
above- and below-ground phytomass	246	100	11225

* mean carbon content of the above-ground phytomass: 44.5 %; **mean carbon content of the below-ground phytomass: 46.0 % (Bohner, unpublished data)

The majority of stored plant carbon (75 %) is found in the below-ground phytomass. Only a minority (9 %) can be removed due to cutting or cattle grazing. These data also emphasize the importance of below-ground phytomass for SOM accumulation in alpine grassland soils. However, there is no direct relationship between organic carbon content in the A horizon of alpine grassland soils and altitude (not shown).

According to Figure 1 and 2, there is a close relationship between organic carbon content and total nitrogen or total sulfur content in the A horizon of alpine grassland soils. A very strong relationship ($R^2 = 0.9$) also exists between total nitrogen and total sulfur (not shown). In the A horizon of unfertilized alpine soils, almost 100 % of the total nitrogen is present in the form of organic nitrogen (Bohner, 1998). The large organic pools of nitrogen and sulfur in many alpine soils are not directly available to plants. Therefore, many alpine soils have only a high content of potentially mineralizable nitrogen and sulfur in topsoil. The rate of nitrogen and sulfur mineralization and hence nitrogen and sulfur availability to plants are reduced mainly because of the low mean soil temperatures and the temporarily high soil water contents. The clear relationship between organic carbon content and effective cation exchange capacity ($BaCl_2$-extract) in the A horizon of alpine grassland soils indicates that SOM accounts for a major portion of the cation exchange capacity of alpine soils low in clay (Figure 3).

Figure 1. Relationship between C_{org} (%) and N_{tot} (%)



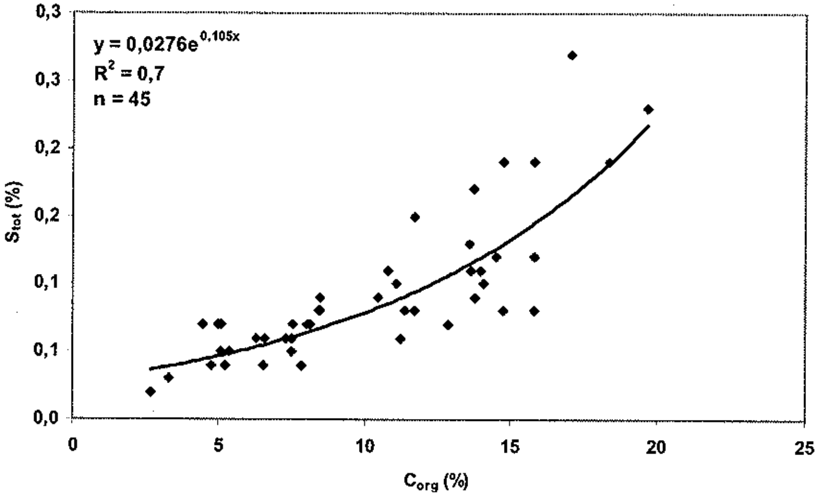


Figure 2. Relationship between C_{org} (%) and S_{tot} (%)

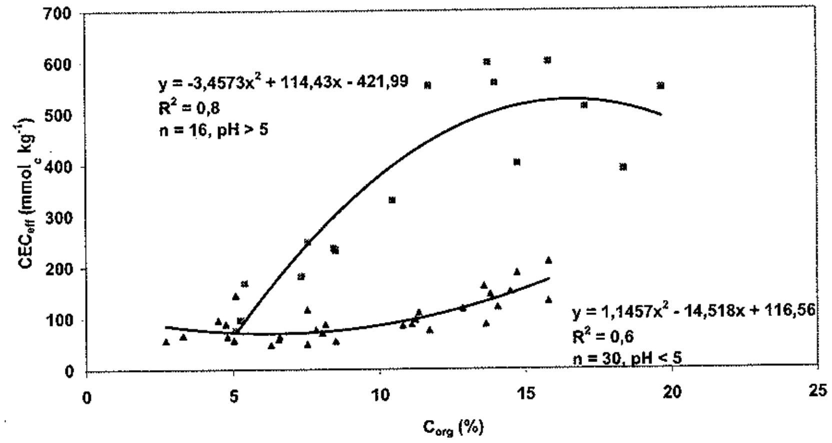


Figure 3. Relationship between C_{org} (%) and effective cation exchange capacity ($BaCl_2$-extract) of alpine soils with pH ($CaCl_2$) > 5.0 and pH ($CaCl_2$) < 5.0

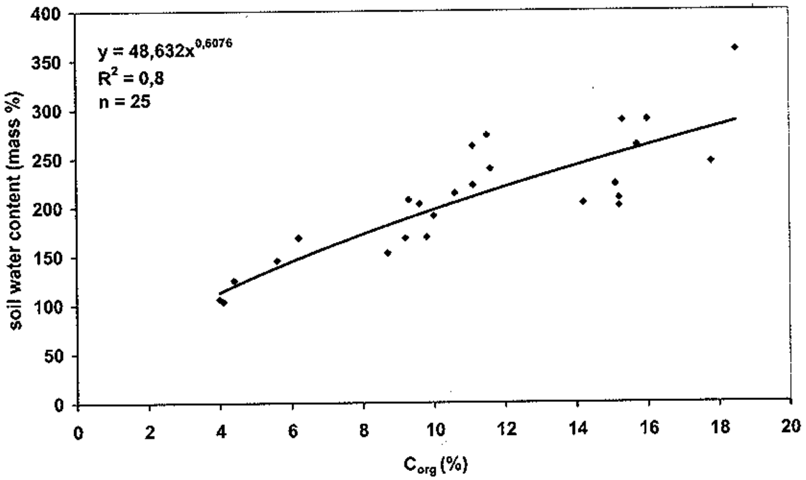


Figure 4. Relationship between C_{org} (%) and soil water content (mass %) at water saturation (liquid limit)

