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Competition for soil water among trees, shrubs and pasture in Iberian Dehesas.

Consequences for pasture and tree productivity

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Abstract. The low tree density in silvopastoral systems results in increased pasture productivity and allows remnant trees to cope with summer water deficit. However, the worldwide phenomenon of savanna shrub encroachment could compromise the benefit of wide tree spacing in these water limited forests. We analyze the effect of shrub encroachment of Iberian dehesas for soil water dynamic and tree water status. The consequences for oak tree and pasture productivity are discussed. Increased tree density resulted in a worsening of tree water status and acorn productivity. *Cistus* shrubs showed a net competitive effect for soil water which influenced negatively the pasture yield, and the functional state and acorn production of the trees. By contrast, *Retama* shrubs affected positively the soil moisture of uppermost soil layers (hydraulically lifted water) and showed a facilitative effect for pasture yield without influencing the functional tree state and acorn production.

Keywords. Competition – Facilitation – Pasture understory – Silvopastoral – Water deficit.

La concurrence pour l'eau du sol entre les arbres, les arbustes et les pâturages dans les dehesas ibériques. Conséquences pour la productivité des pâturages et des arbres

Résumé. La faible densité des arbres dans les systèmes sylvopastoraux est compatible avec une bonne production des pâturages, et permet aux arbres résiduels faire face à un déficit hydrique en été, tout en facilitant le fonctionnement et la productivité des arbres. Cependant, le phénomène mondial de l'embroussaillage des savanes pourrait compromettre l'intérêt de l'espacement des arbres dans ces forêts semi-arides. Nous analysons l'effet de l'embroussaillage des dehesas ibériques avec *Cistus ladanifer* et *Retama sphaerocarpa* sur la dynamique de l'eau du sol et l'état hydrique des arbres. Les conséquences pour la productivité des chênes et des pâturages sont discutées. L'augmentation de la densité des arbres a entraîné une aggravation de l'état hydrique des arbres et la réduction de la productivité gland. *Cistus* a montré un effet concurrentiel net pour l'eau du sol qui a influencé négativement la production du pâturage, et l'état fonctionnel des arbres et la production de glands. En revanche, *Retama* affecté positivement l'humidité des horizons superficiels de sol (ascenseur hydraulique) et a montré un effet de facilitation pour la production des pâturages sans influencer l'état fonctionnel d'arbre et la production de glands.

Mots-clés. Concurrence – Déficit en eau – Facilitation – Silvopastoral – Sous bois.

I – Introduction

Although forest thinning initially increases the availability of light for pasture, this clearance could have also important consequences for tree functioning, particularly in water-limited regions, as Mediterranean Basin countries. A good example is found in the scattered-trees silvopastoral system named Dehesa in the Iberian Peninsula (Moreno and Pulido, 2009). However, woody encroachment of former pasturelands and savannas have recently increased markedly worldwide (van Auken, 2000), including man-made savannas, as Iberian dehesas (Fernández-Ales *et al.*, 2012; Pinto-Correia and Mascarenhas, 1999) and other Mediterranean open woodlands (Papanastasis, 2004). There is a great concern about the ecological and productive consequences of

woody encroachment of pastures and savanoid landscapes. The consequences of woody encroachment of the idealized two layered dehesas are not still well known. Here, we compile data of three published studies that respond to three specific questions: (i) how do scattered-trees affect to soil water dynamic in two-layered dehesas (Cubera and Moreno, 2007); (ii) how do tree density affect to soil water reserve and tree water status (Moreno and Cubera, 2008); (iii) how do shrub understory affect to soil water reserve and tree water status (Moreno and Rolo, 2011).

II – Materials and methods

The study was conducted in 10 dehesas of Central-Western Spain under semi-arid Mediterranean climate (mean annual rainfall ranging 500-600 mm, mean annual temperature 15.5-16.5 °C, and mean annual potential evapotranspiration above 800 mm). Soils are acid, low in soil organic matter (usually < 3%) and of moderate depth (frequently < 100 cm). The vegetation in two-layered plots was formed by scattered oaks (*Quercus ilex* L.; trunk diameter 25-80 cm; 5-200 trees ha⁻¹) plus a herbaceous understory mainly composed by annual species. In three layered-plots, a third vegetation layer (shrub understory) was present. Two contrasting shrub species, in terms of cover and rooting system, were selected for his study, the shallow rooted *Cistus ladanifer* (soil cover 60-80%) and the deep rooted *Retama sphaerocarpa* (soil cover 20-60%) (Rolo and Moreno, 2012).

