Influence of Soil and Topographic Variables on Vegetation Composition and Community Types in Semi-arid Rangeland in Western Iran

Abstract

A large proportion of rangeland in western Iran is in poor condition regarding aspects like vegetation cover and plant composition. The main objective of this study was to investigate the distribution of species composition and community types in relation to explanatory soil and topographic parameters. A number of 43 main plots was sampled in two catchments using a stratified double sampling method. Parametric and non-parametric statistics as well as multivariate techniques were used to analyse the data. Different vegetation community types were identified with TWINSPAN.

The results indicate that species composition was only significantly correlated with the amount of K, the percentage cover of stones, and north-facing aspect. Furthermore, of the measured explanatory variables, only altitude had a significantly linear correlation with species richness. The percentage cover of stones and north-facing aspect were significantly correlated with vegetation attributes. Both community types and catchments showed significant differences in vegetation attributes, while only community types were significantly different in measured soil and topographic variables. Thus, there were only few correlations between explanatory soil and topographic variables and the vegetation (vegetation attributes, species richness and composition). The differences in vegetation might have been caused by other factors such as management. This should be investigated in more detail in further studies.

Introduction

Rangeland is the main land use type of Iran. 55% of the total land area (1.648 Mio km²), is rangeland. Most rangeland is located in the arid and semi-arid regions. It is often intensively used and is in rather poor condition. According to Farahpour and Marshall (2001), only 10% of Iranian rangelands could be classified as being in good condition, 41.4% are in fair and 48.3% in poor condition. In the Kermanshah province in western Iran (2,443,400 ha total area, 30.1% rangeland), a slightly larger percentage of the rangeland is considered to be in good condition (25.5%), but still 47.8% is of poor condition (Badripour, 2004). These evaluations of rangeland condition in Iran are based on parameters such as vegetation cover, plant composition (amount of palatable plants), soil conservation (soil erosion, percentage bare soil), forage dry matter production, propagation, and plant litter accumulation (Mesdaghi, 1998).

Plant species composition and richness are important for rangeland condition. For example, Eldridge and Koen (2003) illustrated that the deterioration of rangeland quality was associated with reductions in plant diversity. Rezaei et al. (2006) suggested that the most important biophysical resource of rangeland is the soil because of its strong relationships with plant properties and plant cover. He concluded that landscape attributes including slope, aspect and elevation affect plant growth through indirect influences on soil properties. For example, topography affects climate and soil moisture, which may lead to a different development of vegetation in northern aspects in comparison to southern ones (Jenny, 1980). Dalle Tussie (2004) suggested that the vegetation composition of rangelands is the result of continuous and complex interactions of plant communities with environmental variables.

So far, studies on plant-environmental interactions in arid and semi-arid regions have mainly focussed on either soil or topographic explanatory variables in relation to either vegetation composition or vegetation attributes. For example, the influence of soil and topographic variables on plant species was investigated by Dalle Tussie (2004) in Ethiopia. The effect of topographic variables on some vegetation cover properties was studied by Florinsky and Kuryakova (1996).

In addition to previous studies, we investigated whether vegetation composition, vegetation attributes, species richness, different community types, and the sites (catchments) react differently to both soil and topographic variables. Interactions between all variables could thus be considered.

The objectives of this study were (1) to evaluate effects of soil characteristics, i.e. phosphorus (P), potassium (K) and organic carbon (OC) content, pH, stone, as well as the content of clay, sand and silt, and topographic variables, i.e. altitude and aspect, on species composition, species richness, and vegetation attributes (biomass and percentage cover of vegetation, bare soil, and litter), (2) to identify different plant community types, and (3) to investigate the distribution of the plant community types in relation to the explanatory variables and vegetation attributes. To this end, plant-environmental relationships were analysed in the Merek and Kabodeh catchments of the Kermanshah province in semi-arid rangeland of different quality. It was hypothesized that (1) explanatory soil and topographic variables influence species composition distribution, species richness and vegetation attributes, and (2) the measured soil and topographic variables explain a large part of the variation in species composition distribution, species richness and vegetation attributes.

