Influence of *Quercus ilex* trees on herbaceous production and nutrient concentrations in southern Portugal

Elena Cubera[1, 2], Jorge Manuel Nunes[3], Manuel Madeira[1]*, and **Luíz Gazarini[3]**

[1] Instituto Superior de Agronomia, Universidade Técnica de Lisboa. Tapada da Ajuda, 1349-017, Lisboa, Portugal
[2] Ingeniería Técnica Forestal. Universidad de Extremadura. Avenida Virgen del Puerto 2, 10600 Plasencia, Spain
[3] Universidade de Évora, Departamento de Biología, 7002–554, Évora, Portugal

Abstract

In an open woodland in Portugal, the nature of interactions between *Quercus ilex* trees and herbaceous plants was assessed during 2 years by studying how manipulation of incident solar radiation, water and nutrient supply affect the herbaceous biomass and N, K, P, Ca, Mg, and Mn concentrations. Measurements were carried out in three environments consisting of (1) open grassland, (2) beneath the tree canopy, and (3) under artificial shade. Each of these environments was subjected to two regimes of fertilization and two water levels in a factorial design. The fertilizer treatment consisted of application of no fertilizer or a combination of 200 kg calcium ammonium nitrate ha^{-1} (26% N) and 350 kg superphosphate ha^{-1} (8% P), while the water-supply treatment consisted of either no irrigation or irrigation fortnightly from February 1 to April 30. Grasses showed significantly lower nutrient concentrations than forbs. However, nutrient concentrations of the whole herbaceous community were within the recommended ranges for cattle nutrition. A negative effect of shade on herbaceous biomass production was observed. The effect of watering on herbaceous biomass was less prominent than the effect of fertilization, irrespective of the environment, suggesting that *Q. ilex* does not compete for soil-water resources with herbaceous biomass in this ecosystem. Fertilization increased total biomass by 106%, 49%, and 97% in the open grassland, beneath the tree canopy, and under artificial shade, respectively. During the first and second year, fertilization increased herbaceous P concentrations by 24% and 83%, respectively, if compared with concentrations obtained at the unfertilized plots. Higher K and Mg concentrations were observed in herbaceous plants beneath the tree canopy than in the open areas, indicating a positive effect of trees on pasture quality. The positive and negative effects of trees on understory forage are discussed.

Key words: herbaceous biomass / shade / fertilization / irrigation

Accepted March 4, 2009

1 Introduction

Trees change environmental conditions in the understory in terms of reduced light, less extreme temperatures, altered water availability, and evapotranspiration, soil nutrient availability, and organic-matter status (*Joffre* and *Rambal*, 1988; *Gallardo*, 2003; *Moreno* et al., 2007a). The composition of grassland species differs under tree canopies compared to adjacent open grassland, and this increases species biodiversity of Mediterranean silvopastoral systems. The presence of trees can reduce (*Marañón* and *Bartolome*, 1994; *Scholes* and *Archer*, 1997; *González-Hernández* et al., 1998) or increase (*Holland*, 1980; *Moreno*, 2008) productivity of understorey vegetation compared to surrounding open areas. The overall effect of canopy cover on understorey plant production is the result of competitive or facilitatory processes occurring between the trees and pasture, both above and below the ground level. The positive response is generally attributed to more favorable physical and chemical soil properties and to more favorable soil and air temperatures under trees (*Moreno* et al., 2007a). However, the relative importance of each factor is not well-known as it varies with tree age, species, phenological status, soil quality, and annual rainfall (*McPherson*, 1997; *Garrett* et al., 2004). It is necessary to consider to what degree each resource limits growth in a particular environment and how the species involved are suited to compete for or to facilitate the use of such resource.

Previous studies in semiarid areas of western Spain have determined that the quality and production of the grassland vary with temporal and spatial gradients (*Pérez-Corona* et al., 1994, 1998; *Vázquez-de-Aldana* et al., 2000), producing a complex environment, which is difficult to manage for optimal livestock production. From energetic and economic points of view, herbaceous quality determines the rational use of these silvopastoral ecosystems. Protein concentration and digestibility of grasslands have been emphasized as the main determinants of forage quality (*Pérez-Corona* et al., 1994). However, much less attention has been paid to mineral elements even though they also influence forage quality and can depress feed intake when levels are low (*Provenza*, 1995). The mineral composition of botanical constituents of the herbage community is of paramount significance as it is a reliable indicator of nutritional value. More information about the

* Correspondence: Dr. M. Madeira; e-mail: mavmadeira@isa.utl.pt

effect of trees on understory production and nutritional quality is necessary for improving and determining the sustainability and profitability of silvopastoral systems.

In Europe, the most extended agroforestry systems are the Iberian "montados" ("dehesas" in Spanish), with about 3 million hectares in Portugal and in southwestern Spain (*Eichhorn* et al., 2006). These man-made savannah-type ecosystems are characterized by a stratum of well-spaced oak trees (10–60 trees ha^{-1}) associated with an herbaceous understorey. In these systems, livestock grazing meets 60%–70% of cattle annual energetic needs (*Campos* et al., 2001). The aim of the present study is to assess the nature of interactions between trees and herbaceous plants in montados by studying how manipulation of incident solar radiation, water and nutrient supply affect the herbaceous biomass and herbaceous nutrient concentrations over 2 years with different rainfall amounts. The positive and negative effects of trees on understorey forage are discussed.