In a first study, we monitored soil water content (SWC) at different distance of scattered trees in four two-layered open dehesas (Control plots). Soil moisture profile was measured in 6-16 trees per dehesa both beneath and out of the canopy (2 and 30 m from the trunk). In a second study, SWC in control plots was compared with SWC in dense forest plots (canopy cover nearby to 20 and 100%, respectively). In dense forest plots, 6 replicated profiles were monitored, while 12 replicated profiles were monitored in open dehesas (6 profiles beneath the canopy and 6 out of the canopy). In a third study, SWC of 6 control plots was compared with SWC of 6 adjacent shrub encroached plots (either with *Cistus ladanifer* or with *Retama sphaerocarpa*). Four different habitats were defined, two from control plots, beneath the tree canopy and out of the tree canopy; and two from encroached plots, beneath trees and away from the tree canopy. Four replicated profiles were monitored in each plot.

SWC was measured either with TDR-probes (Tektronic model 1502C) or the Diviner 2000 probe (Sentek Pty Ltd) at different depths, with intervals of 20 cm for the first meter and then every 50 cm up to a maximum depth of 250-300 cm. Leaf water potential of trees (Ψ_{pd}) was periodically measured before sunrise by means of a Scholander chamber (Skye Instr., UK, model SKPM 1400) once per month (around mid-month from July to September). Details on measurements conducted at each site and parameters are given in Cubera and Moreno (2007), Moreno and Cubera (2008), Rolo and Moreno (2011) and Moreno and Rolo (2011).

III – Results

As a general trend for all the experimental sites, SWC was slightly but significantly higher beyond than beneath tree canopy during both dry and wet periods. Canopy width affected significantly this trend in all sites, with higher differences among distances in the biggest trees (Cubera and Moreno, 2007). Soil recharge beneath and beyond the tree canopy generally is completed during wet season for most of the profile, with soil water content values close or even higher to field capacity irrespective of site and distance to tree. Only at the deepest layers, near 3 m depth, did soil recharge seem incomplete in some cases. At 2 m from the tree trunk, SWC values close to the wilting point were observed at the end of the dry season. However, at 30 m of distance, an important amount of available water remained unused by vegetation in the deeper layers of the soil. Throughout the year, *HD* plots (~ 100% of tree cover) showed significantly lower SWC values than *LD* plots (~ 20 tree cover) (Moreno and Cubera 2008).

SWC was significantly lower beneath *Cistus* and tree+*Cistus* than in open pasture in the three studied sites. This reduction was consistent during the entire study period in depth (Fig.3). *Retama* showed a positive effect on SWC compared to pasture areas, although the effect was not consistent across sites (data not shown). *Retama* played a positive role for SWC in sites with deep soils, but the contrary in shallow soils (Moreno and Rolo 2011). SWC beneath tree+shrub habitat showed intermediate values among SWC found beneath shrub habitat and tree habitat, irrespective of the shrub species (Fig. 1).

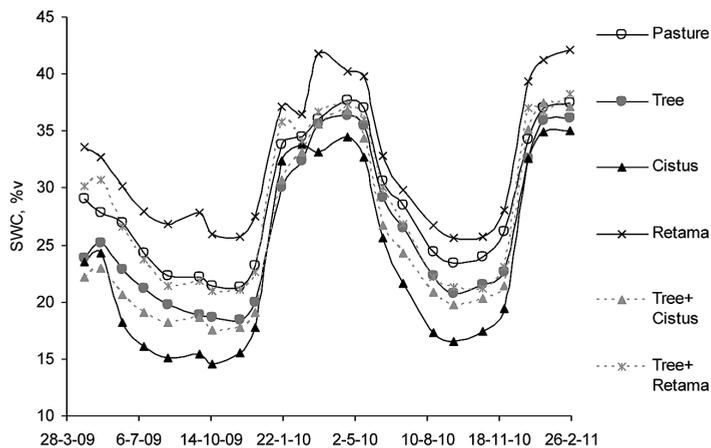


Fig. 1. Seasonal pattern of soil water content in four habitats of dehesas encroached with *Cistus ladanifer* or *Retama sphaerocarpa*. Values are average for three sites x four replicated profiles (0-250 cm depth) in each case. Adapted from Moreno and Rolo (2011).

