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Pasture production in a silvopastoral system in relation with microclimate variables in the atlantic coast of Spain

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Abstract

Grasses and legumes of high productivity and nutritional quality are a good alternative as pasture supplements in rangelands of low quality forage. Orchardgrass (*Dactylis glomerata* L. cv. 'Artabro') and white clover (*Trifolium repens* L. cv. 'Huia') are known as shade tolerant and low flammability species that have been successfully used in agroforestry systems in Galicia, both diminishing fire hazard compared with natural shrublands. In this study, annual and seasonal production of a grass mixture of both species was quantified during 3 years in a pinewood under different tree canopy covers. Regardless of cover, pasture production increased in summer, and decreased from fall to spring. We obtained a significant correlation between annual pasture production and light transmission through the tree canopy ($R^2 = 0.96$, $P<0.05$). Light transmittance through a maritime pine canopy (*Pinus pinaster* Ait.) was higher than through a Scots pine canopy (*P. sylvestris* L.), corresponding to 36–57% and 16–21% of full sunlight respectively. The highest herbage production was obtained in no tree stands and the lowest under a *P. sylvestris* canopy. Fluctuations in light transmission, temperature and PAR (Photosynthetically Active Radiation) under tree canopy were less apparent compared with no tree stands. Variation in seasonal production was more pronounced in stands without trees, and appeared more uniform when percentage of light intercepted by tree canopy increased.

Introduction

The adoption and application of agroforestry practices varies by region and is often driven by local tradition, economic factors, and land ownership patterns. A key feature in developing agroforestry systems appears to be a desire for sustainable agriculture or land-use systems that allow increasing food, forage, and fiber production without causing environmental degradation (Lassoie and Buck 1991).

In Galicia, where the biomass of combustible plant material is abundant, the use of spontaneous vegetation by livestock can be a useful tool to reduce fires (Silva-Pando et al. 1993). However, most of the plants included in these vegetation communities have limited nutritional quality and are unlikely meet nitrogen and energy requirements for livestock (González-Hernández and Silva-Pando 1999). For this reason, grasses and legumes of high productivity and nutritional quality have been used as a pasture supplement in this type of land use. Orchardgrass (*Dactylis glomerata* L.) and white clover (*Trifolium repens* L.) are known as shade tolerant species that have been successfully used in agroforestry systems in Galicia (Rigueiro 1985; Piñeiro and Pérez 1988), both species posing lower fire hazard than natural shrublands. Other studies that deal with sown pastures of high productivity and nutritional quality have reported the response of several populations of *Dactylis glomerata* to different tree cover in Galicia (García et al. 1999).

Light transmitted by tree canopies is influenced by tree species, age and canopy architecture (Sibbald and Sinclair 1990; Armand and Etienne 1996), and rela-

Table 1. Stand characteristics measured during the first and last years of a five-years study of a silvopastoral system in Galicia, Spain.

Plot	Species	Treatment	Density trees/ha	DBH (1992) cm	DBH (1996) cm	Height (1996) m
PS	*Pinus sylvestris*	S, F	700	23.74 ± 0.72	25.64 ± 0.71	12.67 ± 0.18
PP	*Pinus pinaster*	S, F	833	25.34 ± 1.14	26.80 ± 1.21	12.90 ± 0.35
PPGA	*Pinus pinaster*	S, F	833	23.47 ± 0.78	25.46 ± 0.88	11.08 ± 0.20
WT	Without trees	S, F	0	0	0	0
C	Without trees	–	0	0	0	0

PS: *Pinus sylvestris*, PP: *P. pinaster*, PPGA: *P. pinaster* (gap adjacent plot), WT: without trees, C: control. S = sown, F = fertilized. Height and DBH values are mean ± standard error.

tionships between understorey pasture production and tree canopy have been reported (Ovalle and Avendaño 1988; González-Hernández et al. 1998). Understory biomass can be a linear function of intercepted radiation (Sibbald and Sinclair 1990; Knowles et al. 1999), and predictive models of PAR (Photosynthetically Active Radiation) transmittance through tree canopies have been suggested to explain the effect of canopy structure on interception of radiation and photosynthesis (Oker-Blom et al. 1989). The purpose of this study was to estimate the pasture production and its seasonal pattern in a pinewood under different conditions of tree canopy cover. We discuss how tree canopy affects incident radiation and temperature at understory level, and the possible relationships with seasonal and annual herbage production.

Material and methods

Study area

The experiment was conducted in a pinewood of 11 ha located in Galicia (Monfero, A Coruña, Spain) at 650 m. The climate is Atlantic, with mild wet winters and warm summers. Annual precipitation is about 2000 mm, most of it occurring from September to May. Mean annual temperature is 10.6 °C, and temperatures of the coldest and warmest month are 5.4 °C in January and 17.4 °C in August, respectively. Description of vegetation and previous treatments to pasture establishment are detailed in Rigueiro (1985) and Silva-Pando et al. (1993).

