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# EFFECT OF GRASS SWARD ON THE CHEMISTRY OF LYSIMETRIC WATER ON AN ALTITUDINAL GRADIENT OF DEFORESTED MOUNTAIN AREAS AFFECTED BY ACID DEPOSITIONS

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Abstract

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We hypothesize that enhanced acid deposition along an altitudinal gradient will unfavourably impact the lysimetric water chemistry and leach nutrients from old *Calamagrostis villosa* stands. A 3-year field experiment was conducted transferring soil blocks with old *C. villosa* swards into plastic containers modified to hold lysimeters at three different elevations (635, 940 and 1140 m a.s.l.) and characterized by different intensities of acid deposition. The chemistry of lysimetric water was mostly not significantly affected by site in individual parts of growing seasons. Nevertheless, the ANOVA revealed a significant effect of site on the concentration of $Ca^{2+}$ and $Al^{3+}$. Chemistry of percolates was significantly altered with time due to annual differences in acid deposition. Statistically significant positive correlations were found between nitrogen and sulphate inputs in wet depositions and acidity of lysimetric water, and the amounts of leached $Ca^{2+}$ and nitrates at various parts of the growing season. Swards of *C. villosa* partly eliminate excess of nitrogen in soil, due to their large accumulation in plant biomass. They reduce negative processes associated with soil acidification. However, enhanced input of both nitrogen and sulphate loads can lead to increased leaching of both the nitrates and calcium, particularly at higher elevations.

*Key words*: *Calamagrostis villosa*, $Ca^{2+}$, grass growth, lysimetric water, nitrogen, pH

## Introduction

Acid depositions, including higher inputs of nitrogen (N), are linked with negative processes in forest soil and with forest decline in mountain regions (Nihlgard, 1985; Kennedy, 1992). Although some improvements have been made with respect to the reduction of the amount of pollutants in Central Europe (Květ, 1993; Fanta, 1997), ammonia emissions have shown the least reduction (Gregor et al., 2004). Thus high nitrogen pollution is still considered as one of the major threats to the structure and functioning of ecosystems (cf. Bobbink, Roelofs, 1995; Bobbink et al., 1998).

Nitrogen is usually the growth-limiting nutrient in many ecosystems. A chronic excess of nitrogen deposition, however, can lead to "nitrogen saturation", manifested by increased leaching of inorganic nitrogen (generally nitrate), especially after nitrification of ammonium in a weakly buffered environment. Increased leaching of nitrate enhances acidification of soil.

Thus, high inputs of nitrogen associated with soil acidification have caused subsequent leaching of basic cations (Nihlgard, 1985; Schulze et al., 1989; Soukupová et al., 1995). This is reflected in ecosystems on acidic soil in a nutrient imbalance, i.e., deficiencies of macro-nutrients (K, P, Mg and Ca) relative to N in aboveground plant parts. Therefore soil acidification and losses of basic cations from soil have been given high priority in studies of such habitats. For example, Watmough and Dillon (2003) warn and point out if Ca losses, due to acid deposition and harvesting continue at the present rate, forest health and productivity may be impaired within just a few decades.

Ground layer species are sensitive to decreasing soil pH and Ca losses in topsoil and have been demonstrated by a decrease of their frequency (e.g., Falkengren-Grerup, 1986; Rodenkirchen, 1993). However, intensive spreading of acidophilous perennial grasses on deforested sites in the mountain regions of Central Europe was supported by improved light conditions, after destruction of the tree canopy, by soil acidification and increased nitrogen availability (e.g., Fiala et al., 1989; Pyšek, 1990; Koppisch, 1994; Vacek et al., 1999). Plants have a great capacity for the adapting to pollution and acid soil conditions (Mansfield, 1988; Gloser et al., 1996) and the neutralization of the impact of acid environment (van Dam et al., 1990; Takamatsu et al., 1997; Sedláková et al., 1999). The grass vegetation of clear-cut areas can function as an important sink for nitrogen inputs from polluted atmosphere (Betz, 1998; Holub, 2003; Fiala et al., 2005). This is caused by a combination of a high N uptake by plants and an effective N immobilization in the soil organic matter. Biological neutralization due to the presence of grass vegetation is associated with the rapid recycling of elements in the plant-soil system (Takamatsu et al., 1997). However, in comparison with woody species, grass swards on deforested areas, can change the edaphic factors more effectively due to the shorter time of biomass turnover (Fiala, 1998; Emmer, 1999; Tůma, 2002).

We assume that enhanced acid deposition loads increasing with altitude are lowering pH values and $Ca^{2+}$ and nitrates leaching from grass swards although these swards may eliminate the excess of N on polluted deforested sites, and consequently, reduce both the soil acidification and the base cation losses. Therefore we monitored wet bulk deposition, chemistry of lysimetric water and assessed nitrogen uptake by plant biomass of old grass swards growing in lysimeters on clear-cut areas situated along a gradient of increasing altitude.

