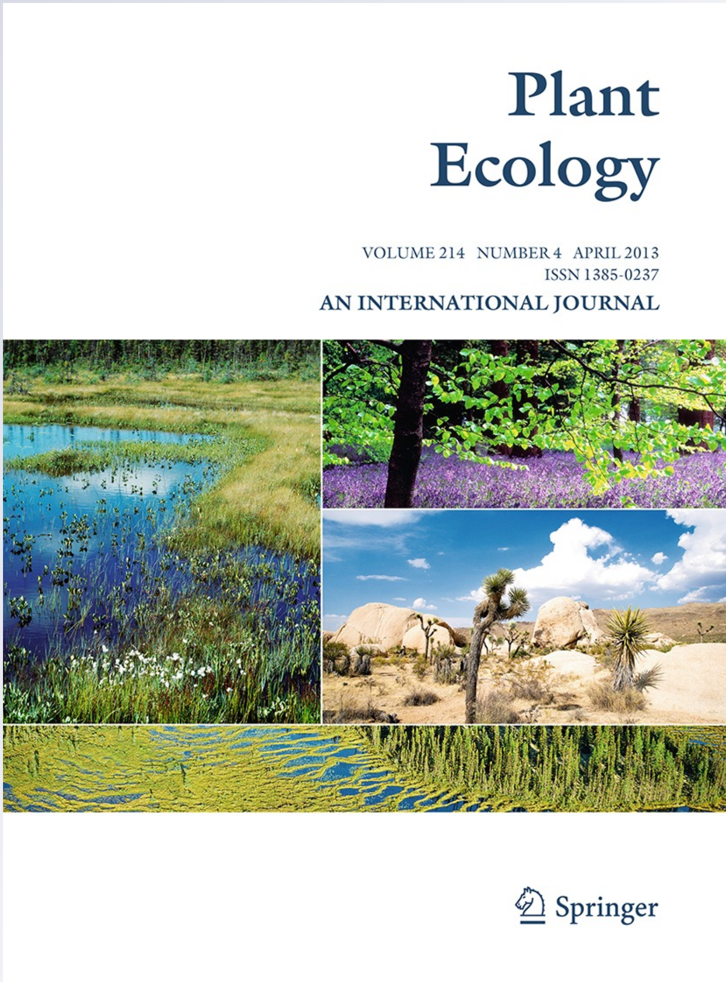
Effects of long-term management practices on grassland plant assemblages in Mediterranean cork oak silvo-pastoral systems

Simonetta Bagella, Lorenzo Salis, Gian Marco Marrosu, Ivo Rossetti, Stefania Fanni, Maria Carmela Caria & Pier Paolo Roggero

Plant Ecology
An International Journal

ISSN 1385-0237
Volume 214
Number 4

Plant Ecol (2013) 214:621-631
DOI 10.1007/s11258-013-0194-x



Plant Ecol (2013) 214:621–631
DOI 10.1007/s11258-013-0194-x

Effects of long-term management practices on grassland plant assemblages in Mediterranean cork oak silvo-pastoral systems

Simonetta Bagella · Lorenzo Salis · Gian Marco Marrosu · Ivo Rossetti · Stefania Fanni · Maria Carmela Caria · Pier Paolo Roggero

Received: 15 November 2012 / Accepted: 18 March 2013 / Published online: 3 April 2013

Abstract The assessment of the effects of long-term management practices is relevant in understanding the current patterns of plant assemblages in semi-natural ecosystems. We hypothesized that the variety of management practices across different farming systems under the same ecological conditions directly and indirectly shapes these patterns via the long-term changes induced in soil features. The aims of this paper were to evaluate the influence of two sets of variables describing long-term management practices and soil features on plant assemblages and their importance in the context of Mediterranean silvo-pastoral systems. The analysis of variance revealed that richness and grazing value were not affected at all by grazing livestock species and soil tillage frequency and that they both showed relatively high absolute values for the specific context under study. *Trifolium subterraneum* was a key species in contributing to grassland grazing value and habitat biodiversity. The Canonical Correspondence Analysis highlighted the influence of management practices and soil features on plant assemblage composition, which was significantly affected by grazing livestock species and stocking rate and by soil pH and K content. The Redundancy Analysis showed that soil pH and related features were in turn affected by stocking rate, supporting our hypothesis that management practices influenced plant assemblage composition directly and indirectly via their long-term effects on soil features. The results also highlighted that a systemic analytical perspective applied at a grazing system scale can be effective in addressing sustainable grassland management issues in Mediterranean silvo-pastoral systems.

Electronic supplementary material The online version of this article (doi:10.1007/s11258-013-0194-x) contains supplementary material, which is available to authorized users.

S. Bagella (✉) · I. Rossetti · M. C. Caria
Dipartimento di Scienze della Natura e del Territorio, Università di Sassari, Via Piandanna 4, 07100 Sassari, Italy
e-mail: sbagella@uniss.it

S. Bagella · P. P. Roggero
Nucleo di Ricerca sulla Desertificazione, Università di Sassari, Viale Italia 39, 07100 Sassari, Italy

L. Salis · G. M. Marrosu
Dipartimento per la Ricerca nelle Produzioni Animali, AGRIS, Bonassai, S.S. 281 km 18.6, 07100 Sassari, Italy

S. Fanni
Dipartimento per la Ricerca nelle Produzioni Vegetali, AGRIS, Viale Trieste 111, 09123 Cagliari, Italy

P. P. Roggero
Dipartimento di Agraria, Università di Sassari, Via de Nicola, 07100 Sassari, Italy

Keywords Grazing systems · Soil features · Stocking rate · Tillage · *Trifolium subterraneum*

Introduction

Semi-natural grasslands represent one of the most relevant land uses in marginal rural areas for their role in nature conservation (European Commission 1992; Bignal and McCracken 2000) and the associated ecosystem services (Bagella and Caria 2011). Plant assemblage composition in these agroecosystems is shaped in the long term by the interplay between natural laws and management practices (Fernández-Moya et al. 2011).