Methods

The study site was divided into five stands, corresponding to a *Pinus sylvestris* tree canopy (PS), *P. pinaster* stand with homogeneous canopy (PP), *P. pinaster* stand adjacent to a natural gap (PPGA), and another two stands without trees, (WT) and control (C) (Table 1). In May 1992, a rectangular 0.3 ha plot divided into three subplots of 10 m × 10 m was established in each stand. A mixture of orchardgrass (*Dactylis glomerata* cv. 'Artabro') and white clover (*Trifolium repens* cv. 'Huia') was sown at densities of 25 kg/ha and 10 kg/ha, respectively. All sown plots were previously fertilized with 100 kg N, 400 kg P_2O_5, 300 kg SO_4K_2, and 2500 kg CO_3Ca per hectare. The control plot was not sown or fertilized.

Sampling was conducted over three years (1993–1995). Sampling dates were selected according to growing periods through the year, corresponding to March, May, August, October and December. Pasture production was estimated by a harvesting method, collecting three randomly selected quadrats of 1 m × 1 m per subplot. Herbage was cut 2 cm above soil level, plant material was dried at 80 °C for 24 h, and then weighed. Production was expressed as Mg of dry matter (DM) per ha.

Light transmission through the tree canopy was measured with solarimetric tubes (Eijkelkamp TSL, range 0.35–2.5μm). Measurements were carried out monthly, by installing one tube in the central subplot of each plot. On that day, light transmission was recorded for 3 minutes at 2 h intervals. Values were expressed as a percentage of incident radiation in the plot without trees (WT), considered 100%.

PAR was measured with LICOR LI-190SA Quantum Sensors located at soil surface level next to the solarimetric tubes. Temperature was measured with LICOR 1000-15 Temperature Sensors at 1.5 m above ground. Both PAR and temperature were sampled at 1 minute intervals and stored as hourly means on LICOR-1000 dataloggers.

For the analysis of data, we used an ANOVA to determine the influence of tree canopy on annual and seasonal pasture production. A subset of data comprising sown and fertilized plots (WT, PS, PP, PPGA) and another subset including plots without tree cover

Table 2. P-value for preplanned comparisons, factors and interactions in the ANOVA, in a three-years study of a silvopastoral system in Galicia, Spain.

	March	May	August	October	December	Overall
PS vs PP	0.3736	0.0121*	0.0000*	0.0136*	0.0000*	0.0001*
PS vs PPGA	0.0000*	0.0000*	0.0000*	0.0027*	0.0000*	0.0000*
PS vs WT	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
PP vs PPGA	0.0000*	0.0000*	0.4500	0.5683	0.2430	0.1820
PP vs WT	0.0000*	0.0000*	0.0000*	0.0000*	0.0001*	0.0000*
PPGA vs WT	0.0000*	0.0000*	0.0000*	0.0000*	0.0042*	0.0000*
Canopy type (C)	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
Subplot (S)	0.2163	0.0579	0.3645	0.5910	0.1498	0.3775
Year (Y)	0.0000*	0.0005*	0.0000*	0.0000*	0.0034*	0.0473*
C × S	0.0208*	0.6556	0.0004*	0.2051	0.0545	0.2717
C × Y	0.0003*	0.0001*	0.0016*	0.0113*	0.0000*	0.0037*
S × Y	0.1903	0.0298*	0.2038	0.8519	0.4274	0.8686
C × S × Y	0.1346	0.0484*	0.8028	0.7881	0.0746	0.9948

An asterisk indicates differences at 0.05 significance level on pasture production between plots at different sampling dates during the study. Sampling dates are the mean of the three years (1993–1995). PS: *Pinus sylvestris*, PP: *P. pinaster*, PPGA: *P. pinaster* (gap adjacent plot), WT: without trees, C: canopy type, S: subplot, Y: year.

Table 3. Annual pasture production and light transmission through the canopy in a silvopastoral system in Galicia, Spain.

Plot	1993		1994		1995	
	Annual production Mg DM/ha	Light transmission %	Annual production Mg DM/ha	Light transmission %	Annual production Mg DM/ha	Light transmission %
PS	1.290 (0.076)	21 ± 6	0.756 (0.053)	20 ± 5	0.981 (0.042)	16 ± 3
PP	3.645 (0.467)	36 ± 7	2.801 (0.169)	29 ± 6	3.778 (0.183)	24 ± 3
PPGA	3.758 (0.352)	49 ± 10	4.310 (0.392)	57 ± 9	4.960 (0.264)	44 ± 11
WT	7.167 (0.594)	100	7.235 (0.631)	100	9.418 (0.452)	100
C	–	100	7.915 (0.356)	100	8.695 (0.331)	100

Production values are total and standard error (in brackets), and percentage of light transmission values are mean ± standard error. PS: *Pinus sylvestris*, PP: *P. pinaster*, PPGA: *P. pinaster* (gap adjacent plot), WT: without trees, C: control.