2 Material and methods

2.1 Study area

The study was conducted in an open oak woodland (montado) at the "Herdade da Mitra" experimental area (38°32′ N, 8°01′ W; 243 m above sea level) located near Évora, some 150 km southeast of Lisbon, Portugal. The climate is Mediterranean, with dry and hot summers contrasting with mild and rainy winters. Long-term (1951–1980) mean rainfall is around 665 mm per year, with considerable variation throughout the year (rain mainly falls from October to May), and mean annual air temperature is 15°C, ranging from 8.6°C to 23.1°C in January and August, respectively. Mean annual potential evapotranspiration estimated following the approach of *Thornthwaite* (1948) is 794 mm. Soils are mainly Haplic Leptosol (Dystric) derived from gneiss (*IUSS Working Group*, 2006), with a sandy-loam texture, low organic-matter content and P status, and acidic. The main chemical properties of soils are shown in Tab. 1.

About 0.2 ha of montado (10% slope) covered by natural annual grassland and scattered *Quercus ilex* trees was selected as the study area. Within the studied area, *Quercus ilex* subsp. *rotundifolia* had an average tree density of 35–45 trees ha^{-1} (61.6% tree-canopy cover). Average tree-canopy diameter was 14 m, and mean diameter at breast height was 0.59 m. The trees had not been pruned for the previous 6 years. The herbaceous understorey layers comprised annual grasses such as *Vulpia bromoides* (L.) S.F. Gray, *Bromus rigidum* Gaudin, *Hordeum murinum* L., and *Briza maxima* L., and forbs such as *Rumex bucephalophorus* L., *Silene gallica* L., *Geranium purpureum* Vill., *Tolpis barbata* (L.) Gaertner, *Tuberaria guttata* L. Fourr. Legumes included *Ornithopus compressus* L. and *Ornithopus pinnatus* (Miller) Druce.

2.2 Experimental layout

Herbaceous production and nutrient concentrations were measured around four trees, in twelve 1 m × 1 m plots established in each of the following three environments: (1) in the open grassland (25 m from the closest tree), (2) beneath the tree canopy (2 m from the trunk), and (3) in the open area under artificial shade. Tree canopy intercepted 70% of the full sunlight, and artificial shade consisted of a plastic mesh (16 threads cm^{-1}) that intercepted 70%–80% of the sunlight. Plots were protected from grazing by a 1 m high fence. At the end of the summer of 2001, all vegetation inside the enclosures was cut at ground level in order to simulate plant consumption by grazing herbivores outside the enclosure. In each environment, plots were subjected to fertilization and watering treatments, distributed in a factorial design, with an average distance of 50 cm between them.

Fertilization treatments consisted of (1) a surface application of 200 kg calcium ammonium nitrate ha^{-1} (CAN, 26% N) and 350 kg superphosphate ha^{-1} (8% P) at the beginning of the growing season (October) (F), as commonly used in the area to regenerate natural pastures (R. Freixial, personal communication), and (2) an unfertilized plot (nF). The watering treatments were (1) water applied fortnightly from February 1 to April 30, by applying at each date 10 L m^{-2} by hand and thus simulating an increase of 70 L m^{-2} of total precipitation from February to April (W) and (2) a nonwatered plot (nW). Herbaceous biomass was measured during two vegetative periods with different rainfall amounts. From September 2000 to April 2001 and from September 2001 to April 2002, total precipitation was 962 and 641 mm, respectively (Fig. 1). Sampling was done in early May, when plants were at the flowering-fruiting stage. Herbaceous plants were clipped inside quadrants of 0.25 m^2 situated at the center of each plot.

Table 1: The main characteristics of the soils at the experimental site. Asterisks indicate significant differences between the average values beneath tree canopies and in the open areas ($p < 5\%$).

Location	Bulk density / $g\,cm^{-3}$	Org C / $g\,kg^{-1}$	N	pH (H_2O)	Ca (Exch. base cations / $cmol_c\,kg^{-1}$)	Mg	K	P (Extract / $mg\,kg^{-1}$)	K
				0–10 cm					
Beneath tree	1.28*	12.1*	0.96*	5.16	2.19	0.94*	0.23*	7	68*
Open area	1.48	8.8	0.64	5.23	1.60	0.55	0.12	5	50
				10–20 cm					
Beneath tree	1.50	6.0	0.50	5.19	1.52	0.50	0.11	5	53*
Open area	1.51	5.4	0.46	5.28	1.64	0.49	0.10	4	37

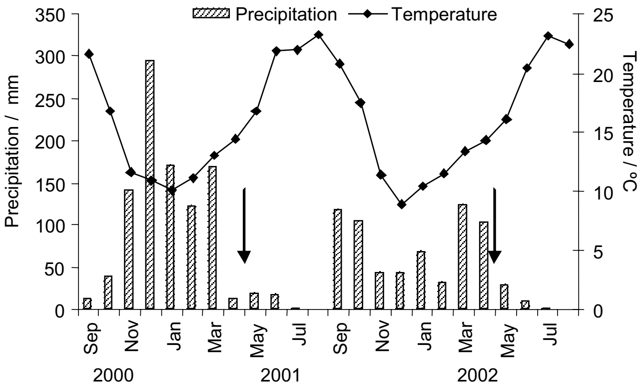

Figure 1: Monthly accumulated precipitation and monthly mean temperature at the experimental site during the study period. Arrows indicate dates during which herbaceous vegetation was clipped.