Material and methods

Study sites

The study areas are formed by two catchments, the Kabodeh (34°14′11″-34°17′25″N; 47°3′30″-47°6′23″E) and the Merek (34°0′46″-34°9′39″N; 47°4′26″-47°22′18″E) catchment, located in the Kermanshah province in the Zagros chain, western Iran. The Zagros chain extends through northwestern Iran and continues into southeastern Iran (Amirshahkarami, et al., 2007). The size of the Kabodeh catchment is 1,494 ha, that of the Merek catchment 24,207 ha, and the area of rangelands of both catchments accumulates to 6,741 ha. Dominant plant species were e.g. *Aegilops* sp., *Astragalus* sp., *Phlomis* sp., *Bromus danthoniae, Festuca ovina, Bromus tomentellus, Bromus tectorum,* and *Taeniatherum crinitum*. The rangeland is grazed mostly by sheep, goats, and sometimes cattle, including both sedentary and migrating animals.
For field sampling, a stratified double sampling design was used (Thompson, 2002). Using ArcView version 3.2a, both study areas were stratified into 5+1 classes of range condition after selecting 600 initial sampling units on satellite images (Landsat, ETM 2002). The range classes were recognized based on visual interpretation of satellite images, where the range condition decreased from class 1 to class 5 (class 1 and class 5 were the best and the worst range condition, respectively) and class 6 was dominated by shrub species. In the second phase, a proportional allocation was used based on the total initial sample units, the initial samples per stratum, and 43 final sample units (Fig. 1) to obtain the number of sample units per stratum by the following formula:

Number of sample units per stratum = (number of final sample units / number of total initial sample units) * number of initial sample units in stratum

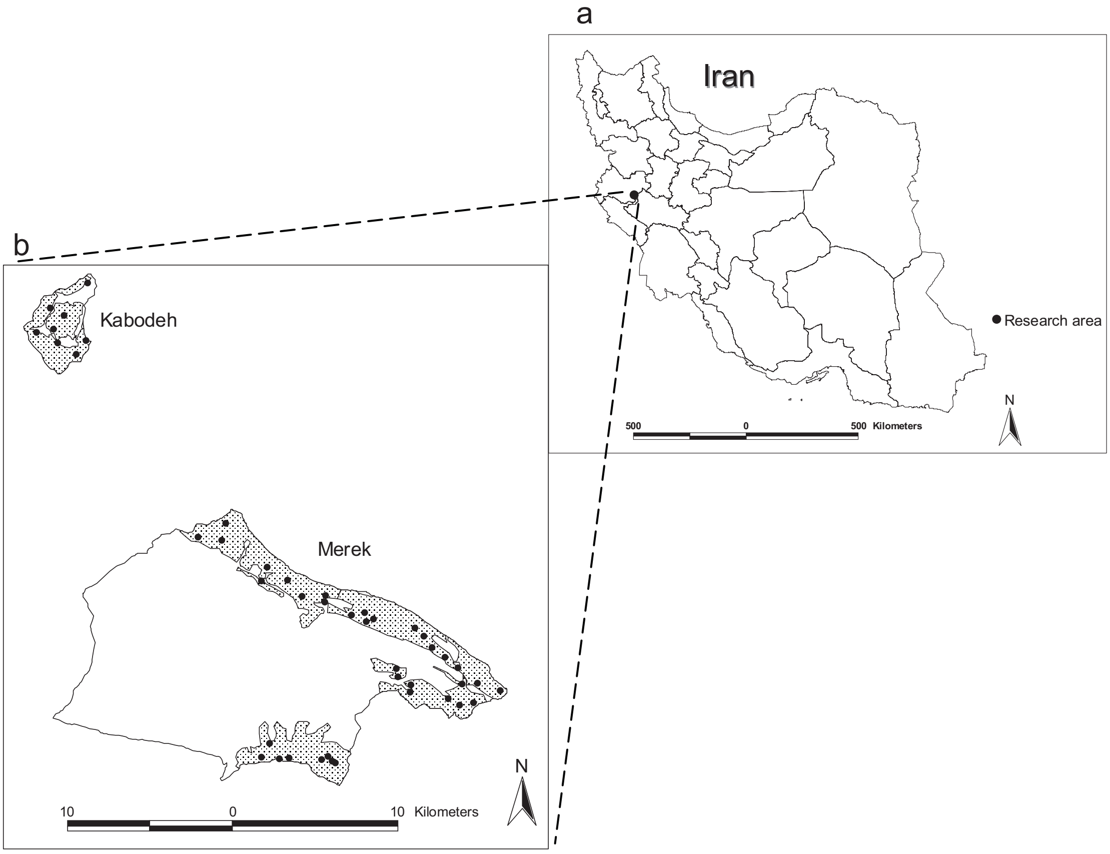

Fig. 1 a: Location of the study area in Iran. b: Map of the research areas (two catchments) in Kermanshah. The shaded area indicates the rangeland of the catchments, larger black dots mark the sampled sites (N= 43).

