

Comparison of plant species composition and heat balance in three mountain grassland communities

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Abstract

A comparison was made of the plant species composition and energy and heat balance in three different types of grassland in the central Bohemian Forest – montane *Trisetion* alliance meadow (association *Cardaminopsidi-Agrostietum*), montane *Nardus* meadow (*Violion caninae*) and wet *Cirsium* meadow (*Calthion palustris*). The variability in their species composition was greater between the sites than within each site, except for the drier part of the wet *Cirsium* meadow, which was similar to the montane *Nardus* meadow – probably as a result of similarity in soil conditions and no human management on either site. The unmanaged montane *Trisetion* meadow can, within decades, probably also develop to this type of community. This assumption is supported by the results of measurement of attenuation of incoming solar radiation. In measurements of heat balance, the highest Bowen ratio (H/LE) was recorded in the unmanaged plot in the montane *Trisetion* meadow. The probable reason was the reduction of evaporation from soil surface by old live and standing dead plant mass and litter, and/or by the weather conditions during the heat-balance measurement. The negative Bowen ratio in the wet *Cirsium* meadow was caused by high groundwater table and groundwater flow and by heat advection from the drier surroundings.

Key words: Bohemian Forest, meadows, phytocenology, gradient analysis, solar radiation, PhAR attenuation, evapotranspiration.

INTRODUCTION

Experimental research on management effects on mountain grassland (see MAŠKOVÁ & al. 2001a) has been carried out only in one type of grassland community, which is typical of the central Bohemian Forest – the montane meadow with dominant *Deschampsia cespitosa* and *Festuca rubra* agg. (phytocenological alliance *Polygono-Trisetion*, association *Cardaminopsidi – Agrostietum* Moravec 1965, herefrom called “*Trisetion* meadow”). There are also other types of biotopes and grassland communities nearby – above all the oligotrophic montane *Nardus* grassland (alliance *Violion caninae*) and wet *Cirsium* meadow (alliance *Calthion palustris*). The comparison of the main study site with them is the general aim of this study. The particular aims of this study were the following comparisons of: (1) The species composition of vascular plants, (2) the heat balance, and (3) attenuation of incident photosynthetically active solar radiation, all in three types of meadow communities characteristic of Zhůří – Huťská hora Mt. grassland enclave in central Bohemian Forest.

Nomenclature of vascular plants follows ROTHMALER & al. (1996).

MATERIAL AND METHODS

The study deals with the following plant communities occurring on three sites within the Zhůří – Hutská hora grassland enclave on the Kvilda Plains in the Bohemian Forest (MAŠKOVÁ & al. 2001a,b, SMEJKAL & al. 2001):

- (a) Montane *Trisetion* meadow – altitude 1180 m, slope 5–7°, SSW aspect, association *Cardamidopsio-Agrostietum* Moravec 1965, with the following important species: *Agrostis tenuis*, *Festuca rubra* agg., *Deschampsia cespitosa*, *Veronica chamaedrys*, *Trifolium repens*, *Ranunculus acris*, *Hypericum maculatum*. Three different types of management have been practised there: mowing (once a year), mulching and leaving the meadows fallow, i.e., unmanaged. For general description of the site see MAŠKOVÁ & al. (2001a).
- (b) Montane *Nardus* grassland – altitude 1174 m, slope 0–2°, SW aspect. This is a species-poor short-stemmed grassland dominated by the graminoids *Nardus stricta*, *Festuca ovina*, *Luzula multiflora* and *Agrostis tenuis*. The important dicotyledonous species are *Vacciniaceae* (*Vaccinium myrtillus*, *V. uliginosum*, *V. vitis-idaea*), *Calluna vulgaris*, *Potentilla erecta* and *Arnica montana*. Scattered short (≤ 5 m) and bushy spruce trees (*Picea abies*) also occur on this site.
- (c) Wet spring-site *Cirsium* meadow with abundant *C. heterophyllum* – mean altitude 1138 m, slope 0–2°, SW aspect. This is a relatively species-rich community with a large proportion of herb coverage. Dicotyledonous plant species are dominant here. The groundwater table is high; somewhere it even rises aboveground. Small differences in surface configuration and ground level are mirrored in differences in species composition of the plant community. Wetter patches are dominated by *Caltha palustris* while drier sites by *Cirsium heterophyllum*, *Bistorta major* and *Deschampsia cespitosa*.