Three replicates per environment and per treatment were considered.

Plants were clipped at ground level and manually sorted into grasses and forbs. Legumes were excluded because their cover values inside the plots were below 8%. Dry matter (DM) was determined by drying samples at 60°C for 48 h in a forced-air oven. The dried plant material was ground with a ball mill prior to analyzing the concentrations of N, P, K, Ca, Mg, and Mn, in grasses and forbs separately. Nitrogen concentration was analyzed with the Kjeldahl method (Digestion System 40, Kjeltec Auto 1030 Analyzer), P was measured colorimetrically, and K, Ca, Mg, and Mn concentrations were determined using atomic-absorption spectrophotometry.

In November 2000, soil samples were taken around five trees at two distances from the trunk: beneath the tree canopy and in the open area (2 and 20 m from the tree trunk, respectively). For each tree and distance, four samples from the 0–10 and 10–20 cm soil layers were combined into one composite sample per soil layer. Samples were sieved (<2 mm), air-dried, and analyzed for organic C, total N, exchangeable Ca, Mg, and K, and extractable P and K. Two undisturbed samples selected at both distances per tree were used for the determination of soil bulk density. Organic C was determined after wet oxidation. Total N was analyzed using the Kjeldhal method (Digestion System 40, Kjeltec Auto 1030 Analyzer). Soil pH was determined potentiometrically in distilled water. Exchangeable Ca, Mg, and K were extracted with ammonium acetate at pH 7 (*Chapman*, 1965). Extractable P and K were determined using the Egnér-Riehm method (*Egnér* et al., 1960) and the molybdate-blue method.

2.3 Data analysis

Normality of data was checked with Kolmogorov-Smirnov tests. In order to analyze the effect of trees on herbaceous production and herbaceous nutrient concentrations, several 4-way ANOVAs were undertaken, using total herbaceous biomass, grasses biomass, and forbs biomass and herbaceous nutrient concentrations as dependent variables, and year (2001 and 2002), environment (open grassland, beneath canopy, and beneath artificial shade), fertilization treatment (F and nF) and watering treatment (W and nW) as factors. Since 3- and 4-way interactions were not significant, two levels of interaction were considered. Least significant differences (LSD) were used to determine differences between means when significant ANOVA results occurred. Relationships between grasses and forbs biomass and total herbaceous N, P, K, Ca, Mg, and Mn concentrations (weighted average) were analyzed by correlation analyses. For statistical analysis, the program STATGRAPHICS Plus v.4.1 was used.

3 Results

Soils beneath tree canopies showed, in the top 10 cm of the soil profile, higher values of organic C, total N, exchangeable Mg and K, and extractable K than soils in the open areas (Tab. 1). Other soil properties in the 0–10 cm and all properties in the 10–20 cm layer except extractable K were not affected by the tree canopy.

3.1 Herbaceous biomass

Total herbaceous biomass was significantly higher in 2001 than in 2002 ($p < 1\%$; Tab. 2), with mean values of 283 and 221 g DM m^{-2}, respectively. Differences in biomass between years were only detected for forbs ($p = 0.1\%$) and not for grasses (Figs. 2, 3). The interaction between environment and fertilization ($p < 0.1\%$; Tab. 2) showed that differences between nF and F were lower beneath tree canopy than in open grassland and under artificial shade. The fertilization treatment in the open area, beneath the tree canopy, and under artificial shade increased total biomass by 106%, 49%, and 97%, respectively. The fertilization treatment increased significantly the biomass of grasses and forbs ($p < 0.1\%$ and

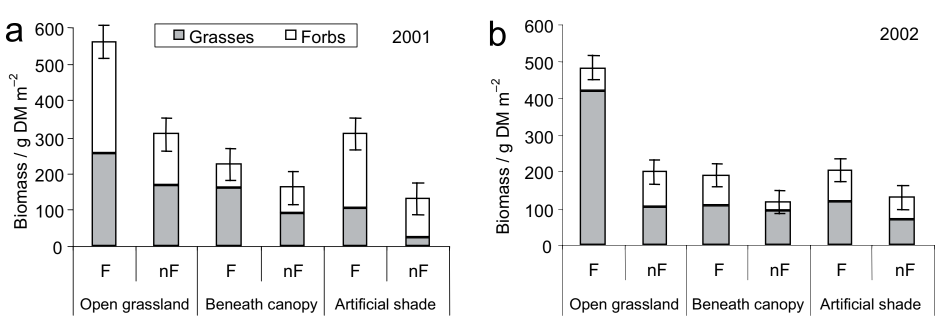

Figure 2: Biomass production of grasses and forbs measured during 2001 (a) and 2002 (b), under three environments (on the open grassland, beneath the tree canopy, and under artificial shade) and two fertilization treatments (F and nF). Vertical bars represent standard errors of total biomass.

