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VEGETATION, SOIL AND MANAGEMENT RELATIONS IN MEADOW COMMUNITIES OF THE VALDEON VALLEY, CORDILLERA CANTABRICA, SPAIN

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Abstract. The objective is to examine the relationships of management, floristic composition, altitude and chemical soil constituents in an area in which traditional systems are still practiced. The results obtained in a numerical analyses indicate that the four variables interact. They also show that the lowland meadows are more productive than the highland meadows and their soils have higher concentrations of Cu, Zn, Al, Ca, N and organic matter. The latter may reflect, in part, the greater use of organic fertilizers. As expected, species diversity in the highland meadows, where haying is infrequent, is higher than diversity in the lowland meadows. The absolute concentration of the elements in the herbage indicate inadequate summer levels of copper and sodium in the highland meadows. The consequences of this for animal production are discussed.

Introduction

In many parts of the world the mineral content of herbage, and/or the soil on which the herbage grows, is insufficient to satisfy the requirements of animals dependent upon the herbage for food (*e.g.*., Lampkin et al. 1961, Hemingway *et al.*. 1968, Statham and Bray 1975, Sherrell 1978). Inadequate levels in the soil may reflect the levels in the parent rock from which the soil was derived, or may arise as a result of the climatic effects through leaching. Whatever the cause, low levels of minerals in soils will generally result in low levels of the same minerals in the herbage. However, due to adverse interactions between different soil components, inadequate levels of any particular mineral may also arise in plants growing in soils apparently rich in that mineral (*e.g.*, Suttle *et al.* 1975). The effect of management practices is clearly influential with regard to the interrelationship between soil and plant mineral concentrations. For example, the application of fertilizers and the use of soil additives such as lime or sulphur can change soil pH and thus alter the availability of certain minerals to plants (Underwood 1981). Since different plant species are adapted to growing in distinct soil conditions, all of the factors mentioned above interplay to influence floristic composition in any given community.

Areas of hay meadows under traditional management regimes are fast-disappearing from Europe and are in need of conservation. The valley in which the present study was conducted - Valdeon in the Cordillera Cantabrica of Northern Spain - preserves still a traditional system of management, i.e cutting for hay in July, grazing in autumn and fertilization with manure. Such practices have led to a high plant species diversity (up to 40 species per 0.25 m^2) which Garcia and Navascues (1989) described. Although permanent pastures, especially those with a high species diversity, have a more constant and balanced mineral content (Coppenet and Simon 1984), situations can arise under management strategies in which the mineral content becomes unbalanced and serious deficiencies of one or more minerals occur.

A report by Goldsmith *et al.* (1985) stresses the importance of preserving areas such as the one under study. However, data is lacking on the effect of the management regimes on the soil and herbage mineral status of such areas and on the combined effects of these variables on the floristic composition. The present report is an attempt to partially rectify this shortage.

Methods

This study uses a data set from semi-natural hay-meadows in the Cantabrian mountains of Spain. Five meadows were chosen to represent five traditional management regimes in the Valdeon valley. The valley is part of the Covadonga National Park and is surrounded by high mountains. The vegetation consists of a mixture of well-conserved beech forests, calcareous grasslands, heathlands and hay-meadows. In each meadow ten 0.5 m x 0.5 m quadrats were randomly chosen and the percentage cover of the species estimated. The vegetation was clipped at 2 cm from ground level, dried to constant biomass at 65 °C and weighed. A soil sample to 20 cm depth was also collected in each quadrat. Chemical soil analyses were performed on dry samples. Total metal content was determined in acid digests and exchangeable metals in ammonium acetate extracts (Allen *et al.*, 1974) by atomic absorption spectroscopy for Mn, Cu, Fe, Zn, Al and flame spectroscopy for Ca, Mg, Na and K. Organic matter (OM), nitrogen, phosphorus and pH were analyzed following the recommendations of the Comision de Metodos del Instituto Nacional de Edafologia y Agrobiologia (1973). Samples of herbage were oven-dried at 65 °C for 72 hours weighed and milled. They were then ashed in a muffle furnace at 550 °C and the ash digested with two aliquots of 3M HCl evaporated to dryness and made up to 50 ml with distilled water (De Ruig 1986).

