



## System report: Iberian Dehesas, Spain

|                     |   |
|---------------------|---|
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## 1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to Objective 2, Deliverable 2.4: “Detailed system description of case study agroforestry systems”. The detailed system description covers the i) agroecology of the dehesa territory (climate and soil); ii) the components (trees, pasture/forage crops and livestock), their interactions, and the biological bases for their productivity; iii) the main marketable products, iv) selected ecosystem services such as carbon sequestration and biodiversity, and v) discussion of the economic value of dehesas.

## 2 Background

The Mediterranean wooded pasturelands known as “dehesa” in Spain and “montado” in Portugal, are agroforestry systems of high natural and cultural value (HNCV) that cover around 3.5 million hectares of the south-western Iberian Peninsula, where they are the main land use systems (Opermann et al. 2012) and form one of the largest agroforestry system in Europe (Eichhorn et al. 2006).

The importance of dehesas rests on both environmental and socio-economic values. First, dehesa plays a prominent role in the economy of rural areas in southwestern Spain (Escribano and Pulido 1998; Campos 2004; Pereira et al. 2004), because they occupy about 50% of grazing lands (Campos and Martín-Bellido 1997). In addition, dehesas are a fundamental component of regional identity, and are the source of high-quality food products derived from livestock production. In addition, dehesas have been valued at an international policy-making level for their biodiversity, aesthetic qualities and potential for tourism and recreation. Dehesas support a large number of species and a high diversity of habitats, being listed in the EU habitat directive as habitat with community-wide interest. Dehesas are among the best preserved low-intensity farming systems in Europe, and in them the integration of traditional land-use and biodiversity conservation is considered an exemplary land use management.

Nevertheless, over the last few decades, dehesas and other agrosilvopastoral systems in Europe have faced several threats due to intensive land use imposed by a concomitant change in the technological and socio-economic conditions and unfavourable agricultural policies (Moreno and Pulido 2009). Increased mechanisation and increase stocking rates, together with the oversimplification of the management practices (notably a lack of livestock herding), have increased at least three sources of environmental degradation: i) soil erosion rates due to changes in the vegetation cover, soil properties and hydrological processes (Schnabel et al. 2004); ii) over-aged oak

stands due to a prolonged lack of regeneration (Plieninger et al. 2010) and iii) loss of diversity at various spatial scales (Díaz et al. 2013). In this context, the sustainability of the dehesa system has been seriously questioned (Moreno and Pulido 2009), and a considerable debate concerning the long-term persistence of dehesas has emerged, because the current low economic profitability of most dehesa farms and because most stands have over-aged trees and saplings are extremely scarce.

To help dehesa farmer to overcome current difficulties and threats the University of Extremadura organised a stakeholder group focused on the Iberian dehesa in 2014. The initial meeting was held on 30 May 2014 in Plasencia at the Forestry School of the University of Extremadura. From the discussion initiated among stakeholders, together with the responses given to a semi-structured questionnaire a categorised list of constraints and opportunities, and a prioritised number of concerns and potential innovations for the development of Iberian dehesas were reported in the Milestone 2 (2.1) “Initial Stakeholder Meeting Report Dehesa farms in Spain” (Moreno 2014). Further on the innovations to be tested by the Participatory Research and Development Network in the course of the AGFORWARD project were reported in January 2015 in the Milestone 3 (2.2) “Report on Innovations for High Nature and Cultural Value Agroforestry” (Moreno et al. 2015a). Finally, in October 2015 the experimental protocol to follow in the field test of the innovations were reported in the Milestone 3 (2.3) “Synthesis of the research and development protocols related to agroforestry of high nature and cultural value” (Moreno et al. 2015b, 2015c).

Here, we present a comprehensive system description based on general descriptions and data compiled from the literature. Besides, the report include data measured in two well studied sites, one studied in SAFE project (<http://www1.montpellier.inra.fr/safe>) by the research team (Cuatro Lugares), and another currently studied in AGFORWARD (Farm 16 Majadas). For the latter case, a baseline assessment of the system functioning and productivity of the different components is currently conducted to provide data for modelling exercises. Missing data will continue to be sourced during 2016. Some issues identified key for dehesa persistence, such as a progressive soil degradation and deficit of tree regeneration, long term vegetation dynamic, and the role of the woody understory (matorral), are not addressed in this report.

