Natural Pastures and Mobile Animal Husbandry Under Pressure:
The Cases of Lapland and the Tibetan Plateau, 12-14 June 2002,
University of Oulu, Oulu, Finland.

Impacts of reindeer grazing on soil properties on Finnmarksvidda, northern Norway

Christian Uhlig*, **Tore E. Sveistrup & Ivar Schjelderup**

Holt Research Centre, The Norwegian Crop Research Institute, 9292 Tromsø, Norway.
*corresponding author (Christian.Uhlig@holt.planteforsk.no).

Abstract: Numerous investigations have documented changes in vegetation due to reindeer grazing in Finnmark County, Northern Norway. However, rather few studies have focused on impacts of reindeer grazing on soil properties. The aim of this investigation was to identify possible changes in physical and chemical soil properties due to reindeer grazing. Furthermore, root distribution was detected. At four different locations on Finnmarksvidda three sample sites each were selected subjectively according to lichen and plant cover: A) ample, B) reduced, and C) poor lichen and plant cover. It was supposed that differences in lichen and plant cover were due to differences in reindeer grazing intensity. Results showed that the organic layer beneath ample lichen cover had an about 20% higher CEC and a 30–50% higher concentration of plant available Ca and Mg, and total Mg compared to those beneath reduced ones. At sites with poor lichen and plant cover, an organic layer was mostly missing. The exposed mineral Eh-horizons at these sites had a significant ($P \leq 0.05$) higher organic C content, higher CEC, concentrations of total P, Ca and K, and plant available K, when compared to E-horizons beneath better lichen covers. Rooting depth and amounts of plant available water in the rooting zone were lower at sites with reduced and poor lichen cover. A relation was found between soil organic C and CEC for all soil samples, indicating that soil organic matter is an essential key factor for soil fertility at the investigate sites on Finnmarksvidda. Assuming that differences in lichen and plant cover are related to differences in grazing intensity, results indicate that overgrazing by reindeers can cause a significant degradation of the organic layer, followed by significant losses of essential plant nutrients, a reduction in plant available water and consequently soil fertility.

Key words: CEC, nutrients, organic matter, podzol, reindeer pasture, soil degradation.

Rangifer, Special Issue No. 15: 83-91

Introduction

Overgrazing is the world's furthermost reason for soil degradation (Oldeman *et al.*, 1991). Also on Finnmarksvidda there is evidence that soil degradation takes place. Evans (1996) found that the organic horizons on less grazed sites were significantly thicker compared to more grazed ones at some sites, and that at some locations the organic horizon was "stripped off" the beneath mineral material. Trampling and grazing of lichens and plants by reindeer are today major factors controlling vegetation cover and composition all over the northern Fennoscandia (Väre *et al.*, 1995; Stark *et al.*, 2000; Kumpula, 2001). During the last three decades the investigation on the effects of reindeers on lichen dominated winter pastures has received special attention (*e.g.* Johansen & Karlsen, 2000). This is due to the importance of lichens as fodder for the survival of reindeers during winter. The condition of lichen ranges still form one of the most important economic bottlenecks for semi-domesticated reindeer management in northern Europe (*e.g.* Kumpula, 2001).

The county of Finnmark, North Norway, manages by tradition, the greatest number of reindeer in Norway. From 1976 to 1988 the reindeer population size in Finnmark County increased from approximately 86 000 to 191 000 animals. Since then the number of animals decreased to about 144 000 animals in 1997

(Johansen *et al.*, 1995; Ims, 1998) and less than 110 000 in 2001 (Hætta, 2002). Causes for these considerably decreases in reindeer population during the last decade are multifaceted, and combinations of historical, social, cultural, political, economical and natural reasons are discussed (*e.g.* Haugerud, 1999).

One commonly discussed cause is the unbalance between numbers of reindeer in relation to steady decreasing pasture resources. Evidence for reindeer grazing is widespread throughout Finnmark: from the almost ubiquitous presence of dung to the disappearance of lichens by trampling in summer grazings and by overgrazing in winter grazings (*e.g.* Johansen *et al.*, 1995; Johansen & Karlsen, 1998); to the present of bare soil in many localities (Evans, 1996). Thus, there is widespread evidence for overgrazing by reindeers throughout Finnmark County.

Serious changes in soil structure and nutritional composition have been reported at locations with heavy trampling, as for example along reindeer fences (Evans, 1996; Olofsson *et al.*, 2001). It has been general questioned, whether plants of the original vegetation still possess the ability to grow at these locations (Johansen & Karlsen, 1996). However, little is known about the impacts of reindeer grazing on soil properties of lichen dominated winter pastures.

The aim of this investigation was to document changes in physical and chemical soil properties due to reindeer winter grazing.