We compared the species composition according to phytocenological relevés of 5×5 m using the Braun-Blanquet scale (MORAVEC & al. 2000). The relevés are presented in Table 3. On site “a” we laid down 3 transects in the mown, mulched and unmanaged plot, respectively. In each transect, 5 relevés were recorded, spaced at 20 m distances. On site “b” we laid down 3 transects with 2 relevés along each transect. On site “c” we laid down 3 transects, each with 3 relevés.

We analysed the phytocenological relevés by linear ordination method (lengths of the gradients were < 3) – Principal Component Analysis (PCA). We used the statistical program CANOCO for Windows (TER BRAAK & ŠMILAUER 1998). For graphical interpretation of the results, we used the program CANODRAW (ŠMILAUER 1992). Data from the Braun-Blanquet scale were transformed to values ranging from 1 to 7 (VAN DER MAAREL 1979).

We took 24-hour-measurements of incoming solar energy, its reflectance, and of heat balance in the grassland stands. In July 2000 (on the sites “a” – mown, mulched, unmanaged and site “b”) and in July 2001 (site “c”) on prevalingly sunny days with few clouds or even clear sky. On the basis of these measurements, we estimated the evapotranspiration by the heat balance method (BĀR 1987, PRIBĀN & al. 1992). We used the following sensors and instruments: both incident and reflected radiation was measured with radiometric sensors with a linear conductivity response to irradiance within the spectral ranges of global shortwave radiation (270–3000 nm). The global radiation sensors were attached to integrators summarising radiation totals over time intervals of 30 minutes at daytime and of 3 hours or more during the night. These instruments were designed and constructed by Š. Kubín (Institute of Microbiology, Czech Academy of Sciences, Třeboň, Czech Republic). Sunshine duration, measured with a Campbell – Stokes heliograph (respecting also relative cloudiness) and air temperature measured at 2 m above the vegetation were used to calculate the long-wave radiation emitted from the soil and vegetation surfaces (ROSENBERG 1974):

$$R_n = (1-r)R_s - 16 \times 10^{-4} (0.2 + 0.8n/N) (100-T)$$

Where "R_n" is net radiation, "r" is reflectivity (albedo), "R_s" is total incoming radiation, "n/N" is percent possible sunshine (ratio of actual to possible duration), and "T" is temperature.

Soil temperatures were measured with mercury-in-glass thermometers placed at 0.05 or 0.1, and 0.2 depth, respectively. Air temperature and relative air humidity were measured with psychrometers containing resistance sensors (Comet, Czech Republic).

Microclimatic parameters (air and soil temperature, relative air humidity, wind speed, solar radiation input) were measured at 30-minute intervals between sunrise and sunset and at 3-hour intervals during the night (on sites "b" and "c" only once in the whole night). We calculated the average Bowen ratio (ratio between sensible heat flux and energy used for evapotranspiration) and 24-hour values of energy fluxes. The measurements were taken on different days because of the limited number of instruments available, but the weather conditions were similar on all the days.

We also measured the attenuation of incoming photosynthetically active radiation (PhAR, 380–720 nm) by the fully developed grassland stands in June 2001, at midday hours (9:30 to 14:30 h Central European time) on days with more or less evenly overcast sky. For measuring instantaneous values of relative PhAR irradiance at different levels within the grassland stands, we used a pair of inter-calibrated PU 550 luxmeters (Metra Blansko, Czech Republic) with the sensors adjusted to equal response within the PhAR range (380–720 nm) by a special filter, also constructed by Š. Kubín (Institute of Microbiology, Czech Academy of Sciences, Třeboň, Czech Republic). Of the two luxmeters, one recorded PhAR irradiance in the open while the other was recording it simultaneously at a certain level above or within the grassland vegetation. The relative PhAR irradiance was then calculated as percentage of incoming PhAR. The measurements were taken at 0.5 to 0.6 m, 0.2 m and 0.05 m above the ground level, i.e., above the canopy, at the canopy top and at its bottom, respectively. There were 10 sites of PhAR measurement within each 5×5 m plot in which a phytocenological relevé had been recorded. The data for each level of measurement were analysed by hierarchical ANOVA (nested design) in the program Statistica v. 6.0. The sites were compared by Tukey HSD test. Logarithmic transformation of the data had been made.