The dramatic changes towards intensification and abandonment that are occurring in the grasslands and agro-silvo-pastoral systems of many less-favoured areas in the world (Caballero 2007) can result in a general decline of grassland plant assemblage diversity (Strijker 2005; Peco et al. 2006; Klimek et al. 2007) and associated productivity (Karakosta and Papanastasis 2007). In the European Union, the biodiversity issues are being addressed by various policy schemes (European Commission 1992; Kleijn and Sutherland 2003). However, the efficiency and effectiveness of such schemes have been questioned (Kleijn et al. 2006) also because they are often insufficiently supported by scientific knowledge on the relationships between long-term management practices and vegetation dynamics.

Cork oak silvo-pastoral systems are agroforestry grassland-dominated landscapes occurring in the warmer parts of the western Mediterranean basin, covering approximately 1.5 Mha in Europe and 1.0 Mha in North Africa (Bugalho et al. 2011). They have a sparse cork oak tree cover with a heterogeneous shrubby understorey interspersed with grasslands, fallows and, less often, cereal and other crops (Diaz et al. 1997), looking like a savanoid ecosystem (Rackham 2007). In these contexts, the productivity is constrained by summer drought, erratic early autumn precipitation regime and low soil fertility (Gallardo 2003; Gea-Izquierdo et al. 2009), and grazing is the main farming activity (Montero et al. 2000). These kind of ecosystems, which are known in other regions with different names (e.g. *dehesa* in Spain, *montado* in Portugal), are of interest for a wide scientific community which is addressing the changes in ecosystem services associated with the dynamics of grassland plant assemblage composition as influenced by long-term management practices (Bugalho et al. 2011).

Although there is evidence that management by grazing at a moderate level contributes to improve diversity (Klimek et al. 2007), there is considerable debate around which management practices can contribute in the long term to the maintenance of diverse and productive grasslands (Rook et al. 2004; Catorci et al. 2011). In particular, the knowledge on the most suitable indicators of long-term effects of the grazing management systems in different contexts is often unclear or based on fragmentary evidence (Rook et al. 2004).

Management is a key factor affecting species richness and composition of semi-natural grasslands (Klimek et al. 2007; Cousins et al. 2009); however, soil properties such as pH and nutrient concentrations are also important (Lagomarsino et al. 2011; Merunková and Chytrý 2012). In the long term, management can also affect soil features that in turn are relevant in understanding actual plant assemblage patterns (Decocq 2000; MacDonald et al. 2000; Catorci and Gatti 2010; De Sanctis et al. 2012).

This paper is focused on the *ex-post* assessment of long-term effects of grazing and soil management practices on plant assemblage composition, richness and grazing value (GV) of grassland vegetation in Mediterranean silvo-pastoral systems. The changes in vegetation are interpreted here not only according to a pure environmental spatial scale, as prescribed for example by the EU Habitat Directive (European Commission 1992), but also in relation to the changes associated with the farming systems, as emerging from the managerial decisions and practices of the farmers, which in turn shape the environment and can generate new habitats.

Starting from the general assumption that under the same ecological conditions, different land use histories are relevant in shaping plant assemblages at different spatial scales (Poschlod et al. 2005; Gustavsson et al. 2007; Catorci and Gatti 2010), we hypothesized that in Mediterranean silvo-pastoral systems

(1) Grassland plant assemblage richness and GV were affected by livestock species and soil tillage frequency (Cousins et al. 2009);
(2) Grassland plant assemblage composition was also affected by management practices

associated with the specific livestock farming systems, including grazing livestock species (Olff and Ritchie 1998; Adler et al. 2001) and soil tillage frequency (Austrheim and Olsson 1999; Römermann et al. 2005), and by the specific soil features (Robson et al. 2007);

(3) Long-term management practices induced changes on soil features (Peco et al. 2006), which in turn affected plant assemblage composition.

To test these hypotheses, we evaluated the influence of a range of long-term field management practices and soil features on the variability of grassland plant assemblages and the effects of the same management practices on soil features, in the context of a typical Mediterranean cork oak silvo-pastoral system.

Materials and methods

Study sites

The experimental sites were located in NE Sardinia (Italy) at 250–300 m a.s.l. (40°47′N; 9°15′E). The natural potential vegetation is represented by cork oak woods of the *Violo dehnhardtii-Quercetum suberis* association (Bagella et al. 2013). Average annual precipitation is 632 mm, with at least 70 % of rain falling from October to May, and mean annual temperature is 14.2 °C. We chose sites characterized by the same soil type (*Typic Dystroxerept,* Soil Survey Staff 2010) and morphology on a granitic substratum.

In this area, grazing is practiced since centuries and to test the hypotheses we identified fields that have been managed in the same way for over 50–60 years. The grazing systems are mainly based on pasture as the feeding source (Caballero et al. 2009): animals graze hay crops, fallow grasslands and occasionally shrubs all year round according to a mix of continuous and rotational schemes. Sheep are occasionally sheltered overnight when necessary in winter. Pastures on average contribute to 73 and 82 % of the total energetic requirements of sheep and cattle, respectively, and are closely grazed during winter (Salis 2011). Grazing livestock are mainly Sarda dairy sheep or crossbred beef cattle.

Soils are periodically (between 2 and more than 10 years) fertilized and tilled at a depth of 20–25 cm using mouldboard or most frequently disc plough to clear the fallow grassland from thorny weeds and to establish hay crops of annual forage grasses (oats or Italian ryegrass) and legumes (clovers or vetch) that start a new grass fallow period, relying on the seed bank.

Experimental design

The experimental sites were represented by fields of at least 1 ha characterized by uniform management for at least the past 50 years. They were selected according to an unbalanced factorial design considering (i) grazing livestock species, sheep (6 sites) or cattle (7 sites), and (ii) soil tillage frequency; control: >20 years (4 sites); intermediate: 5–10 years (5 sites); and frequent: 2 years (4 sites). Three replicated sampling areas (5×5 m^2) were randomly chosen in the unshaded areas of each field and fenced to assess plant assemblage composition, GV and richness. Soil and grazing management practices were also surveyed in each site.

Data collection

Vegetation surveys were carried out in the fenced plots in May 2009 using the point quadrat method (Bullock 1996). A needle was vertically lowered through the vegetation every 20 cm along two 5-m-long parallel transects. At each point, all plant species intercepted by the needle were recorded. The specific percentage contribution of each species (CSP_i) for each site was calculated as the average value from the three fenced plots:

$$\mathrm{CSP}_i = \frac{\mathrm{FS}_i}{\sum \mathrm{FS}_i} 100$$

where FS_i is the absolute specific frequency of species *i*.