Measurements

Vegetation

Vegetation data in the 43 sites was gathered from May to July 2006 both in quadrats and in transects as follows.

i. Biomass: Per site, standing herbaceous vegetation was harvested (cut 1 cm above the ground) in eight quadrats of 1 x 1 m² (Fig. 2). Harvested plants were oven-dried at 80°C for 48 hours before measuring biomass.

ii. Species composition: For each site, there were two perpendicular transects of 60 m each (Fig. 2). Per 2-m section of each transect, the occurring plant species were determined and their expansion (per species), as well as that of bare soil, stones and litter was recorded, resulting in 30 data sets per transect.

Note that for describing the shrub area in each site, the tree and shrub plants were defined as both woody perennial species (with a single major stem for tree) (FAO,

2002) and reaching more than one meter in height, whereas the herb species were less than one meter tall (Dalle Tussie, 2004; Mueller-Dombois and Ellenberg, 1974). *Astragalus* sp. formed an exception, as it may be smaller than one meter. Nevertheless, we treated it as a shrub based on the report of Badripour (2004) that illustrated that many species of *Astragalus* sp. are woody, shrub-like, and spiny plants in the Zagros forest.

Measured variables

For all sites, the following categories of variables were recorded: explanatory soil and topographic variables and vegetation attributes. Vegetation attributes considered were the biomass, percentage cover of vegetation, bare soil, and litter, which were investigated as explained above. The measurement of soil parameters and topographic variables has been carried out as follows.

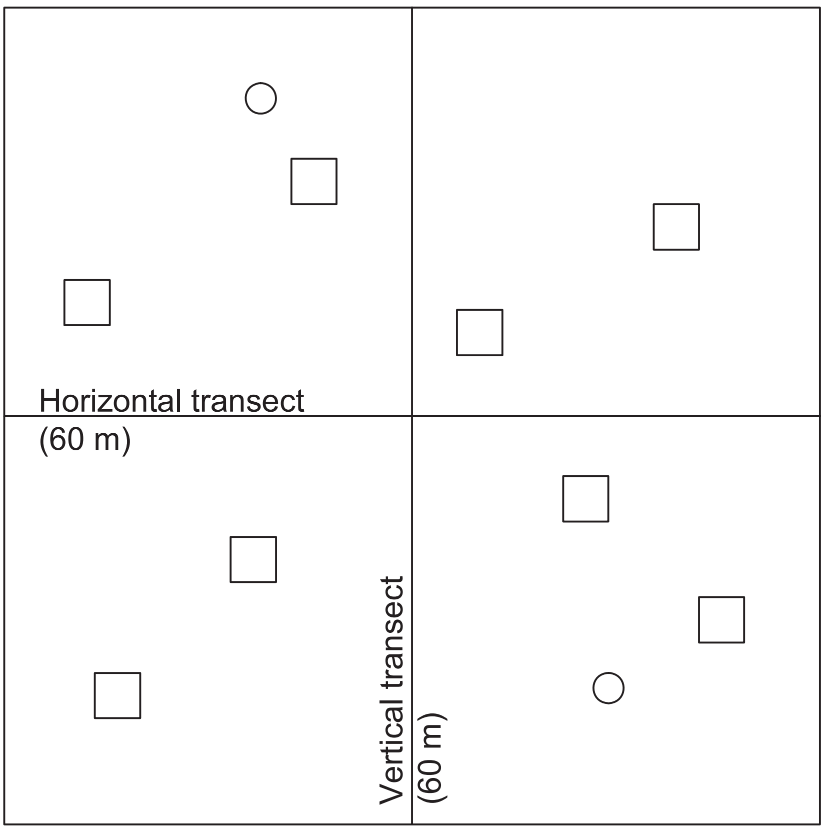

Fig. 2: Examplatory sketch of a typical site, showing the distribution of the eight quadrats (squares) used for measuring biomass, two transects for measuring species

composition, and two extra spots (circles) for taking soil samples (not drawn to scale).