Material and methods

Selection of sample sites

The investigation was performed between the two sami villages of Kautokeino and Karasjok on the continental part of Finnmarksvida. The climate is characterized by a mean annual air temperature of -3.1 °C and an annual precipitation of 366 mm (Siččajavri; DNMI, 1999). Johansen & Karlsen (1996) characterized this area according to lichen cover as moderately grazed to overgrazed. However, remaining islands with apparently ample lichen cover are found solitarily. The following locations were chosen: 1) Suosijavrre I (69° 22.235'N, 24° 4.921'Ø); 2) Suosijavrre II (69° 21.849'N, 24° 23.080'E); 3) Lappoluobbal (69° 12.579' N, 23° 45.021' E); and 4) Bieddjučårro (69° 13.099'N, 23° 46.713'E). At each location 3 sample sites (only two found at Lappoluobbal) were selected due to a subjective evaluation of the lichen and plant cover in accordance with the classification of Johansen & Karlsen (1996): A) ample, B) reduced, and C) poor lichen and vegetation cover. The sampling areas chosen were to be topographically and edaphically uniform, allowing us to assume that the vegetational differences between the sample sites are caused by grazing and not by environmental variation. Thus, to increase comparability between soil profiles all sample sites were established at locations with no or little inclination (0-2°) and a continuously morainic till as basic substrate. The morainic till were deposited by the glaciers of the Pleistocene glaciations and covers most of Finnmarksvidda (Olsen *et al.*, 1996). Vegetation types chosen were lichen rich mountain birch forest (Suosijavrre I, Lappoluobbal and Bieddjučårro) and lichen rich dwarf shrub tundra (Suosijavrre II), which by area and usage represents important habitats for reindeer husbandry.

Soil description, sampling and analysis

At each sample site soil profiles with an approximately dimension of 100 cm x 100 cm x 80 cm were carefully excavated and thoroughly described by horizons according to FAO (1990) during the first weeks of September 1999 and 2000. Size, amount, orientation and distribution of roots were described in accordance to Hodgson (1976). The rooting zone was measured as the thickness of the O-horizon plus the depth of the mineral soil with root development. Due to the very stony composition of the morainic substrate, soil samples were taken from one open pit per sample site only. For chemical analysis soil samples were collected into polyethylene bags according to horizons and stored at approximately +5 °C until further treatments at the Chemical Analysis Laboratory of the Holt Research Centre. Prior to chemical and textural analysis, all samples were dried at 105 °C and passed through a 2 mm sieve to remove stones and large roots. Soil samples were analyzed for the following parameters: Particle-size distribution (Elonen, 1971), pore-size distribution (Richards, 1947; Richards, 1948), particle density (De Boodt *et al.*, 1967), pH_{H2O} (1:2,5 soil water suspension), organic carbon (Leco IG 212 carbon system), Kjeldahl-N (Bremner, 1960), base saturation (BS) and potential cation exchange capacity (CEC_{pot}) (Ogner *et al.*, 1975; Ogner *et al.*, 1977), plant available Ca, Mg, K and P (Egnér *et al.*, 1960). Analysis of filtered solutions were performed using a Perkin-Elmer Optima 3300 DV. Plant available water was calculated on basis of as the difference between field capacity (100kPa) and permanent wilting point (1500kPa).

Statistical analysis

The number of soil samples in this investigation was not sufficient to check for normality in the data. However, in a similar study with fully comparable soil data, normality tests showed, that the investigated soil chemical parameters are normally distributed in general. Thus, analysis of variance was performed on all data using the GLM procedure of SAS (version 6.12). Chemical properties of the different soil horizons with different lichen cover were compared using the different locations as replicates. The individual means were compared using the Student-Newman-Keuls test. Significance was assigned to a test if $P \leq 0.05$.

Results

Soils were shallow podzols, stony with coarse-textured gritty matrix and a generally low clay fraction (Table 1). The soil texture was rather uniform, and all samples were loamy sands or sandy loams boardering to the loamy sand texture class. Soil densities were between 1.4 and 1.7 g/cm^3, the soil porosity between 40 and 50%, and air-filled porosity between 16 and 32% (data not shown) and there were rather little differences between sites. The pH in the soil profiles increased with increasing soil depth from about 4.0 in the organic layer to approximately 6.0 in the mineral C-horizon (Table 1).

The organic layer was generally thickest where lichen cover had the greatest thickness. Humus beneath ample lichen cover had a significant higher content of organic C and a higher CEC compared to humus beneath moderate lichen cover. There was a high correlation ($r = 0.99$) between organic C and CEC (Fig. 1). Furthermore, humus beneath ample lichen cover had higher concentrations of plant available Ca and Mg and total Mg (Fig. 2a). Contents of Kjeldahl-N in the O-horizons varied between 0.86-1.48%, and were thus about 10-fold of those detected in the Eh-horizons (on weight basis). N concentrations in the B-horizons were in general below the detection limit of 0.05%.