Table 2: Significance levels of multifactorial ANOVAs analyzing the significance of the herbaceous production and herbaceous nutrient concentrations for 2 years (2001 and 2002), under three environments (on the open grassland, beneath the tree canopy, and under artificial shade), two fertilization treatments (F and nF) and two watering regimens (W and nW). Asterisks indicate levels of significance (***$p < 0.1\%$; **$p < 1\%$; *$p < 5\%$), and ns indicates not significant. 3- and 4-way interactions were not significant.

Factors	Biomass	N	P	K	Ca	Mg	Mn
Year	**	ns	**	ns	ns	ns	ns
Environment	***	***	ns	***	ns	**	***
Fertilization	***	ns	***	ns	ns	ns	ns
Watering	*	ns	ns	ns	ns	ns	ns
Year × environment	ns	ns	ns	ns	ns	ns	ns
Year × fertilization	ns	ns	**	ns	ns	ns	ns
Year × watering	*	ns	ns	ns	ns	ns	ns
Environment × fertilization	***	ns	ns	ns	ns	ns	ns
Environment × watering	ns	ns	ns	ns	ns	ns	ns
Fertilization × watering	ns	ns	ns	ns	ns	ns	ns

$p = 1\%$, respectively; Fig. 2). The interaction between environment and fertilization was also observed for the biomass values of grasses (Fig. 2). During both years, unfertilized plots showed higher herbaceous biomass in open areas than beneath the tree canopy or under the artificial shade (254, 139, and 131 g DM m^{-2}, respectively, $p < 0.1\%$). Fertilized plots also showed higher herbaceous biomass in open areas than beneath the tree canopy or under the artificial shade (523, 208, and 257 g DM m^{-2}, respectively, $p < 0.1\%$). In fertilized and unfertilized plots, no differences in biomass production were observed beneath the tree canopy and under artificial shade.

The effect of watering on total herbaceous biomass was also significant, irrespective of the environment (no interaction environment × watering; Fig. 3). Total herbaceous biomass showed significant differences between W and nW only during the humid year 2001 (interaction year × watering), with mean values of 329 and 238 g DM m^{-2}, respectively. In 2001, these differences were mainly due to the higher biomass values of forbs under W than under nW (186 and 114 g DM m^{-2}, respectively).

Considering only the untreated plots (unsheltered, unfertilized, and not irrigated), total biomass during both years was significantly higher on the open area than beneath the tree canopy (258 and 97 g DM m^{-2}, $p < 0.1\%$; respectively). This trend was observed for both grasses ($p = 1\%$) and forbs ($p = 2\%$). The plot submitted to artificial shade (unfertilized and not irrigated) showed similar total herbaceous-biomass values to the untreated plot beneath the tree canopy.

3.2 Herbaceous nutrient concentrations

Nutrient concentrations of herbaceous plants did not differ between 2001 and 2002 except for P (Tab. 2), which was 1.9 and 2.3 mg g^{-1}, respectively. Phosphorus concentrations of grasses and P concentrations of forbs were similar for the three environments studied (Tab. 3). The average N, K, Mg, and Mn concentrations of grasses were higher beneath the tree canopy than on the open area. Grasses under artificial shade showed similar N concentration to grasses under the tree canopy, and intermediate K and Mg values between those observed under the tree canopy and on the open area.

Fertilization treatments only affected the P concentration of herbaceous plants ($p < 0.1\%$, Tab. 2). Differences of herbaceous P concentrations between F and nF were higher in 2002 than in 2001, as indicated by the interaction between year and fertilization (Tab. 2). In 2001 and 2002, fertilization increased herbaceous P concentration by 24% and 83%, respectively. Watering treatments did not affect any of the nutrient concentrations analyzed (Tab. 2). Forbs showed higher N, P, K, Ca, and Mg concentrations than grasses ($p < 0.1\%$), but similar values of Mn (Tab. 3).

In untreated plots, higher herbaceous K and Mg concentrations were observed beneath the tree canopy than in the open grassland ($p = 0.36\%$ and $p = 4\%$ for K and Mg, respectively, Tab. 3). Phosphorus, Ca, and Mn concentrations were similar, however, in both untreated environments. The correlation analysis pointed to a decrease of N, K, Ca, and Mg concentrations in the plant community with increasing biomass of grasses (Tab. 4). Calcium concentration was positively correlated with forbs biomass.

4 Discussion

Herbaceous biomass significantly increased with fertilization and irrigation, indicating that herbaceous plants in montados

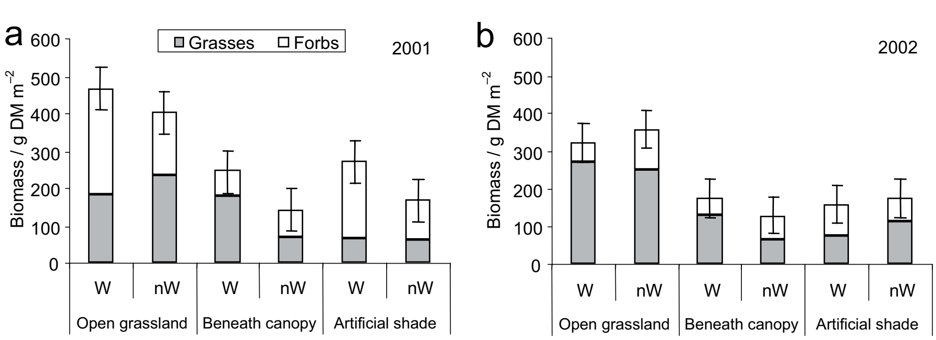

Figure 3: Biomass production of grasses and forbs measured during 2001 (a) and 2002 (b), under three environments (on the open grassland, beneath the tree canopy, and under artificial shade) and two watering regimens (W and nW). Vertical bars represent standard errors of total biomass.