Grazing value was assessed according to Daget and Poissonet (1971) using the specific indices (Is) of Roggero et al. (2002), which indicate the agronomic value of each species contributing to the CSP (see Electronic appendix):

$$\mathrm{GV} = 0.2 \sum_{i=1}^{i=n} \mathrm{CSP}_i \times \mathrm{Is}_i.$$

Species richness was calculated as the cumulative value of all identified species over 12 monthly sampling in each site in the year 2009 (Whittaker et al. 2001). Plant nomenclature and life forms follow Pignatti (1982).

The farmers managing the surveyed sites were interviewed using a structured questionnaire to collect data on grazing livestock, stocking rate, tillage frequency and fertilization practices. The average annual nitrogen and phosphorus fertilization rates were derived from the actual practices made in the last 10 years. The stocking rate was assessed as an average annual value for each site from the information collected on fortnight grazing management and it was expressed as Livestock Units ha^{-1} (1LU = 500 kg cattle live weight = 6.6 dairy ewes). Considering the seasonal changes in grazing management, the stocking rate indicator was complemented by the calculation of an overgrazing index, i.e. the ratio between the energy requirements of the actual number of grazing animals in each site and the estimated energy offered by the grasslands, both expressed as daily milk forage units (UFL ha^{-1} day^{-1}) according to Jarrige (1989). The energy offer of the grassland was estimated on the basis of the average daily herbage growth rate (kg DM ha^{-1} day^{-1}) as reported by Salis (2011) and its estimated forage net energy (Jarrige 1989).

In each site, a soil profile was dug down to about 1 m depth and sampled according to the horizon to check that the soil types of all sites were uniform and comparable. A set of soil physical–chemical analyses was performed following Violante (2000) and Pagliai (2001) on a bulk sample taken from ten cores (0–30 cm in depth) randomly taken in each site (Conant and Paustian 2002). They included texture, pF, cation exchange capacity, saturated conductivity, pH in H_2O and in KCl, Walkley–Black C (hereafter named soil organic C), Kjeldhal N, Olsen P, ammonium acetate extractable K (hereafter named K), $BaCl_2$ extractable Ca Mg Na K and available water (soil moisture at pF2.5–pF4.2).

Statistical analysis

To test hypothesis 1 whether plant species richness and GV were directly influenced by the livestock species x tillage frequency, an unbalanced factorial ANOVA (completely randomized design, using the three replicated fenced areas per site as pseudoreplicates) was performed to test the following null hypotheses: H_0:$\mu_{sheep} = \mu_{cattle}$; H_0:$\mu_{control} = \mu_{intermediate} = \mu_{frequent}$; H_0 = no animal species x tillage interaction. Prior to ANOVA, the Cochran and Shapiro–Wilk tests were performed to check for homoscedasticity and normality, respectively, and heteroscedastic variables were log-transformed. The post hoc mean separation was based on Fisher's Protected LSD test (Steel and Torrie 1992). Moreover, Pearson correlation coefficients (r_p) were calculated to describe the linear relationships between CSP values of the species bearing the highest specific indices and the GVs of each site.

Two separate Canonical Correspondence Analyses were performed using Hill's scaling with a focus on sample distances to test hypothesis 2 whether management practices (CCA1) or soil features (CCA2) influenced plant assemblage composition.

A Redundancy Analysis (RDA) was performed to test hypothesis 3 whether management practices influenced soil features.

The explanatory variable matrices were 13 sites × 9 management practices (CCA1) or ×7 soil features (CCA2), as listed in Table 1. The RDA response variable matrix was 13 sites × 7 soil features.

Prior to run CCA or RDA, a Detrended Correspondence Analysis was performed to select the appropriate canonical ordination (ter Braak and Šmilauer 2002). A subset of variables derived from the 12 most relevant soil features that were likely to be independently influenced by the long-term management practices (soil organic C, C/N, pH in H_2O, Olsen P, K, cation exchange capacity, $BaCl_2$ extractable K, Ca, Mg and Na % base saturation, available water) was used to build the explanatory matrix for the CCA2 and the response variable matrix for the RDA. Variables with variation inflation factors ≥20 were removed from the analysis to prevent high collinearity (McCune and Grace 2002). Consequently, the CCA's response variable matrix was composed by 13 sites × 23 plant species CSP. Grazing livestock species and tillage frequencies were included in the analyses as dummy variables. Prior to submitting to the CCA or RDA, soil features (except pH) and management practices were ($\log_n + 1$) transformed and CSP values were square-root-transformed and down-weighted for rare species. The statistical significance of axes 1 and 2 was tested by a Monte Carlo test with 499 permutations under the full model.

All multivariate analyses were carried out using CANOCO v4.5 for Windows (ter Braak and Šmilauer 2002), ANOVA with SAS software (SAS Institute 1999).

Table 1 Management practices and soil features (0–30 cm) recorded at each site (1–13) and used in the multivariate analyses

	Site no.												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Management practices													
Livestock species													
Sheep	1	1	1	1	1	1	0	0	0	0	0	0	0
Cattle	0	0	0	0	0	0	1	1	1	1	1	1	1
Tillage frequency													
Control (>20 years)	0	0	1	0	0	0	1	0	0	1	0	0	1
Intermediate (5–10 years)	1	0	0	1	0	1	0	1	0	0	1	0	0
Frequent (2 years)	0	1	0	0	1	0	0	0	1	0	0	1	0
Grazing pressure													
Stocking Rate (LU ha^{-1})	0.9	0.7	2.2	1.7	1.6	1.8	0.7	0.7	0.5	0.4	0.5	0.6	0.8
Overgrazing Index	0.37	0.24	0.89	0.66	0.67	0.48	0.10	0.18	0.10	0.22	0.48	0.25	0.29
Fertilization rate													
N (kg ha^{-1} $year^{-1}$)	0	20	0	0	0	0	0	0	120	0	0	20	0
P_2O_5 (kg ha^{-1} $year^{-1}$)	60	60	120	120	60	60	0	0	90	70	40	40	0
Soil features													
pH in H_2O	5.23	5.00	5.15	5.15	5.15	5.54	5.55	5.56	6.22	5.34	4.96	5.68	5.12
Walkley–Black soil organic C (g kg^{-1})	14.1	13.9	13.1	17.2	15.1	14.0	23.6	12.9	19.3	10.0	9.0	11.1	8.6
C/N	11.4	6.6	10.9	11.1	10.8	8.4	10.2	8.9	9.4	10.5	11.2	9.7	7.6
Cation exchange capacity (meq 100 g^{-1})	15.5	17.3	16.9	18.5	13.9	16.2	19.0	13.8	16.1	11.2	11.5	18.7	13.9
Olsen P (mg kg^{-1})	5.9	21.1	2.0	17.2	4.6	12.9	64.6	5.3	62.1	1.3	5.4	3.9	18.5
Acetate extractable K (mg kg^{-1})	119	180	170	135	94	139	397	145	128	44	34	106	238
Available water (m m^{-1})	12.4	9.4	10.3	12.2	14.2	10.2	10.7	12.8	9.6	9.4	8.8	10.0	10.9