RESULTS

The results of PCA analysis show appreciable differences between the sites (the first ordination axis explains 33.8% of data variability, the second one does 18.2%). Remarkable is the similarity between the relatively drier part of the wet *Cirsium* meadow and the oligotrophic *Nardus* meadow, although at first glance the vegetation seems closer to the mown or mulched part of the *Trisetion* meadow. In general, there is great variability in the species composition in the wet *Cirsium* meadow. The other important fact is that the different types of management applied to the *Trisetion* meadow caused relatively small differences in species composition of its vegetation. The mown plot is somewhat more different from the others. The influence of the presumed gradient of moisture supply and soil conditions on the vegetation along the slope (from top to bottom of each plot) was found to be unimportant. Exceptions are the relevés M4 and, especially, M5 (bottom part of the mulched plot) where the plant species composition is similar to that in the unmanaged plot (Fig. 1).

Most of the plant species are typical of only one of the sites, but some species are common to two sites (e. g. *Festuca rubra* and *Agrostis tenuis* in "a" and "b", *Deschampsia cespitosa* in "a" and "c" and *Potentilla erecta* in "b" and "c") (Fig. 2).

Table 1 shows 24-hour energy and heat balance in the vegetation of each of the sites. The

differences between the daily totals of incoming global solar radiation on different days of measurement are rather small. An important comparison is that between the Bowen ratio values (H/LE). This ratio is an indicator of the water balance on the respective site (Bowen ratio is usually less than 0.5 in well-watered terrestrial ecosystems, ŠMÍD 1973 and 1975). Bowen ratio is higher in the unmanaged plot within the *Trisetion* meadow: this indicates relative overheating of the vegetation and obstacles to water loss from the soil (shading by the tall vegetation) and possibly also high stomatal resistance in prevalently old leaves forming the stand canopy. Also, the air temperatures at 0.05 m level were highest here.

Negative Bowen ratio (less than zero, found in the *Cirsium* meadow) is unusual and implies heat advection into the grassland stand (ŠMÍD 1975). The possible reasons for this situation are analysed in the Discussion.

The measurement of attenuation of incident solar radiation at the level of 0.05 m above ground level shows differences between the three sites ($p < 0.01$) while the transects within each site do not differ from one another. An exception is the unmanaged plot in the *Trisetion* meadow, which is similar to the oligotrophic *Nardus* meadow. (Table 2 and Fig. 3a).

Measurements at 0.2 m above ground level did not show any differences between the sites; only the transect "Calthion III" (on site "c") was different from all the other transects ($p < 0.01$, Fig. 3b).

Table 1. – Radiation and heat balance (measured for 24 h on different summer days with bright sunshine) in three differently managed plots within site "a" (*Trisetion* meadow) and in unmanaged vegetation on sites "b" (*Nardus* meadow of *Violion caninae* alliance) and "c" (spring-head vegetation of *Calthion palustris* alliance). Daily sums of: GR - global solar radiation measured above the grassland canopy, RA - reflected solar radiation, NR - net radiation ($NR = GR - RA - LWR$, LWR = long-wave radiation of the Earth), G - ground heat flux, H - sensible heat flux ($H = NR - LE - G$), LE - evapotranspiration energy (L = specific heat of water evaporation, 2.45 kJ.g^{-1}), E - evapotranspiration in mm of water ($= \text{l.m}^{-2}$), Bowen ratio = H / LE .