Three data sets are used: species abundance of within quadrats expressed as % cover; soil chemical data at the same sites; herbage mineral content. In the first instance a principal component analysis (PCA) was performed on the first data set of vegetation based on a variance-covariance matrix. The component axes were then correlated with the second (mineral content of soils) and third (mineral content of herbage) data sets, using correlation matrices, to reveal relationships. For all the analyses the programmes of Orlóci and Kenkel (1985) were used.

Results

The position of quadrats in species-component space is plotted in Fig. 1, which also shows the species with the highest loadings on axes I and II. The first two axes with a 40.5% cumulative variance (27%, axis; 13.5%, axis II). was considered sufficient to summarize internal relationships in the original data matrix. Different sites are indicated by symbols in the diagram showing the result of superimposing management regimes upon the quadrat ordination. The samples on the left side of the diagram correspond to meadows located at 900 m above sea level in a flat area. These meadows are regularly fertilized by organic manure, cut for hay in July, and in some years in spring also, and grazed in autumn. The samples taken from the low irrigated meadows (A) are found at the extreme left of the diagram, while the next grouping to the right (B) are samples from a non-irrigated meadow. The meadows situated at 1300 m of altitude are found along the first axis to the right. These meadows are not as easily distinguished from each other as the two lower meadows previously mentioned. The first of these (C) is from an irrigated and fertilized meadow, that is cut for hay in July and grazed in autumn. On the left side of the same axis is meadow (D), which is not irrigated, but is cut for hay and occasionally fertilized. The final grouping (E) includes samples from a meadow which has been unattended over the last few years, although it is cut for hay in some years and always grazed in autumn.

Examination of the Pearson and Kendall correlations between axes of PCA and species helped to identify the species correlated with the positive part of the first axis that are characteristic of soils of low nutrient status, such as *Festuca rubra, Agrostis capillaris, Anthyllis vulneraria, Rhynanthus minor, Sanguisorba minor, Carum carvi, Luzula campestris* among others. These species are from meadows that have very little fertilization, experience the lowest temperatures, and have most acid soils. Some years no cuts are taken for hay. The opposite end of the first axis is occupied by species such as *Arrenatherum elatius, Lolium perenne, Poa trivialis, Lathyrus pratensis, Trifolium pratense, T. repens, Rumex acetosa, Cerastium fontanum, Herachleum spondilium* which are characteristic among others of fertile conditions. These species belong to meadow communities heavily fertilized as judged by the standards of the valley. These are located near the villages on alluvial soils and are managed with care.

In Table 1 correlations of the chemical properties of the soils with the axes derived by PCA are seen together with the means of each of the constituents of each meadow community. The results accord with the correlations of species with the axes. Thus concentration of N, Ca, Zn, P, Al, Cu and OM were negatively correlated with axis I and therefore with those species