Results

In all, 151 plant species were identified within the fenced plots. Therophytes (67 %) were much more abundant than perennials, mainly represented by hemicriptophytes (see Electronic appendix). Legumes and grasses represented on average 23 and 34 % of the total CSP, respectively. Unpalatable species were the most numerous, whilst the only excellent forage species were *Lolium rigidum*, *Trifolium subterraneum*, *T. incarnatum* and *T. michelianum*. Overall, six species contributed to 77 % of the total GV: *T. subterraneum*, *L. rigidum*, *Avena barbata*, *Medicago arabica*, *Vulpia ligustica* and *Hordeum leporinum*.

The results of the ANOVA (Fig. 1) confirmed the null hypothesis 1 as no significant differences in terms of species richness or GV were found between tillage frequencies ($F_{2,7} = 0.72$ and $F_{2,7} = 0.31$, respectively) or livestock species ($F_{1,7} = 2.30$ and $F_{1,7} = 0.58$, respectively), and the livestock species x tillage frequency interaction was not significant (richness: $F_{2,7} = 0.42$; GV: $F_{2,7} = 1.43$). GV was significantly and positively correlated to the sum of *T. subterraneum* and *L. rigidum* CSP under sheep grazing ($r_p = 0.91$*; $n = 6$) and to *L. rigidum* CSP ($r_p = 0.87$*; $n = 7$) under cattle grazing.

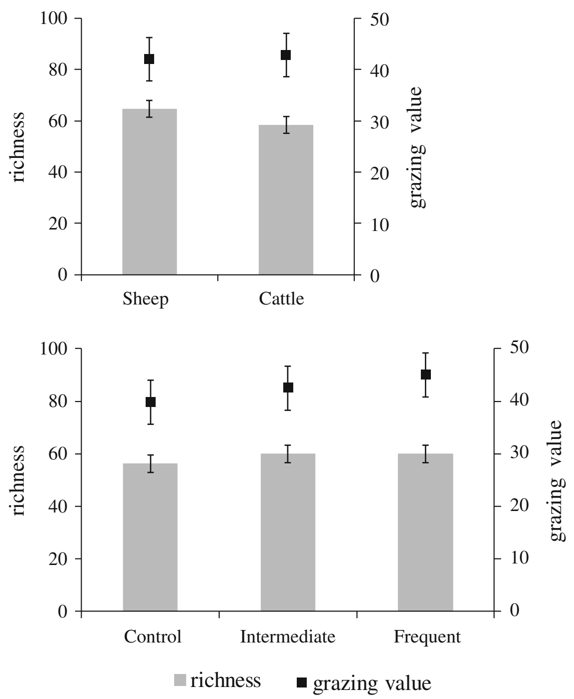


Fig. 1 Richness and grazing values under the different grazing livestock species (sheep vs cattle) and tillage frequencies (control vs intermediate vs frequent). *Vertical bars* indicate the SE

The estimated average stocking rate ranged between 0.4 and 2.2 LU ha^{-1}. Sheep farms showed a higher stocking rate than cattle farms (1.5 vs 0.6 LU, $P \leq 0.009$) and a higher overgrazing index (0.55 vs 0.23, $P \leq 0.02$). Nevertheless, the overgrazing index was always less than 1, indicating no overgrazing in any of the sampled sites. Fertilization rates ranged from no application to 120 kg ha^{-1} year^{-1} both for N and P_2O_5 mineral fertilizers (Table 1).

The soils had a uniform sandy loam texture (67 ± 3 % sand, 22 ± 2 % silt 11 ± 1 % clay), with a medium–low water-holding capacity, medium CEC, pH ranging from very strong to slight acid, corresponding to a % base saturation ranging from 12 to 51 %, mostly represented by Ca (69 ± 2 %) and Mg (16 ± 2 %) ions, and variable contents of SOC, C/N, P and K (Table 1).

Amongst the nine explanatory variables included in the CCA1 (Fig. 2) to test hypothesis 2 regarding the effects of management practices on plant assemblage composition, only stocking rate and livestock species were significant (Table 2), explaining 51 % of the total variance. Plant species associated with sheep grazing and higher stoking rates, e.g. *Carlina corymbosa, Onopordum illyricum*, *Sherardia arvensis*, *T. michelianum* and *V. ligustica*, were positioned towards the right side of the graph. The most abundant species associated with cattle grazing and lower grazing pressure, positioned on the left side, were *Echium plantagineum*, *M. arabica*, *M. hispida* and *L. rigidum*. Therefore, sheep and cattle grasslands differed substantially in plant assemblage composition. Furthermore, cattle grassland plant assemblages were more variable than sheep grasslands. *T. subterraneum*, which was the most abundant species, was positioned in the centre of the graph, since its CSP was similar under all the management conditions.

Amongst the seven explanatory variables included in the CCA2 (Fig. 3) to test hypothesis 2 regarding the effects of soil features on plant assemblage composition, K and pH were the most significant, explaining 53 % of the total variance (Table 2). *Plantago coronopus* and *Lophochloa cristata* were abundant under low soil K levels, whilst *Bunias erucago* and *Daucus carota* were abundant under high soil pH.