Locality:	Dates	GR [MJ.m ⁻²]	RA [% GR]	NR [MJ.m ⁻²]	G [% NR]	H [% NR]	LE [% NR]	E [mm]	Bowen ratio
"a" - mown	08-10/11-00	18.1	18.2 %	11.0	11.8 %	29.1 %	59.1 %	2.65	0.49
"a" - mulched	08-11/12-00	19.1	18.8 %	11.3	23.9 %	23.9 %	52.2 %	2.84	0.45
"a" - unmanaged	08-14/15-00	15.9	19.1 %	8.9	5.6 %	43.8 %	50.6 %	1.85	0.87
"b" - <i>Violion</i>	08-16/17-00	17.6	19.3 %	10.8	27.8 %	27.8 %	44.4 %	1.97	0.63
"c" - <i>Calthion</i>	07-18/19-01	20.7	19.3 %	12.2	14.8 %	-54.9 %	140.2 %	7.02	-0.39

Table 2. – Solar radiation extinction at 0.05 m level – values of significance in Tukey HSD test between different transects. "a", "b" and "c" refer to the labels for the three sites studied. The numbers refer to the numbers of the transects. Mulched, mown and unmanaged are the types of management on site "a".

Locality	"a" - mulched	"a" - mown	"a" - unmanaged	"b" - 1	"b" - 2	"b" - 3	"c" - 1	"c" - 2
"a" - mown	1.000							
"a" - unmanaged	<0.001	<0.001						
"b" - 1	0.006	0.025	1.000					
"b" - 2	0.005	0.020	1.000	1.000				
"b" - 3	0.001	0.003	1.000	1.000	1.000			
"c" - 1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
"c" - 2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.999	
"c" - 3	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.916	0.561

DISCUSSION

In general, greater differences were found between the sites than between the transects on each site. This is not surprising, but we expected greater differences to occur between the differently managed plots in the *Trisetion* meadow. The absence of such differences may be due to the relatively short duration of the experiment (4 years), although research in the upper Lužnice floodplain (altitude 450 m) showed great differences in species composition after 4 years for which the grassland had remained unmanaged (PRACH 1993). The next explanation may be a relative great variability of plant species composition on site "a" and human impact (including scientific research) on this site. Nevertheless, the mown vegetation is different from the mulched or unmanaged one. At the same time, a vegetation gradient was detected from the top to the bottom parts of each site, probably reflecting a gradient in soil moisture and fertility. The mulched plot is similar to the unmanaged one. This similarity may be the result of the presence of standing dead material and litter in the unmanaged plot, and of decomposing mulch in the mulched plot. The decomposition of these materials definitely plays an important role in mineral nutrient turnover and nutrient supply to the plants. Remarkable is the similarity between the relatively drier transect on site "c" and all transects on the wet site "b". The average precipitation (rain + snow) is very high in this area (> 1100 mm per year), so there is little danger of long-term drought (even if it may occasionally occur in the mown and unmanaged plots – see below). In general, the area is poor in nutrients, except for sites with a high groundwater table. The montane *Nardus* meadow represents a relatively dry and nutrient-poor habitat in this area whereas the *Cirsium* meadow on site "c" represents a wet and relatively nutrient-rich habitat. Absence of management of both sites, "c" and "b", is probably responsible for a certain similarity of their vegetation. Long-term lack of grassland management would probably result in a similar type of vegetation also on site "a".

This forecast is supported by the results of an experiment made and reported by JAKRLOVÁ (1999) from a *Nardus* meadow (association *Polygalo-Nardetum strictae*) in the Žďárské vrchy hills (E Bohemia, Czech Republic, altitude 624 m). In that experiment, the number of vascular plant species increased in a mown 0.1×0.1 m plot (from 19 to 25, after 7 years of regular mowing once a year), while it remained constant in the control unmown plot (19 species). The coverage of *Nardus stricta* decreased in the mown plot (from 20.8% to 11.1% after 7 years). The impossibility to draw final conclusions from our 4-year study is most probably due to the slow rate of vegetational changes on the experimental sites. This is not surprising under the harsh climatic conditions at altitudes above 1000 m in the Bohemian Forest, strengthened by the exposure of the Zhůří enclave to winds from the NW, W and SW directions.