(WT and C) were used. Pasture harvested in March and August corresponded to two months of production, and in May, October and December corresponded to three months; thus, to avoid the effect of unequal time spacing between sampling dates on generalization of results, an ANOVA by sampling date was applied and mean monthly values over the three years were utilized. Regression techniques were used to explore the relationship between incident radiation and pasture production.

Results

Differences in annual and seasonal pasture production between plots without trees and under *P. sylvestris* and *P. pinaster* were significant ($P<0.05$). Tree canopy affected pasture production (Table 2), and a considerable decrease in herbage production occurred under tree canopy cover compared with the stands with no trees (Table 3). Annual pasture production ranged from 40 to 55% under *P. pinaster*, and from 10 to 18% under *P. sylvestris*, according to the phytomass harvested in plots without trees (Table 3).

Light transmission through the tree canopy of *P. sylvestris* was 16–21% of daily solar radiation (Table 3). This percentage was estimated at 24–36% under *P. pinaster* (PP), and 44–57% under the *P. pinaster* stand with an adjacent gap (PPGA). We obtained a linear relationship between relative annual production and light transmission ($R^2 = 0.90$, $P < 0.05$), both expressed as percentage of herbage production and light transmission through the canopy relative to no tree canopy conditions. This result is similar to that of Knowles et al. (1999) where a strong linear relationship ($R^2 = 0.89$) was shown to exist between the

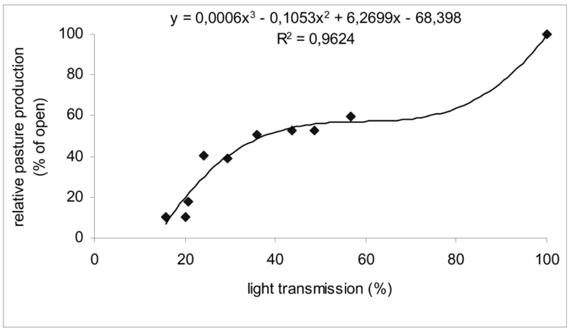


Figure 1. Relationship between annual pasture production under tree canopy and light transmission in a silvopastoral system in Galicia, Spain. Data are expressed as relative values of production and percentage of light transmission in no tree canopy conditions.

measured pasture production and the predicted canopy closure. These authors also examined more complicated polynomial functions which did not improve the fit of such relationship. However, we found a better adjustment of our data to a third order polynomial function ($R^2 = 0.96$) (Figure 1).

Seasonal fluctuations in herbage production were more pronounced in the plot without trees, and these variations became less apparent as percentage of light intercepted by the tree canopy increased (Figures 2 and 3). Variation in seasonal production was lower under *P. sylvestris* than in the rest of the stands (Figure 2a), this is also shown by its lowest standard error for annual production (Table 3). Total annual pasture production showed no significant differences between plots of *P. pinaster* (Table 2), and there were no differences in seasonal production except in March and May when herbage production was higher in PPGA than in PP ($P < 0.05$) (Table 2, Figure 2b, 2c). The lack of homogeneity in light transmission through PPGA is shown by the highest standard error (Table 3).

Maximum pasture production occurred in early summer for all the stands (Figure 2), which corresponded to the months when temperatures and radiation levels are the highest and precipitation is close to moderate levels (Figure 4). Minimum pasture production occurred from fall to spring. We found some regrowth of pasture during the fall but only in plots with trees (Figure 2).

Higher fluctuations of temperature and PAR in June than in November were observed (Figure 5a and Figure 5b). Minimum temperatures during the night were tempered under the tree canopy, and maximum temperatures during the day were lower than in plots without trees (Figure 6). Fluctuations of temperature and PAR (Figure 5) under tree canopies were less apparent than in no tree canopy conditions, and a similar pattern was reflected in the seasonal variation of production (Figure 2).

Discussion

We found a significant effect of tree canopy on pasture, the lowest herbage production occurring under the highest tree canopy cover. Papanastasis et al. (1995) reported significantly higher herbage production under *P. pinaster* stands with 300 trees/ha than in medium and high-density stands with 600 and 1200 trees/ha respectively. These tree-herbage production interactions are less significant in young plantations, and understory herbage production may not be affected by the overstory until about the tenth year after tree establishment (Platis et al. 1999).

The linear relationship between relative annual production and light transmission in our study agrees with findings such as Sibbald (1996), which concluded that shading by the trees was the main factor in reducing annual pasture production. Some caution is necessary, however, in extrapolating these findings from different authors, since it would be more accurate to have in our study some data in the range between 60–100% light transmission.