## Materials and methods

### Study sites

A field experiment was carried out involving transfer of soil blocks from an old and well developed *Calamagrostis villosa* sward to three different deforested localities in the Moravian-Silesian Beskydy Mts (the Czech Republic): (1) Černá Ostravice river valley (latitude 49°28´ N, longitude 18°32´ E, 630 m a.s.l., 7.1 °C annual mean air temperature, 869 mm sum of precipitation, further referred to as Site I), locality Bílý Kříž ( 49°31´ N, 18°32´ E, 945 m a.s.l., 6.5 °C, 948 mm, Site II) and near the top of the Malý Smrk Mtn. (49°31´ N, 18°32´ E, 1140 m a.s.l., 5.6 °C, 1111 mm, Site III) (Hadaš, 1993). Thus, localities were characterized by different inputs of acid depositions, since impact of pollution and acid deposits increased in the region with increasing altitude (Hadaš, 1991) (see Results).

The transferred soil blocks with *C. villosa* sward were ten years old and characterized by 360–430 g m$^{-2}$ of aboveground biomass (dry mass), about 1920 g m$^{-2}$ of total below-ground plant matter and 412–486 g m$^{-2}$ of undecomposed plant litter (Fiala et al., 1998). The amount of nitrogen bound in this sward corresponded to more than 34 g m$^{-2}$, of which 36% was contained in aboveground living biomass (Fiala, Jakrlová, 1996). The shallow soil, ferro humic podzol, sandy loam on the deluvium of Godula sandstone was characterized by a rather low soil pH (3.77 pH-$H_2O$, 3.11 pH-KCl), a low calcium ($Ca^{2+}$) content (628 mg kg$^{-1}$) and a relatively high content of aluminium ($Al^{3+}$) ions (1028 mg kg$^{-1}$). Soil organic matter averaged 30.4% at the beginning of the experiment.

### Lysimetric study

Undisturbed soil blocks (36x53x16 cm) with a part of *Calamagrostis villosa* sward were carefully isolated, inserted into plastic containers and transferred to three selected deforested sites (see text above) on May 16, 1997. A trench was dug for each container in the soil on the chosen sites. A total of 9 containers (three replications at each site) modified to free-tension lysimeters were installed in these trenches with their upper surface at the level of the surrounding soil. Percolates from the lysimeters was collected at about 1-month intervals in 15 litre polyethylene vessels. Bulk wet deposition was collected at a height of 1 m, using a funnel of 4.5 dm$^2$ in area. Collecting polyethylene vessels placed in soil were covered to prevent assimilation of nutrients by algae. The volume of percolates was measured in situ, and aliquots (ca. 1 L) were brought back to the laboratory. Experiments started on May 16, 1997 and continued till October 21, 1999.

Data obtained from another field experiment, running simultaneously in the same region and years (Fiala et al., 2005), concerned with the chemistry of lysimetric water intercepted from soil without grasses, and recorded at the locality Malý Smrk Mt. (Site III), were compared with the chemistry of percolates from lysimeters with *C. villosa* swards. These lysimeters, each replicated three times, represented lysimeters with inserted blocks of bare forest soil. These soil blocks were from a partly damaged Norway spruce stand, situated near the top of the Malý Smrk Mt. and characterized also by a low soil pH (3.38 pH-$H_2O$, 2.72 pH-KCl), calcium ($Ca^{2+}$) content (248 mg kg$^{-1}$) and a relatively high content of aluminium ($Al^{3+}$) ions (1199 mg kg$^{-1}$). Soil organic matter averaged 32.0% at the beginning of the experiment.

### Grass growth

At the end of the growing seasons 1997, 1998 and 1999, the aboveground biomass of *C. villosa* was clipped from the lysimeters for estimation of nitrogen levels in the grass biomass. In 1997 and 1998, fresh aboveground biomass was weighed and small aliquots of biomass were oven-dried (60 °C, for 2–3 days). In 1997 and 1998, the clipped aboveground parts were distributed over the area of lysimeters as fresh litter and were collected together with old litter in the next years, dried and weighed. A micro-kjeldahl analytical method was used to assess N content in plant biomass (for detailed description see Fiala et al., 2005).

### *Water analysis*

Samples of water, collected usually once a month, were analyzed for pH and conductivity. An Orion 290 A (USA) pH meter and conductometer GRYF 107 (the Czech Republic) were used. The content of basic cations ($Ca^{2+}$ and $Mg^{2+}$) was assessed complexometrically. The concentration of magnesium in percolates was mostly below the level of determinability by this method. The content of N-$NH_4^+$ was estimated spectrophotometrically with Nessler´s reagent and that of N-$NO_3^-$ also spectrophotometrically with sodium salycilate. The contents of leached N-$NH_4^+$ from lysimeters were not assessed due to tinted extracts from soil of the old grass sward. In 1997 and 1998, labile $Al^{3+}$ was assessed in one sample of each site using the method described by James et al. (1983). The concentration of sulphates was determined by electrophoresis using a DIONEX (USA) analyzer. A more detailed description of applied method is given by Fiala et al. (2005).

### *Statistical analysis*

Two-way ANOVA analysis was used to test the effect of site and years, as independent variables, on the chemistry of lysimetric waters as dependent variables. Data on plant biomass, N uptake and nutrient leaching from soil were also subjected to analysis of variance (ANOVA) and significant differences among means were tested using LSD test ($P < 0.05$). Regression analysis was performed to evaluate the relationships between acidic depositions and amounts of leached $Ca^{2+}$, N-$NO_3^-$ and other parameters of percolates. The statistical package STATISTICA 6.0 was used.

