

Growth characteristics and nutrient content of some herbaceous species under shade and fertilization

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Abstract

Herbage production and nutrient content are affected by light interception and soil fertility. The objective of this study was to assess the effects of artificial shade and fertilization on herbage production, growth characteristics, and nutrient content of the grass species *Dactylis glomerata* and *Festuca ovina*, and the legume species *Trifolium subterraneum* and *Medicago lupulina*. Each plant species was placed under three shading treatments of 90% (heavy shade), 50% (moderate shade) and 0% (control). Fertilization (225 kg ha⁻¹ N, 450 kg ha⁻¹ P, and 225 kg ha⁻¹ K) was applied to half of the pots of every species and shading treatment. Reduced light intensity (90% shading) significantly lowered herbage production from 18% for *F. ovina* to 48% for *D. glomerata* and decreased the root:shoot (R/S) ratio of all species but the moderate reduction of light intensity (50%) did not affect R/S ratio and herbage production of the grasses and *M. lupulina*, while it resulted in an increase of the production of *T. subterraneum* by 10.5%. Reduced light intensity increased by 25% on average, the crude protein concentration of the grass species while moderate shading did not affect the crude protein concentration of *T. subterraneum*. Fertilization increased herbage production from 16% for *F. ovina* to 59% for *D. glomerata* and ameliorated its nutrient content. Among the tested species, *D. glomerata* and *T. subterraneum* demonstrated the highest shade tolerance and could be incorporated into silvopastoral systems of the Mediterranean region.

Additional keywords: agroforestry, grasses, herbage production, legumes, root/shoot ratio.

Resumen

Efecto del sombreado y la fertilización sobre las características del crecimiento y contenido en nutrientes de algunas especies herbáceas

La intensidad de luz y la fertilización del suelo pueden afectar a la producción de biomasa y al contenido en nutrientes de los vegetales. El objetivo de este trabajo fue establecer los efectos del sombreado artificial y de la fertilización sobre la producción, las características de crecimiento y el contenido en nutrientes de las gramíneas *Dactylis glomerata* y *Festuca ovina*, y de las leguminosas *Trifolium subterraneum* y *Medicago lupulina*. Cada una de las especies vegetales se sometió a los siguientes tratamientos: 90% (sombreado intenso), 50% (sombreado moderado) y 0% (control). Se aplicó fertilización (225 kg ha⁻¹ N, 450 kg ha⁻¹ P y 225 kg ha⁻¹ K) a la mitad de las macetas de cada especie y tipo de sombreado. La reducción en la intensidad de luz (90%) disminuyó significativamente la producción (del 18% de *F. ovina* al 48% de *D. glomerata*) y la relación raíz:tallo (R/S) de todas las especies. Sin embargo, la reducción moderada de la intensidad de luz (50%) no afectó a la relación R/S ni a la producción de *M. lupulina*, promoviendo un incremento del 10,5% de la producción de *T. subterraneum*. La reducción en la intensidad de luz incrementó en un 25% de media la concentración de proteína cruda de las especies de gramíneas, mientras que el sombreado moderado no afectó a la concentración de proteína cruda de *T. subterraneum*. La fertilización aumentó la producción (del 16% de *F. ovina* al 59% de *D. glomerata*) y mejoró el contenido en nutrientes. Entre las especies estudiadas, *D. glomerata* y *T. subterraneum* demostraron alta tolerancia al sombreado y podrían ser incorporadas a sistemas silvopastorales de la región mediterránea.

Palabras clave adicionales: agroforestal, gramíneas, producción herbácea, leguminosas, relación raíz/tallo.

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Introduction

Silvopastoral systems include the competition between woody plants, herbaceous vegetation and grazing animals (Nair, 1989). Woody plants affect in various ways the understory herbaceous vegetation and have an essential role in minimizing erosion by reducing run off and thus improving water conservation (Young, 1989), modifying the microclimate by moderating extremes in daily photosynthetically active radiation (PAR) and soil temperatures (Feldhake, 2001), and by reducing evapotranspiration (Belesky, 2005). Consequently, they can affect the quantity and quality of forage produced (Devkota and Kemp, 1999). These functions are very important especially for semiarid areas of the Mediterranean region.