Scattered oaks growing in open dehesas, at low density, maintained a high water potential during summer drought, with predawn leaf water potential (Ψ_{pd}) ranging from above -1 MPa or slightly below -2.0 MPa (Table 1), depending of the soil depth. When tree grew in dense stands (~ 100% tree cover) Ψ_{pd} decreased very significantly (from -0.53 to -2.77 MPa on average). The presence of a *Cistus ladanifer* understory beneath and among scattered oaks also produced a significant decrease of Ψ_{pd} , although the reduction was not so acute (from -1.74 to -2.02 MPa on average). By contrast, the presence of *Retama sphaerocarpa* did not produce a significant change in the water status of oaks.

Table 1. Monthly dynamic of Ψ_{pd} for oak trees growing in dehesas at low and high tree density (adapted from Moreno and Cúbera, 2008) and in open and encroached stands (with *Cistus ladanifer* or *Retama sphaerocarpa* understory; adapted Rolo and Moreno, 2011). Different letters between habitats indicate significant differences at $P < 0.05$

	July	August	September	Average
Low tree density	-0.34 ± 0.12 a	-0.66 ± 0.32 a	-0.58 ± 0.25 a	-0.53 ± 0.21 a
High tree density	-2.27 ± 0.43 b	-2.83 ± 0.52 b	-3.21 ± 0.43 b	-2.77 ± 0.64 b
Open dehesa	-0.99 ± 0.08 a	-1.92 ± 0.10	-2.32 ± 0.19 a	-1.74 ± 0.04 a
<i>Cistus</i> encroached	-1.34 ± 0.09 b	-2.05 ± 0.11	-2.68 ± 0.11 b	-2.02 ± 0.04 b
Open dehesa	-1.46 ± 0.06	-1.80 ± 0.04	-2.07 ± 0.14	-1.78 ± 0.03
<i>Retama</i> encroached	-1.28 ± 0.05	-1.51 ± 0.18	-2.19 ± 0.13	-1.66 ± 0.04

V – Conclusions

Tree thinning traditionally practiced for dehesa creation is a useful mechanism for *Q. ilex* to cope with summer drought, especially at dry sites. The improved water status of scattered trees allows them to assure an important acorn production most of the year.

The deep rooting system together with the slow-growing attitude of many oak species could determine a low competitive potential of oaks with herbaceous layer. Its low competitiveness together with its capacity to thrive in poor soils make oaks genre very suitable for long-term agroforestry systems in Iberian Peninsula. However, evergreen oaks frequently produce a diminution of soil moisture respect to open pasture. Hence, the potential benefit of trees has a small actual facilitative effect because the competitive use of soil water by trees overrides its positive effects, especially under semi-arid conditions of many Iberian dehesas and other Mediterranean open woodlands.

Encroachment of scattered-oak woodlands with *Cistus* understory produces a reduction of soil moisture, with negative consequences for both pasture and tree production. By contrast, the potential of *Retama* to use very deep water and to pump it to upper soil layers produce a significant increase of soil moisture in the pasture-rooted soil, with a positive effect on pasture understory production. By contrast the effects for tree water status and acorn production result rather negative. Although dehesa shrubs compete with trees for soil resources stronger than herbaceous plants do, the mature oaks are not substantially affected. Hence, dehesa encroachment can be recommended as mechanism to favour tree regeneration of dehesas (Pulido *et al.*, 2010) without compromising the short term productivity of trees. Nevertheless, these findings should not be generalized and further studies focusing specific combination of tree-shrubs species under different edaphoclimatic conditions will be needed.

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