## Results

### *Wet bulk depositions*

In the three growing seasons (1997–1999), the wet bulk depositions of both N-$NH_4^+$ and N-$NO_3^-$ on the Site III (1140 m a.s.l.) were mostly two to three times higher than those at other two localities situated at the lower altitudes (Table 1). The deposition of sulphates was also substantially greater on the Site III, in 1997 and 1998 particularly, ranging between 33.5 to 40.1 kg $SO_4^{2-}$ $ha^{-1}$. However, there were no great differences between sites in acidity and conductivity of rain waters fluctuating from 3.97 to 5.08 pH and 10 to 47 µS $cm^{-1}$, respectively. Comparison of total nitrogen inputs between Site III and Site I represented, respectively, 10.79, 17.43 and 8.97 kg N $ha^{-1}$ and 7.02, 6.68, 4.03 kg N $ha^{-1}$ in the growing seasons 1997, 1998 and 1999 (Table 1). A high input of sulphates dominates and the co-deposition of sulphates and ammonium is considered to be the major source of acidity. The levels of loads of the incoming acidity, associated in studied sites with sulphate and ammonium inputs, were determined by precipitation volume, which was usually higher on Site III and at the beginning of the growing season and during autumn.

### *Biomass of grass sward and nutrient uptake*

The aboveground biomass of *Calamagrostis villosa* ranged in a relatively broad range (Table 2). Lower values (142–313 g $m^{-2}$) were mostly recorded on Site I in the Černá Ostravice river

Table 1. Sum of precipitation (mm) and mean values of pH and conductivity (µS $cm^{-1}$) in rain water and amounts of N-$NH_4^+$, N-$NO_3^-$ and $SO_4^{2-}$ in wet bulk depositions (kg $ha^{-1}$) at three localities of different altitudes in the Moravian-Silesian Beskydy Mts as recorded in 1997, 1998 and 1999 growing seasons.

| Period / Site | Precipitation | pH | Conductivity | N-$NH_4^+$ | N-$NO_3^-$ | $SO_4^{2-}$ |
|---|---|---|---|---|---|---|
| 14/5 – 2/10, 1997 | | | | | | |
| site I | 890 | 4.56 | 18.4 | 2.66 | 4.36 | 17.46 |
| site II | 918 | 4.25 | 22.5 | 3.44 | 4.04 | 19.02 |
| site III | 1097 | 4.39 | 23.5 | 6.28 | 4.51 | 33.51 |
| 11/5 – 6/10, 1998 | | | | | | |
| site I | 636 | 4.47 | 15.8 | 2.79 | 3.89 | 17.4 |
| site II | 660 | 4.29 | 20.0 | 2.29 | 4.47 | 15.3 |
| site III | 934 | 4.59 | 18.6 | 8.06 | 9.37 | 40.11 |
| 13/5 – 21/10, 1999 | | | | | | |
| site I | 628 | 4.49 | 29.2 | 2.43 | 1.60 | 15.41 |
| site II | 622 | 4.71 | 25.4 | 2.78 | 1.29 | 15.28 |
| site III | 698 | 4.48 | 36.4 | 5.36 | 3.61 | 21.60 |

Table 2. Amount of dry mass (g $m^{-2}$) and nitrogen (g $m^{-2}$) in living above-ground plant matter and litter of *Calamagrostis villosa* on three sites of different altitudes in the Moravian-Silesian Beskydy Mts as recorded at the end of 1997, 1998 and 1999 growing seasons. Different letters within columns indicate significant differences (LSD test, $P < 0.05$). Means and one standard error are given. Compared are differences between sites.

| Years / Site | Aboveground | | Aboveground litter | |
|---|---|---|---|---|
| 1997 | dry mass | N | dry mass | N |
| site I | 313.9 ± 42.9bc | - | - | - |
| site II | 464.3 ± 40.1d | - | - | - |
| site III | 411.3 ± 21.4cd | - | - | - |
| 1998 | dry mass | N | dry mass | N |
| site I | 291.1 ± 28.1a | 1.69 ±0.17ab | 289.0 ± 36.1a | 4.15 ± 0.60a |
| site II | 470.0 ± 53.7d | 3.61 ± 0.35d | 342.0 ± 11.9ab | 4.89 ± 0.20a |
| site III | 233.1 ± 44.5ab | 1.91 ± 0.30ab | 391.8 ± 22.5b | 7.48 ± 0.53b |
| 1999 | dry mass | N | dry mass | N |
| site I | 142.1 ± 27.4a | 1.12 ± 0.16a | 312.7 ± 64.4ab | 4.61 ± 0.32a |
| site II | 243.5 ± 45.0ab | 2.50 ± 0.62bc | 279.3 ± 13.9ab | 4.61 ± 0.29a |
| site III | 276.3 ± 15.6ab | 3.11 ± 0.12cd | 287.6 ± 26.9a | 4.63 ± 0.41a |