Competition for light in silvopastoral systems is a critical factor controlling herbage growth (Sibbald *et al.*, 1991; Braziotis and Papanastasis, 1995) along with soil water and nutrients (Rao *et al.* 1997; Nissen *et al.*, 1999). Herbage production decreases as light intensity decreases (Knowles, 1991; Devkota and Kemp, 1999). In contrast, Anderson and Moore (1987) and Kyriazopoulos *et al.* (1999) found greater production of understory vegetation under reduced light intensity. Most research however has been on the effect of natural shade on herbaceous vegetation and only a few studies have examined the effects of artificial shade. Koukoura and Nastis (1989) found a higher herbage production under moderate shade (50%) compared to herbage production of the control or heavier shade (70%, 90%). Kyriazopoulos (2001) has reported similar findings. Low light intensity has also been shown to reduce the root:shoot (R/S) ratio (Urbas and Zobel, 2000). Furthermore, shading reduces tillering and specific leaf weight which in turn affects forage quality (Devkota and Kemp, 1999) since it increases the crude protein (CP) content (Koukoura, 1988; Kyriazopoulos *et al.*, 1999; Burner and MacKown, 2006) and decreases the total non structural carbohydrate content (TNC) (Ciavarella *et al.*, 2000; Mayland *et al.*, 2000), thus reducing the energy for the animals. However, this reduced TNC under shading may increase forage digestibility of the forages (Garrett and Kurtz, 1983).

To implement successful silvopastoral systems it will be necessary to quantify the physiological and morphological characteristics of a wide range of forage plants in the microclimate to which they will be subjected. Obviously, the proper choice of the understory forage will have a significant impact to the success of the sil-

vopastoral system. Devkota and Kemp (1999) reviewed economic and ecological features of silvopasture in temperate regions and found that successful and productive systems depended on shade tolerant forages.

Fertilization of the understory herbaceous vegetation may increase herbage yield (Papanastasis *et al.*, 1995; Rigueiro-Rodríguez *et al.*, 2000). To the contrary, Eriksen and Whitney (1981) have found a decrease in dry matter (DM) production under shade and fertilization for six forage grasses. However, herbaceous species respond differently to various fertilization rates (Hart *et al.*, 1970).

In agroforestry research, artificial shading is an important tool to simulate tree shade on understory vegetation. Artificial shade structures provide a practical way to examine morphological and physiological changes in plants and to screen for shade tolerant species for agroforestry species (Varella, 2002). Artificial shading was used in order to isolate a potential shading effect and to remove the interspecific below-ground competition. Studies with controlled gradients of each factor, light, water and nutrients would help to clarify the relative importance of each factor as limiting factors of pasture yield in silvopastoral systems (Moreno, 2008). The artificial shade structure used in this experiment closely replicated the radiation environment of an agroforestry system.

The objective of this paper was to study the effects of artificial shade and fertilizer nutrient inputs on growth characteristics, forage production and nutrient content of some grass and legume species.

Material and methods

The experiment was conducted at the Aristotle University of Thessaloniki farm (40° 34' E, 23° 43' N, at sea level) in Northern Greece. The climate is characterized as semiarid, with mean annual precipitation of 415 mm and mean annual temperature of 15.5° C.

The perennial grass species *Dactylis glomerata* L. and *Festuca ovina* L., and the annual legume species *Trifolium subterraneum* L. and the biannual legume species *Medicago lupulina* L. were seeded in 26 x 26 cm pots in early autumn 2001. The total planting density was eight plants per pot, in order to mimic field conditions.