### **3 Description of System**

#### **3.1 The system**

Dehesa agroecosystems are wood pastures where trees, native grasses, crops, and livestock interact positively under specific management practices. Basically, dehesas result from a simplification, in structure and species richness, of Mediterranean forests and shrublands, and are attained by clearing of evergreen woodlands, reducing tree density, eliminating shrub cover, and favouring the grass layer by means of grazing and crop culture. At present, dehesas occupy 2.3 million hectares in Spain and 0.7 million hectares in Portugal, where they are called “montados”.

Dehesas are characterized by the rearing of traditional livestock breeds at low stocking densities (cattle, sheep, pigs, and goats). For this reason the plant components of the system are managed according to the nutritional needs of the livestock. In a simple way the dehesa is structured in two plant layers, the herbaceous and the trees. The first generally consist of natural pasture although

crops and improved/sown pasture are also common. Trees, dispersed in low density, are regularly pruned with the aim of maximising acorn production, providing leafy branches in summer and winter when the herbage production is low, and woodfuel for household use and sale. Trees also provide shelter from heat in summer, prevent soil erosion and desertification, enhance the vegetation and structural complexity of the ecosystem, provide habitat and resources for many species, and are an important food resource for livestock, especially for pigs.

A third layer, shrub understory, is also common in dehesas. This usually has high diversity (it is frequent to find at least half a dozen of shrub species together, such as rockrose, heather, laurustine, strawberry tree, broom). These shrub species may have high nutritional interest (Hajer et al. 2004) both for the domestic livestock as well as for the game species. Recurrent shrub encroachment of dehesas may be needed to ensure the natural regeneration of the trees (Pulido and Díaz 2005). Nevertheless, this report will focus only on pasture/crop and tree layers.