No or only rather thin partial fragments of an earlier humus layer were found at sites with strongly reduced lichen cover. The accumulations of coarse mineral soil particles as coarse sand and gravel on the surface at these sites indicate that wind erosion has taken place to some extent. However, growth of pioneer lichens (*e.g. Lecidea* spp.) and mosses (*e.g. Polytrichum* spp.) had partly consolidated some of the exposed mineral soil. Characteristic for these sites were the occurrence of an Eh-horizon with a significant higher organic C content (3%) than E-horizons (0.4%) beneath better lichen covers. Furthermore, Eh horizons contained higher concentrations of total P, Ca and K, plant available K (Figs. 2a, 2b), and a significant higher CEC. However, base saturations were generally below 5% (Table 1).

In B- and C-horizons no differences in physical and chemical soil properties between sites with different lichen cover were detected

Growth of plant roots was concentrated in or directly below the O-layer with a mainly horizontal distribution. A more shallow root development and lower amounts of plant available water were found at sites beneath reduced and poor lichen cover (Fig. 3). Vascular plants like *e.g. Empetrum nigrum* or *Vaccinium vitis-idaéa* growing at sites with poor lichen cover had a somehow stunted growth, and some chlorosis were observed.

Discussion

Due to no significant differences in chemical soil properties of C- and B- horizons, it was concluded that all investigated soils had developed from rather similar morainic till. The degree of podzolization, concerning the thickness of the E and B-horizons and the chemical properties, indicates further that soil genesis has taken place under rather similar conditions at all locations. If present differences in lichen and vegetation cover had existed for a longer period, more profound differences *e.g.* in pH or in the thickness of the characteristic podzolic-horizons would be expected. The general similarity of all soil profiles indicate that differences in vegetation, and thus also the variability in soil characteristics of the uppermost soil horizons, are of rather recent character. Thus, based on the results about changes in lichens cover on Finnmarksvidda (Johansen & Karlsen, 1998) we assume that the most profound differences in soil properties between the investigated sites have occurred during the last 30 years.

Table 1. Selected soil properties for representative pedons of the four study sites. O = organic, E = eluvial, B = illuvial horizon.

Locations and horizons	Depth of horizon (cm)	Color (moist)	pH (H_20)	Coarse % >2 mm	Particle size % sand 2-0.063 mm	silt 0.063-0.002 mm	clay < 0.002 mm	base saturation %
Suosijavrre I "ample"								
O	9-0	5YR 2/2	4.1					22.0
E	0-12	7.5YR 3/2	4.7	15	77.0	21.4	1.7	3.3
Bs	12-35	7.5YR 2/2	5.1	34	78.4	20.3	1.3	2.7
Bs-C	35-41	7.5YR 3/3	5.3	25	68.4	29.6	2.0	2.7
C	>41	7.5Y 5/2	5.5	30	70.3	26.9	2.8	2.9
Suosijavrre I "reduced"								
O	5-0	7.5YR 1/1	4.1					14.1
E	0-4	5Y 7/4	4.7	8	85.2	13.3	1.5	4.1
Bs	4-33	7.5YR 2/2	5.9	23	78.1	20.2	1.7	2.0
Bs-C	33-41	10YR 5/2	5.6	15	72.8	25.9	1.3	2.6
C	>41	7.5Y 5/2	5.7	19	45.3	47.7	7.0	5.1
Suosijavrre I "poor"								
Eh-Bs	0-8	2.5Y 2/1	5.0	25	79.8	18.3	1.8	7.1
Bs	8-40	7.5Y 4/2	5.5	14	69.1	29.1	1.7	4.0
C	>40	5Y 5/1	6.0	26	64.5	31.1	4.5	6.9
Suosijavrre II "ample"								
O	1-0	10YR 2/2	3.8					12.6
E	0-4	10YR 6/2	4.4	7.0	73.6	24.9	1.4	3.9
Bs	4-21	10YR 4/6	5.4	24.0	72.3	26.1	1.6	2.4
Bs-C	21-40	2,5 Y5/3	5.2	29.0	70.4	28.1	1.5	2.8
Suosijavrre II "reduced"								
O	2-0	10YR 2/1	4.1					9.4
E	0-10	10YR 6/2	4.6	7.0	76.5	21.8	1.6	2.5
Bs	10-21	7,5YR 3/4	5.2	19.0	74.5	24.5	1.1	1.0
Bs-C	21-40	2,5Y 5/3	5.2	27.0	71.1	27.9	1.1	2.0
Suosijavrre II "poor"								
Eh-Bs	0-3	7,5YR 4/3	5.1	23.0	69.6	28.3	2.1	1.3
Bs	3-21	7,5YR 3/4	5.0	26.0	67.8	29.2	3.1	1.1
B-C	21-40	2,5Y 5/4	5.1	21.0	69.1	28.5	2.5	2.7
Lappoluobbal. "ample"								
O	1-0	10YR 2/1	4.0					12.0
E	0-3	10YR 5/1	4.5	10	76.6	21.6	1.9	4.4
Bs	3-21	10YR 4/4	5.1	14	72.3	24.4	3.3	2.5
Bs-C	21-30	2.5Y 4/3	5.3	19	54.6	42.9	2.6	3.6
C*	>30	7.5YR 2/1	5.8	28	68.6	29.1	2.4	7.6