Each species was planted in pots filled with soil of a *Pinus brutia* forest understory from Chrisopigi, Serres. Soil texture is described as sandy loam. Different shad-

ing levels were provided by shade cloths placed over a greenhouse frame. Average light intensity was $600 \mu\text{E m}^{-2} \text{s}^{-1}$ (50% of the total radiation) and $120 \mu\text{E m}^{-2} \text{s}^{-1}$ (10% of the total radiation), while light intensity in an adjacent open area was $1200 \mu\text{E m}^{-2} \text{s}^{-1}$ (100% of the total radiation). Light intensity was measured by using a LiCor quantum sensor (Li 190 SB). There were two artificial shade treatments with 90% (heavy shade), and 50% (moderate shade) reduction of the total radiation and a control (0%). Ten pots of each species were placed in each shade treatment and the control. All the pots were randomized within each shading treatment biweekly. Half of these pots were fertilized with the equivalent of 225 kg ha^{-1} of N, 450 kg ha^{-1} of P and 225 kg ha^{-1} of K after sowing. Additionally 395 kg ha^{-1} of NH_4NO_3 were top-dressed in April.

At the end of growing season (June 2002) growth characteristics (root length, shoot length) of the plants were measured and the R/S ratio was calculated. Above ground total herbage biomass of each pot was cut at ground level and sampled. At the same time the roots biomass of each plant per plot was separated from the soil by careful rinsing. After oven-drying at 60°C for 48 h samples were weighed and the dry weight of herbage produced and of roots was calculated. The dried herbage samples were ground to fit through a 1 mm screen and analyzed for N using a Kjeldahl procedure (AOAC, 1990), and for K and P concentrations using standard methods (Papamichos and Alifragis, 1985). CP was then calculated by multiplying the N content by 6.25. Nitrogen utilization efficiency (NUE) was estimated as plant DM production/concentration of N in the plant (Siddiqi and Glass, 1981) where concentration of N (g g^{-1}) is expressed as dry weight.

The experimental design consisted of two factors (three shading treatments and two fertilization levels) in a completely randomized-block design with five replications. Species were analysed separately. General linear models procedure (SPSS 14 for Windows) was used for ANOVA. The LSD test (Steel and Torrie, 1980) at the 0.05 probability level was used to detect the differences among means within each species.

Results

Significant differences were detected among the shading treatments and the fertilization levels for DM production, R/S ratio, nutrients and NUE for all the tested species. Additionally, significant interaction between

shading treatments and fertilization levels was not observed for DM production R/S ratio, nutrients and NUE, indicating that the effect of the shading treatments was consistent regardless of nutrient inputs. Therefore, data for these parameters are summarized over shading and fertilization treatments.

DM production of all species in the 90% shading treatment decreased drastically (Table 1) compared with the other two treatments. On the other hand, there was no significant difference between herbage production of the control and the 50% shading treatment for *D. glomerata*, *F. ovina* and *M. lupulina*. Vegetative production under the 50% shading treatment was similar to that of the control. However *T. subterraneum* had 10.5% greater production under the 50% shading treatment ($P < 0.05$) compared to the control. Fertilization increased significantly ($P < 0.05$) the DM production of all tested species compared to the control (Table 2).

R/S ratio decreased significantly under the 90% shading treatment for all species (Table 3). However, no statistical differences were detected between the control and the 50% shading treatment. Fertilization decreased significantly the R/S ratio of *D. glomerata* (Figure 1) by 69% compared to control. In contrast, R:S ratio of *F. ovina* and the legume species were not affected by fertilization.

CP content of the grass species increased as light intensity decreased (Table 4). On the contrary, CP content of the legume species *M. lupulina* was higher under the control. CP content of *T. subterraneum* reduced significantly only under the heavy shading treatment (90%), while the control did not differ compared to the 50% shading treatment. K content of all the species increased as light intensity decreased. P content of *T. subterraneum* also increased as light intensity decreased. However, P content of *D. glomerata*, *F. ovina* and *M. lupulina* increased only under the heavy shading treatment (90%). Fertilization, moreover, resulted in an

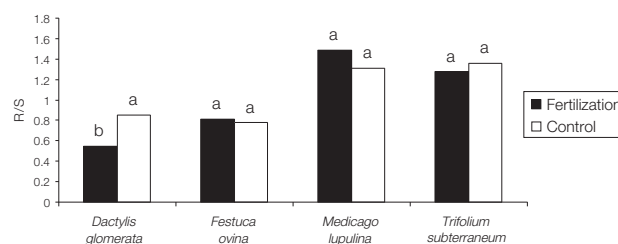


Figure 1. Root/Shoot (R/S) ratio at the fertilization treatments. Means within each species followed by the same letter are not significantly different at the 0.05 significance level.