It is not easy to interpret how light interception by the crown affects understory layers. Light transmission lower than 20% is known to negatively affect *D. glomerata* establishment and growth, even with fertilization, under *Pinus brutia* (Koukoura and Papanastasis 1996). Whether the increase in interception of radiation is due to an increase in stand density or tree size (leaf area per crown) appeared to be of little importance regarding the photosynthetic production per unit of intercepted radiation (Oker-Blom et al. 1989).

Despite having a similar tree density and canopy architecture, light transmission was higher in PPGA than in PP (Figure 3), probably because of a ″side lighting″ effect (Anderson et al. 1969) since PPGA is next to a natural gap facing southwest. Conversion efficiency between intercepted radiation and photosynthesis depends on the temporal and spatial distribution of irradiance on the foliage area which is the integrated result from the distribution of incident radiation during the specified period and from canopy structure (Oker-Blom et al. 1989).

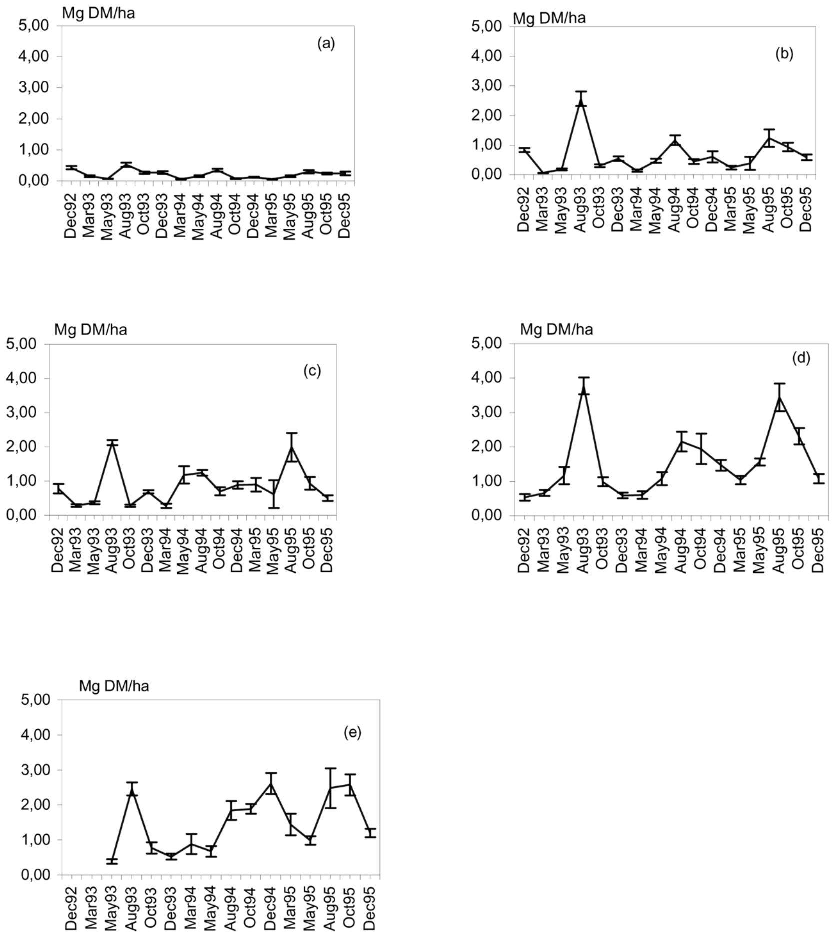


Figure 2. Seasonal variation of pasture production under different tree canopy conditions in a silvopastoral system in Galicia, Spain. (a) under PS (*Pinus sylvestris*), (b) under PP (*Pinus pinaster* canopy), (c) under PPGA (gap adjacent *Pinus pinaster* canopy), (d) production in the sown plot without trees, (e) production in the control plot.