Table 1
(Continued)

Lappoluobbal.								
"reduced"								
O	1-0	10YR 2/1	4.0					8.6
E	1-5	2,5 Y5/2	4.7	24	75.7	23.1	1.3	3.6
Bs	10-15	10YR 4/4	5.2	30	72.3	25.5	2.2	2.5
BsC	28-32	2,5Y 4/4	5.3	39	67.9	29.1	3.0	7.2
C*	>32	7.5YR 2/1	5.8	28	68.6	29.1	2.4	7.6
Biěddjučårro								
"ample"								
O	5-0	7.5YR 2/1	3.9					15.0
E	0-5	2.5Y 6/2	4.8	2	64.5	34.0	1.5	3.4
Bs	5-30	10YR 4/6	5.5	23	68.4	29.3	2.3	2.4
C	>30	7.5Y 5/2	6.0	12	67.9	29.7	2.3	6.3
Biěddjučårro								
"reduced"								
O	2-0	10YR 2/2	4.2					11.2
E	0-3	10YR 6/1	4.9	16	73.6	24.6	1.7	6.5
Bs	3-29	10YR 4/4	5.4	17	72.9	24.7	2.5	1.8
C	>29	7.5Y 6/2	5.8	36	74.8	22.9	2.3	6.0
Biěddjučårro								
"poor"								
Eh	0-2	10YR 3/3	5.2	10	58.7	38.3	3.0	4.5
Bs	2-30	10YR 3/4	5.5	8	63.5	34.2	2.3	1.7
C	>30	10Y 5/1	6.0	18	71.4	26.7	2.0	6.5

*Results from analysis of one combined sample of the C-horizons at *Lappoluobbal.*

Levels of plant available Ca, Mg, K and P in the O-layer beneath ample lichen cover corresponded well with results reported from mountain birch forests in Kevo and Kilpisjärvi (Wielgolaski, 2001). Differences in soil chemistry between sites with different lichen covers were limited to the O- and E-horizons, thus generally the uppermost 10 cm of soil profiles. The approximately 20% lower organic C content, the about 27% reduction in CEC, and the between 30 to 50% reduction in total and plant available Ca and Mg at sites with moderate lichen cover indicate, that considerable qualitative changes of the humus has taken place. A reduction in plant available Ca and Mg in the organic layer of about 50% at sites with reduced lichen cover, is of a similar magnitude as reported for a North Finnish pine forest at heavily grazed sites (Väre *et al.*, 1996). In contrast, no significant decrease of either total P or K could be detected in this investigation.

Despite the distinct differences between chemical soil properties of the organic layer beneath ample and reduced lichen cover, there were no differences in the mineral E-horizon. However, significant differences in chemical soil properties were found between the E- and Eh-horizons. The organic C contents in mineral E-horizons at sites with poor lichen cover were about 8-fold increased compared to sites with better lichen cover. Indications for the existence of a previous superficial O-layer at sites with poor lichen cover suggest, that the significant increase in soil carbon contents is a result of the incorporation of previous O-layer fractions with the underlying E-horizon due to grazing and trampling by reindeers. Differences in soil organic matter content are hold responsible for the detected differences in CEC and nutritious status between the Eh-and E-horizons. However, CEC of the mineral Eh-horizon was, on weight basis, less than 10% compared to that of the O-layers. Furthermore, base saturation of Eh-horizons was in average 4% (Table 1), about 3 to 4 times less than in the O-layer. Poor root development and stunted vascular plant growth at heavy degraded sites indicate that losses of lichen cover and O-layer effect growing conditions negatively.

The decreasing thickness of the organic horizon with supposed increasing grazing pressure until its final loss, as also reported by Evans (1996), indicate considerable quantitative losses of soil organic matter. A high correlation (r = 0.99) between the organic C content and CEC (Fig. 1) emphasize that the organic matter, in particular due to the rather low clay content (Table 1) of the morainic till, possesses a key function for soil fertility.

Consequently, any loss of organic matter would decrease soil fertility. There are no indications that the degradation of the superficial O-horizon has enhanced the nutritious status of mineral soils below, except for the E-horizons. Detected changes in C and nutritious status of Eh-horizons are significant, but too small to compensate losses from O-horizons. Therefore, it is assumed that a considerable amount of organic matter and nutrients were lost from sites with reduced and poor lichen cover.