Table 1. Herbage production (g m⁻²) at the three shading treatments

Species	0%	50%	90%
<i>Dactylis glomerata</i>	444.7 a	435.3 a	229.9 b
<i>Festuca ovina</i>	278.9 a	269.5 a	229.9 b
<i>Medicago lupulina</i>	335.4 a	326.0 a	180.9 b
<i>Trifolium subterraneum</i>	326.0 b	359.9 a	231.8 c

Means within each species followed by the same letter are not significantly different at the 0.05 significance level.

increase of CP and of P content of all species (Table 5). K content of *F. ovina* and of *M. lupulina* increased significantly with fertilization, although K content of *D. glomerata* and of *T. subterraneum* was not significantly affected.

Concerning the NUE value no statistical differences were detected between the control and the moderate shading treatment (50%) of any species (Table 6). By contrast, heavy shading led to a significant decrease of NUE only for the grass species. Fertilization decreased significantly NUE of the grasses compared to the control, while it had no effect on the legumes (Table 7).

Discussion

Heavy shading (90%) reduced significantly herbage production of all the species. According to research undertaken by Boardman (1977) and Koukoura (1987), plants growing under shade, in their effort to cope with the reduced intensity of solar radiation, exhibit lower overall photosynthetic efficiency because respiration rates exceed carbohydrate production. Nevertheless, moderate shading (50%) had no negative effects on vegetative production of *D. glomerata*, *F. ovina* and *M. lupulina*. This can be explained by the increased soil moisture under this treatment due to the modification of microclimate (Rao *et al.*, 1997). It is known that under

Table 2. Herbage production (g m⁻²) at the two fertilization treatments

Species	Fertilization	Control
<i>Dactylis glomerata</i>	520.1 a	212.9 b
<i>Festuca ovina</i>	354.3 a	297.7 b
<i>Medicago lupulina</i>	354.3 a	233.7 b
<i>Trifolium subterraneum</i>	307.2 a	254.4 b

Means within each species followed by the same letter are not significantly different at the 0.05 significance level.

Table 3. Root/Shoot (R/S) ratio at the three shading treatments

Species	0%	50%	90%
<i>Dactylis glomerata</i>	0.78a	0.71a	0.19b
<i>Festuca ovina</i>	0.71a	0.76a	0.35b
<i>Medicago lupulina</i>	2.1a	2.3a	0.64 b
<i>Trifolium subterraneum</i>	1.18a	1.2a	0.72b

Means within each species followed by the same letter are not significantly different at the 0.05 significance level.

Mediterranean conditions shading provided by tree canopy is considered as a determinant climatic factor (Ovalle and Avendano, 1987) decreasing the dry conditions. Additionally, soil moisture is the critical factor for plant growth and herbage production in the Mediterranean region (Etienne, 1996). *T. subterraneum* had greater herbage production under the 50% shading treatment in comparison to the control. Koukoura and Kyriazopoulos (2007) have reported that this species is well-adapted to partially shaded habitats, which is consistent with this finding.

Devkota and Kemp (1999) reported that responses to fertilizer by plant species under shade are commonly different from under full sun. The results of the present study do not support the previous evidence. In this research, fertilization increased the herbage production of all species in all shading treatments and under full sun. Similar results have been obtained by Steele and Percival (1984). Braziotis and Papanastasis (1995) concluded that fertilizer application increased understorey herbage production in various plant densities in a *Pinus pinaster* plantation.