Table 3: Nutrient concentrations (N, P, K, Ca, Mg, and Mn) of grasses and forbs measured during 2001 and 2002, in fertilized (F) and unfertilized (nF) plots under three environments (open grassland, beneath the tree canopy, and under artificial shade). For each year within columns, different letters indicate significant differences ($p < 5\%$).

			Nutrient concentration / mg g^{-1}											
			grasses						forbs					
Year	environment	Fert	N	P	K	Ca	Mg	Mn	N	P	K	Ca	Mg	Mn
2001	open grassland	F	6.7^{a}	1.5^{ab}	9.1^{a}	1.5^{a}	0.7^{a}	0.08^{a}	10.7^{a}	2.2^{ab}	14.0^{a}	8.8^{a}	2.3^{a}	0.10^{a}
		nF	7.3^{a}	1.1^{a}	9.3^{a}	1.3^{a}	0.7^{a}	0.11^{ab}	12.3^{ab}	1.9^{a}	16.9^{a}	9.3^{a}	2.3^{a}	0.13^{a}
	beneath canopy	F	10.4^{b}	2.2^{b}	20.3^{b}	2.2^{b}	1.1^{b}	0.16^{c}	11.8^{a}	2.9^{b}	27.4^{b}	7.1^{a}	2.8^{ab}	0.16^{a}
		nF	10.2^{b}	1.4^{ab}	16.3^{b}	2.0^{b}	1.1^{b}	0.13^{c}	13.1^{ab}	1.8^{a}	25.6^{b}	7.3^{a}	3.1^{b}	0.12^{a}
	artificial shade	F	10.4^{b}	1.8^{ab}	14.3^{ab}	2.0^{b}	0.9^{ab}	0.10^{ab}	15.9^{b}	1.9^{a}	18.1^{a}	8.1^{a}	2.5^{ab}	0.10^{a}
		nF	10.3^{b}	1.3^{a}	14.8^{ab}	2.1^{b}	0.9^{ab}	0.12^{ab}	13.0^{ab}	1.9^{a}	26.1^{b}	7.4^{a}	2.7^{ab}	0.12^{a}
2002	open grassland	F	8.1^{a}	2.4^{bc}	12.2^{a}	1.5^{abc}	0.6^{ab}	0.08^{a}	13.5^{a}	3.2^{abc}	19.8^{a}	8.1^{a}	2.3^{ab}	0.10^{a}
		nF	7.3^{a}	1.4^{a}	12.2^{a}	1.2^{a}	0.6^{a}	0.12^{ab}	12.3^{a}	2.2^{ab}	21.1^{a}	9.6^{a}	2.5^{ab}	0.15^{a}
	beneath canopy	F	10.5^{b}	3.0^{c}	24.3^{c}	1.8^{cd}	1.0^{c}	0.22^{c}	11.2^{a}	3.6^{bc}	31.4^{b}	8.4^{a}	2.7^{ab}	0.14^{a}
		nF	8.9^{b}	1.2^{a}	23.4^{cb}	1.2^{ab}	1.0^{c}	0.15^{bc}	12.5^{a}	2.0^{a}	30.9^{b}	8.5^{a}	3.1^{b}	0.12^{a}
	artificial shade	F	11.4^{b}	3.1^{c}	14.6^{ab}	2.0^{d}	0.8^{abc}	0.07^{a}	14.0^{a}	3.7^{c}	19.4^{a}	9.5^{a}	2.2^{a}	0.10^{a}
		nF	10.1^{b}	1.8^{ab}	18.4^{abc}	1.6^{bcd}	0.9^{bc}	0.12^{ab}	14.0^{a}	1.9^{a}	23.9^{ab}	7.3^{a}	2.5^{ab}	0.10^{a}

experience deficit of nutrients and soil water. The increase of biomass due to fertilization, albeit lower beneath tree canopy than in the open area and under artificial shade, could be explained by the higher values of organic C, N, exchangeable K, and extractable K observed in soils beneath canopy than in adjacent soils. A positive effect of trees on soil fertility has also been described for grazed "dehesas" (*Gallardo*, 2003; *Moreno* et al., 2007b), North American oak savannas (*Jackson* et al., 1990; *McPherson*, 1997), and other agroforestry systems (*Young*, 1997).