valley and characterized by a lower amount of precipitation, whereas the highest values were assessed on site II (411–470 g $m^{-2}$). Nevertheless, 233 to 411 g $m^{-2}$ of aboveground biomass was produced at the uppermost mountain zone (Site III) affected by higher nitrogen inputs. Data on nitrogen uptake in aboveground biomass are also rather variable (Table 2). Nevertheless, they indicate increasing accumulation of nitrogen in *C. villosa* swards with altitude. Table 2 data show accumulation of undecomposed aboveground plant parts on the soil surface and the amount of nitrogen immobilized in this several years´ old litter. They fluctuate from 279 to 392 g $m^{-2}$ of dry mass and from 4.15 to 7.48 g N $m^{-2}$. The highest values were recorded on site III in 1998 characterized by higher input of acid depositions (the amount of nitrogen significantly exceeds that in other sites and years).

*The chemistry of lysimetric water of grass swards at an altitudinal gradient*

There were usually no significant differences between sites in pH, conductivity, $Ca^{2+}$ and N-$NO_3^-$ concentrations in percolates in individual periods of three growing seasons (Figs 1–5).

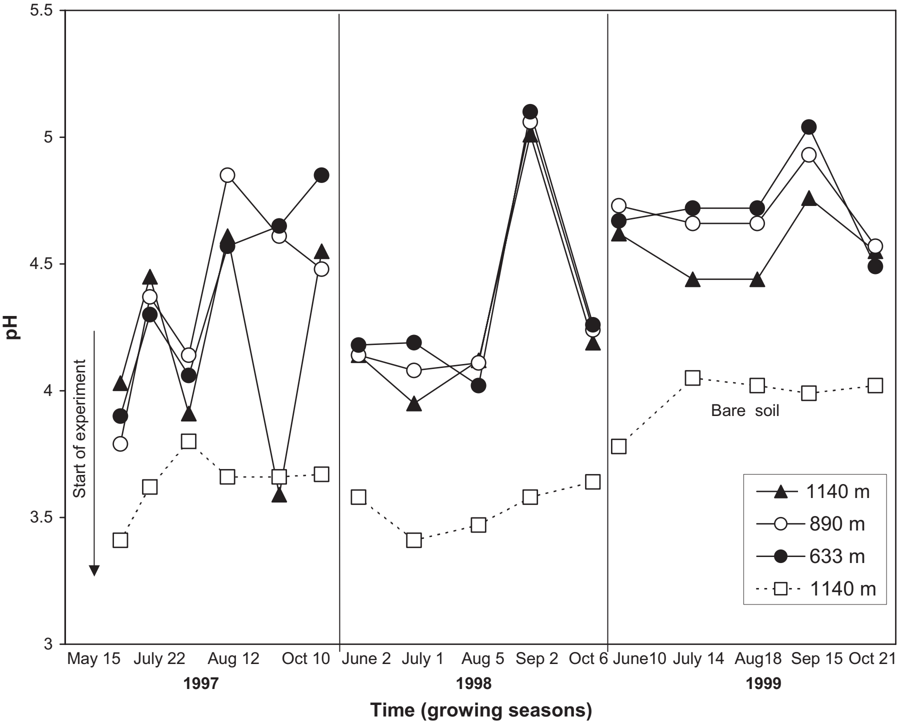

Fig. 1. Changes in pH values of lysimetric water leached from old *Calamagrostis villosa* swards on different sites and from bare forest soil (1140 m a.s.l. – Malý Smrk Mt.) during 1997, 1998 and 1999 growing seasons. Mean values are shown.

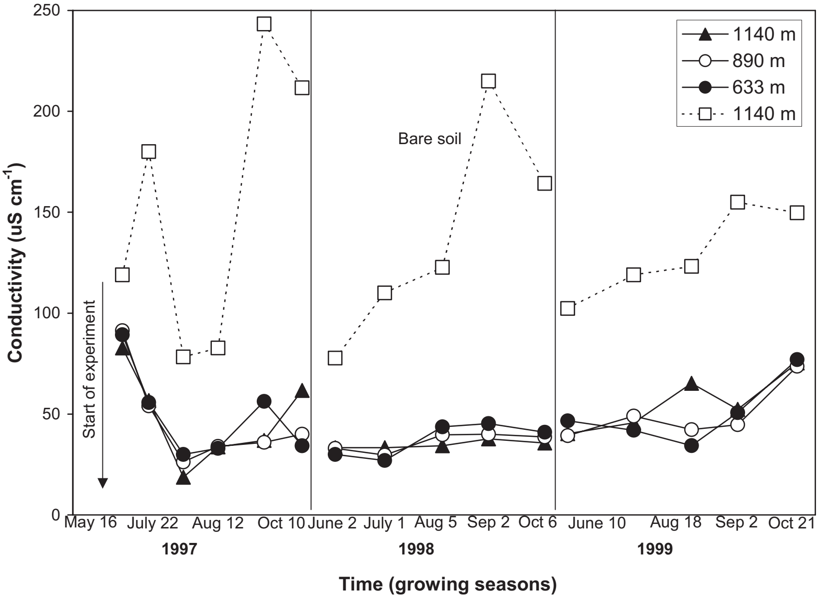

Fig. 2. Changes in conductivity of lysimetric water leached from old *Calamagrostis villosa* swards on different sites and from bare forest soil (1140 m a.s.l. – Malý Smrk Mt.) during 1997, 1998 and 1999 growing seasons. Mean values are shown.