Soil and topographic parameters

Soil was sampled in two locations per site (a 70-mm diameter soil core, 0-20 cm deep) at each side of the vertical transects (Fig. 2). These samples were analyzed for the following parameters: available P_{Olsen} (Olsen and Sommers, 1982), available K using the ammonium acetate extraction method (Knudsen, et al., 1982), and OC using the Walkley-Black method (Walkley and Black, 1934). The pH was measured in a saturated paste with distilled water using a pH electrode, and to measure soil texture, the hydrometry method was used (Dane, 2002).

The altitude was recorded per site by GPS (GARMIN; eTrex VISTA) and the aspect of the slope was determined. The GPS was calibrated twice a week at a reference site with known elevation.

Data analysis

Data collected per site (transect and quadrat data) were averaged for further analyses. For species composition, species data was analyzed based on the percentage cover of individual species along transects.

Multivariate statistical analyses were carried out using CANOCO for Windows version 4.5 (ter Braak and Šmilauer, 2002) to assess the relationships between species composition and soil and topographic variables. Detrended Correspondence Analysis (DCA) was used to get estimates of the gradient lengths in standard deviation (SD) units (ter Braak and Šmilauer, 2002). If the SD was less than four, a linear method of multivariate analysis, e.g. RDA, is recommended (Lepš and Šmilauer, 2003; ter Braak and Šmilauer, 2002).

A Monte Carlo permutation test (999 permutations) was used to test significance of variables. Only significant variables (α=0.05) were included in the final models (Lepš and Šmilauer, 2003; ter Braak and Šmilauer, 2002).

Stepwise multiple linear regression was used to test the correlation between species number and explanatory soil and topographic variables. If the explanatory variables were not significant (α=0.05), they were excluded from the final model.

TWINSPAN (TWo way INdicator SPecies ANalysis) program of the CAP (Community Analysis Package) version 2.0 was used for classification of both herbaceous and woody species that were recorded in the transects. The default settings of the TWINSPAN program were used with the following parameters: maximum number of indicators per division = 5, maximum level of division = 6, and minimum size of groups to be divided = 5 (Dalle Tussie, 2004; Lepš and Šmilauer, 2003; PISCES, 2003). The TWINSPAN division was stopped in the second level of division (El-Sheikh, 2005; Lu, et al., 2006).

Multivariate Analysis of Covariance (MANCOVA) was used followed by Wilks' lambda test to analyse whether both the measured explanatory variables (soil and topographic variables) and vegetation attributes differed between the community types classified by TWINSPAN analysis as well as the two catchments (Wellstein, et al., 2007). Then, analysis of covariance (ANCOVA) was carried out to determine differences between both the community types and the catchments for the measured variables. The Shapiro–Wilk test was used to test normality of the data. Non-normally distributed variables were transformed to achieve normality with the following methods. Sand, clay, OC, pH, vegetation cover, and biomass were transformed with natural logarithm (ln) (Fenton and Bergeron, 2007; Stanley, 2006), litter with reciprocal method (Hoyle, 1973). In addition, we rescaled the value of pH (=pH-7) in order to use natural logarithm (ln) to normalize it. As a post-hoc test, Tukey's HSD was conducted to determine which measured variables were significantly different for each group (community types and catchments). SPSS (version 15) was used for this part of the data analysis.

Two slope aspects (north-facing aspect = N, east-facing aspect = E) were measured and are presented as codes for further analyses of these variables in CANOCO. Thus, the number 1 encodes both north and east, -1 south and west. For example, a north-west facing aspect (NW) was represented by N = 1 and E = -1, a north-facing aspect by N = 1 and E = 0. To analyse aspect variables in SPSS, they were coded with four dummy variables (north-facing aspect (NA), south-facing aspect (SA), east-facing aspect (EA), and west-facing aspect (WA)). For example, a north-west facing aspect (NW) was translated to the dummy variables N = 1, S = 0, E = 0, and W = 1.

Results

A total of 113 vascular plant taxa were sampled in the study areas (both genera and species, see Appendix 1), of which 106 were herbaceous and seven woody. In Merek, there were slightly more taxa than in Kabodeh (94 versus 82, respectively).

The soil variables and topographic variables varied between catchments (see Table 1). These differences influenced species composition as well as vegetation attributes like vegetation cover. In the following, we will present the results of the multivariate analyses of data collected on both the two 30-m transects and eight quadrats per plot. In addition, we will explain the classification of the samples into community types, as well as the influence of the measured variables on the communities.

