Relationship between vascular plant species richness and soil chemical properties of alpine meadows and pastures

Bohner A.
Agricultural Research and Education Centre Raumberg-Gumpenstein, Dept of Environmental Ecology, Irdning, Austria
Corresponding author: andreas.bohner@raumberg-gumpenstein.at

Abstract

In unfertilized mountainous grassland communities in the Austrian Alps, there is a hump-shaped or unimodal relationship between vascular plant species richness and soil pH (pH-$CaCl_2$). Only the combination of nutrient-poor grassland soil, minimal stress (well-drained grassland soil in the silicate buffer range) and moderate disturbance (periodical or episodical mowing, extensive grazing) in the plant habitat, and a high regional species pool is associated with maximum species richness. There is, however, no relationship between vascular plant species richness and the commonly used indicators for forage quality.

Keywords: alpine meadows and pastures, vascular plant species richness, soil chemical properties, calcifuges, calcicoles, forage quality

Introduction

Grassland communities differ not only in species composition, but also in vascular plant species richness, yield, and forage quality. The aims of this study were (1) to investigate the significance of soil chemical properties in influencing vascular plant species richness, (2) to examine the influence of soil chemical properties on the distribution of the calcifuge and calcicole species, and (3) to investigate the relationship between vascular plant species richness and forage quality.

Materials and methods

This investigation was carried out in unfertilized mountainous grassland communities in the Austrian Alps on 42 different sites, distributed over Carinthia. To determine vascular plant species richness (alpha-diversity), the total number of vascular plant species within a homogenous investigation area of 50 m² was recorded. Only unfertilized and extensively used montane, subalpine, and alpine meadows and pastures were investigated and only vascular plants were taken into consideration. The altitude ranged from 1,340 to 2,220 m a.s.l. Soil moisture regime was generally well balanced or periodically moist in topsoil. The vegetation types considered in this study belong to the Nardo-Agrostion tenuis, Nardion strictae, Festucion variae, Caricion curvulae, Caricion ferrugineae, and Seslerion caeruleae (Grabherr and Mucina, 1993; Mucina *et al*., 1993). These are the most widespread semi-natural grassland communities in the Austrian Alps and they represent a vegetation and soil gradient from plant communities on very acid soils to grasslands on neutral and alkaline soils.
Soil samples were collected from the 0-10 cm soil layer (A horizon) in the vegetation period. From field-moist soil samples, a saturation extract was produced according to ÖNORM L 1092-93 (Austrian Standards). Ions were analysed by ICP and ion chromatography. Dissolved organic carbon (DOC) was determined by oxidation with $K_2Cr_2O_7$-H_2SO_4. Mineral element content in the harvestable above-ground plant biomass and forage quality (crude fibre, crude protein, crude fat, crude ash, digestibility of organic matter, net energy) were analysed by using standard methods. SPSS (Version 14.0) was used for all statistical data analyses.

Results and discussion

Across all sites investigated, species richness varied between 16 and 96 vascular plant species per 50 m², and soil pH($CaCl_2$) ranged from 3.4 to 7.6. Especially the grassland communities on soils formed from calcareous mica schists have the greatest plant species richness. There was a hump-shaped or unimodal relationship between vascular plant species richness and soil pH (Figure 1).

Tyler (2003) also observed in non-fertilized grasslands in south-eastern Sweden that the highest number of plant species per 25 m² was in the intermediate pH range and lower values at pH_{KCl} 4 and 7.5. According to Ulrich (1981) the soils can be grouped into different buffer ranges. Statistical analyses (Kruskal-Wallis test, Mann-Whitney test) revealed, that highly significant differences ($P < 0.005$) between the grouped soils in Table 1, in terms of mineral element concentrations in the saturation extract, were restricted to P, Si, K, Ca, Zn, and Cu.

Table 1. Mean ion concentrations in the saturation extract; n = number of soil analyses.

pH-$CaCl_2$ buffer range	n	P	Si	K	Ca	Zn (mg L^{-1})	Cu	Al	Fe	Mn
< 4.2	22	0.72	2.35	2.64	5.16	0.07	0.01	0.51	0.52	0.07
4.2-5.0	9	0.20	1.31	2.78	7.23	0.03	0.01	0.36	0.16	0.24
5.0-6.2	8	0.26	1.45	1.41	12.49	0.05	0.03	0.43	0.54	0.09
> 6.2	5	0.38	1.71	1.42	38.22	0.02	0.02	0.65	0.53	0.07

Table 2. Mean molar ratios in the saturation extract.

pH-$CaCl_2$ buffer range	Ca:K	Mg:K	Ca:Mg	Ca:Al	Mg:Al	C:Al	C:(Al+Fe)
< 4.2	2.4	0.8	3.0	8.3	2.8	177	132
4.2-5.0	4.0	1.2	3.2	14.6	5.6	368	306
5.0-6.2	13.0	4.8	2.6	100.6	55.9	719	356
> 6.2	45.0	12.7	10.5	93.5	9.1	415	249