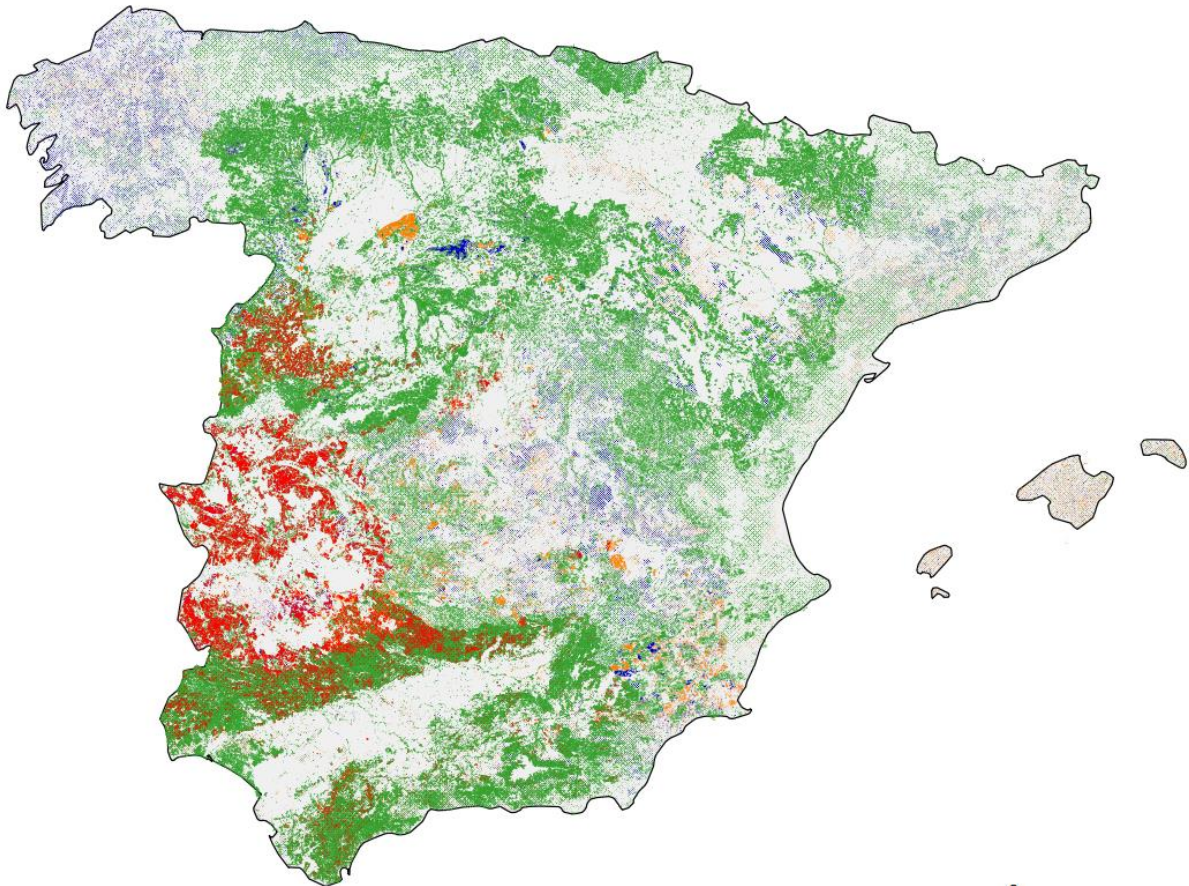


Figure 1. Distribution of dehesas in Spain (in red). Elaborated from SIOSE (2012) database.



Table 1. Main characteristics of the dehesas (adapted from Miguel et al. 2000)

| Main characteristics of the dehesas               |  |
|---|--|
| Productivity                                      | Low: 500-3000 forage units per hectare per year (Oviedo et al. 2013); 1-4 sheep ha <sup>-1</sup> .<br>Complements forest production or associated crops                    |
| Efficiency (production/resources used)            | High   |
| Variability                                       | High, both spatial and temporal  |
| Stability (productivity variation along the time) | High. Strong dependency on the variability of the annual Mediterranean climate   |
| Elasticity  | High. The system is able to recover after moderate human interventions   |
| Diversity   | High, biological as well as economic   |
| Direct Products                                   | Cereals, fodder/forage, meat (bovine, sheep, goat), cheese, hunting (partridge, rabbit, turtledove, deer, roe deer, wild boar), cork, fuelwood, charcoal, mushrooms, honey |
| Environmental Goods                               | High value landscape, erosion control, genetic resources (habitat of protected species), carbon sink   |



Figure 2. Holm oak dehesas managed for a grassland understory using periodic cultivation. Some shrubs invade locally and periodically some patches.