However, the cation exchange capacity of humus-rich alpine soils is markedly pH-dependent, even at low pH. Acid alpine soils (pH $CaCl_2$ < 5.0) have low effective cation exchange capacities compared to alpine soils with pH $CaCl_2$ > 5.0 (Figure 3). Thus, soil acidification considerably decreases the cation holding capacity of alpine soils low in clay. No relationship was found between organic carbon content and pH ($CaCl_2$) or percentage base saturation in the A horizon of alpine grassland soils. Only a weak relationship was found between C:N ratio and pH ($CaCl_2$) or percentage base saturation; the same is valid for C:S ratio and pH ($CaCl_2$) or percentage base saturation (not shown). These circumstances indicate that both in acid, base-poor alpine soils, and in neutral or alkaline, base-rich alpine soils, an accumulation of SOM is possible with a weak tendency of narrower C:N and C:S ratios at higher pH values.

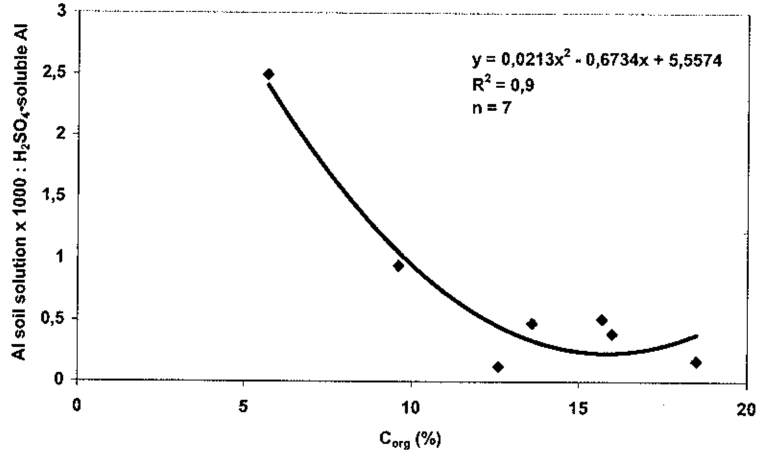


Figure 5. Effect of Soil Organic Matter on aluminum solubility (Al in soil solution x 1000 : H_2SO_4-soluble Al) in acid alpine soils (pH < 4.2)

In coarse-textured alpine soils, the water-holding capacity is determined mainly by SOM (Figure 4). A high SOM content enhances the soil water content, thereby reducing soil temperature (retarded warming) and slowing down the mineralization of SOM. This causes a reduced supply of nitrogen and sulfur to plants and promotes the growth of herbs instead of grasses. In this respect, a high humus content is not a benefit concerning soil fertility and soil quality in cool and humid alpine regions. In humus-rich alpine soils, there is a relatively poor relationship between pH and aluminum concentration in the soil solution of A horizons (not shown) due to the high humus content. This can be concluded from Figure 5. Figure 5 illustrates that with increasing organic carbon content the ratio between Al in soil solution to H_2SO_4-soluble Al is decreasing, indicating lower aluminum solubility at higher humus content. This is beneficial to plants growing on acid alpine soils.

CONCLUSIONS

It is very difficult to assess optimal SOM contents because of the numerous factors influencing it, such as soil reaction (higher in strongly acid soils than in neutral or alkaline soils), soil texture (higher in sandy soils than in clayey soils), and climate (higher in dry regions than in humid regions). Nevertheless, this study contributes to conclude that in cool and humid mountainous regions sandy grassland soils with lower humus content are more favourable than humus-rich, clayey soils, whereas in warm and dry lowland areas, deep and finer-textured, humus-rich grassland soils are characterized by a comparatively higher soil fertility. The amount of SOM can be modified by fertilizing especially with farmyard manure.

REFERENCES

Birch, H.F. and M.T. Friend, 1956: The organic-matter and nitrogen status of East African soils. Journal of Soil Science, Vol. 7, 156-167.

Bohner, A., 1998: Almwirtschaft und Gebirgs-Ökosysteme. Diss. BOKU Wien.

Franz, H., 1979: Ökologie der Hochgebirge. Ulmer Verlag, 495 p.

Hitz, Ch., M. Egli and P. Fitze, 2001: Below-ground and above-ground production of vegetational organic matter along a climosequence in alpine grasslands. J. Plant Nutr. Soil Sci. 164, 389-397.

Jenny, H., 1980: The soil resource. Springer-Verlag, 377 p.

Körner, Ch., 2003: Alpine plant life. Functional plant ecology of high mountain ecosystems. Springer-Verlag, 344 p.

Lichtenegger, E., 1997: Bewurzelung von Pflanzen in den verschiedenen Lebensräumen. Spezieller Teil. Stapfia 49, 55-331.

Seybold, C.A., M.J. Mausbach, D.L. Karlen and H.H. Rogers, 1998: Quantification of soil quality. In: Lal, R. and J. Kimble (ed.): Soil Processes and the carbon cycle. CRC Press, 387-404.

Accepted, June 2005; reviewer – Prof. Dr. Othmar Nestroy

Dr. Andreas Bohner, Agricultural Research & Education Centre Raumberg-Gumpenstein, Raumberg 38, A-8952 Irdning, e-mail: andreas.bohner@raumberg-gumpenstein.at