Very acidic alpine topsoils in the aluminium and/or iron buffer range (pH-$CaCl_2$ < 4.2) are characterized by a relatively high concentration of P, Si, K, and Zn in the soil solution, primarily due to an intensive chemical weathering and mineral dissolution (Table 1), by a relative excess of K- and Al-ions, and by a complementary lack of Ca- and Mg-ions in the soil solution (Table 2). Furthermore, these soils have a comparatively high mean NH_4-N:NO_3-N ratio of 69 in the LiCl-exchangeable fraction, compared with soils in the silicate buffer range (pH-$CaCl_2$ 6.2-5.0) or carbonate buffer range (pH-$CaCl_2$ > 6.2) with ratios of 32 and 11, respectively. Only calcifuge species are adapted to the prevailing acid and nutrient stress mainly caused by the unfavourable ratios between nutrients as well as potentially toxic elements (e.g. Al) in the soil solution. Especially the uptake of Ca and Mg by plants seems to be inhibited, whereas the uptake of Na, Fe, Mn, Zn, Cd, and Cr might to be promoted (data not shown). Therefore, vascular plant species richness is very low, and calcifuges are dominating the species composition of the vegetation. Al-toxicity *per se* appears not to influence the vascular plant species richness, because humus-rich alpine topsoils have a relatively low Al-concentration in the soil solution (Table 1). Therefore, the molar ratios of Ca:Al, Mg:Al, and C:Al are relatively wide (Table 2). Furthermore, the excess of DOC promotes the formation of complexes of Al with DOC and, hence, Al-detoxification. Only in extremely acidic soil solutions does this form of Al-detoxification become ineffective, and Al occurs mainly as toxic, monomeric Al^{3+} in the soil solution. On the other hand, calcareous soils in the carbonate buffer range are characterized by an absolute and relative excess of Ca-ions in the soil solution (Table 1 and 2). Only calcicole species are adapted to this disharmonic nutrient supply and the resulting discrimination of individual nutrients. Especially the uptake of P, S, Mn, Zn, and Cu by plants seems to be inhibited, whereas the uptake of Ca might be promoted (data not shown). Therefore, vascular plant species richness is moderately high, and calcicoles are prevailing. Soils in the silicate buffer range and soils in the upper part of the cation exchange buffer range (cation exchange buffer range: pH-$CaCl_2$ 5.0-4.2) are generally characterized by a balanced composition of the soil solution (Table 1 and 2). Therefore, both calcifuges and calcicoles can be present at these sites, allowing a high vascular plant species richness. There was, however, no relationship between vascular plant species richness and commonly used indicators for forage quality such as crude protein, crude fat, crude ash, digestibility of organic matter or net energy (unpublished data).

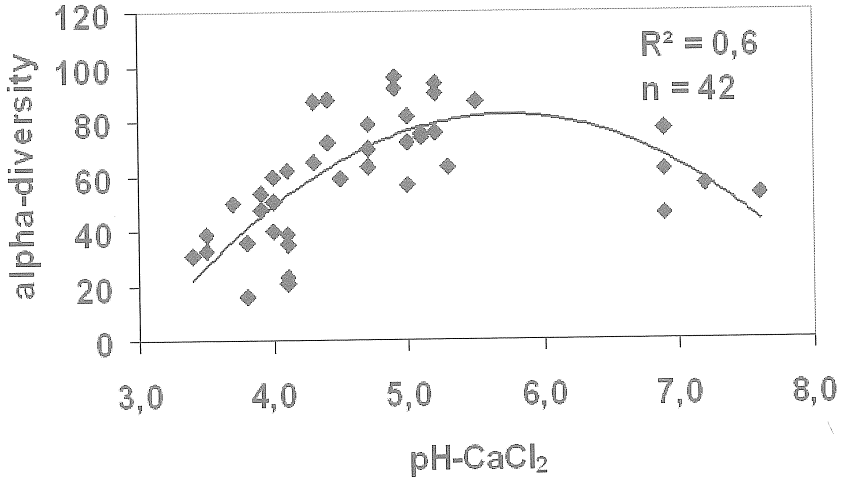

Figure 1. Relationship between vascular plant species richness per 50 m² and soil pH.

Conclusions

In unfertilized mountainous grassland communities in the Austrian Alps, the pH-dependent soil chemical properties in topsoil are of utmost importance to vascular plant species richness. Nutrient-poor plant habitats are potentially rich in vascular plant species if the grassland soils are in the silicate buffer range or in the upper part of the cation exchange buffer range. They are particularly poor in vascular plant species if the grassland soils are in the aluminium and/or iron buffer range.

References

Grabherr G. and Mucina L. (eds.) (1993) *Die Pflanzengesellschaften Österreichs. Teil II*, Gustav Fischer Verlag, 523 pp.

Mucina L., Grabherr G. and Ellmauer T. (eds.) (1993) *Die Pflanzengesellschaften Österreichs. Teil I*, Gustav Fischer Verlag, 578 pp.

Tyler G. (2003) Some ecophysiological and historical approaches to species richness and calcicole/calcifuge behaviour-contribution to a debate. *Folia Geobotanica,* 38, 419-428.

Ulrich B. (1981) Ökologische Gruppierung von Böden nach ihrem chemischen Bodenzustand. *Zeitschrift für Pflanzenernährung, Bodenkunde,* 144, 289-305.