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An evaluation of overall fodder production in extensive silvopastoral systems with different cover of shrub understory. The case of Iberian dehesas

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Abstract. Grazed Mediterranean open woodlands, as the Iberian dehesa, are an outstanding example of silvopastoral system where shrub encroachment has been proposed as an effective means to facilitate tree seedling recruitment and ensure the system persistence. The aim of this essay is to test the effects of different intensity of shrub encroachment on different fodder components of the system: acorn production, forage shrub and grassland yield. Metabolic Energy (ME) was increased by *R. sphaerocarpa* due to the increase of grass production and the contribution of shrub fodder in addition to the supply of acorns. Instead, the ME supplied by *C. ladanifer* layer, did not compensate the reduction in grassland and acorn production because of the low metabolic energy that *C. ladanifer* canopy provides.

Keywords. Forage shrub – Acorn production – *Cistus ladanifer* – *Retama shaerocarpa* – Pasture yield.

Une évaluation de la production fourragère globale dans systèmes sylvo-pastoraux avec de différents types de sous-étage arbustif. Le cas des dehesas Ibériques

Résumé. *Dans plusieurs systèmes sylvopastoraux méditerranéens, tels que la dehesa ibérique, la gestion de la végétation arbustive est considéré de plus en plus comme un moyen effectif pour faciliter la régénération naturelle des arbres et assurer la persistance des agrosystèmes. Nous avons testé les effets de différents types de couvert arbustif sur le rendement en glands, en fourrages arbustifs et en pâturage herbacé. Deux espèces arbustives présentant des traits fonctionnels contrastés ont été utilisées comme modèles d'étude :* Cistus ladanifer *et* Retama sphaerocarpa. *L'énergie métabolique était supérieure dans le système intégrant* R. sphaerocarpa*, notamment en raison d'une augmentation du rendement du pâturage herbacé. L'énergie métabolique apportée par la couverture de* C. ladanifer *n'a pas compensé son effet négatif sur le rendement du pâturage herbacé et sur la production de glands.*

Mots-clés. *Arbuste fourrager – Production de glands –* Cistus ladanifer – Retama sphaerocarpa – *Rendement.*

I – Introduction

The Iberian dehesa is usually defined as a two-layered silvopastoral system, where native grasses cohabit with a scattered widely-space tree layer, usually belonging to *Quercus* genus. In dehesas, livestock production is characterized by its diversified diet that is made up mainly of grassland, fruits and shrub browse. In the last decades, the intensification have led to a progressive increase of stocking rate, mechanisation of dehesa farming and tree clearance, with special attention to pasture improvement. In consequence, most of dehesas have an even aged tree population, with a minimal incorporation of new trees (sexual precedence) (Pulido and Díaz, 2005). Recently, several authors have shown different positive effects of encroachment on the silvopastoral systems functioning: tree natural regeneration (Pulido and Díaz, 2005) or diversification of animal diet. However, shrubs strata could produce a competitive effect to trees and pasture respect to nutrient and water. The aim of this study is to investigate the effects of the dehesa encroachment on whole productivity.

II – Materials and methods

The experiment was carried out in several dehesas of Spain between 2007 and 2010. They presented two kinds of shrubs: *Retama sphaerocarpa* (L.) Boiss (20 dehesas) and *Cistus ladanifer* L (20 dehesas). *C. ladanifer* forms extensive and mostly aggregated populations and shallow, dense root systems that retain water in the upper soil layers. *R. sphaerocarpa* is a leguminous shrub with N_2-fixing capabilities that generally grows scattered and has long and very deep roots that allow the plant to tap deep-water sources.

The mean tree diameter at breast height (dbh) was 45 and 49 cm in the dehesas with *C. ladanifer* and *R. sphaerocarpa*, respectively. The crown diameter and the density of the trees were 9.93 m and 29 trees ha^{-1}, respectively, in the dehesas with *Cistus ladanifer*, and 12.3 and 24 trees ha^{-1} with *Retama sphaerocarpa.*

For determining acorn production, four randomized quadrats (0.25x0.25 m) were sampled (one in each orientation) per tree. Respect to shrub browse production, it was determined measuring the annual sprouts (*C. ladanifer*) and fruit biomass (*R. sphaerocarpa)*, which are considered the browse production of both shrubs. There were taken along three transects (50x4 m) randomly in each dehesa, where shrub height (each meter) and cover were measured. Moreover, three plants from each transect were measured and weighed. After that, annual sprouts (in *C. ladanifer*) and fruit (in *R. sphaerocarpa*) were weighed.