At the doses used here, the response of herbaceous biomass to fertilization was more pronounced than to watering. Even in drier "dehesas", *Moreno* (2008) reported that pasture production was more nutrient-limited than water-limited. The similar herbaceous biomass observed beneath the tree canopy and under the artificial shade indicate, however, that grasses and forbs were not strongly competing with trees for soil nutrients. Higher herbaceous biomass in the W plots than in the nW plots were only detected during the humid year 2001. It seems that the effect of watering treatment on herbaceous biomass was more influenced by the precipitation accumulated during April than by the total precipitation accumulated during the months prior to clipping. In 2001 and 2002, April precipitation was 13 and 103 mm, respectively (Fig. 1), and W treatments increased these values by 61% and 16%, respectively. This may explain why additional water applied during 2002 did not produce higher herbaceous biomass. Herbaceous plants in montados may depend on the available water accumulated in the first centimeters of the soil, a hypothesis sustained by the fact that shallow herbaceous root systems have been reported for "dehesas" of *Q. ilex* (*Joffre* et al., 1987; *Moreno* et al., 2005). Since watering had a similar effect in the three environments studied, it seems that trees and herbaceous plants must have explored different soil layers and do not strongly compete for soil water resources in montados, as stated in previous studies (*Moreno* et al., 2005; *Cubera* and *Moreno*, 2007).

The lower understory biomass registered under tree canopy and artificial shade compared to open areas could be attributed to light reduction. Limiting radiation was a main factor determining density and productivity of herbaceous species in the understorey of similar oak woodlands in California (*Parker* and *Muller*, 1982; *Marañón* and *Bartolome*, 1993). In our study, interception of 70%–80% of the incident radiation exceeded the value assumed to produce the maximum pasture biomass in Mediterranean systems, *i.e.*, around 50% (*Étienne*, 1996). In the Midwestern U.S., many cool-season forage species benefit from shading equivalent to 40%–60% of light interception (*Garrett* et al., 2004) and in Spain, a positive effect of 50% light interception on pasture yield was

Table 4: Correlation coefficients between biomass of grasses or forbs and N, P, K, Ca, Mg, or Mn concentrations of the plant community (grasses + forbs). Asterisks indicate levels of significance (***$p < 0.1\%$; **$p < 1\%$; *$p < 5\%$).

	Plant nutrient concentration					
Factors	N	P	K	Ca	Mg	Mn
Biomass of grasses	–0.61**	0.05	–0.62**	–0.53**	–0.71**	–0.20
Biomass of forbs	0.10	0.02	–0.34	0.51**	0.29	–0.27

recently confirmed (*Moreno*, 2008). Pruning our trees would reduce light interception and probably would avoid the negative effect of shade on herbaceous production.

Interannual differences in the nutrient concentrations of the plant community were small, suggesting that in semiarid montados, factors other than those related to interannual climatic variation are more important in determining the nutrient concentrations of the herbaceous plants. A similar conclusion has been previously drawn for "dehesas" in western Spain (*Vázquez-de-Aldana* et al., 1996; *García-Ciudad* et al., 1997). *Vázquez-de-Aldana* et al. (1996) showed that mineral concentration in plant tissues varies along the topographic slope through differences in soil nutrient status and the texture of the soil. Trees improved the herbaceous quality by increasing their K and Mg concentrations, and this effect may be related to the high exchangeable-K and -Mg values observed in the soil (0–10 cm depth) beneath the tree canopy. According to observations of *Escudero* et al. (1985) for "dehesas", greater K and Mg concentrations observed in the soil beneath the tree may be associated with additional inputs through litterfall (0.61 kg m^{-2} y^{-1}), throughfall (1.9 and 0.53 g m^{-2} y^{-1} for K and Mg, respectively), and stemflow (0.09 and 0.007 g m^{-2} y^{-1} for K and Mg, respectively). Variations of herbaceous nutrient concentrations depending on the distance from the trunk of *Q. ilex* have been recently reported (*Gea* et al., 2007; *Moreno* et al., 2007b). Herbaceous plants may depend significantly on the nutrients located in the uppermost soil layer, where most of their roots are located. However, in deciduous *Q. douglasii* savanna similar plant N accumulation was observed beneath and beyond the tree canopy despite the higher N availability of soils under the trees (*Jackson* et al., 1990), as was also found in our study. Caution must be taken when comparing and interpreting nutrient concentrations of herbaceous plants, especially if plant densities are excluded from the calculations. If the nutrient concentrations of plants were expressed per surface area, herbaceous K and Mg would show similar values in the open areas, beneath the tree canopy, and under artificial shade (3.6, 3.1, and 2.9 g K m^{-2} and 0.37, 0.24, and 0.27 g Mg m^{-2}, respectively). Therefore, to study the effect of tree × fertilization on pasture quality a similar range of plant densities under and beyond the tree canopy should be considered.