Losses of organic matter and nutrients from sites with disturbed lichen cover could be partly due to erosion. Results from Fahnestock *et al.* (2000) indicate that the redistribution of litter by wind and snow during winter is an important mechanism of nutrient transfer across the arctic landscape. At sites with continuous vegetation cover redistribution of litter may be limited to above ground plant debris. However, once vegetation cover is disrupted, either by grazing, trampling or digging, also soil organic matter may get exposed to erosional forces, like *e.g.* deflation processes (Thannheiser, 1977). Evans (1996) reports that many of the descriptions of erosion in northern Scandinavia refers to the importance of wind erosion. Incidences of erosion due to reindeer grazing has been noted previously in Finnmark (Lyftingsmo, 1965; Väre *et al.*, 1995; Johansen & Karlsen, 1998).

The declining amounts of actual plant available water in the rooting zone with reduced vegetation and humus cover indicates (Fig. 3), that reindeer grazing also has a significant impact on soil water budget. In general, a well developed lichen surface acts as an effective mulch and elevates the soil moisture status throughout the summer period by preventing evaporation (Larson & Kershaw, 1976; Kershaw, 1977; Kershaw, 1985). In subarctic well-drained terrain acute summer droughts are quite common which are assumed to be lethal to fine roots of trees and dwarf shrubs, that develop close to the soil surface (Crittenden, 2000). The observed reduction in root development (Fig. 3) may therefore to some extent be due to decreasing amounts of plant available water during the growing season. Thus, in addition to decreasing soil mineral nutrients, periodic drought may also be a significant factor suppressing vascular plant vigour.

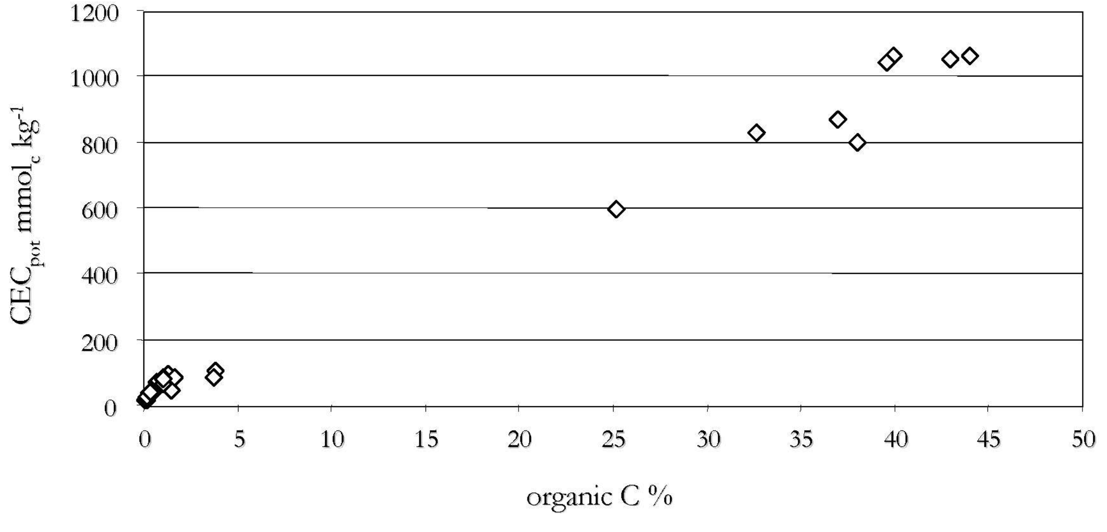

Fig. 1. Correlation between organic carbon (%) and CEC_{pot} ($mmol_c\ kg^{-1}$) in soil material from all soil horizons and sample sites studied on Finnmarksvidda.