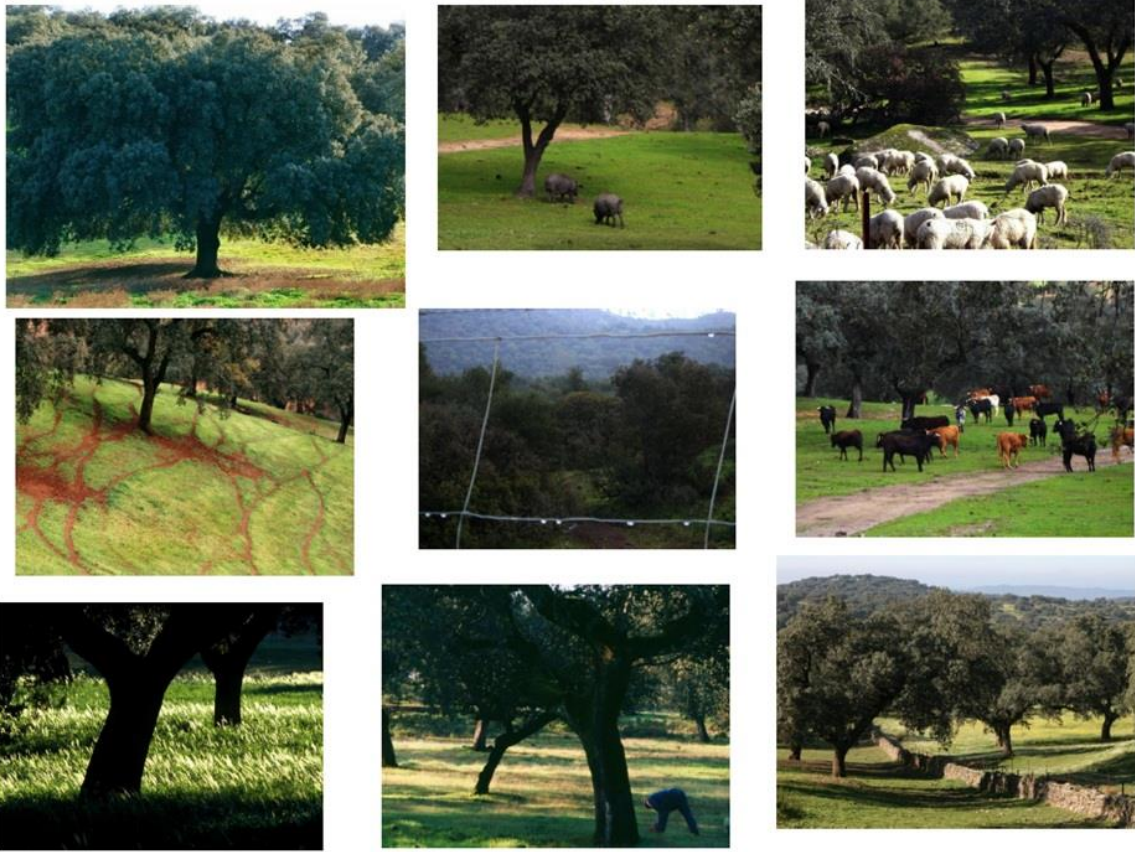


Figure 3. Details of dehesa agro-ecosystems where trees, pasture, livestock and human-built features are prominent

### 3.2 Biophysical characteristics

#### 3.2.1 Climate

The dehesa is mainly distributed in the southeast quadrant of the Iberian Peninsula where the climate is typically Mediterranean, with high climatic intra- and inter-annual variability. Rainfall is concentrated during the cooler months of the year and there is a long period of summer drought, with high temperatures and without relevant rain. The average rainfall in the areas where dehesas are found varies from 400 to 800 mm and the mean annual temperature ranges from 14 to 17°C. During periods of dry and sunny weather, with high evapotranspiration, plant-available water is quickly exhausted. In most years there is a water deficit between June and September. The typical climate of the dehesa is characterized in Figure 4 showing a four-month water deficit.

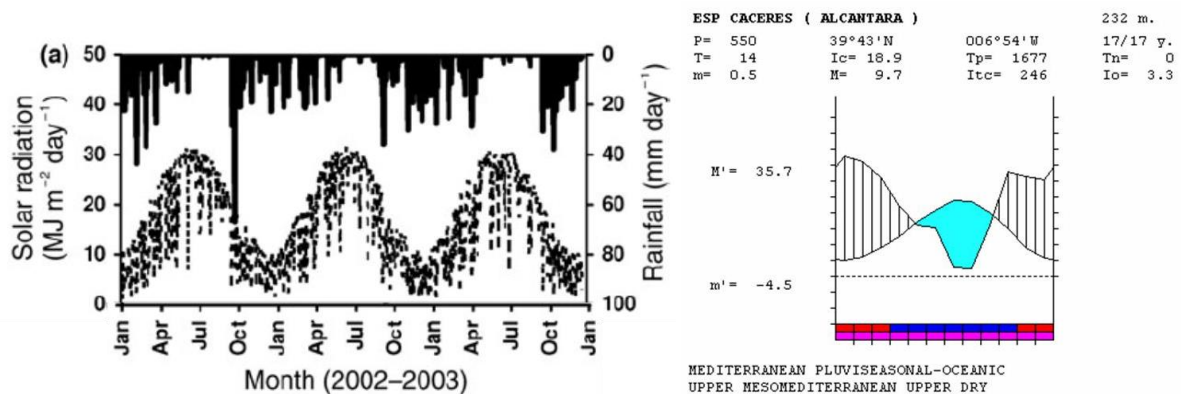


Figure 4 Seasonal variation of climatic variable in the Mediterranean territory

#### 3.2.2 Soil

The dehesas are basically in areas with undulating relief and moderate slopes. The plain areas are often cultivated and the more mountainous or steep areas are covered with forest or shrubs. The majority of the dehesas are between 350 and 550 m.a.s.l., although in the provinces in the North they are also frequently found at 800-900 m altitude and in the South at less than 100 m of altitude. Dehesas are usually found on acid soils (originating from siliceous nature (slate, granites, quartz rocks), with predominantly acid reaction), poor in nutrients and with shallow soils (rarely > 50 cm). This low fertility has limited the utilization for crops devoting most of the area to natural pasture. Soil variability is high in the dehesas as a result of erosion, transportation and sedimentation processes from hillsides and seasonal streams. The soil within a small area can range from red deep soils with a thick clay soil layer (e.g. luvisols) to shallow, stony soils (e.g. leptosols), and cambisols with different depths and development. A diversity of dehesa properties is likely to be found on any given farm.