Bowen ratio was relatively low in the mown and mulched plots, which indicates good water supply to the respective plots. If most of incoming radiant energy is used for evapotranspiration, it supports local evaporation and is released when local precipitation (rainfall) occurs. In the unmanaged plot, the Bowen ratio was higher. ŠMÍD (1979) reported similar results: the Bowen ratio found in unmanaged and also in mown grassland was higher, but the difference between the two respective Bowen ratios was almost the same as in our study. In ŠMÍD's study, the daily sums of net radiation were higher (up to 21 MJ.m⁻²), perhaps because of lesser cloudiness at the lower altitude (624 m). The possible explanation of a high Bowen ratio in the unmown vegetation is that the remaining old biomass and litter insulate bottom parts of the stand and keep moisture below this cover. Overheating of relatively dry air is then recorded above the litter and standing dead plant parts. But the measurement should be repeated in order to see if the result reported above was not just due to the actual weather situation.

Negative Bowen ratio on site "c" may have been caused by a high groundwater table. In addition, the groundwater is flowing downhill. This causes the temperatures at 0.05 m to be

lower than those above the vegetation (cooling effect of water); that is also why heat convection (H) is in the opposite direction and warms up the wet soil. This hypothesis is supported by the fact that the soil temperature was almost constant for the whole day of measurement, because of the great heat capacity of the slowly flowing water. The other evidence supporting this hypothesis is provided by the air temperatures at 0.3 m: they were higher than those above the vegetation, because the cooling effect was not any more important at the 0.03 m level.

The differences between the sites in the attenuation of incoming solar radiation by the vegetation are conspicuous, but not surprising. The similarity between the attenuation in the unmanaged plot on site "a" and by the vegetation on site "b" (montane *Nardus* meadow) at the level of 0.05 m is, however, somewhat surprising. In unmanaged plots, litter accumulation can bring about a decrease in plant diversity. This decrease took place both in the unmanaged plot on site "a" and in the species-poor *Nardus* meadow (site "b"), mainly because of little opportunity for seedling establishment (see e. g. ARMESTO & PICKETT 1985). The difference between the attenuation in transect "Calthion 3" (site "c") and that in all the other transects at the level of 0.2 m is due to shading by a high number of *Caltha palustris* individuals with numerous large leaves at a relatively high level.

CONCLUSIONS

The following general conclusions can be drawn from the research results reported in this paper:

- (a) The vegetation of the experimental grassland – site "a", is still quite homogeneous even after 4 years of its differentiated management. It is distinctly different from the vegetation of both the unmanaged *Nardus* meadow – site "b", and that of a spring amidst the mountain meadows (site "c").
- (b) Different management of the three experimental plots on site "a" seems to have already initiated different slow changes in the species composition of the mountain meadow community. Especially the meadow vegetation of the unmanaged plot seems to be shifting from a community belonging to *Trisetion* alliance to a more oligotrophic one belonging to *Violion caninae* alliance (such as on site "b").
- (c) Differentiated management of the grassland area, or the absence of its management, is reflected in differences in reflectance by the vegetation (albedo), in its heat balance, microclimate and evapotranspiration. In the unmanaged plot on site "a", the heat balance is somewhat similar to that in the *Nardus* grassland. The wet spring site ("c") has a heterogeneous vegetation whose heat balance and high evapotranspiration are affected by advection of drier air from the surroundings and by water flow both above and below ground level.
- (d) The attenuation of incident PhAR measured at the higher leaf canopy level (0.2 m above ground) differed between the meadow stands compared, but hardly any differences were detected at the canopy bottom (0.05 m above ground level).

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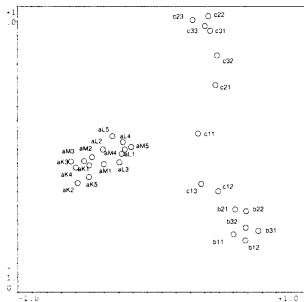


Fig. 1. – PCA analysis of phytocenological relevés – graph of sites. Axis “x” is the first ordination axis (explains maximum variability in species composition), “y” axis is the other one. The letters refer to the sites described in the text: K – mown plot, L – unmanaged plot and M – mulched plot of site “a”. Each number attached to K, L and M refers to the relevé number on the respective transect (numbering from top to bottom of each differently managed plot). Each first digit at B or C refers to the respective transect number, and the second one refers to the relevé number.