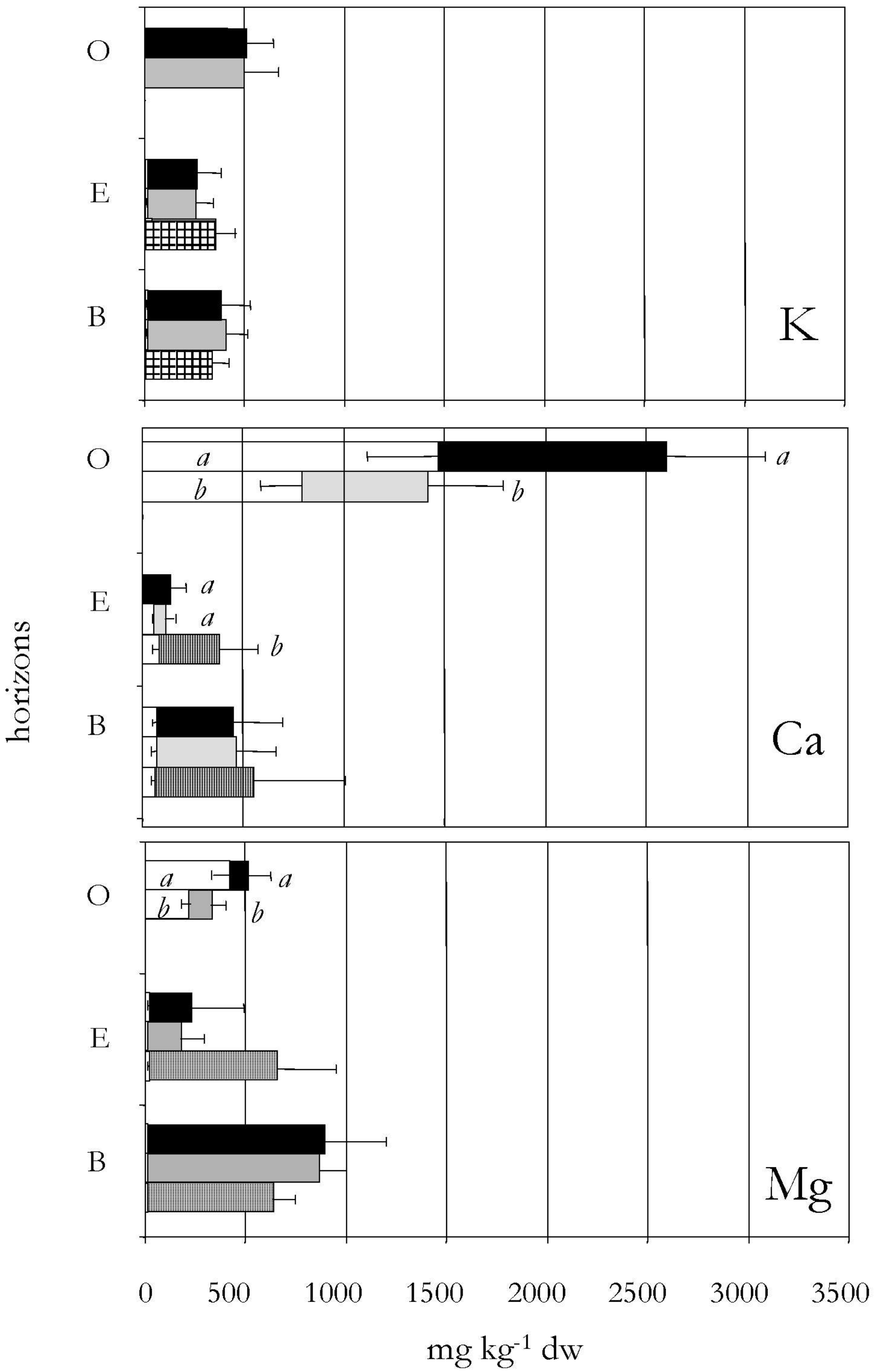

Fig. 2a. Total concentration of K, Ca and Mg in different soil horizons beneath different fruticose lichen cover: ■ ample, ▣ reduced , ⊞ poor. □ indicates plant available concentrations of the cations. Significant differences ($P \leq 0.05$) between plots with different lichen cover are indicated by letters.

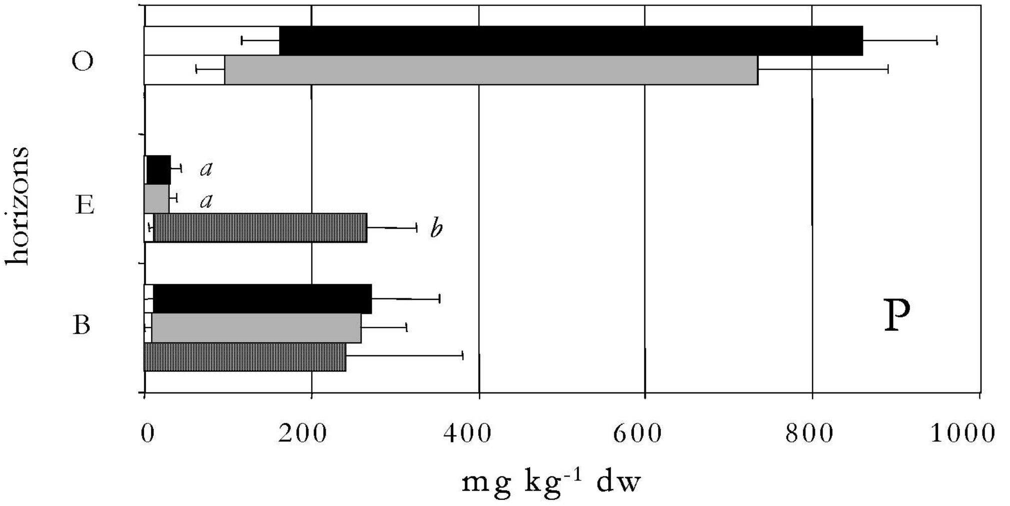

Fig. 2b. Total concentration of P in different soil horizons beneath different fruticose lichen cover: ■ ample, ▩ reduced, ◫ poor. □ indicates plant available concentrations of P. Significant differences ($P \leq 0.05$) between plots with different lichen cover are indicated by letters.