For determining pasture production, in each dehesa with *C. ladanifer*, 12 trees were selected, with (six trees) and without (six trees) shrubby understorey. In each tree, pasture exclusion cages (1x1 m) were located beneath and beyond (10 m out of the tree crowns) tree canopy for collecting pasture. In the dehesas with *R. sphaerocarpa*, the design of the experiment was changed because there was not shrub presence beneath trees. In this case, eight trees were selected and pasture exclusion cages were situated in three different positions: beneath crown and out of the trees in areas without shrub and out of the trees in areas with shrubby layer. It was considered that tree influence to pasture production was limited to the area under crown (Rivest *et al.*, 2011). In the same dehesas, another sampling was carried out for determining the surface of grassland which is influenced by shrub plants. In spring 2010, nine (*C. ladanifer*) and ten (*R. sphaerocarpa*) herbage samples were taken using hand clippers at different distances respect to shrub plants. The difference of sample number is due to the differences between size species. It was observed that, in each *C. ladanifer* plant, there was not pasture production in the innermost circle of the crown which accounts for 25% of total (i.e. trunk surface). In both cases, the first sample was taken cutting just below shrub crown periphery, that corresponded with third (0.30-0.45 m) and four (0.45-0.60 m) sample in *C. ladanifer* and *R. sphaerocarpa*, respectively. Next, two (*C. ladanifer*) and three samples (*R. sphaerocarpa*) were cut under plant cover. The remainder samples were located from peripheric crown position to outside. Respect to *R. sphaerocarpa*, it was assumed that the pasture production in the innermost surface (a circle which is 35% of the crown, approximately) was similar to the first sample (0-0.15 m).

A non linear least square fit to a Bolztman function was realized for distinguishing different types of influence surface around shrubs. Shrub encroachment effects on acorn yield and grassland production were determined using repeated-measures ANOVA, with two between-subject factors (site and shrub understorey presence) and one within-subject factor (year). We used LSD test to separate treatment means when ANOVA showed significant effects ($p<0.05$). All statistical analyses were performed using Statistica 7.0 (StatSoft, Inc., OK, USA).

III – Results and discussion

The results obtained in Fig. 1 indicate that we can establish two zones according to the influence of shrub plants (which mean crown surface was 1.09 m^2 for *C. ladanifer* and 2.60 m^2 for *R. sphaerocarpa*) on grassland production: the zone with the highest influence in pasture production below shrub (B) are 0.6927 m^2 $plant^{-1}$ (*C. ladanifer*) and 0.724 m^2 $plant^{-1}$ (*R. sphaerocarpa*) which suppose the highest influence was detected at 0.49 m and 0.48 m respect to plant center. The zone with an intermediate influence (I) are 1.7341 m^2 $plant^{-1}$ (*C. ladanifer*; 0.89 m radio respect to plant center) and 1.1487 m^2 $plant^{-1}$ (*R. sphaerocarpa*; 0.77 m radio respect to plant center). In *C. ladanifer* plants, the total influence surface (B+I) was greater than the mean crown size, whereas this effect did not exceed their crown in *R. sphaerocarpa* plants. This figure allows us to know the percentage of variation between the grass production of the intermediate influence (I) and beyond shrub.