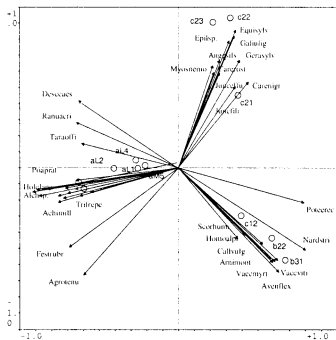


Fig. 2. – PCA analysis of phytocenological relevés – graph of species and sites. Labels of sites refer to the labels in Fig. 1. Agrotenu = *Agrostis tenuis*, Achimill = *Achillea millefolium*, Alchsp. = *Alchemilla* sp., Angesily = *Angelica silvestris*, Arnimont = *Arnica montana*, Avenflex = *Avenella flexuosa*, Callvulg = *Calluna vulgaris*, Carenigr = *Carex nigra*, Carerost = *Carex rostrata*, Desiccaes = *Deschampsia cespitosa*, Epilisp. = *Epilobium* sp., Equisylv = *Equisetum sylvaticum*, Festrubr = *Festuca rubra* agg., Galiulg = *Galium uliginosum*, Gerasylv = *Geranium sylvaticum*, Holclana = *Holcus lanatus*, Homoalpi = *Homogyne alpina*, Juncfil = *Juncus effusus*, Juncfil = *Juncus filiformis*, Myosnemo = *Myosotis nemorosa*, Nardstri = *Nardus stricta*, Poaprat = *Poa pratensis*, Poteerec = *Potentilla erecta*, Ranuacri = *Ranunculus acris*, Scorhumi = *Scorzonera humilis*, Taraoffi = *Taraxacum officinalis*, Trifrepe = *Trifolium repens*, Vaccmyrt = *Vaccinium myrtillus*, Vaccviti = *Vaccinium vitis-idaea*.

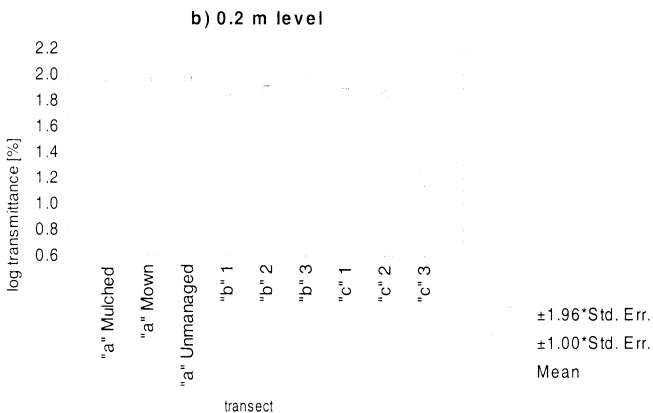
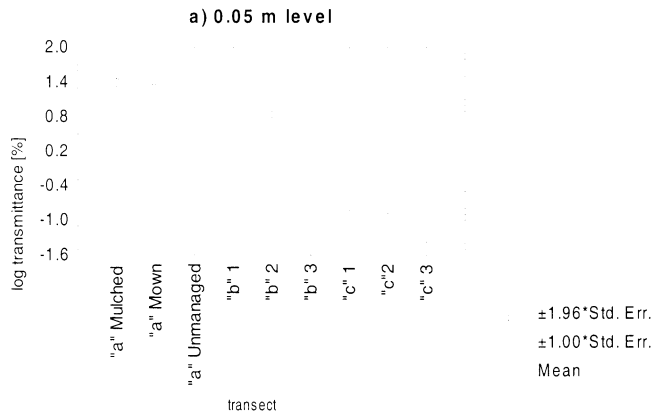


Fig. 3. – Solar radiation attenuation by the meadow vegetation (June 2001). Axis “y” shows the transmittance (logarithmically transformed) – i. e., percentage of total incident photosynthetically active radiation (PhAR) penetrating into the stand at the given level above ground.

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