Since pasture production and nutrient deficiencies limit feed intake (*Christian*, 1987; *Provenza*, 1995), both biomass and nutrient concentrations of herbaceous plants should be included in guidelines for efficient pasture management. In our study, herbaceous production in the open untreated areas were around 2500 kg of DM ha^{-1} y^{-1}, far above the minimum required for cattle maintenance (500–600 kg of DM ha^{-1} y^{-1}; *Christian*, 1987), although during drier years lower herbaceous production would be obtained. Although minor N and P deficiencies were observed, nutrient concentrations of the whole herbaceous community were mostly within the range recommended for cattle nutrition (*ARC*, 1980). In any year or treatment, N and Ca concentrations of grasses (Tab. 3) did reach the level recommended for cattle nutrition (11.2 and 3 mg g^{-1}, respectively; *ARC*, 1980). However, N and Ca concentrations of forbs were above the established requirements. In the first year of study, grasses and forbs in all plots showed P concentrations below the recommended level (2.5 mg g^{-1}; *ARC*, 1980), while in the second year, P concentrations of fertilized plots were above this level. Similar effects of fertilization on P concentrations of Iberian pastures have been reported (*Moreira* and *Ribeiro*, 1990; *García-Ciudad* et al., 1997). In both study years, K and Mn concentrations in grasses and forbs were above the recommended level (6.0 and 0.04 mg g^{-1}; *ARC*, 1980). Grasses contained significantly lower nutrient concentrations than forbs, which coincides with the findings of a study carried out in Spanish "dehesas" (*García-Ciudad* et al., 1997).

5 Conclusions

Although grasses showed significantly lower nutrient concentrations than forbs, herbaceous plants in *Q. ilex* montados appear to be suitable for cattle feeding, especially if the soil is fertilized for two consecutive years. A negative effect of shade on herbaceous-biomass production was observed, suggesting that pruning would favor herbaceous production. Water supply increased total herbaceous biomass irrespective of the environment, suggesting that *Q. ilex* does not compete for soil-water resources with herbaceous plants in this ecosystem. Nutrient supply significantly increased total herbaceous biomass and herbaceous P concentrations, especially on the open grassland, supporting the traditional fertilization practices that farmers apply to the montados. Finally, higher K and Mg concentrations were observed in herbaceous plants beneath the tree canopy than in those in the open areas, suggesting a positive effect of trees on pasture quality.

Acknowledgments

We thank the staff of *Instituto de Ciências Agrárias Mediterrânicas (ICAM, Évora)* for their valuable collaboration in field work and *Departamento de Ciências do Ambiente and Centro de Pedología (Instituto Superior de Agronomia, Lisboa)* for analyzing the herbaceous nutrient concentrations and *Dougal Quin* for the English revision. Comments by Profs. *G. Moreno* and *A. Solla* greatly improved the manuscript. This study was supported by the project "Impacto da árvore e da pastagem melhorada na qualidade do solo e sustentabilidade dos montados: Quantidades e dinâmicas do C e do N" *(POCTI/AGG/48914/2002)*, and by the activities of the *Centre of Pedology (FCT, Plurianual Programme)*, through the subproject "Soil management and sustainability of forestry and agroforestry systems" (SUSTAINFOR). Elena Cubera was awarded a postdoctoral fellowship by *Consejería de Infraestructuras y Desarrollo Tecnológico (Junta de Extremadura)* and *Fondo Social Europeo*.

References

ARC (Agricultural Research Council) (1980): The Nutrient Requirements of Ruminant Livestock. CAB, Farnham Royal, UK.

Campos, P., Rodríguez, Y., Caparrós, A. (2001): Towards the dehesa total income accounting: theory and operative Monfragüe study cases. *Invest. Agrar.: Sist. Recur. For. Fuera de Serie* 1, 43–62.

Chapman, H. D. (1965): Cation-exchange capacity, in Black, C. A.: Methods of Soil Analysis – Chemical and Microbiological Properties. Agronomy 9, Am. Soc. Agron., Madison, WI, pp. 891–901.

Christian, K. R. (1987): Matching pasture production and animal requirements, in Wheeler, J. L., Pearson, C. J., Robards, G. E.: Temperate Pastures; Their Production, Use and Management. Australian Wool Corporation/CSIRO, Melbourne, pp. 463–476.

Cubera, E., Moreno, G. (2007): Effect of single *Quercus ilex* trees upon spatial and seasonal changes in soil water content in dehesas of central western Spain. *Ann. For. Sci.* 64, 355–364.

Egnér, H., Riehm, H., Domingo, W. R. (1960): Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II. Chemische Extraktionsmethoden zur Phosphor- und Kaliumbestimmung. *Kungl. Lantbr. Högsk. Ann.* 26, 199–215.

Eichhorn, M. P., Paris, P., Herzog, F., Incoll, L. D., Liagre, F., Mantzanas K., Mayus, M., Moreno, G., Pilbeam, D. J. (2006): Silvoarable agriculture in Europe – past, present and future. *Agrofor. Syst.* 67, 29–50.

Escudero, A., García, B., Gomez, J. M., Luis, E. (1985): The nutrient cycling in *Quercus rotundifolia* and *Quercus pyrenaica* ecosystems ("dehesas") of Spain. *Acta Oecol.- Oec. Plant.* 20, 73–86.

Étienne, M. (1996): Western European Silvopastoral Systems. Science Update series. INRA, Paris.

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

García-Ciudad, A., Ruano-Ramos, A., Vázquez-de-Aldana, B. R., García-Criado, B. (1997): Interannual variations of nutrients concentrations in botanical fractions from extensively managed grassland. *Anim. Feed Sci. Technol.* 66, 257–269.

Garrett, H. E., Kerley, M. S., Ladyman, K. P., Walter, W. D., Godsey, L. D., Van sambeek, J. W., Brauer, D. K. (2004): Hardwood silvopasture management in North America. *Agrofor. Syst.* 61, 21–33.