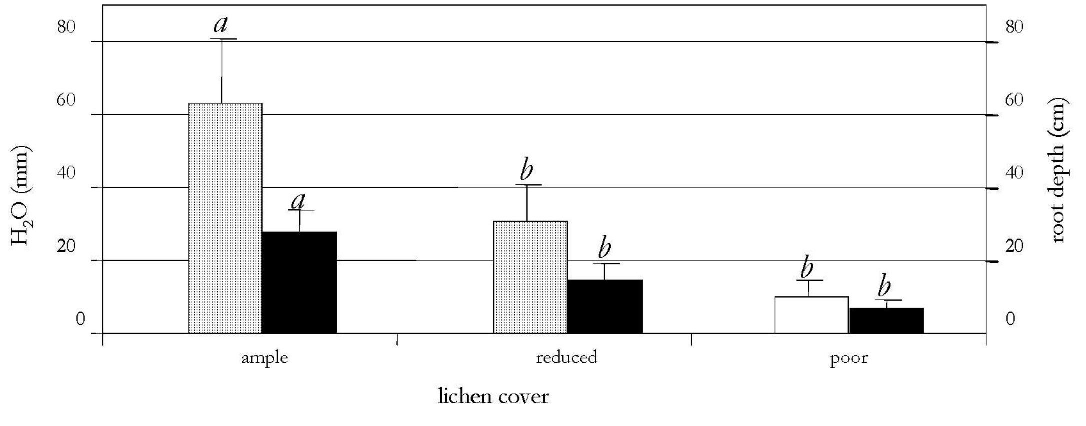

Fig. 3. Comparison of plant available water (▥) and rooting depth (■) at plots with different lichen cover. Significant differences ($P \leq 0.05$) between plots with different lichen cover are indicated by letters.

Conclusions

The O-horizon posses a key role for soil fertility in the lichen dominated tundra-mountain birch forest on Finnmarksvidda. Over-grazing by reindeers can cause a significant degradation of the organic layer, followed by significant losses of essential plant nutrients, a reduction in plant available water and consequently soil fertility. Thus, over-grazing of winter lichen pastures may reduce vascular plant productivity and thus pasture quality and quantity. Further studies should focus on processes and extension of soils degradation due to reindeer grazing on Finnmarksvidda.

Acknowledgements

This work was supported by the Reindeer Research Fund under auspices of the Norwegian Ministry of Agriculture. We also thank Dr. Marit Jørgensen for her valuable comments on the manuscript.

References

Bremner J.M. 1960. Determination of nitrogen by the Kjeldahl method. – *J. Agric. Sci.* 55: 11-33.

Crittenden, P.D. 2000. Aspects of the ecology of mat-forming lichens. – *Rangifer* 20(2-3): 127-139.

De Boodt, M., De Leenheer, L., Frese, H., Low, A.J. & Peerlkamp, P.K. (eds.). 1967. *Determination of the particle density according to the 'alcohol-method'. West European Methods for Soil Structure Determination,* Chap. 5, 8. The West European Working Group on Soil Structure of the International Soil Science Society, the State Faculty of Agricultural Sciences, Ghent, Belgium.

DNMI. 1999. Normaler 1961-1990. Lufttemperatur og nedbør. Foreløpig liste pr 23.03.1999, DNMI Klima.

Egnér, H.H. & Riehm, W.R. 1960. Untersuchungen über die chemische Boden-Analyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. – *The Royal Agricultural High School Annals* 26: 199-215.

Elonen, P. 1971. Particle-size analysis of soil. – *Acta Agral. Fenn.* 122: 1-122.

Evans, R. 1996. Some impacts of overgrazing by reindeer in Finnmark, Norway. – *Rangifer* 16(1): 3-19.

FAO. 1990. Guidelines for Soil Description. 3rd Editions (Revised). FAO Rome.

Fahnestock, J.T., Povirk, K.L. & Welker, J.M. 2000. Ecological significance of litter redistribution by wind and snow in arctic landscapes. – *Ecography* 23: 623-631.

Haugerud, R.E. (ed.). 1999. Proceedings of the Tenth Nordic Conference on Reindeer Research. Kautokeino, Norway, 13 - 15 March 1998. – *Rangifer Report* No. 3.