Based on large-scale monitoring of dehesa soils conducted in Extremadura region (54 soil profile analysed), Schnabel et al. (2013) reported the main characteristics of dehesas soils. They have thin "A" horizons ranging from 2 to 8 cm and a sharp lower limit. Soil organic carbon content (SOC) is generally low, with a mean value of 11.6 g kg<sup>-1</sup>. Soils are acid, with 80% of samples being strongly to moderately acid (pH = 5.0–5.9). They have low contents of exchangeable cations and available phosphorus (Table 2). Bulk density is fairly high, with an average of 1.52 g cm<sup>-3</sup>, corresponding to a total porosity of 43%. Soils of the surface horizons have a poorly developed crumb structure and aggregates are of low stability, mainly related to low content of organic matter and clay.

Table 2. Soil characteristics of dehesa soils in the region of Extremadura. Data refer to mean values of 0-10 cm depth of samples taken in 54 dehesa farms (Schnabel et al. 2013)

| Soil property                   | Mean | Median | Percentile 0.1 | Percentile 0.9 | Standard deviation |
|---------------------------------|------|--------|----------------|----------------|--------------------|
| Clay (%) <sup>a</sup>           | 10.8 | 10.1   | 50.3           | 18.0           | 4.9                |
| Silt (%) <sup>a</sup>           | 38.9 | 40.0   | 18.5           | 53.2           | 12.5               |
| Sand (%) <sup>a</sup>           | 50.2 | 49.4   | 35.1           | 68.1           | 12.8               |
| Rock fragments (%) <sup>b</sup> | 20.0 | 18.5   | 8.1            | 32.6           | 12.5               |
| BD (g cm <sup>-3</sup> )        | 1.52 | 1.52   | 1.42           | 1.63           | 0.09               |
| pH                              | 5.43 | 5.40   | 4.99           | 5.87           | 0.46               |
| CEC (cmol kg <sup>-1</sup> )    | 8.3  | 8.0    | 4.1            | 11.9           | 3.3                |
| Ca (cmol kg <sup>-1</sup> )     | 3.3  | 3.2    | 1.2            | 5.6            | 2.4                |
| Mg (cmol kg <sup>-1</sup> )     | 1.0  | 0.7    | 0.2            | 2.0            | 1.1                |
| K (cmol kg <sup>-1</sup> )      | 0.2  | 0.2    | 0.1            | 0.4            | 0.2                |
| Na (cmol kg <sup>-1</sup> )     | 0.7  | 0.7    | 0.1            | 1.6            | 0.4                |
| Base saturation (%)             | 66.5 | 63.0   | 36.4           | 95.2           | 35.8               |
| N (g kg <sup>-1</sup> )         | 1.0  | 0.9    | 0.4            | 1.7            | 0.6                |
| P (g kg <sup>-1</sup> )         | 5.8  | 2.0    | 0.4            | 16.9           | 9.4                |
| SOC (g kg <sup>-1</sup> )       | 11.6 | 11.0   | 6.3            | 17.4           | 4.6                |

<sup>a</sup> Clay, silt and sand expressed as percentage weight of the fine fraction

<sup>b</sup> Rock fragments present the percentage weigh of the bulk sample

### 3.2.3 Canopy-caused resource gradients

In dehesas isolated trees have an important effect on the spatial and temporal heterogeneity of soils, which can determine the structure and function of the herbaceous and animal communities in the soil. Isolated oaks strongly reduce light availability for the plants beneath them. Montero et al. (2008) reported a 75% reduction in light close to the trunks of evergreen holm oaks in Spanish dehesa. Light availability increased rapidly with distance from the trunk, with 70% of the full sunshine reaching plants at the edge of the canopy, and 100% beyond about four times the canopy radius (Figure 5.). As a consequence of tree shade and interception of long-wave radiation at night, daily and seasonal variations of temperature are buffered under the canopy (Moreno et al. 2007a).