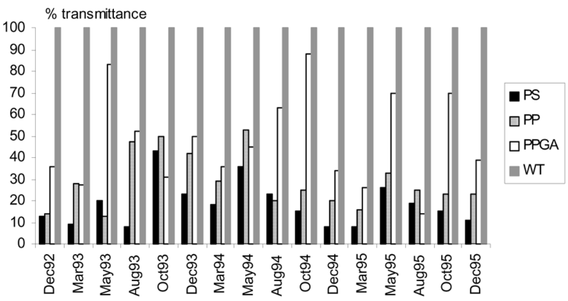
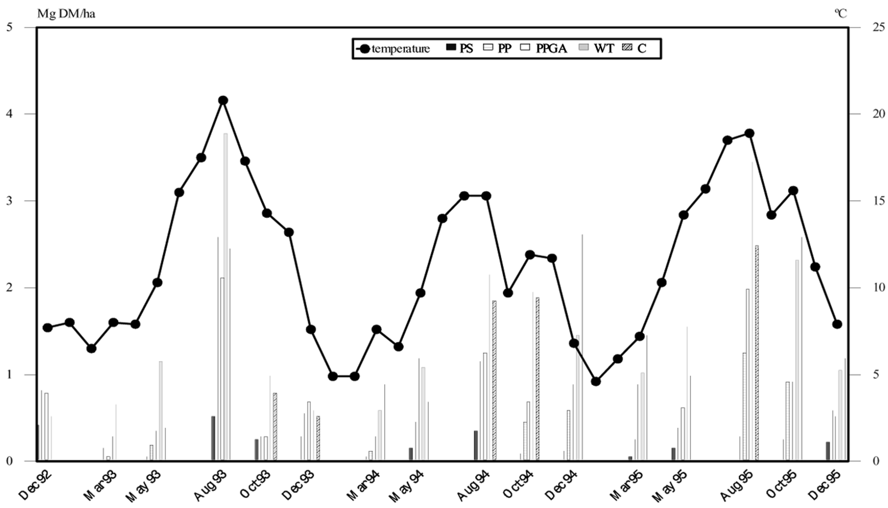


Figure 3. Light transmission under different tree canopy conditions in a silvopastoral system in Galicia, Spain. Values reflect fractional transmission of radiation through the canopy, considered 100% in plot without trees (WT). *Pinus pinaster* (PP), *Pinus pinaster* (gap adjacent *Pinus pinaster* canopy, PPGA) and *Pinus sylvestris* (PS).

Seasonal influences of temperature on net productivity (Hawke 1991), and the microclimatic effect of trees on herbaceous productivity and quality have been reported previously (Vales and Burnell 1988). We observed higher fluctuations of temperature and PAR in June than in November, in accord with findings that show different tree canopy effects depending on season (Frost and McDougald 1989).

A skilled management of tree canopy cover can play a key role in shifting forage productivity towards strategic periods by reducing seasonality (Armand and Etienne 1996). Less apparent fluctuations of temperature and PAR (Figure 5) under tree canopies, as well as a similar pattern in the seasonal variation of production (Figure 2) could be a result of the tree canopy tempering effect. Several studies have reported the tempering effect of tree canopy on sown pasture production under severe climatic conditions (Ovalle et al. 1989). Higher minimum temperatures



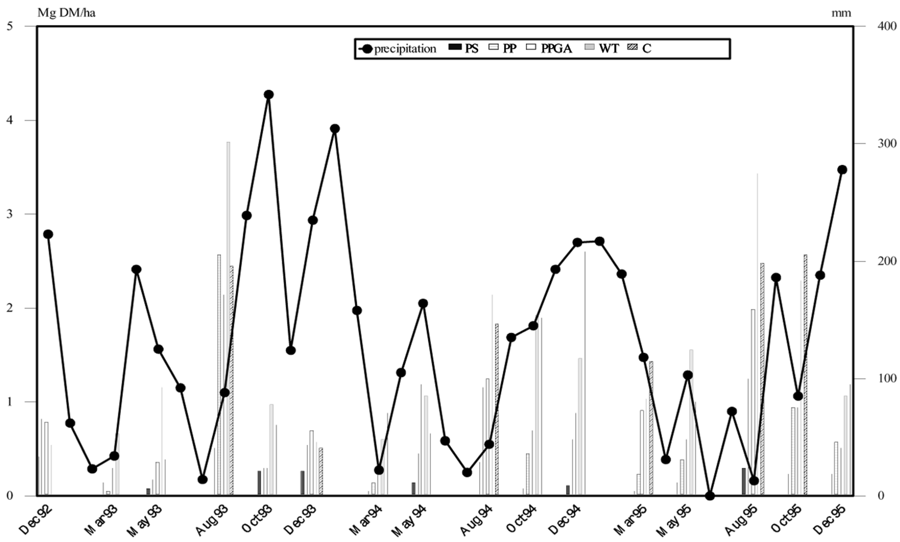


Figure 4. Pasture production (columns) in the different study plots and monthly mean temperature (above) and precipitation (below) in a three-years study in a silvopastoral system in Galicia, Spain. Data were recorded from December 1992 to December 1995. Temperature as monthly mean and precipitation as total by month. PS = *Pinus sylvestris*, PP = *Pinus pinaster*, PPGA = gap adjacent *Pinus pinaster*, WT = without trees, C = control.

below the trees at the start and end of the growing season may determine a higher understory herbage production than in the stand without trees (Figure 2). This trend has been also reported from similar observations on temperate sown pastures (Sibbald 1996).

The significantly higher production we found in the control stand compared to the sown plot without trees in March and December could be the result of a low sown pasture production at this time of the year when the temperatures are low, and also to the presence of evergreen spontaneous vegetation in the control plot.