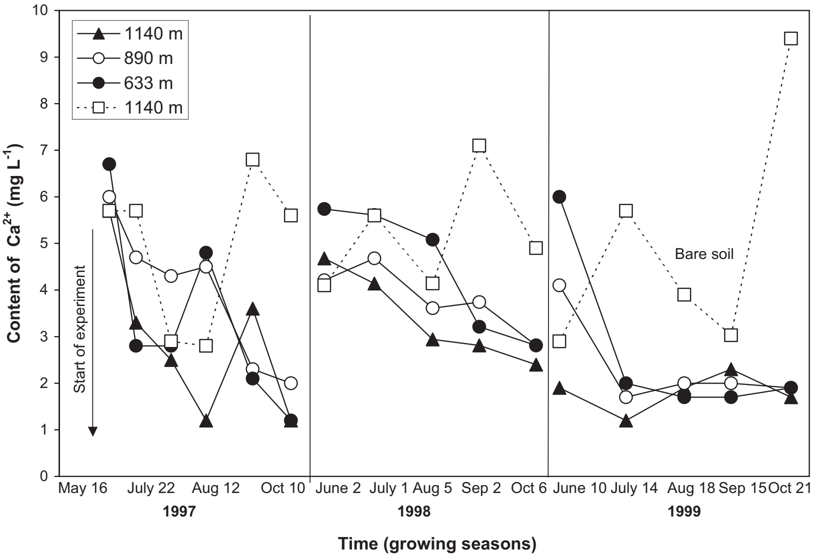

Fig. 3. Changes in concentration of $Ca^{2+}$ of lysimetric water leached from old *Calamagrostis villosa* swards on different sites and from bare forest soil (1140 m a.s.l. – Malý Smrk Mt.) during 1997, 1998 and 1999 growing seasons. Mean values are shown.

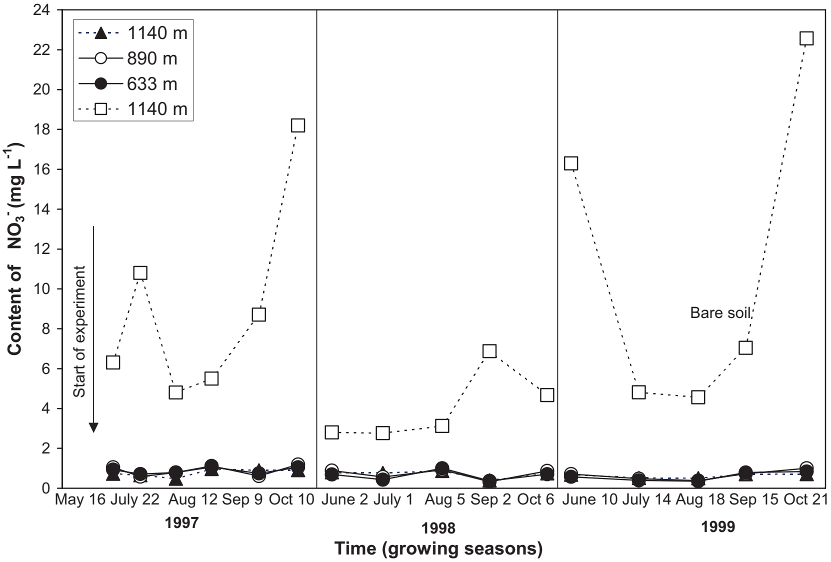

Fig. 4. Changes in concentration of N-$NO_3^-$ of lysimetric water leached from old *Calamagrostis villosa* swards on different sites and from bare forest soil (1140 m a.s.l. – Malý Smrk Mt.) during 1997, 1998 and 1999 growing seasons. Mean values are shown.