Lower R/S ratio under reduced light intensity (90% shading treatment) was the result of elongated shoots of all species, but especially for the shade tolerant grasses *D. glomerata* and *F. ovina*. Several studies have shown that plants respond to lowered light intensity by producing elongated shoots (Koukoura, 1987; Urbas and Zobel, 2000), while root length decreased with shade. However, moderate shading (50%) did not affect the R/S ratio of all the tested species. This indicates that growth characteristics of all the species were not affected under this shading level. Only R/S ratio of *D. glomerata* was significantly reduced by fertilization. This was due to a nutrient deficient environments leading to a higher R/S ratio because of the increased biomass allocation to roots (Nielsen *et al.*, 2001). The R/S ratio of *F. ovina* was not affected by fertilization probably because of finer roots which have less ability to penetrate soils with high bulk density (Bennie, 1991). More-

Table 4. Nutrient contents (CP, %; K, %; and P, mg g⁻¹) at the three shading treatments

	0%			50%			90%		
	CP	K	P	CP	K	P	CP	K	P
<i>Dactylis glomerata</i>	14.7 b	1.8 b	2596 b	15.0 b	2.4 a	2766 b	17.9 a	2.9 a	3319 a
<i>Festuca ovina</i>	14.2 c	1.0 b	2592 b	16.6 b	1.7 a	2803 b	20.4 a	1.9 a	3326 a
<i>Medicago lupulina</i>	23.5 a	1.2 b	2284 b	20.2 b	1.8 a	2432 b	20.5 b	1.5 ab	3155 a
<i>Trifolium subterraneum</i>	22.4 a	1.7 b	2221 c	21.3 a	1.6 b	2555 b	19.2 b	2.0 a	3268 a

Means within each species for the same component followed by the same letter are not significantly different at the 0.05 significance level.

over, fertilization did not affect root growth rate which was significantly lower for the slow growing *F. ovina* (0.03 cm d⁻¹) compared to this of the fast growing *D. glomerata* (0.14 cm d⁻¹) (unpublished data). It is known that *F. ovina* is a species typical of nitrogen-poor habitats. Hansson and Goransson (1993) reported that *F. ovina* allocated more biomass to fine roots when grown at nitrogen limitation compared to a nitrogen free access environment. Concerning the legumes, fertilization had no impact on their R/S ratio, as P distribution is greater in the surface soil horizons (Chu and Chang, 1966), and tap-rooted plants such as legumes are not affected by fertilizer application.

Reduced light intensity increased CP content of the grass species (Buegler *et al.*, 2006; Parissi and Koukoura, 2009). This increase could be associated with the stage of maturity. According to Kilcher (1981), CP content of herbaceous plants decreases as they reach maturity. Under reduced light intensity plants reach maturity slower than under normal light intensity (Blair *et al.*, 1983; Koukoura and Nastis, 1989). In addition, Peri *et al.* (2004) remarked that shade increased soil N content by conserving soil moisture which increased N mineralization. In contrast, CP content of the legume species decreased as light intensity decreased. This is probably connected to the lower structural protein content of the plants that grew under reduced light intensity compared to those that grew under full light. It could also be relat-

ed to the fact that nodulation in shaded legumes was adversely affected and nodule numbers declined with increasing shade intensity (Wong, 1991; Congdon and Addison, 2003). Sugawara *et al.* (1997) reported that nitrogen fixation by *Trifolium repens* was considerably decreased under shade. However, Buxton and Mertens (1995) stated that the response of CP concentration of legumes to shading is generally less than that of grasses, and shading typically has less effect on forage quality than on morphology. Shading of legumes may have reduced the ratio of leaf:stem as it can induce elongation of stems (Buxton and Mertens, 1995). An increase in proportion of stem could decrease CP concentrations of the legume species. K and P content of all the species increased as light intensity decreased. This increase could be associated with stage of plant maturity (Papanastasis *et al.*, 1995). Fertilization increased CP and P content of all species as it has also been reported by Papanastasis *et al.* (1995), as well as K content of *F. ovina* and of *M. lupulina*. Similar results for CP and P have been found by Mosquera -Losada *et al.* (2001) for *D. glomerata* and *Trifolium repens* in a silvopastoral system with *Pinus radiata* under different fertilizer application. In addition Soder and Stout (2003) have been reported an increased of CP and K content of *D. glomerata* under various fertilization levels in different type of soils.