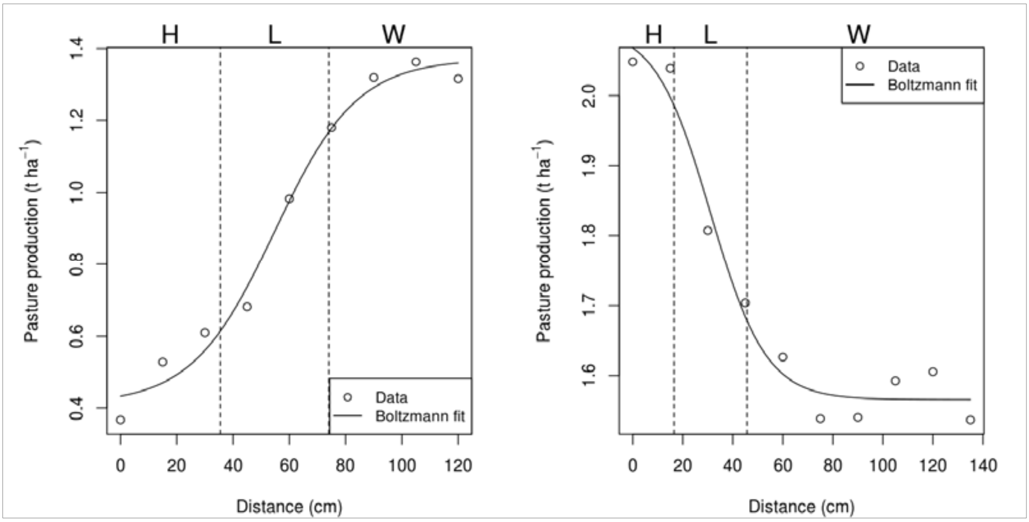

Fig. 1. Pasture production at different distances respect to *C. ladanifer (*left*)* and *R. sphaerocarpa* (right) plants. The origen of x-axis = the beginning of the samplings. Surface with the highest influence in pasture production below shrub (B); intermediate (I); and without shrub influence (O).

In Table 1, acorn, pasture and shrub browse production variation respect to *C. ladanifer* and *R. sphaerocarpa* presence are shown. The mean shrub canopy, height and crown radio were 53.65%, 2.25 m and 0.59 m, respectively, in *Cistus ladanifer*, and 37.85%, 1.7 m and 0.91 m in *R. sphaerocarpa*. Moreover, browse production was directly proportional to shrub cover as indicate: *C. ladanifer*: sprouts production (kg ha^{-1}) = 13.1278 x % shrub cover; R^2= 0.78; *R. sphaerocarpa:* fruits production (kg ha^{-1}) = 1.5307 x % shrub cover; R^2= 0.63. One of the most important parameters used to determine the quality of food is Metabolic Energy. Different authors have analyzed the ME of acorns (9.5-11.1 MJ kg^{-1} MS; Robles *et al.*, 2008), *C. ladanifer* sprouts (6.59 MJ kg^{-1} MS; Patón *et al.*, 2004), and *R. sphaerocarpa* (10.4 MJ kg^{-1} MS; Robles *et al.*, 2008) fruits and natural grassland of dehesa (7.6-10 MJ kg^{-1} MS; Martín Polo *et al.*, 2003). Table 1 shows that the obtained ME was increased by the presence of *R. sphaerocarpa.* It is due to the increase of grass production and the contribution of shrub fodder in addition to the supply of acorns, which did not change significantly with the shrub encroachment. Instead, the ME supplied by the *C. ladanifer* strata did not compensate the reduction of grassland and acorn production, because of the low metabolic energy (6.59 MJ kg^{-1} MS; Patón *et al*., 2004) that this shrub provides.

Table 1. Acorn, grassland and shrub browse production (kg ha^{-1}) and Metabolic Energy (ME; MJ ha^{-1} $year^{-1}$) variation respect to *C. ladanifer* and *R. sphaerocarpa* presence. Ns: not-significant, **: *P*<0.01, *: *P*<0.001.**

	Year	Control	*Cistus*	Sign.	Control	*Retama*	Sign.
Acorn	2007	363.78	211.3	**	339.86	276.98	ns
	2008	150.99	141.30	ns	133.74	120.96	ns
	2009	325.25	198.48	***	183.26	216.34	ns
Shrub	2008	0	704.3		0	57.9	
Grassland	2007	2732	1461	***	2354	2553	ns
	2008	2342	1412	ns (0.07)	2376	2483	ns
	2009	991	470	ns	359	403	ns
	2010	1837	1198	**	1576	1672	ns
ME		20370	15903		17884	18765	

IV – Conclusions

The presence of *C. ladanifer* reduces the overall productivity of the dehesa system, due to negatively effect of its presence on acorn and grass production which is not compensated by shrub fodder production. In contrast, the facilitation effect of *R. sphaerocarpa* increases the productivity of the system. We recommend that future research be guided towards determining whether or not the management of shrub cover (e.g., promoting *R. sphaerocarpa* understorey and clearing *C. ladanifer*, while retaining only some patches of the latter) may aid early tree recruitment without compromising overall productivity of the system.

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