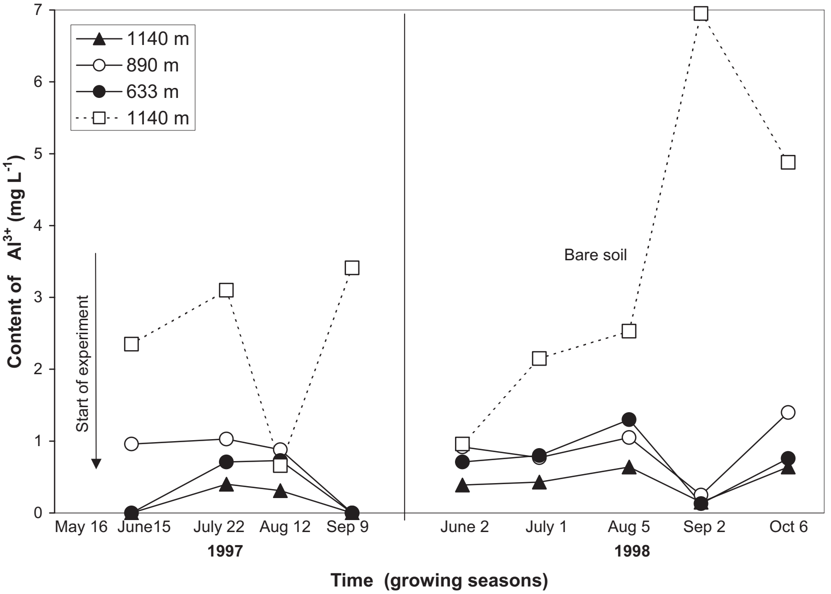

Fig. 5. Changes in concentration of labile $Al^{3+}$ of lysimetric water leached from old *Calamagrostis villosa* swards on different sites and from bare forest soil (1140 m a.s.l. – Malý Smrk Mt.) during 1997, 1998 and 1999 growing seasons. Mean values are shown.

T a b l e 3. The effect of site and year (1997, 1998 and 1999) on the chemistry of lysimetric waters leached from soil with *Calamagrostis villosa* sward at three sites of different altitudes in the Moravian-Silesian Beskydy Mts. Results of two-way ANOVA analyses.

| Effects | | pH | | Conductivity | | $Ca^{2+}$ | | $N\text{-}NO_3^-$ | | | $Al^{3+}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | df | F | | F | | F | | F | | df | F | |
| site (S) | 2 | 2.68 | NS | 0.14 | NS | 3.58 | * | 0.67 | NS | 2 | 3.76 | * |
| year (Y) | 2 | 15.3 | *** | 8.27 | ** | 12.7 | *** | 8.36 | *** | 1 | 3.52 | NS |
| S x Y | 4 | 0.29 | NS | 0.24 | NS | 0.67 | NS | 0.63 | NS | 2 | 0.19 | NS |

Notes: df – degree of freedom, F – values of F test, NS – non significant, * – $P < 0.05$, ** – $P < 0.01$, *** – $P < 0.001$

T a b l e 4. The correlation coefficients for measured data on the amount of nitrogen and sulphate depositions and pH values of rain water related to pH and conductivity values of percolates and to the amount of leached $Ca^{2+}$ and $N\text{-}NO_3^-$ from soil with *Calamagrostis villosa* sward (in kg per ha and growing season) at three sites of different altitude in the Moravian-Silesian Beskydy Mts. as recorded in the 1998 and 1999 growing seasons (Pearson´s correlation was used, NS – non significant, * – $P < 0.05$, ** – $P < 0.01$, *** – $P < 0.001$).

| Site (alti-tude) | Site I (630 m) | | | Site II (945 m) | | | Site III (1175 m) | | |
|---|---|---|---|---|---|---|---|---|---|
| deposi-tion | pH | N min. | $SO_4^{2-}$ | pH | N min. | $SO_4^{2-}$ | pH | N min. | $SO_4^{2-}$ |
| pH | 0.385* | -0.672*** | -0.401* | 0.170 NS | -0.615* | -0.620* | 0.059 NS | -0.620*** | -0.503** |
| conduc-tivity | -0.102 NS | -0.184 NS | 0.089 NS | -0.123 NS | - 0.002 NS | -0.042 NS | -0.182 NS | -0.332 NS | -0.316 NS |
| $Ca^{2+}$ | -0.651*** | 0.467** | 0.300 NS | -0.744*** | 0.407 NS | 0.746*** | 0.051 NS | 0.695*** | 0.487** |
| $N\text{-}NO_3^-$ | -0.605*** | 0.410* | 0.619*** | -0.642* | 0.773*** | 0.894*** | -0.540** | 0.553** | 0.468** |

During the first year of the experiment, the disturbance associated with the transplanting of sward parts can mask any site effects due to large fluctuations of measured parameters. Nevertheless, in the next two years, features of percolates were more favourable than those recorded in soil percolates collected from bare forest soil without grasses at the locality Malý Smrk Mt. (Site III) in a parallel experiment (Fiala et al., 2005). Consequently, the analysis of variance did not confirm a significant effect of site on pH, conductivity and content of $N\text{-}NO_3^-$ in lysimetric water (Table 3). Site location affected significantly only the content of $Ca^{2+}$ and $Al^{3+}$ (in mg $L^{-1}$) leached from soil. In contrast, the chemistry of lysimetric water was changed highly significantly with years. Quality of percolates was not affected by site x year interactions (Table 3).

The effect of different amounts of acidic deposition on character and quantity of substances leached from soil (in kg $ha^{-1}$), as recorded in individual parts of growing seasons, is clearly demonstrated by correlation analysis (Table 4). Negative correlations, statistically significant, were found between wet bulk depositions of both nitrogen and sulphate (in kg $ha^{-1}$) and pH of percolates. The enhanced acidity of rain water

Table 5. Amount of leached N-$NO_3^-$, $Ca^{2+}$ and $Al^{3+}$ (kg $ha^{-1}$) from soil with *Calamagrostis villosa* sward at three localities of different altitudes in the Moravian-Silesian Beskydy Mts as recorded in the 1998 and 1999 growing seasons. Means and one standard error are given where available. Different letters indicate significant differences ($P < 0.05$) according to the LSD-test ($n = 3$). Amount of leached $Al^{3+}$ was assessed only in 1998 (see Materials and method).