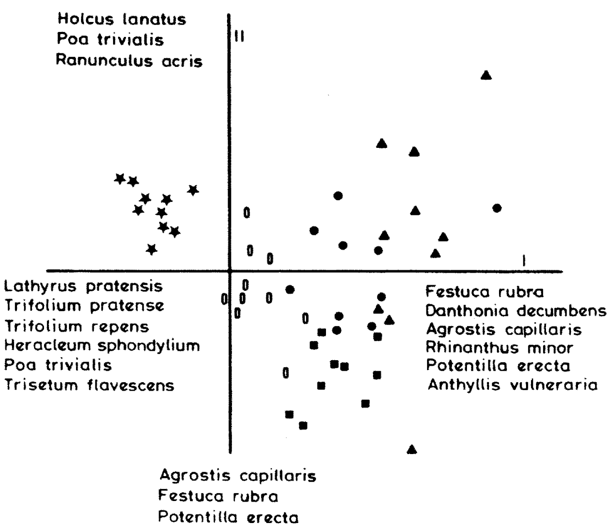

Figure 1. Distribution of meadows on the 1st and 2nd PCA axes by species composition. Symbols represent different meadows with distinct management regimes. Meadow A (★) - 900 m, irrigated, manured, 1 or 2 cuts/year, autumn-grazed. Meadow B (O) - 900 m, non-irrigated, manured occasionally, 1 cut/year, autumn-grazed. Meadow C (●) - 1300 m, irrigated, not manured, 1 cut/year, autumn-grazed. Meadow D (■) - 1300 m, non-irrigated, not manured, 1 cut/year, autumn-grazed. Meadow E (▲) - 1300 m, non-irrigated, not manured neglected for some years.

Table 1. Mean values (n = 10) of soil chemical elements and their correlations with the PCA axes. Mineral concentrations are expressed as $\mu g/g$, N and OM as percent and P as mg/100g. Values in parentheses represent the standard error. Lettering is as in Figure 1.

	A	B	C	D	E	Ax I	Ax II
Al	8316 (597)	8996 (430)	11149 (514)	12944 (318)	7610 (317)	-0.75	0.25
Ca	1791 (237)	3107 (257)	2282 (122)	4025 (54)	2007 (262)	-0.53	-0.45
Cu	0.0 (0.0)	5.1 (3.4)	7.7 (3.9)	23.2 (2.6)	2.6 (2.6)	-0.61	0.28
Fe	35001 (1413)	39954 (613)	34820 (859)	39061 (318)	33960 (1213)	-0.13	0.32
K	116 (9)	139 (24)	113 (4)	108 (6)	141 (12)	0.14	0.04
Mg	233 (20)	221 (12)	257 (25)	245 (4)	258 (21)	0.01	0.23
Mn	860 (58)	1276 (154)	636 (34)	1078 (10)	1600 (179)	0.33	0.33
Na	49.4 (10.0)	45.6 (8.1)	46.6 (2.8)	44.3 (7.2)	43.2 (10.6)	-0.05	-0.01
P	13.0 (4.2)	11.0 (1.2)	11.6 (0.7)	13.5 (1.3)	10.0 (0.0)	-0.20	-0.02
Zn	120 (4)	173 (19)	174 (23)	525 (168)	215 (22)	-0.37	-0.43
N	0.41 (0.01)	0.43 (0.02)	0.51 (0.03)	0.51 (0.01)	0.42 (0.02)	-0.60	0.16
OM	13.6 (0.5)	13.8 (0.6)	15.1 (0.6)	14.0 (0.4)	11.9 (0.4)	-0.48	-0.09
pH	5.5 (0.2)	6.3 (0.2)	4.9 (0.1)	5.8 (0.1)	5.1 (0.1)	-0.05	0.23

characteristic of more fertile soils. Table 2 displays mean concentrations of minerals in herbage from the 5 meadows and their correlation coefficients vis-a-vis the axes from PCA. With respect to axis I Ca, Cu and Zn were significantly correlated with the negative part, while Al, Fe and Na were significantly correlated with the positive portion. With the exception of the Ca, Cu and Zn concentrations that were correlated with the negative part of axis I for both soils and herbage, the other constituents examined in soils and herbage did not show uniformity with respect to their correlations with the PCA axes.