Hodgson, J.M. (ed.). 1976. Soil survey field handbook. Describing and sampling soil profiles. – *Soil Survey Technical Monograph* 5, Harpenden, 99 pp.

Hætta, E.I.O. 2002. Ressursregnskap for reindrifts-næringen. Reindriftsforvaltningen, 9510 Alta, Norway.

Ims, A. A. 1998. Ressursregnskap for reindriftsnæringen, drifsåret 1997/98. – *Reindriftsnytt* 4: 30-35.

Johansen, B.E., Johansen, M.E. & Karlsen, S.R. 1995. *Vegetasjons- og beitekartlegging in Finnmark og Nord-Troms.* NORUT Information Technology. IT2026/1-1995, 60 p.

Johansen, B. & Karlsen, S.R. 1996. *Reingjerder i Finmark.* NORUT Informasjonsteknologi AS 2033/01-96, 123 p.

Johansen, B. & Karlsen, S.R. 1998. *Endringer i lavdekket på Finnmarksvidda 1987-1996 basert på Landsat 5/TM data.* NORUT IT Rapport, IT475/1-98, 12 p.

Johansen, B. E. & Karlsen, S. R. 2000. *Finnmarksvidda–kartlegging og overvåkning av reinbeiter–status 1998.* NORUT Informasjonsteknologi AS, Rapport IT546/1-2000, 68 p.

Kershaw, K.A. 1977. Studies on lichen-dominated systems. XX. An examination of some aspects of the northern boreal lichen woodlands in Canada. – *Can. J. Bot.* 55: 393-410.

Kershaw, K.A. 1985. *Physiological Ecology of Lichens.* Cambridge University Press, Cambridge.

Kumpula, J. 2001. Productivity of semi-domesticated reindeer (*Rangifer t. tarandus* L.) stock and carrying capacity of pastures in Finland during 1960-1990`s. PhD Thesis Department of Biology, University of Oulu. *Acta Universitatis Ouluensis* A 375.

Larson, D.W. & Kershaw, K.A. 1976. Studies on lichen-dominated systems. XVIII. Morphological control of evaporation in lichens. – *Can. J. Bot.* 54: 2061-2073.

Lyftingsmo, E. 1965. Oversyn over Fjellbeite i Finnmark. *Norsk Fjellbeite* Bind 15.

Ogner, G., Haugen, A., Opem, M. & Sørlie, M. 1975. Kjemisk analyseprogram ved Norsk institutt for skogsforskning. *Meddr. Norsk. Inst. Skogforsk.* 32, pp. 207-232.

Ogner, G., Haugen, A., Opem, M. & Sørlie, M. 1977. Kjemisk analyseprogram ved Norsk institutt for skogsforskning. – *Meddr. Norsk. Inst. Skogforsk.* 33, Suppl. 1, pp. 87-101.

Oldeman, L.R., Hakkeling, R.T.A. & Sombroek, W.E. 1991. *World map of status of human-induced soil degradation. An explanatory note.* Second revised edition. International Soil Reference and Information Centre, United Nations Environment Programme, Wageningen.

Olofsson, J., Kitti, H., Rautiainen, P., Stark, S. & Oksanen, L. 2001. Effects of summer grazing by reindeer on composition of vegetation, productivity and nitrogen cycling. – *Ecography* 24: 13-24.

Olsen, L., Reite, A., Riiber, K. & Sørensen, E. 1996. Finnmark County, map of quaternary geology, scale 1:500,000 with description. *Geological Survey of Norway.*

Richards, L.A. 1947. Pressure-membrane apparatus, construction and use. – *Agric. Eng.* 28, pp. 451-454, 460.

Richards, L.A. 1948. Porous plate apparatus for measuring moisture retention and transmission by soils. – *Soil Sci.* 66: 105-110.

Stark, S., Wardle, D. A., Ohtonen, R., Helle, T. & Yeates, G. W. 2000. The effect of reindeer grazing on decomposition, mineralization and soil biota in a dry oligotrophic Scots pine forest. – *Oikos* 90: 301-310.

Thannheiser, D. 1977. Subarctic birch forests in Norwegian Lapland. – *Naturaliste can.* 104: 151-156.

Väre, H, Ohtonen, R. & Oksanen, J. 1995. Effects of reindeer grazing on vegetation in dry *Pinus sylvestris* forests. – *J. Veg. Sci.* 6: 523-530.

Väre, H., Ohtonen, R., & Mikkola, K. 1996. The effect and extent of heavy grazing by reindeer in oligotrophic pine heath in northeastern Fennoscandia. – *Ecography* 19: 245-253.

Wielgolaski, F.E. (ed.). 2001. Nordic mountain birch ecosystems. Series Editor: Jeffers, J.N.R. Series Title: *Man and the biosphere.* UNESCO (Paris) and The Parthenon Publishing Group. Vol. 27: 23-33.