The RDA, performed to test hypothesis 3, (Fig. 4) revealed that stocking rate was the only significant indicator of management practices influencing soil

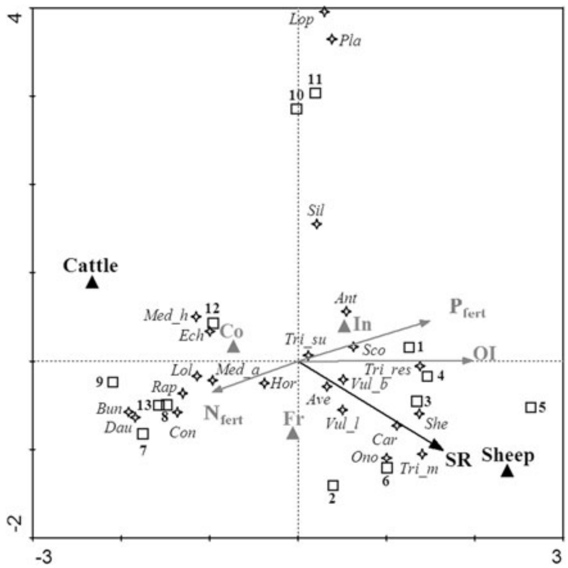


Fig. 2 Triplot from the CCA1 showing the position of (i) □ sampling sites (1–13); (ii) ✧ plant species with a specific contribution higher than 10 %; (iii) significant (*black arrows*) and not significant (*grey arrows*) management practices. Dummy variables are represented by *solid triangles*. Eigenvalues: axis 1 = 0.189; axis 2 = 0.154; axis 3 = 0.03. Cumulative percentage variance: axis 1 = 24.0; axis 2 = 43.6; axis 3 = 54.1. *CO* control; *FR* frequent tillage frequency; *IN* intermediate tillage frequency; N_{fert} Nitrogen fertilization rate; *OI* Overgrazing Index; P_{fert} Phosphorus fertilization rate; *SR* Stocking rate. The correspondence between codes and taxa names is given in the Electronic appendix

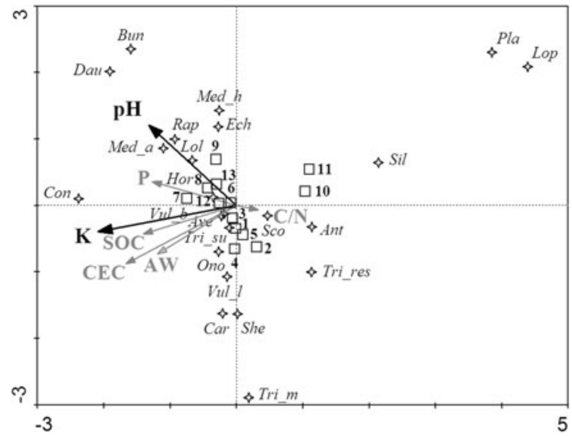


Fig. 3 Triplot from the CCA2 showing the position of the following: (i) □ sampling sites (1–13); (ii) ✧plant species with a specific contribution higher than 10 %; (iii) significant (*plain black arrows*) and not significant (*plain grey arrows*) soil features. Eigenvalues: axis 1 = 0.201; axis 2 = 0.143; axis 3 = 0.066. Cumulative percentage variance: axis 1 = 25.5; axis 2 = 43.7; axis 3 = 52.1. *AW* available water; *CEC* cation exchange capacity; *K* acetate extractable K; *P* Olsen P; *SOC* Walkley–Black soil organic C. The correspondence between codes and plant names is given in the Electronic appendix

features (Tab. 2), explaining 36 % of the total variance. Stocking rate was collinear with overgrazing index. The RDA results also revealed that stocking rate or overgrazing index were inversely related to pH, whilst they were roughly orthogonal to soil organic C, C/N, cation exchange capacity and K.

Discussion

The *ex-post* analysis of the effects of the long-term management practices on grassland plant assemblages revealed the inconsistency of hypothesis 1, as plant species richness and GV were not affected at all; confirmed hypothesis 2, as plant assemblage composition was influenced by grazing livestock species, stocking rate and soil features (K and pH); and confirmed hypothesis 3, as stocking rate significantly affected soil features.

A common characteristic of all the grassland sites under study was a higher plant species richness than that found in similar habitats (Tárrega et al. 2009; Farris et al. 2010), which was related to the moderate grazing pressure (Noy-Meir et al. 1989). The dominance of therophytes is typical of cork oak silvo-pastoral grassland communities (Tárrega et al. 2009; Fernández-Moya et al. 2011) because this life form is particularly well suited to disturbance tolerance (Grime 1977) and soil disturbance by trampling favoured seedling

Table 2 Significant explanatory variables and related percentage of the total explained variance resulting from CCA1, CCA2 and RDA

Response variables	Ordination	Explanatory variables	% of the total explained variance	Probability level
CSP	CCA1	Livestock species	32.0	0.008
		Stocking rate	18.8	0.050
CSP	CCA2	K	30.5	0.002
		pH	22.9	0.020
Soil features	RDA	Stocking rate	36.1	0.006

CSP percentage specific contribution

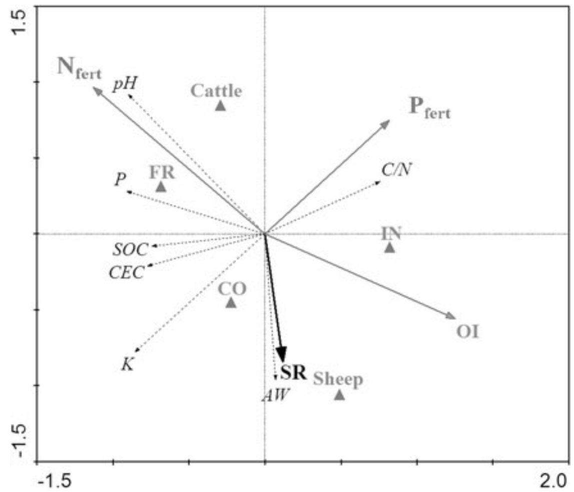


Fig. 4 Biplot from the RDA showing the position of the following: (i) soil features (*dotted arrows*); (ii) significant (*plain black arrows*) and not significant (*plain grey arrows*) management variables. Dummy variables are represented by *solid triangles*. Eigenvalues: axis 1 = 0.343; axis 2 = 0.140; axis 3 = 0.088. Cumulative percentage variance: axis 1 = 34.3; axis 2 = 48.3; axis 3 = 57.2. *AW* available water; *CEC* cation exchange capacity; *K* acetate extractable K; *P* Olsen P; *SOC* Walkley–Black soil organic C; *CO* control; *FR* frequent tillage frequency; *IN* intermediate tillage frequency; N_{fert} nitrogen fertilization rate; *OI* overgrazing index; P_{fert} phosphorus fertilization rate; *SR* stocking rate