The mechanisms underlying the linear relationships between radiation interception and biomass production should be analyzed further by taking into account all the physiological aspects of tree and pasture growth. Under different circumstances other factors may become limiting and affect the overstorey/understorey relationship. Lee and Yun (1985) have reported that tiller density and dry matter yield increased with enhanced NPK rates, while decreases occurred with

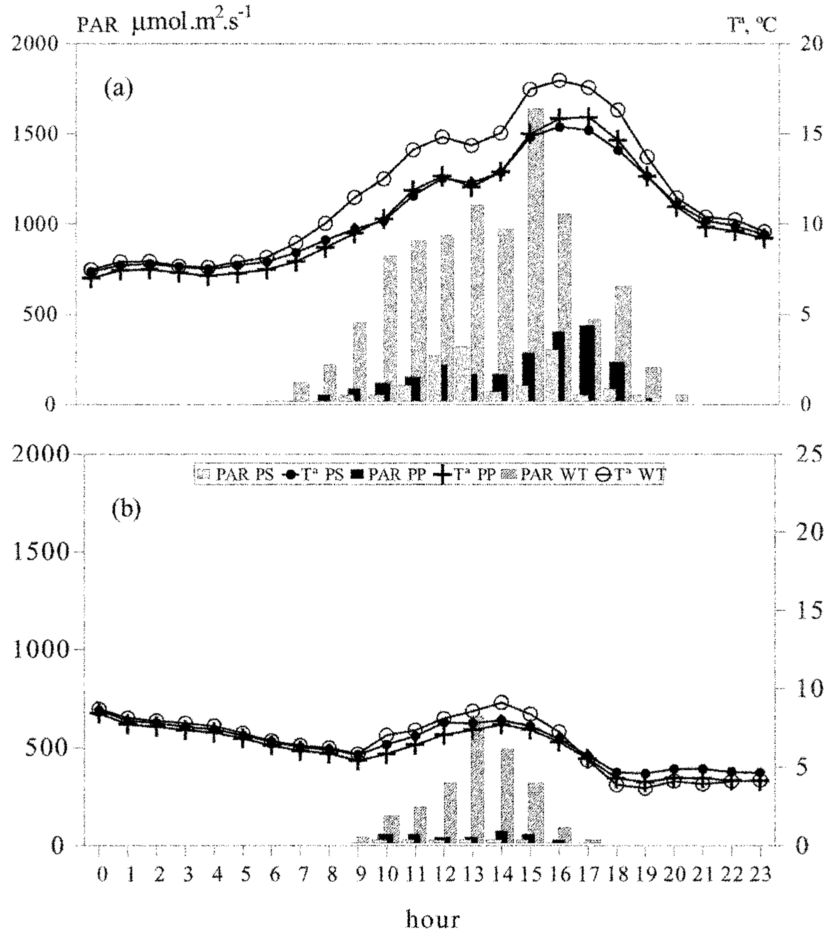
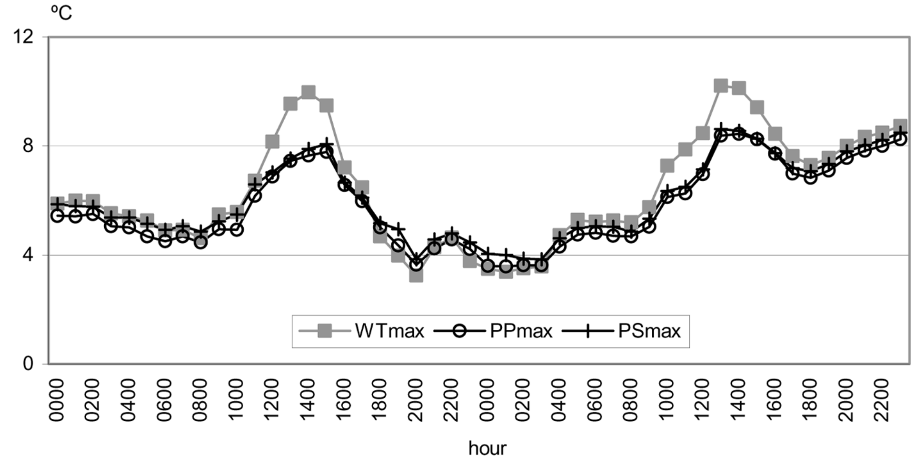


Figure 5. PAR and temperature under different tree canopy cover conditions in a silvopastoral system in Galicia, Spain. Data were recorded at 1h intervals during (a) one summer (June) and (b) one winter (November) day from 0.00 to 24.00 h. PS = *Pinus sylvestris*, PP = *Pinus pinaster*, WT = without trees.

shading. In the same study it was concluded that optimum rates of fertilizers depended on shading intensity, and forests with 40% or more shade offered no prospect of pasture improvement. Fertilization may affect the relation between herbage yield and pine canopy density, and it can also modify the response of the understory vegetation to the tree canopy (Koukoura and Papanastasis 1996). Based on these findings, we could expect that 80–85% of shade under *P. sylvestris* could also limit the response of pasture production to fertilization.