Oaks are long-lived trees, frequently more than 100 years old, and often over 300 years of age. Over an extended period, trees significantly affect the fertility of the soil, mostly by recycling leaf litter and by the turnover of nutrients that are moved through the root systems from deep in the soil and out beyond the canopy. Trees bring up nutrients from lower soil layers, inaccessible to herbaceous vegetation, and move nutrients laterally from areas beyond the canopy. As a result, more than 50% of the nutrients are annually recycled beneath the canopy in dehesas with a canopy cover of only 20% of the dehesa surface (Escudero 1992). Litterfall in dehesas is unusually high, with 1,900 kg ha<sup>-1</sup> as compared to 1,600 kg ha<sup>-1</sup> in dense holm oak sites (Escudero 1992). Additionally, the turnover rate on the soil surface of dehesa ecosystems is unusually high (Escudero et al. 1985). Dehesa litterfall decomposes up to 24 times faster than that in dense forest. The amount of litterfall accumulated on the soil surface is estimated at, respectively, 400 and 8,000 kg ha<sup>-1</sup> in dehesa and dense forest (Escudero et al. 1985). This rapid decomposition is explained by the action of herbivores, which can consume and recycle up to 85% of the plant mass, and also because net



mineralization is higher beneath than beyond the canopy cover, as Gallardo et al. (2000) reported for nitrogen dynamics.

In addition, trees are effective at retaining atmospheric solutes due to their high surface area and aerodynamic resistance, and throughfall and stemflow may contribute to soil nutrient inputs. Moreover, trees reduce possible losses of nutrients by erosion and leaching. In addition, part of the nutrient accumulation in the sub-canopy soil could occur at the expense of the adjacent area given that animals tend to concentrate below the tree canopies and the wide lateral root system of trees in dehesas can bring nutrients from the areas between the trees. As a result, nutrients show higher values beneath oaks than in adjacent open areas (González-Bernáldez et al. 1969; Escudero 1985; Puerto 1992; Gallardo 2003; Moreno et al. 2007a). Soil nutrient content generally decreases rapidly with distance and the influence of the trees disappears only a few metres beyond the canopy projection (Moreno et al. 2013). The nutrient content in these savannoid soils depends largely on the build-up of soil organic matter (SOM; Figure 5.). Values below  $10 \text{ g kg}^{-1}$  in the open and  $20 \text{ g kg}^{-1}$  beneath the canopy are frequent (Moreno et al. 2007b; Fernández-Moya et al. 2011). Nutrients affected by biological mechanisms, such as available nitrogen, reflect the spatial distribution of soil organic matter. The same is true for other nutrients; but phosphorus, which is principally determined by geochemical mechanisms, shows a highly variable spatial pattern more closely linked to physical variations in soils and parent material (Gallardo 2003).