| Site | 1998 | | | 1999 | |
|---|---|---|---|---|---|
| | N-$NO_3^-$ | $Ca^{2+}$ | $Al^{3+}$ | N-$NO_3^-$ | $Ca^{2+}$ |
| site I | 1.47 ± 0.11a | 10.20 ± 8.3b | 2.65 | 1.19 ± 0.09a | 5.01 ± 0.64a |
| site II | 2.03 ± 0.21ab | 10.14 ± 0.47b | 2.65 | 1.69 ± 0.29ab | 5.23 ± 0.51a |
| site III | 2.45 ± 0.46b | 10.54 ± 1.53b | 1.32 | 1.49 ± 0.32a | 4.05 ± 0.95a |

was mostly associated with greater losses of $Ca^{2+}$ and nitrates from the soil. Depositions of sulphates also correlated positively with the amount of leached nitrates. Relationships between the nitrogen and sulphate depositions and the studied features of soil percolates were more distinct on Site III, due to higher acid loads recorded there, than on other sites (Table 1). They affected significantly all evaluated parameters (pH values, leaching of $Ca^{2+}$ and nitrates). Correlation coefficients, however, do not indicate significant influence of acid depositions on conductivity of lysimetric water collected at any of the sites.

Leaching of N-$NO_3^-$ from soil with grass swards on Sites I and III (1.47 and 2.45 kg of N per hectare, significant difference between both localities at $P < 0.05$) was measured in the course of the second growing season (1998), whereas in the next year (1999), the leaching represented only 1.19 and 1.49 kg of N per ha (difference not significant) (Table 5). In 1998, an enhanced input of acid deposition caused a significantly higher leaching of $Ca^{2+}$ from soil, ranging between 10.20 and 10.54 kg $ha^{-1}$, whereas losses of calcium reached only 4.05 to 5.01 kg $ha^{-1}$ in the next (1999) growing season. However, differences between sites were not significant. The amount of $Al^{3+}$ leached from the soil corresponded to 1.32 (Site III) to 2.76 kg $ha^{-1}$ (Site II) in the 1998 growing season (Table 5).

## Discussion

### *The chemistry of lysimetric water of grass swards at an altitudinal gradient*

Our data demonstrate there were usually no significant differences in pH, conductivity, and in the content of N-$NO_3^-$ of lysimetric water between sites situated at different altitudes during three growing seasons (Figs 1–5). Although inputs of acid depositions were two to three time greater at Site III situated in the uppermost mountain zone than at lower altitudes, an analysis of variance of lysimetric water chemistry revealed no significant effect of different sites on these features of collected percolates. Nevertheless, concentration of $Ca^{2+}$ and $Al^{3+}$ (in mg $L^{-1}$) leached from soil were significantly affected by site location. Quality of lysimetric water changed highly significantly because the amount of acid deposition was different in individual years.

Results obtained in a lysimeter experiment performed with planted grasses at the locality Malý Smrk Mt. (Site III) in the same three years (Fiala et al., 2005) indicate that values of pH assessed in lysimetric water, collected from young two to three year old grass swards of *C. villosa* ranged from about pH 4.2, whereas in percolates from bare forest soil without planted grasses about pH 3.7. Conductivity of soil percolates averaged 34 µS cm$^{-1}$ for grass swards and 139 µS cm$^{-1}$ for bare soil. About 5 mg L$^{-1}$ of $Ca^{2+}$ leached from bare soil, which had a three to four times higher concentration than young grass swards. The amount of nitrogen mostly did not reach more than 2 mg L$^{-1}$, however, the amount in percolates from bare soil was two to four times higher. Similarly, lower values of acidity, conductivity and contents of $Ca^{2+}$ and nitrates were recorded in percolates collected in our experiment from old *C. villosa* swards than were assessed by Fiala et al. (2005) in lysimetric water from bare forest soil without grasses (Figs 1–5).

An enhanced nitrification rate was recorded by Novák (1999) on sites exposed to heavy pollution in the Beskydy Mts. Significant increase in nitrate losses with nitrogen deposition was reported by Aber et al. (2003). Increased nitrification potential and subsequent $NO_3^-$ production can increase after site disturbance (Burger, Pritchett, 1984). For example, nitrate losses were enhanced 5 years after clear felling Sitka spruce stands (Titus, Malcolm, 1992). These processes resulted not only from a decreased uptake by the vegetation, but also from an increased N mineralization due to improved soil moisture and temperature conditions for decomposition (Donaldson, Henderson, 1990). However, a less intensive leaching of nitrogen, particularly of nitrates, from soil covered by grasses than from forest soil was recorded (Záhora, 1997). Leaching of $Ca^{2+}$ was also significantly higher from different types of soil in the most acidic irrigation water (pH 3.5, Ervio, 1991). Similarly, Sherman and Fahey (1994) reported that leaching of base cations and labile $Al^{3+}$ was also accelerated in the most intensive acid treatment and $Ca^{2+}$ leaching even at the pH 4.1.