Table 1: Means and standard deviations of explanatory topographic and soil variables for the Merek and Kabodeh catchments

measured variables	Merek (Mean ± SD) (n = 36)	Kabodeh (Mean ± SD) (n = 7)
Altitude [m]	1880 ± 156	1595 ± 166
North aspect	0.16 ± 0.91	0.43 ± 0.73
East aspect	-0.05 ± 0.71	0.14 ± 0.83
K [µg g^{-1}]	486.7 ± 97.6	456.4 ± 52.8
P [µg g^{-1}]	10.7 ± 4.1	11.1 ± 5.1
Clay [%]	43.2 ± 12.2	48.4 ± 6.1
Silt [%]	35.9 ± 5.5	34.8 ± 4.6
Sand [%]	21.0 ± 12.0	16.8 ± 9.5
OC [%]	2.2 ± 0.5	1.9 ± 0.3
pH	7.3 ± 0.04	7.3 ± 0.03
Stone [%]	22.0 ± 13.8	27.4 ± 6.4

Influence of explanatory variables on species composition, vegetation attributes and species richness

The only environmental variables significantly correlated with the composition of herbaceous and woody species based on the Monte Carlo permutation test were north-facing aspect, the percentage cover of stones and the amount of K in the soil (Table 2).

Table 2: F-ratio and P-value (Monte Carlo permutation test) of all significant measured variables in RDA ordination diagrams

Measured Variables	K	Percentage cover of stone	North-facing aspect
F-ratio	2.89	2.56	1.88
P-value	0.004	0.01	0.043

Fig. 3 shows the distribution of the species concerning the significant measured variables. The first axis was characterised by north-facing aspect (positive correlation), the amount of K and the percentage cover of stones (negative correlations) (Fig. 3 and Table 3). This axis was related with species such as *Astragalus* sp. and *Daphne mucronata*. The second axis was mainly correlated with the amount of K (positive correlation), to a lesser extent also with the percentage cover of stones (negative correlation) and the north-facing aspect (positive correlation). A number of species, e.g. *Phlomis* sp. and *Eryngium* sp. were positively correlated with the second axis as well as K.

Table 3: Correlation between measured variables and the first two ordination axes (RDA ordination diagram)

Variables	K	Percentage cover of stone	North-facing aspect
Axis 1	-0.40	-0.36	0.40
Axis 2	0.54	-0.44	0.32