Axis I can be interpreted as being diagnostic of a complex and not a single factor, which represents a gradient from the most fertile sites (negative side) to the nutrient-poor sites (positive side). In addition, the scatter of the samples from each meadow is a reflection of the variety of species to be found in that meadow, and, furthermore, reflects the management regime to which each meadow is subjected. Although axis II is difficult to interpret, if the species list correlated with this axis is used, we find that, at least in part, it can be related to a soil moisture gradient. Species at the positive side are usually associated with irrigated meadows with such species as *Anthoxanthum odoratum*, *Arrenatherum elatius*, *Holcus lanatus*, *Poa trivialis*, *Trisetum flavescens*, *Lathyrus pratensis*, *Cerastium fontanum*, *Ranunculus acris*, *Rumex acetosa*, and *San-*

Table 2. Mean mineral concentrations in μg/g (n = 10) of herbage and their correlations with the PCA axes. Values in parentheses represent standard errors. Lettering is as in Figure 1.

	A	B	C	D	E	Ax I	Ax II
Al	40	46	53	54	127	0.31	0.21
	(2.9)	(2.6)	(9.2)	(7.2)	(15.0)		
Ca	9920	9410	11110	11850	9820	-0.33	0.11
	(386)	(650)	(401)	(1273)	(651)		
Cu	4.4	5.6	5.6	6.5	5.5	-0.37	0.39
	(0.3)	(0.4)	(0.3)	(0.3)	(0.2)		
Fe	93	99	100	75	244	0.43	0.13
	(7)	(7)	(14)	(2)	(37)		
K	10900	11800	13140	15020	16333	-0.05	0.50
	(407)	(288)	(437)	(623)	(1062)		
Mg	2710	2298	2300	2954	3083	-0.09	0.30
	(98)	(112)	(99)	(207)	(219)		
Mn	154	59	74	133	147	0.001	0.05
	(29)	(10)	(12)	(23)	(8)		
Na	2395	2130	840	330	313	0.30	-0.35
	(310)	(240)	(88)	(51)	(34)		
Zn	40.7	36.1	29.9	41.6	34.7	-0.23	0.14
	(2.1)	(1.1)	(1.2)	(3.1)	(1.4)		

guisorba minor. The community located on the opposite side of axis II include a mixture of species from more acid, dryer and cold meadows, such as *Agrostis capillaris, Festuca rubra, Lotus corniculatus, Potentilla erecta, Polygala vulgaris, Luzula campestris,* and *Polygonum bistorta,* and others characteristic of the nearby forest, such as *Anemone nemorosa, Euphorbia hyberna, Astrantia major, Stellaria graminea* among others.

To examine the relationship between the mineral content of the soils and herbage, a correlation matrix was constructed for all elements measured in soils and herbage on the same quadrats. There was no significant (linear) correlation found between the concentration of any element in the herbage and its concentration in the soil, except in the case of copper. The concentration of this element in the herbage was positively correlated with its concentration in the soil.

Discussion

The results obtained by PCA suggest strong relationships to be found between soil chemical composition, management practices, climate and the floristic composition of meadow communities. That such relationships exist has been recognized, of course, for centuries. However, to the authors knowledge, although studies have been conducted to examine such relationships in intensive systems of agriculture (*e.g.*, Archer 1970) or in uncultivated areas (*e.g.*, Gomez-Gutierrez and Duque 1973, Miles and McDowell 1983, Garcia-Ciudad *et al.* 1980), these did not attempt to quantify the relationships under traditional management systems.

The results also reveal that species found in any particular area are good indicators of environmental conditions. Regarding soil fertility, most typically *Arrenatherum elatius, Lolium perenne, Trifolium pratense* are abundant on fertile soils, while other species such as *Festuca rubra, Agrostis capillaris, Potentilla erecta, Luzula campestris* etc., are adapted to less fertile soils. *Agrostis capillaris* and *Polygala vulgaris* are characteristic of dryer, colder and much more acid soils. It is clear that any management practice that alters soil conditions, specifically its moisture content, pH level, organic matter content, and mineral content will affect the species composition of the meadow community. The lowland pastures in this study, provide evidence of the effect of irrigation on community composition with increased biomass production. This is also true for the higher meadows, although not as clearly evident from the PCA ordination.