recruitment (Noy-Meir et al. 1989). The non-significant effects of management practices on the GV are consistent with the small proportion of species with high specific indices contributing to the GV and to the fact that the differences amongst plant assemblages were related to ungrazed or occasionally grazed species. Despite the climatic and soil acidity constraints, the GVs were reasonable, being above 25 in all sites, when compared to the ones reported in the literature (Bagella 2001; Bagella and Roggero 2004; Argenti et al. 2006; Catorci et al. 2009). The lack of clear effects of tillage frequencies on plant species richness and GV may not be widening. The plentiful soil seed bank of the annual grasslands was not hampered by the recurrent shallow tillage practices adopted to clear the pasture of shrubby and thorny species (Díaz-Villa et al. 2003). Similarly, in the Spanish *dehesa*, a few years of fallow grazing were sufficient to allow the recovery of the annual grassland vegetation following several years of cereal cropping (Hernández et al. 2003). In similar contexts, ploughing caused species loss, but after few years, the original diversity was recovered in most cases (Montalvo et al. 1993).

The differences found in plant assemblage composition emerged from a variety of long-term management practices associated with the different livestock farming systems (CCA1). Such practices include the choices made by the farmers on grazing management and stocking rates, which add up to the different behaviour of livestock species (Caballero et al. 2009). Even if the stocking rate was generally lower than the carrying capacity of the grasslands, a higher stocking rate characterized the sheep than cattle livestock systems, as already observed in the *dehesa* (Moreno and Pulido 2009). The analyses of the discriminant plant species between the cattle and sheep grazing systems pointed out that they were mostly ruderal or very common and hence not very effective in qualifying the quality of grassland, with few exceptions. For instance, the thorny *O. illyricum* and the good forage species *T. michelianum* were more frequent under sheep grazing and the good forage species *L. rigidum* and *M. arabica* were more frequent under cattle grazing. *T. subterraneum* was equally associated with sheep or cattle grazing. This species provides a significant contribution to the overall GV and is an indicator of biodiversity at the habitat level. It is characteristic of the phytosociological class *Poetea bulbosae* which is related to the EU priority habitat type 6220*-Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea and includes many associated species that are well adapted to sheep treading and inorganic fertilizer application (Galán de Mera et al. 2000). The similar abundance of *T. subterraneum* under both sheep and cattle grazing indicates that some common management practices of the two grazing systems enhanced the competitive ability of this species which is favoured vs. annual grasses by close grazing in winter and its self-reseeding allowed under relatively low stocking rates in spring (Smetham 2003). Besides the differences, it was also observed that a higher extent of heterogeneity in plant assemblage composition was associated with cattle than with sheep grazing, which is in agreement with the observations of Sebastià et al. (2008). This was interpreted as a consequence of the more flexible choices of fertilization and grazing management practices by cattle breeders (Salis 2011).

The observed relationships between plant assemblages and soil features (CCA2) confirmed that soil pH is one of the key factors controlling grassland vegetation (Merunková and Chytrý 2012), particularly for plant assemblages with similar water and temperature requirements (Catorci and Gatti 2010). Even within the relatively narrow pH range explored in our sites, some species known to be intolerant to strong acid soils (Pignatti 2005) clearly responded to slightly increased pH. Soil K has a major role in plant nutrition (Mahdi et al. 1989) and is more abundant in grazed than in ungrazed grasslands (Catorci et al. 2011). Our results evidenced the relationships between very low K content and the abundance of some minor species adapted to oligotrophic soils (Pignatti 2005). However, none of the chosen management practice indicators explained soil K variability; hence, further studies are worthwhile to better understand the role of this macroelement in the Mediterranean grazing systems.

The results showed the relevance of stocking rate as a proxy variable to assess the long-term impact of grazing systems on soil features, particularly on soil acidity and related fertility indicators. On the other hand, the impact of occasional and relatively low rates of N fertilizers was negligible. The relationships between grazing and soil acidification, particularly in legume-based pastures on sandy soils, are well documented as an outcome of, e.g. increased nitrate leaching or heavy grazing (Bolan et al. 1991). In the context of the cork oak silvo-pastoral systems of Sardinia, legumes represent some 25 % of the sward composition, and the typical water surplus in the cool wet season under sandy soils and close grazing can potentially lead to significant nitrate leaching (Sulas et al. 2012). Our results suggest that soil acidification is worth some attention in these ecosystems as it may be enhanced by increased stocking rates even within the observed moderate grazing pressures. However, the seed bank of the weedy fallows of these grazing systems proved to be very well adapted to such pressures, particularly the very good wild germplasm of forage legumes such as *T. subterraneum, T. resupinatum* and *T. michelianum*, and the related *Rhizobia*, that already represent valuable genetic resources of acid-tolerant forage legume varieties and N-fixing bacteria strains (Nichols et al. 2007).

The comparison of the CCA2 and RDA provided a rich picture of the effects of grazing management practices, of which the stocking rate was a proxy, on soil features and plant assemblage composition, unveiling the links between management and farming systems. This supports our hypothesis that the plant assemblage composition was affected directly by management practices and indirectly by the long-term impact of management on some relevant soil features such as pH and other fertility indicators.

Conclusions

Under the relatively uniform abiotic conditions which characterize the cork oak silvo-pastoral systems, the long-term practices associated with different animal grazing species were most relevant in shaping plant assemblages. In the specific case, all the systems under comparison allowed the long-term maintenance of relatively high levels of floristic richness and GV. Moreover, the priority habitat 6620*, which was previously linked to sheep grazing, was also maintained under cattle grazing, independent of tillage frequency.

The long-term impact of grazing management systems on soil fertility and plant assemblage composition was mainly related to the average stocking rate, which in the specific context is associated with the grazing animal species and hence quite different farming systems. A trend of soil acidification was associated with higher sheep stocking rates and whilst this did not result in apparent negative effects on plant assemblage composition, it is worth some attention to prevent soil degradation.

This study revealed that the variation of Mediterranean grassland plant assemblage composition emerged from complex interactions of long-term management practices associated with livestock grazing systems, the conservation of which is closely linked to the economic viability and maintenance of the current farming systems. This has implications on the rural development policies, the investments on the capacity building of the farmers and the generational turnover of the pastoral society.