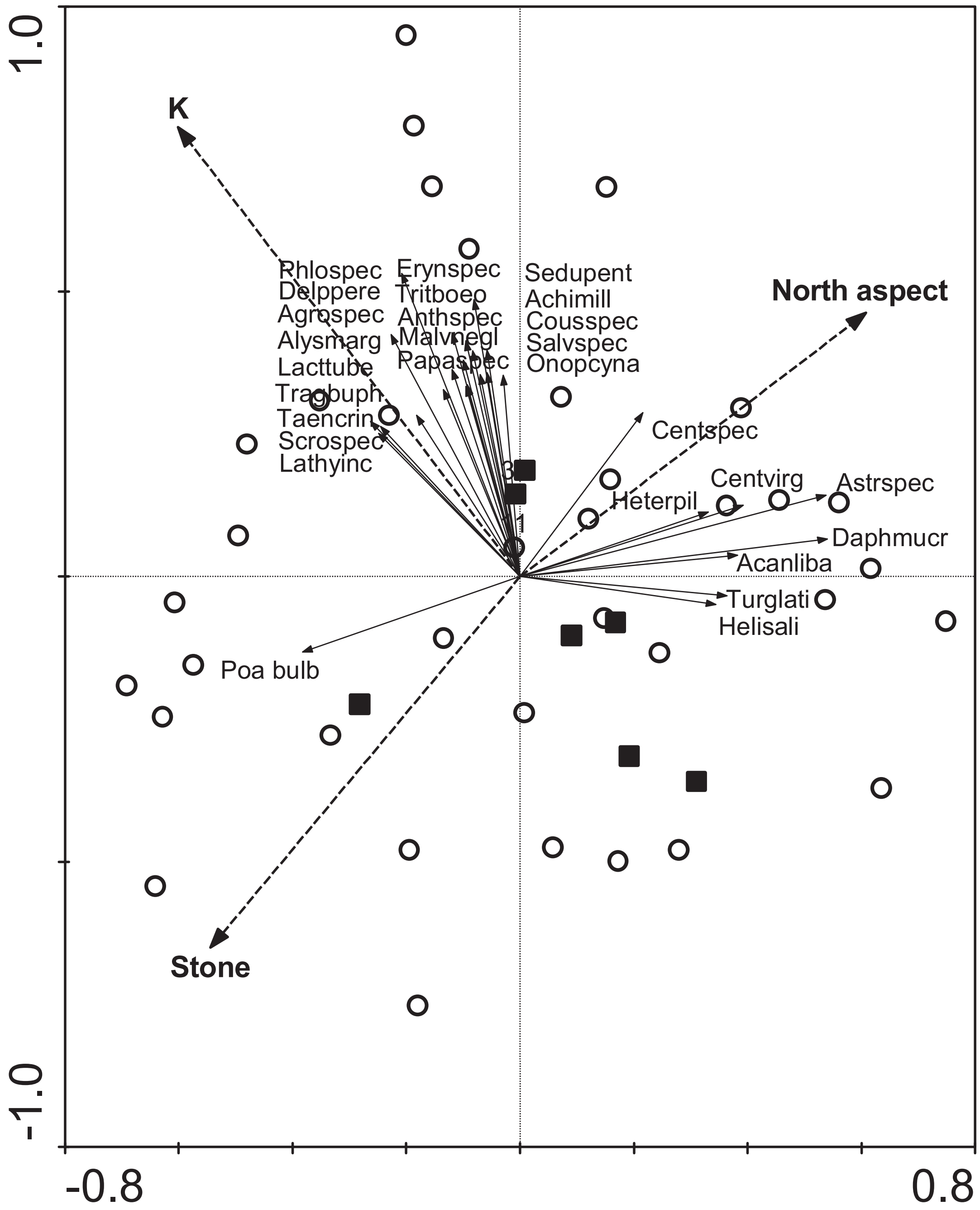

Fig. 3: Ordination diagram based on RDA gradient analyses of species, samples, and measured variables in the Merek and Kabodeh catchments (circles and squares represent samples of the Merek and Kabodeh catchments, respectively). For species labels, please see Appendix 1. Only species with a fit better than 10% are presented to increase legibility.

Table 4: Correlation between environmental variables and vegetation attributes. Spearman's rank correlation and Rho-values of explanatory soil and topographic variables (**p < 0.01, * p < 0.05, and ns = not significant).

Variable	Vegetation cover	Biomass	Litter
K	0.15^{ns}	-0.04^{ns}	0.34*
P	-0.15^{ns}	-0.19^{ns}	0.08^{ns}
Clay	-0.04^{ns}	-0.20^{ns}	-0.28^{ns}
Silt	-0.04^{ns}	-0.05^{ns}	-0.01^{ns}
Sand	0.08^{ns}	0.14^{ns}	0.29^{ns}
OC	0.14^{ns}	0.08^{ns}	0.55**
pH	-0.12^{ns}	0.04^{ns}	-0.31*
Stone	-0.61**	-0.34*	-0.27^{ns}
Altitude	0.01^{ns}	-0.24^{ns}	0.22^{ns}
North-facing aspect	0.46**	0.36*	0.12^{ns}
East-facing aspect	-0.01^{ns}	-0.01^{ns}	-0.10^{ns}

There were few significant correlations between soil and topographic variables with vegetation attributes (Table 4). The vegetation cover as well as biomass production was related with the percentage cover of stone and the north-facing aspect. The amount of litter was correlated with the amount of K, OC and the pH.

Furthermore, a multiple linear regression analysis indicated that correlations between measured soil or topographic variables and species richness were very weak or not significant. Among all environmental factors, only altitude was negatively correlated with species number (P=0.009). However, also altitude explained just 16% (R^2=0.16) of the variation in species numbers.

Plant community classification

The TWINSPAN classification of the 43 plots and 113 taxa from the two catchments resulted in four main classes on the second dendrogram level (Fig. 4). The four main community types can be described as follows:

C1: *Astragalus* sp.- *Daphne mucronata:*

This community was present at 11 sites, found mainly in the Merek catchment. It was dominated by *Daphne mucronata* and *Astragalus* sp. in the tree/shrub layer, and *Aegilops* sp., *Bromus danthoniae*, and *Festuca ovina* in the herb layer. This