Soil chemical properties as indicators of plant species richness in grassland communities

BOHNER, A.

Agricultural Research and Education Centre Raumberg-Gumpenstein, Austria

Abstract

The influence of soil chemical properties and various management regimes on plant species richness in grassland communities was investigated. Selected soil chemical properties were tested to define indicators for sustainable grassland management. For plant species richness in agriculturally-used permanent grassland communities, the lactate-soluble P content in topsoil is an important environmental factor. Species-rich grassland communities are restricted to soils with less than 25 mg P per kg fine earth fraction in topsoil.

Keywords: α-diversity, soil indicators, lactate-soluble phosphorus, threshold values, intensity of grassland management

Introduction

Soil indicators are important for nature conservation, as they allow the evaluation of the state of the environment and changes in it, and the establishment of the limits of intensification for grassland management. The primary aim of this study was to identify soil indicators for the intensity of grassland management, soil fertility and plant species richness in order to maintain and to utilize species-rich grassland ecosystems in a sustainable way. Further objectives were (1) to identify threshold values at which α-diversity changes clearly appear and (2) to provide information on the influence of various management regimes on plant species richness in agriculturally-used permanent grassland communities in a mountainous region, in Austria.

Materials and Methods

This investigation was conducted in the Styrian Enns valley and in the Styrian Salzkammergut (Styria, Austria). In the study area, ranging from 640 to 1275 m in altitude, mesozoic limestones, paleozoic phyllites, mica schists and gneisses predominate. Soils are mainly Cambisols, Leptosols, Gleysols, Gleyic Fluvisols and Eutric Histosols. The suboceanic climate is relatively cool and humid, with a mean annual air temperature of 5–7 °C and annual precipitation of 1000–1600 mm, of which 50–60% falls during the growing season (April–September). The mean monthly temperature is –3 °C to –5°C in January and 14 °C to 17 °C in July. The growing season is relatively short due to a long duration of snow cover. The climate favours grassland management: thus arable farming has no economically importance.

The studies were conducted exclusively on farms under practical conditions. The study area is suitable for this investigation, because (1) it represents a typical grassland region in Austria, (2) many soil types and grassland communities could be found within a small area and (3) a wide range of management intensities are present as a result of the small-sized farm structure and high site heterogeneity in the mountainous area. Only regularly managed permanent grassland communities with at least 10 relevès and soil analyses per association were selected for study.

The relevès were carried out according to the Braun-Blanquet approach (Braun-Blanquet, 1964). To determine plant species richness (α-diversity), the total number of vascular plant species within a homogenous investigation area of 50 m² was recorded. This area represents the minimal area of species-rich grassland communities. Soil samples from the topsoil (0–10 cm depth) were collected in autumn. Soil and water analyses have been conducted according to the ÖNORM methods (Austrian Standards Institute). Yield and mineral element content in the above-ground plant biomass were determined by using standard methods. For each plant community, the arithmetic mean and coefficient of variability were calculated. Relationships were determined by regression analysis.

Results and Discussion

Table 1 shows the plant species richness of managed grassland communities in ascending order. α-diversity varies greatly between the associations investigated. There was a clear relationship with the intensity of grassland management; plant species richness was generally lower under intensive management. The relative intensively-used pastures (*Alchemillo monticolae-Cynosuretum cristati* community) and mowing pastures (*Trifolium repens-Poa trivialis*-community) are characterized by a comparatively low plant species richness.

Table 1. Intensity of grassland management, plant species richness (vascular plants) and selected soil chemical properties (0–10 cm of soil depth) of important grassland communities

				mg kg^{-1}			
				CAL/DL		H_2O	
Plant community	n	igm	a-d	P	K	P	C_{org}:N_{tot}
Alchemillo monticolae-Cynosuretum cristati	24	4-5	36	57*	161*	8*	9.0
Trifolium repens-Poa trivialis-community	52	4-5	40	44*	139*	5*	9.3
Cardaminopsido halleri-Trisetetum flavescentis	30	2-3	41	38*	97*	10*	10.1
Alchemillo monticolae-Arrhenatheretum elatioris	45	3-4	42	36*	91*	7*	9.5
Cirsium oleraceum-Persicaria bistorta-community	19	2	44	28*	88*	5*	10.6
Festuca rubra-Agrostis capillaris-community	45	1-2	45	30*	108	6*	12.0
Geranio sylvatici-Trisetetum flavescentis	46	2-3	46	40*	103*	8*	9.8
Iridetum sibiricae	28	1	50	15	115*	2*	11.8
Festuco commutatae-Cynosuretum cristati	13	egr	54	23*	73*	2*	9.4
Mesobrometum erecti	22	1-2, egr	68	14	104*	2*	10.5
Narcissus radiiflorus-community	41	1-2, egr	70	16*	99*	3*	11.2

n = number of relevés and soil analyses; igm = intensity of grassland management (number of cuts/grazings; egr = extensive grazing); a-d = average number of species (vascular plants) per grassland community (α-diversity); P and K CAL/DL = lactate-soluble phosphorus and potassium content; P H_2O = water-soluble phosphorus content; * = coefficient of variability > 30 %

At the community scale, there was a relatively strong relationship between lactate-soluble (Figure 1) or water-soluble (not shown) P content in topsoil and plant species richness. Other soil chemical properties demonstrate no (pH, eC, C_{org}, N_{tot}, lactate-soluble K) or only a weak relationship (C:N ratio) with α-diversity. Obviously, a high plant species richness in grassland communities is associated primarily with a low P content in topsoil (Janssens *et al.*, 1998; Critchley *et al.*, 2002). The clear relationship between lactate-soluble P content in topsoil and plant species richness does exist only when comparing different grassland communities. However, within each vegetation type studied, there was no comparable relationship. This result demonstrates the scale-dependence of such investigations.