Although grass swards can partly eliminate negative processes associated with soil acidification (Takamatsu et al., 1997; Fiala et al., 2005), varying intensities of pollution occurring on fully exposed sites in different time periods can change the content of mineral nitrogen, especially nitrates, in percolates, and coincide with higher amounts of $Ca^{2+}$ and $Al^{3+}$ leached from the soil.

### *Plant nitrogen uptake and amount of leached nutrients*

Our results have shown that grass swards on deforested areas strongly retain nitrogen in the system by plant uptake and immobilization in plant litter. At the end of the second (1998) and third (1999) growing seasons, the aboveground biomass of *C. villosa* in lysimeters accumulated 16.9–36.1 and 11.2–31.1 kg N ha$^{-1}$, respectively. Amount of 41.5 to 74.8 kg N ha$^{-1}$ was immobilized in plant litter. The amounts of nitrogen bound in produced aboveground plant matter mostly exceeded the amounts of nitrogen recorded in wet deposition during the growing seasons: 1.1 to 5.3 times in 1998 and 2.8-6.1 times in 1999. Higher values of both aboveground biomass produced and nitrogen bound in it coincided probably with higher input of nitrogen and increase of precipitation at higher altitude sites. Fiala et al. (2005) reported that in two to three years old *C. villosa* swards 13.4–14.0 kg N $ha^{-1}$ was bound in aboveground biomass, 14.5–22.7 in litter (1 year and 1+2 years old), but even 86.1 and 99.3 kg N $ha^{-1}$ in below-ground parts (1+2 year and 2+1 years old). Similarly, Betz (1998) reported that *C. villosa* swards were able to take up nitrogen quantities twice as high as those under the prevailing anthropogenic nitrogen immissions. The growth of *C. villosa* in the field was enhanced six times at a tenfold increase of nitrogen supply (Koppisch, 1996).

Results of correlation analysis demonstrate clearly the effect of different acid deposition loads on the amount of leached substances from lysimetric water. On all sites, the amount of leached $Ca^{2+}$ and nitrates, as well as of water acidity mostly increased with increasing inputs of nitrogen and sulphate in wet depositions and with decreasing pH values of rain water. Most of these differences were highly significant (mostly at $P < 0.001$, Table 4). The most pronounced effect of acid depositions on the amount of leached substances in soil percolates was found near the top of the Malý Smrk Mt. (Site III).

Despite differences recorded between two growing seasons, data on leaching of $N\text{-}NO_3^-$ and $Ca^{2+}$ from soil of old grass swards at different altitudes (1.19–2.45 kg of $N\text{-}NO_3^-$ and 4.05–10.54 kg $Ca^{2+}$ per hectare) are mostly close to values recorded in the parallel experiment with young *C. villosa* swards running in the same region and years (Fiala et al., 2005). They reported that leaching of $N\text{-}NO_3^-$ from soil of variants with fully developed young *C. villosa* swards, recorded in the course of the second and third growing seasons (1998, 1999) was 1.3 kg $ha^{-1}$, whereas the leaching from bare forest soil represented substantially higher values (16.4–32.2 kg of N per ha). Similarly, the losses of $Ca^{2+}$ (8.9 and 9.5 kg $ha^{-1}$) under young *C. villosa* swards were less than a half of those from bare soil without grasses.

The ability of grass swards to reduce an excess of soil nitrogen is the principal mechanism associated with the elimination of other negative processes caused by acid depositions. It is due to a combination of enhanced N-uptake by plants and increased N-immobilization in soil organic matter and in the litter layer. Furthermore, plants taking up ammonium from ammonium salts acidify the soil solution whereas alkaline effects are associated with nitrate nutrition (Kennedy, 1992). Preference of nitrate to ammonium ions in substrate was observed in *Calamagrostis villosa* (Gloser et al., 1996). Even most of the N added can be retained within the soil-plant system (see also van Dam, 1990; Úlehlová, 1993; Fiala et al., 2005). The biological soil neutralization by grass vegetation may function effectively because elements are recycled rapidly in the plant-soil ecosystem (Takamatsu et al., 1997). For example, the amount of plant remnants entering the decomposition food chain yearly in *C. villosa* from aboveground and below-ground plant parts is considered to be about 130+620 g dry biomass per $m^2$ and year, respectively (Fiala, 1998; Tůma, 2002). In old *C. villosa* swards 42.3–54.7% of $Ca^{2+}$ and 63.8–77.4% of $Mg^{2+}$ bound in litter was released in the first year of litter decomposition (Tůma, 2002).

We can conclude that the acidification of soil solution and leaching of nitrates, $Ca^{2+}$ and $Al^{3+}$ from soils can be mitigated by grass swards spreading on deforested areas influenced by acid deposition. A rapid regeneration of vegetation cover following disturbance tends to minimize losses of nutrients from the ecosystem and promotes the return to steady-state cycling (e.g., Marks, Borman, 1972; Vitousek, Stanford, 1986; Pyšek, 1993). An increase of soil pH and concentration of nutrients in the upper soil layer may also increase with the duration of succession (Donaldson, Henderson, 1990). Nevertheless, the effect of enhanced acid deposition on studied sites may always influence negatively the soil environment even in old, rich grass stands.

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