Trees may have significant effects in decreasing pH or levels of some nutrients, while increasing concentrations of other nutrients (Hawke and O'Connor 1993). Significant reductions in soil water content and surface water yield under forests versus pastures may also occur (Yunusa et al. 1995). These changes in nutrient and moisture status are certain to have impacts on understorey pasture production in addition to that introduced by canopy closure. Several studies carried out in Chile report a decrease of herbage production when partial or total reduction of tree cover from *Acacia caven* occurs (Ovalle et al. 1989). The canopy of this species reduces incident radiation to the herbaceous layer, but the radiation received is sufficient to maintain the photosynthetic activity of herbaceous species while increasing soil water availability by attenuating extreme temperatures and reducing evaporation. Also, *A. caven* reinforces soil nutrient availability, mainly by increasing organic matter, N and K contents (Ovalle and Avendaño 1988). The effect on understorey herbage production was different under *Pinus radiata*, the authors concluding that in the *A. caven* system efforts should be concentrated on im-



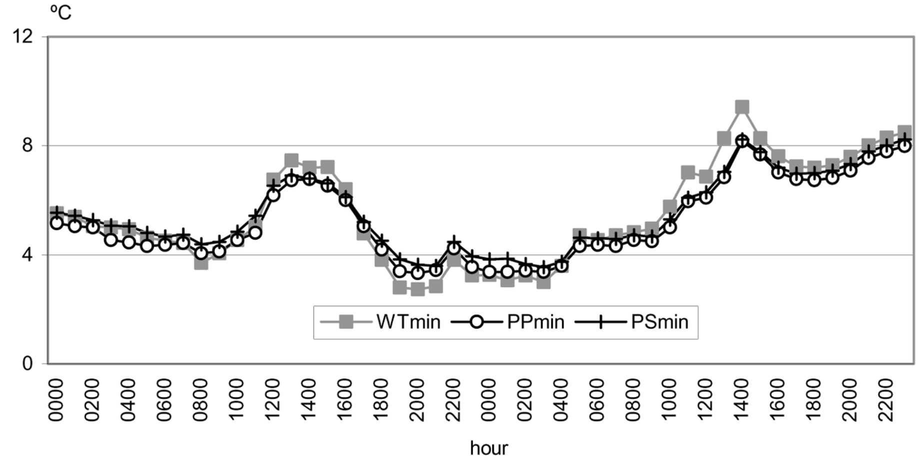


Figure 6. Maximum and minimum temperature under different tree canopy cover conditions in a silvopastoral system in Galicia, Spain. Data were recorded 1.5 m above soil level and measured at 1h intervals during two winter days (November) from 0.00 to 48.00 h. PS = *Pinus sylvestris*, PP = *Pinus pinaster*, WT = without trees.

proving the tree component whereas in systems such as *Pinus radiata* it is necessary to strengthen the herbage component by appropriate silviculture and pasture improvement measures (Etienne et al. 1994).

Knowles et al. (1999) concluded that for *any specific region* the direct assessment of canopy closure, combined with a measurement of understorey pasture production, may be a simpler and more cost effective research technique than relying entirely on the continuous measurement of understorey pasture in the development of understorey/overstorey relationships. Information on the effect of tree canopy cover on pasture production helps to determine how pine agroforestry should be managed, although it is unlikely that a single prescription will meet all the objectives. Age, season and tree canopy cover were the three key determining factors for assessing the productivity of subterranean clover overseedings (Armand and Etienne 1996). We can conclude from our results that tree canopy architecture affects production of understory layers, by producing different microclimatic conditions which influence pasture yield and its seasonal pattern.

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References

Anderson R.C., Loucks L.O. and Swain A.M. 1969. Herbaceous response to canopy cover, light intensity and throughfall precipitation in coniferous forests. Ecology 50(2): 255–263.

Armand D. and Etienne M. 1996. Impact of tree canopy cover on subterranean clover overseeding productivity and use in southeastern France. In: Etienne M. (ed.), Western European Silvopastoral Systems. INRA, France, pp. 71–81.

Etienne M., Ovalle C. and Ovalle M.C. 1994. Le sylvopastoralisme au Chili. Agroforesterie en zone temperee. Revue Forestiere Francaise 46(numero special): 42–48.

Frost W. and McDougald N. 1989. Tree canopy effect on herbaceous production of annual rangeland during drought. Journal of Range Management 42(4): 281–283.