It is noteworthy that NUE was higher for the grass species compared to the legumes at the 0% and the 50%

Table 5. Nutrient contents (CP, %; K, %; and P, mg g⁻¹) at the two fertilization treatments

Species	Fertilization			Control		
	CP	K	P	CP	K	P
<i>Dactylis glomerata</i>	18.5 a	2.4 a	3404 a	13.1 b	2.5 a	2596 b
<i>Festuca ovina</i>	18.8 a	1.7 a	3504 a	15.8 b	1.4 b	2594 b
<i>Medicago lupulina</i>	22.8 a	1.9 a	3869 a	19.3 b	1.5 b	2279 b
<i>Trifolium subterraneum</i>	22.7 a	1.8 a	3924 a	19.8 b	1.7 a	2235 b

Means within each species, for same component, followed by the same letter are not significantly different at the 0.05 significance level.

Table 6. Nitrogen-utilization efficiency (NUE) (g g⁻¹) at the three shading treatments

Species	0%	50%	90%
<i>Dactylis glomerata</i>	42.5 a	41.7 a	34.9 b
<i>Festuca ovina</i>	44.0 a	37.7 a	30.6 b
<i>Medicago lupulina</i>	26.6 a	30.9 a	30.5 a
<i>Trifolium subterraneum</i>	27.9 a	29.3 a	32.6 a

Means within each species followed by the same letter are not significantly different at the 0.05 significance level.

shading treatments. Grasses seem to have higher NUE due to their root systems. Differences in the depth of the roots system have an affect on the plants ability to retain N from different soil layers (Burns, 1980) and are, therefore, important for NUE. Moreover, the placement of fertilizer N below the surface soil layer can decrease immobilization and increase plant uptake of N (Sharpe *et al.*, 1988) for the shallow-rooted species as grasses (Thorup-Kristensen and Nielsen, 1998). The reduction in the NUE due to fertilization was not unexpected, as similar results having been found by other researchers (Gauer *et al.*, 1992; Delogu *et al.*, 1998) who reported that NUE decreases with increasing nitrogen availability. According to Hiremath *et al.* (2002), NUE is inversely proportional to soil nutrient availability. This parameter helps to explain why the plants at nitrogen poor-sites are adapted to these environments by either genetic or phenotypic agents that increase the NUE (Shaver and Melillo, 1984).

As conclusions, the success of silvopastoral systems depends on the selection and management of appropriate shade tolerant herbage species for optimal productivity and sustainability (Devkota and Kemp, 1999). Among the tested species of this study, the highly productive perennial grass *D. glomerata* and the annual legume *T. subterraneum* demonstrated the highest shade tolerance and could be incorporated into

Table 7. Nitrogen-utilization efficiency (NUE) (g g⁻¹) at the fertilization treatments

Species	Fertilization	Control
<i>Dactylis glomerata</i>	33.8 b	47.7 a
<i>Festuca ovina</i>	33.3 b	39.7 a
<i>Medicago lupulina</i>	27.4 a	32.4 a
<i>Trifolium subterraneum</i>	27.5 a	31.6 a

Means within each species followed by the same letter are not significantly different at the 0.05 significance level.

silvopastoral systems with moderate shade in semiarid areas of the Mediterranean region. However, there is a need for a carefully analysis when the results of studies under artificial shade are extrapolated to an agroforestry environment (Varella, 2002) because tree - pasture interactions are a complex phenomenon to understand. Further studies with controlled gradients of each factor, light, water and nutrients would help to clarify the relative importance of each factor as limiting factors of pasture yield in silvopastoral systems (Moreno, 2008).

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