Gea, G., Cañellas, I., Peña, M. B., Montero, G. (2007): Influencia de la encina sobre la calidad bromatológica de comunidades herbáceas anuales en dehesas: Consecuencias sobre el manejo silvopastoral. Los Sistemas Forrajeros: entre la Producción y el Paisaje. Reunión científica XLVI, SEEP, Vitoria 4–8 Junio.

González-Hernández, M. P., Silva-Pando, F. J., Casal Jiménez, M. (1998): Production patterns of understory layers in several Galician (NW Spain) woodlands. Seasonality, net productivity and renewal rates. *For. Ecol. Manage.* 109, 251–259.

Holland, V. L. (1980): Effect of blue oak on rangeland forage production in central California, in Plumb, T. R. (tech. coord.): Ecology, Management and Utilization of California Oaks. USDA Gen. Tech. Report PSW-44, pp. 314–318.

IUSS Working Group (2006): World Reference Base for Soil Resources 2006 – A framework for international classification, correlation and communications. World Soil Resources, Reports 103, FAO, Rome.

Jackson, L. E., Strauss, R. B., Firestone, M. K., Bartolome, J. W. (1990): Influence of tree canopies on grassland productivity and nitrogen dynamics in deciduous oak savanna. *Agric. Ecosyst. Environ.* 32, 89–105.

Joffre, R., Rambal, S. (1988): Soil water improvement by trees in the rangelands of southern Spain. *Oecol. Plant.* 9, 405–422.

Joffre, R., Leiva Morales, M. J., Rambal, S., Fernandez Ales, R. (1987): Dynamique racinaire et extraction de l'eau du sol par des graminées pérennes et annuelles méditerranéennes. *Acta Oecol.- Oec. Plant.* 8, 181–194.

Marañón, T., Bartolome, J. W. (1993): Reciprocal transplants of herbaceous communities between *Quercus agrifolia* woodland and adjacent grassland. *J. Ecol.* 81, 673–682.

Marañón, T., Bartolome, J. W. (1994): Coast live oak (*Quercus agrifolia*) effects on grassland biomass and diversity. *Madroño* 41, 39–52.

Mcpherson, G. R. (1997): Ecology and Management of North American Savannas. University of Arizona Press, Tucson, p. 208.

Moreno, G. (2008): Response of understorey forage to multiple tree effects in Iberian dehesas. *Agric. Ecosyst. Environ.* 123, 239–244.

Moreno, G., Obrador, J. J., Cubera, E., Dupraz, C. (2005): Fine root distribution in Dehesas of central-western Spain. *Plant Soil* 277, 153–162.

Moreno, G., Obrador, J. J., García, E., Cubera, E., Montero, M. J., Pulido, F. J., Dupraz, C. (2007a): Driving competitive and facilitative interactions in oak dehesas with management practices. *Agrofor. Syst.* 70, 25–40.

Moreno, G., Obrador, J., García, A. (2007b): Impact of evergreen oaks on soil fertility and crop production in intercropped dehesas. *Agric. Ecosyst. Environ.* 119, 270–280.

Moreira, O. M. S. C., Ribeiro, J. M. C. R. (1990): Mineral composition of some Portuguese pastures and its value for grazing ruminants. *World Rev. Anim. Prod.* 25, 69–72.

Parker, V. T., Muller, C. H. (1982): Vegetational and environment changes beneath isolated live oak trees (*Quercus agrifolia*) in a California annual grassland. *Am. Midl. Nat.* 107, 69–81.

Pérez-Corona, M. E., García-Criado, B., Vázquez-de-Aldana, B. R., García-Ciudad, A. (1994): Effect of topographic and temporal (maturity) gradients on the nutritive quality of semiarid herbaceous communities. *Commu. Soil Sci. Plant Anal.* 25, 2047–2061.

Pérez-Corona, M. E., Vázquez-de-Aldana B. R., García-Criado, B., García-Ciudad, A. (1998): Variations in nutritional quality and biomass production of semiarid grasslands. *J. Range Managem.* 51, 570–576.

Provenza, F. D. (1995): Postingestive feedback as an elementary determinant of food preference and intake in ruminants. *J. Range Manage.* 48, 2–17.

Scholes, R. J., Archer, S. R. (1997): Tree-grass interactions in savannas. *Annu. Rev. Ecol. Syst.* 28, 517–544.

Thornthwaite, C. W. (1948): An approach towards a rational classification of climate. *Geogr. Rev.* 38, 55

Vázquez-de-Aldana, B. R., Pérez-Corona, M. E., García-Ciudad, A., García-Criado, B. (1996): Mineral content in semiarid grassland systems as affected by community structure and soil characteristics. *Acta Oecol.* 17, 245–259.

Vázquez-de-Aldana, B. R., García-Ciudad, A., Pérez-Corona, M. E., García-Criado, B. (2000): Nutritional quality of semi-arid grassland in western Spain over 10-year period: changes in chemical composition of grasses, legumes and forbs. *Grass Forage Sci.* 55, 209–220.

Young, A. (1997): Agroforestry for Soil Management. CAB International, Wallingford, p. 320.