The correlation of the negative side of PCA axis 1 and Cu, Zn, Al and Ca concentration, as well as of soil organic matter and Cu and Ca in the herbage, arises from a combination of factors. On this side of the axis 1, the lower meadows are to be found which are rich in N and may receive minerals and organic matter from the higher slopes in runoff or seepage. Another factor, undoubtedly contributing to amelioration, is the frequent application of manure. The lower, manured meadows are richer in organic matter, minerals and N, whereas the higher meadows, located in the ordination at the opposite pole of axis 1, have not been manured for several years and have been neglected by management. The latter contribute to the more scattering configuration of the sample on the positive side, owing to higher floristic diversity. In all this, it must be emphasized that even in the lower meadows with lower relative species diversity, the variety of species found far exceeds the one in intensively managed systems with regular cutting before the plants have produced seed. Thus diversity and management are closely linked.

When we begin to examine relationships between soil composition and the elemental composition of the leaf tissue, we must not assume a causal relationship even if significant correlations were found. Results discussed by Hemphill (1977) emphasize the point that from the evidence so far accumulated, in the majority of situations, there is often little direct relationship between soil chemistry and mineral composition of the herbage. This lack of direct relationship arises precisely because mineral content in herbage is a function of the interactions of all the factors - soil, plant metabolism, stage of maturity, yield, management, climate, and so on (McDowell *et al.* 1985). Our results reflect this fact: among all the elements measured only herbage copper concentration is positively and significantly correlated to soil copper concentration, and even in this case the coefficient of determination is very low.

It has been found that as soil pH increases, availability of Fe, Mn, Zn, Cu and Co is reduced, but poor drainage may increase the content of extractable trace elements, owing to dissolved salts in the soil water, from which they can be taken up by plants (Mitchell 1957, Wilkins 1979). The results from the study reported here, however, reveal no significant relationship between pH and either copper or iron, but do indicate a negative correlation between plant Mn levels and soil pH. As stressed earlier, no causality should be assumed.

Due to this lack of relationship between soils and plants with respect to their elemental composition, it is preferable, when considering the likelihood of deficiencies in animals to examine the concentration of the element in the herbage, as opposed to the soils. As we have seen high levels in soils do not necessarily imply high levels in plants. Considering the herbage mineral content during the summer in comparison with the levels recommended as minimum dietary requirement by A.R.C. (1980) indicates that deficiencies of copper are likely to arise in grazing animals on a complete herbage diet. Dick (1954) suggested that 1 mg copper per kg dry diet should satisfy ruminant requirements for this element, if no other factor is limiting its availability. However, Suttle (1974) emphasized the importance of molybdenum in copper nutrition and later Mills *et al.* (1976) suggested that even where molybdenum levels in herbage are not excessive the ruminant requirement for copper may be closer to 10 mg per kg dietary dry matter. In none of the pastures studied here were the levels of copper in the herbage higher than 6 mg per kg dry matter. Previous results for pasture analysis from this area (Garcia *et al.* 1990) taken over three seasons, have shown marked seasonal variation in the concentration of minerals in the herbage. In addition to considering absolute concentrations of any element when assessing the likelihood of a deficiency of that element in grazing ruminants, it is thus necessary also to take account of such seasonal variations. Furthermore, as illustrated by the copper/molybdenum interaction, the effects of other components of the diet should be borne in mind. Unfortunately results for Mo analysis of the herbage in this study are not available and we cannot, therefore, comment on the likelihood of a Mo-induced Cu-deficiency. Strong evidence also exists for a zinc/phytate/calcium interaction (Tucker and Salmon 1955, Zeigler *et al.* 1961). The calcium levels in this study, however, while being adequate by current recommendations are not sufficiently high to lead us to suspect that there may be a danger of a calcium-induced zinc deficiency. According to the findings of Morris and Murphy (1972), Morris and Gartner (1971) and Underwood (1981) the levels of sodium in pasture D and E in this study are deficient for grazing ruminants in the summer and marginal-deficient in pasture C, pointing to a requirement for enrichment of animals feed during this time of year.

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