Acknowledgements This research was supported by AGRIS Sardegna and by SOILSINK (www.soilsink.entecra.it). We acknowledge the support of Giovanna Seddaiu and Stéphanie Gascón for the statistical analyses. We also acknowledge the farmers that provided the pasture management information and allowed soil and plant sampling in their fields.

References

Adler P, Raff D, Lauenroth W (2001) The effect of grazing on the spatial heterogeneity of vegetation. Oecologia 128(4):465–479

Argenti G, Bianchetto E, Ferretti F, Staglianò N (2006) Proposta di un metodo semplificato di rilevamento pastorale nei piani di gestione forestale. Forest@ 3(2):275–280

Austrheim G, Olsson EG (1999) How does continuity in grassland management after ploughing affect plant community patterns? Plant Ecol 145(1):59–74

Bagella S (2001) Valore pastorale delle associazioni vegetali: un esempio di applicazione nell'Appennino umbro-marchigiano (Italia). Fitosociologia 38(1):153–165

Bagella S, Caria MC (2011) Vegetation series: a tool for the assessment of grassland ecosystem services in Mediterranean large-scale grazing systems. Fitosociologia 48((2) suppl. 1):47–54

Bagella S, Roggero PP (2004) Integrating phytosociological and agronomic analysis to support the sustainable management of Mediterranean grasslands. Fitosociologia 41((1) suppl.1): 101–107

Bagella S, Satta A, Floris I, Caria MC, Rossetti I, Podani J (2013) Influence of plant community composition and flowering phenology on honeybee foraging in Mediterranean sylvo-pastoral systems. Appl Veg Sci. doi: 10.1111/avsc.12023

Bignal EM, McCracken DI (2000) The nature conservation value of European traditional farming systems. Environ Rev 8:149–171

Bolan NS, Hedley MJ, White RE (1991) Processes of soil acidification during nitrogen cycling with emphasis on legume based pastures. Plant Soil 134(1):53–63

Bugalho MN, Caldeira MC, Pereira JS, Aronson J, Pausas JG (2011) Mediterranean cork oak savannas require human use to sustain biodiversity and ecosystem services. Front Ecol Environ 9:278–286

Bullock JM (1996) Plants. In: Sutherland WJ (ed) Ecological census techniques. Cambridge University Press, Cambridge, pp 111–138

Caballero R (2007) High nature value (HNV) grazing systems in Europe: a link between biodiversity and farm economics. Open Agric J 1:1–19

Caballero R, Fernández-Gonzáles F, Pérez Badia R, Molle G, Roggero PP, Bagella S, D'Ottavio P, Papanastasis VA, Fotiadis G, Sidiropoulou A, Ipikoudis I (2009) Grazing systems and biodiversity in Mediterranean areas: Spain, Italy and Greece. Pastos 39(1):3–154

Catorci A, Gatti R (2010) Floristic composition and spatial distribution assessment of montane mesophilous grasslands in the central Apennines, Italy: a multi-scale and diachronic approach. Plant Biosyst 144(4):793–804

Catorci A, Cesaretti S, Gatti R (2009) Biodiversity conservation: geosynphytology as a tool of analysis and modelling of grasslands systems. Hacquetia 8(2):129–146

Catorci A, Ottaviani G, Vitasović Kosić I, Cesaretti S (2011) Effect of spatial and temporal patterns of stress and disturbance intensities in a sub-Mediterranean grassland. Plant Biosyst 146(2):352–367

Conant RT, Paustian K (2002) Spatial variability of soil organic carbon in grasslands: implications for detecting change at different scales. Environ Pollut 116:S127–S135

Cousins SA, Lindborg R, Mattson S (2009) Land use history and site location are more important for grassland species richness than local soil properties. Nord J Bot 27:483–489

Daget P, Poissonet J (1971) Une méthode d'analyse phytologique des prairies Critères d'application. Ann Agron 22(1): 5–41

De Sanctis G, Roggero PP, Seddaiu G, Orsini R, Porter CH, Jones JW (2012) Long term no tillage increased soil organic carbon content of rain-fed cereal systems in a Mediterranean area. Eur J Agron 40:18–27

Decocq G (2000) The 'masking effect' of silviculture on substrate-induced plant diversity in oak-hornbeam forests from northern France. Biodiv Conserv 9:1467–1491

Diaz M, Campos P, Pulido FJ (1997) The Spanish dehesas: a diversity of land uses and wildlife. In: Pain D, Pienkowski M (eds) Farming and birds in Europe: the common agricultural policy and its implications for bird conservation. Academic, London

Díaz-Villa MD, Marañón T, Arroyo J, Garrido B (2003) Soil seed bank and floristic diversity in a forest-grassland mosaic in southern Spain. J Veg Sci 14:701–709

European Commission (1992) Council Directive 92/43 EEC of 22.7.92. Off J European Comm L. 206/7

Farris E, Filigheddu R, Deiana P, Farris GA, Garau G (2010) Short-term effects on sheep pastureland due to grazing abandonment in a Western Mediterranean island ecosystem: a multidisciplinary approach. J Nat Conserv 18: 258–276

Fernández-Moya J, San Miguel-Ayanz A, Cañellas I (2011) Variability in Mediterranean annual grassland diversity driven by small-scale changes in fertility and radiation. Plant Ecol 212:865–877

Galán de Mera A, Morales R, Vicente JA (2000) Pasture communities linked to ovine stock. A synthesis of the Poetea bulbosae class in the western Mediterranean region. Phytocoenologia 30(2):223–267

Gallardo A (2003) Effect of tree canopy on the spatial distribution of soil nutrients in a Mediterranean Dehesa. Pedobiologia 47:117–125

Gea-Izquierdo G, Montero G, Cañellas I (2009) Changes in limiting resources determine spatio-temporal variability in tree–grass interactions. Agroforest Syst 76:375–387

Grime JP (1977) Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. Am Nat 111:1169–1195

Gustavsson E, Lennartsson T, Emanuelsson M (2007) Land use more than 200 years ago explains current grassland plant diversity in a Swedish agricultural landscape. Biol Conserv 138:47–59

Hernández AJ, Gil A, Pastor J (2003) Estudio de barbechos en el territorio arcósico de Toledo sobre distintos tipos de suelo sometidos a diferentes usos. Actas de la XLIII Reunión Científica de la SEEP, Granada, E, p 735–741