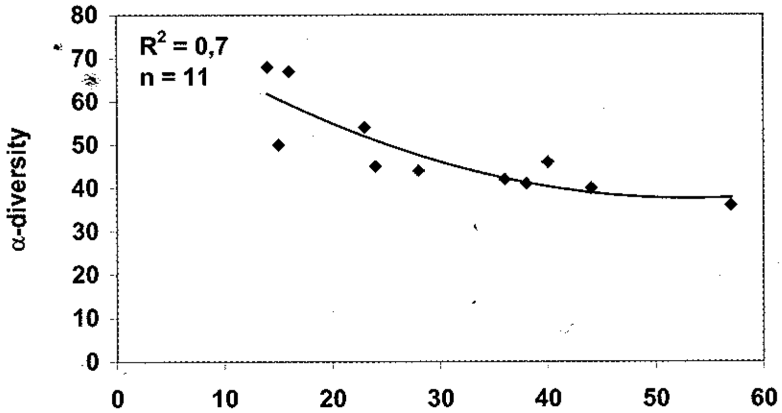

Figure 1. Relationship between plant species richness (vascular plants) and lactate-soluble phosphorus content in topsoil (0–10 cm)

The threshold value between grassland communities with high and medium plant species richness is a lactate-soluble P content of about 25 mg P per kg fine earth fraction. Nevertheless, a low lactate-soluble P content in topsoil is no guarantee of a high plant species richness. Only the combination of nutrient-poor soil, minimal environmental stress, moderate levels of disturbance (site regularly mowed or grazed) and a high regional species pool ensures a maximum of plant species richness.

Table 2. Nutrient leaching losses under permanent grassland at the location HBLFA Raumberg-Gumpenstein (Cambisol, monolithic lysimeter)

	mm	kg ha^{-1}					
year	sw	N_{anorg}	P	K	Ca	Mg	Na
2002	613	3.5	0.06	4.4	216.8	31.1	8.8
2003	266	1.4	0.03	1.0	85.0	14.3	3.8

sw = seepage water; $N_{anorg} = NH_4\text{-}N + NO_3\text{-}N + NO_2\text{-}N$

A high lactate-soluble P content in topsoil is a good indicator of a long-term application of fertilizers and intensive grassland management at present and/or in the past. Phosphorus accumulates in topsoil in the case of adequate fertilizer application more easily than nitrogen or potassium, because leaching losses of phosphorus (Table 2) and its removal due to harvesting the above-ground plant biomass (Table 3) are comparatively lower. Fertilizer is the main source for phosphorus enrichment in topsoil, as phosphorus input from wet deposition is insignificant (Table 4) and phosphorus from (rock) weathering is released in small amounts. Therefore, naturally-occurring lactate-soluble P content in topsoil is generally very low. Unfertilized alpine and grassland soils, for example, have a lactate-soluble P content in topsoil of about 4 to 25 mg P per kg fine earth fraction.

Table 3. Dry matter yield and amounts of nutrients in the above-ground plant biomass of selected grassland communities (1st growth respectively 1st cut)

Plant community	n	dt ha^{-1} DM yield	kg ha^{-1} N	P	K	Ca	Mg	Na
Alchemillo monticolae-Cynosuretum cristati	11	36	88	13	94	30	8	0.7
Trifolium repens-Poa trivialis-community	13	35	86	12	98	41	13	0.7
Alchemillo monticolae-Arrhenatheretum elatioris	25	37	86	11	93	30	10	0.7
Geranio sylvatici-Trisetetum flavescentis	18	33	75	10	66	32	10	0.7
Cardaminopsido halleri-Trisetetum flavescentis	23	36	74	10	68	28	10	0.7
Festuca rubra-Agrostis capillaris-community	10	16	35	4	24	9	4	0.1
Mesobrometum erecti	7	17	33	3	27	15	3	0.1

n = number of forage samples

The relatively strong relationship between lactate-soluble P content and potentially mineralizable N in topsoil indicates, that lactate-soluble P content is also an indirect measure of the N mineralization potential of agriculturally-used grassland soils (Bohner, 2005).

Table 4. Nutrient input from wet deposition at the location HBLFA Raumberg-Gumpenstein

year	mm pr	kg ha^{-1} N_{anorg}	P	K	Ca	Mg	Na
2002	1371	10	0.4	2	37	6	2
2003	871	7	0.2	2	25	4	2

pr = precipitation; N_{anorg} = NH_4-N + NO_3-N

Conclusions

In grassland communities, the lactate-soluble P content in topsoil is at the community scale a good indicator of the intensity of grassland management and soil fertility as well as a measure of sustainable grassland management. Species-rich grassland communities are restricted to soils low in lactate-soluble P content in topsoil; the threshold value for a high plant species richness was found to be 25 mg P per kg fine earth fraction. Indeed, higher naturally-occurring lactate-soluble K contents are obviously compatible with a high plant species richness.

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