García A., Rozados M.J., Silva-Pando F.J. and Lindner R. 1999. Evaluation of natural populations of *Dactylis glomerata* for grazing under pinewoods. In: Papanastasis V.P., Frame J. and Nastis A.S. (eds), Grasslands and Woody Plants in Europe. EGF, pp. 167–169.

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

González-Hernández M.P. and Silva-Pando F.J. 1999. Nutritional attributes of understory plants known as components of deer diets. J Range Management 52(2): 132–138.

Hawke M.F. 1991. Pasture production and animal performance under pine agroforestry in New Zealand. Forest Ecology and Management 45: 109–118.

Hawke M.F. and O'Connor M.B. 1993. Soil pH and nutrient levels at Tikitere agroforestry research area. NZ J For Sci 23(1): 40–48.

Knowles R.L., Horvath G.C., Carter M.A. and Hawke M.F. 1999. Developing a canopy closure model to predict overstorey/understorey relationships in *Pinus radiata* silvopastoral systems. Agroforestry Systems 43: 109–119.

Koukoura Z. and Papanastasis V. 1996. Establishment and growth of seeded grasses and legumes in pine silvopastoral systems. In: Etienne M. (ed.), Western European Silvopastoral Systems. INRA, France, pp. 83–91.

Lassoie J.P. and Buck L.E. 1991. Agroforestry in North America: New challenges and opportunities for integrated resource management. In: Garret H.E. (ed.), Proc. 2d Conf. Agrofor. Univ. of Missouri, North Am. Springfield, Mo, Columbia, pp. 1–19.

Lee I.D. and Yun I.S. 1985. Studies on the improvement and utilization of pasture in the forest. The effect of shade degree and fertilization levels on the early seedling growth and dry matter yield of forest pastures. Journal of the Korean Society of Grassland Science 5(2): 162–166.

Oker-Blom P., Pukkala T. and Kuuluvainen T. 1989. Relationship between radiation interception and photosynthesis in forest canopies: effect of stand structure and latitude. Ecological Modelling 49: 73–87.

Ovalle C. and Avendaño J. 1988. Interactions of the tree layer with the herbaceous layer in *Acacia caven* plant communities in Chile. Part 2. Effects of trees on some environmental factors: microclimate and soil. Oecologia Plantarum 9(2): 113–134.

Ovalle C., Avendaño J., Avendaño R.J. and Ovalle M.C. 1989. The sylvopastoral utilization of spinal (Acacia caven savanna) in the Mediterranean climatic zone of Chile. In: Influence of the Trees on the Grassland Vegetation. Proceedings of the XVI International Grassland Congress, Nice, France.

Papanastasis V.P., Koukoura Z., Alifragis D. and Makedos J. 1995. Effects of thinning, fertilization and sheep grazing on the understorey vegetation of *Pinus pinaster* plantations. Forest Ecology and Management 77: 181–189.

Piñeiro J. and Pérez M. 1988. Pasture species under pines. In: Proceedings of the 12th General Meeting of the European Grassland Federation, Dublin, Ireland., pp. 209–213.

Platis P.D., Mantzanas K.T. and Papanastasis V.P. 1999. Effects of tree spacing and annual cutting on herbage production in a young *Pinus brutia* plantation. In: Papanastasis V.P., Frame J. and Nastis A.S. (eds), Grasslands and Woody Plants in Europe. EGF, pp. 221–225.

Rigueiro A. 1985. La utilización del ganado en el monte arbolado gallego. Un paso hacia el uso integral del monte. In: Vélez R. and Vega J.A. (eds), Estudios Sobre Prevención y Efectos Ecológicos de Los Incendios Forestales. I.C.O.N.A.-M.A.P.A., Madrid, pp. 61–78.

Sibbald A.R. and Sinclair F.L. 1990. A review of agroforestry research in progress in the U.K. Agrof Abst 3(4): 149–164.

Sibbald A.R. 1996. Silvopastoral systems on temperate sown pastures: A personal perspective. In: Etienne M. (ed.), Western European Silvopastoral Systems. INRA, France, pp. 23–36.

Silva-Pando F.J., González-Hernández M.P. and Prunell Tuduri A. 1993. Prácticas agroforestales en pinares y eucaliptales atlánticos. I. Producción del sotobosque. In: Silva-Pando F.J. and y Vega Alonso G. (eds), Ponencias y Comunicaciones Congreso Forestal Español-Lourizán 1993, II., pp. 637–642.

Vales D.J. and Burnell F.L. 1988. Relationships between transmission of solar radiation and conifer forests stand characteristics. Agricultural and Forest Meteorology 43: 201–223.

Yunusa I.A.M., Mead D.J., Lucas R.J. and Pollock K.M. 1995. Process study in a *Pinus radiata*-pasture agroforestry system in a subhumid temperature environment. II. Analysis of dry matter yields in the third year. Agroforestry Systems 32(2): 185–204.