Jarrige R (1989) Ruminant nutrition. Recommended allowances and feed tables. INRA/John Libbey, Montrouge

Karakosta CC, Papanastasis V (2007) Changes in biomass in relation to shrub cover in semi-arid Mediterranean rangelands. In: Vliegher A, Carlier L (eds) Permanent and temporary grassland: plant environment economy. Proceedings of the 14th Symposium of the European Grassland Federation, Ghent, p 122–125

Kleijn D, Sutherland WJ (2003) How effective are European agri-environment schemes in conserving and promoting biodiversity? J Appl Ecol 40:947–969

Kleijn D, Baquero RA, Clough Y, Díaz M, De Esteban J et al (2006) Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecol Lett 9:243–254

Klimek S, Kemmermann gen AR, Hofmann M, Isselstein J (2007) Plant species richness and composition in managed grasslands: the relative importance of field management and environmental factors. Biol Conserv 134(4):559–570

Lagomarsino A, Benedetti A, Marinari S, Pompili L, Moscatelli MC, Roggero PP, Lai R, Ledda L, Grego S (2011) Soil organic C variability and microbial functions in a Mediterranean agro-forest ecosystem. Biol Fert Soils 47(3): 283–291

MacDonald D, Crabtree JR, Wiesinger G, Dax T, Stamou N et al (2000) Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. J Environ Manage 59:47–69

Mahdi A, Law R, Willis AJ (1989) Large niche overlaps among coexisting plant species in a limestone grassland community. J Ecol 77:386–400

McCune B, Grace JB (2002) Analysis of ecological communities. MjM Software, Glenedon Beach

Merunková K, Chytrý M (2012) Environmental control of species richness and composition in upland grasslands of the southern Czech Republic. Plant Ecol 213(4):591–602

Montalvo J, Casado MA, Levassor C, Pineda ED (1993) Species diversity patterns in Mediterranean grasslands. J Veg Sci 4:213–222

Montero G, San Miguel A, Cañellas I (2000) Systems of Mediterranean silviculture. La dehesa, Grafistaff

Moreno G, Pulido FJ (2009) The functioning, management and persistence of dehesas. In: Rigueiro-Rodriguez A, McAdam J, Mosquera-Losada MR (eds) Agroforestry in Europe: Current Status and Future Prospects. Advances in Agroforestry, vol 6. Springer, Amsterdam, pp 127–160

Nichols PGH, Loi A, Nutt BJ et al (2007) New annual and short-lived perennial pasture legumes for Australian agriculture—15 years of revolution. Field Crop Res 104(1):10–23

Noy-Meir I, Gutman M, Kapplan Y (1989) Responses of Mediterranean grassland plants to grazing and protection. J Ecol 77:290–310

Olff H, Ritchie ME (1998) Effects of herbivores on grassland plant diversity. Trends Ecol Evol 13(7):261–265

Pagliai M (ed) (2001) *Metodi di analisi fisica del suolo*. Collana di metodi analitici per l'agricoltura, Edizione Franco Angeli, Milano Peco B, Sánchez AM, Azcárate FM (2006) Abandonment in grazing systems: consequences for vegetation and soil. Agr Ecosyst Environ 113:284–294

Pignatti S (1982) Flora d'Italia. Edagricole, Bologna

Pignatti S (2005) Valori di bioindicazione delle piante vascolari della flora d'Italia. Braun-Blanquetia 39:1–95

Poschlod P, Bakker JP, Kahmen S (2005) Changing land use and its impact on biodiversity. Basic Appl Ecol 6:93–98

Rackham O (2007) Woodlands. Collins, London

Robson TM, Lavorel S, Clement JC, Le Roux X (2007) Neglect of mowing and manuring leads to slower nitrogen cycling in subalpine grasslands. Soil Biol Biochem 39:930–941

Roggero PP, Bagella S, Farina R (2002) Un archivio dati di Indici specifici per la valutazione integrata del valore pastorale. Rivista di Agronomia 36:149–156

Römermann C, Dutoit T, Poschlod P, Buisson E (2005) Influence of former cultivation on the unique Mediterranean steppe of France and consequences for conservation management. Biol Conserv 121:21–33

Rook AJ, Dumont B, Isselstein J, Osoro K, Wallis DeVries MF, Parente G, Mills J (2004) Matching type of livestock to desired biodiversity outcomes in pastures: a review. Biol Conserv 119:137–150

Salis L (2011) Mediterranean grazing systems and plant biodiversity. Dissertation, University of Sassari

SAS Institute (1999) SAS/STAT user's guide, vol 8. SAS Inst, Cary

Sebastià MT, De Bello F, Puig L, Taull M (2008) Grazing as a factor structuring grasslands in the Pyrenees. Appl Veg Sci 11:215–222

Smetham ML (2003) A review of subterranean clover (*Trifolium subterraneum* L.): its ecology, and use as pasture legume in Australasia. Adv Agron 79:303–350

Soil Survey Staff (2010) Keys to soil taxonomy, 11th edn. USDA-Natural Resources Conservation Service, Washington

Steel RGD, Torrie JH (1992) Principles and procedures of statistics: a biometrical approach, 2nd edn. McGraw-Hill, New York

Strijker D (2005) Marginal lands in Europe—causes of decline. Basic Appl Ecol 6:99–106

Sulas L, Piluzza G, Rochon JJ, Goby JP, Greef JM, Sölter U, Headon D, Scholefield D (2012) Assessing the potential for nutrient leaching from beneath grazed leguminous swards at four European sites. Grass Forage Sci 67(3):320–336

Tárrega R, Calvo L, Taboada Á, García-Tejero S, Marcos E (2009) Abandonment and management in Spanish dehesa systems: effects on soil features and plant species richness and composition. Forest Ecol Manag 257:731–738

ter Braak CJF, Šmilauer P (2002) Reference manual and CanoDraw for windows user's guide: software for canonical community ordination. version 4.5. Microcomputer Power, Ithaca

Violante P (2000) Metodi di analisi chimica del suolo. Collana di metodi analitici per l'agricoltura, Edizione Franco Angeli

Whittaker RJ, Willis KJ, Field R (2001) Scale and species richness: towards a general hierarchical theory of species diversity. J Biogeogr 28:453–470