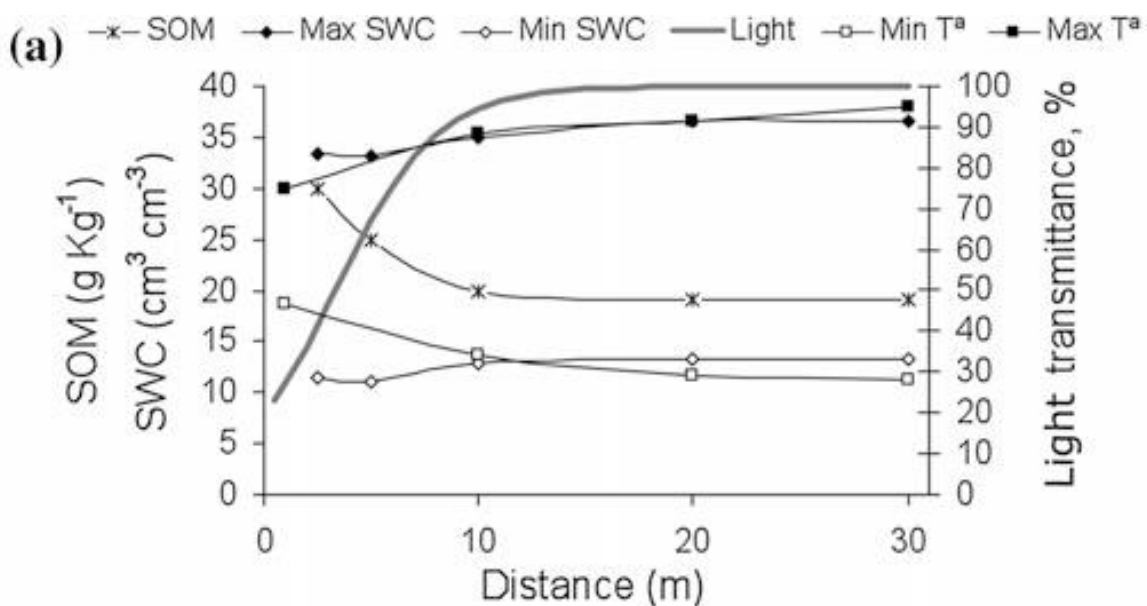


Figure 5. Distribution of resources under and around isolated holm oaks. Soil organic matter (SOM; 0–30 cm depth); Maximum and minimum soil water content (SWC; measured over 3 years at 0–100 cm depth); Light (Percentage of light transmitted measured by fish eye photograph method); Min Tª and Max Tª (Mean values of daily minimum temperature measured in coldest month and mean values of daily maximum temperatures measured in hottest month, July). Adapted from Moreno et al. (2007a).



Figure 6. Species composition, duration of green growth, and production may all differ under the oak canopy as compared to outside the canopy as in these examples from North Extremadura in Spain in midwinter (above) and early summer (below).

Oaks significantly modify soil physical properties beneath the canopy in Spanish dehesas, increasing soil water-holding capacity, macroporosity and infiltration rates compared to open areas (Joffre and Rambal 1988; Puerto and Rico 1989; Cubera and Moreno 2007a), explained mostly by the increase in soil organic matter and the decreased bulk density near the trees. Changes in physical properties explain much of the observed increases in soil water content (SWC) under tree cover found by Puerto and Rico (1989) and Joffre and Rambal (1993) in sub-humid (about 700 mm of annual rainfall) holm oak dehesa. In contrast, Cubera and Moreno (2007a), Gea-Izquierdo et al. (2009), and Moreno and Rolo (2011) found decreased soil water content near dehesa evergreen oaks, especially on the driest sites and/or during the driest years. This phenomenon is attributed to decreased water input because of interception, and an increase in water loss through transpiration under the canopy, which could outweigh the positive effects of trees on water-holding capacity (Cubera and Moreno 2007a). Evergreen oaks intercept rainfall; in one holm oak example 30% of the rainfall was

intercepted (Luis-Calabuig (1992) and Mateos and Schnabel (2002) reported values of 36.7% and 26.8% of the annual rainfall being intercepted, respectively), and the trees can absorb water from the soil continuously throughout the year with moderately high transpiration rates in winter and summer (Infante et al. 2003; David et al. 2004). The reasons for differences among sites are not yet clear, although Moreno et al. (2013) hypothesize that the net effect of trees on soil moisture becomes negative with the increase of aridity.

#### 3.2.4 *Rooting system*

Spatial separation between herbaceous plants and tree root systems has been reported by Joffre et al. (1987), Gómez-Gutiérrez et al. (1989), Moreno et al. (2005) and Rolo and Moreno (2012). They found that roots of native grasses were located mostly in the upper 30 cm, and root length density (RLD) decreased exponentially with depth to 70 cm (Figure 7.). In the same plots, holm oak had a lower root density in the first 10 cm of the soil, and oak root density remained almost uniform with depth at a given distance from the tree.

The limited vertical overlap of herb and oak root profiles suggests that competitive effects of understory herbs are unimportant for tree water uptake in dehesa. Cubera and Moreno (2007a) reported spatial separation between herbaceous plants and trees in relation to soil water uptake. Soil dried uniformly beneath and outside the canopy only for the uppermost 50 cm of the soil, while at deeper layers soil water content increased with the distance from the tree trunk, indicating that herbaceous plants did not use water below 50 cm depth, as is consistent with their root system. Joffre et al. (1987) reported similar values, with annual and perennial grasses absorbing water from the uppermost 40 and 60 cm of the soil, respectively.

By contrast, during summer drought holm oak trees show a high dependence on water below 3 m depth (Cubera and Moreno 2007a). The low dependence of trees on water in the uppermost soil layer was shown in an experimental irrigation trial, where holm oak did not respond to irrigation in terms of fecundity, acorn production or shoot elongation (Pulido et al. 2013). Thus, while water limitation is an important feature in most dehesas, water consumed by grasses (and cereal crops) probably does not cause significant water stress to mature dehesa trees if tree roots can reach deep soil layers (Cubera and Moreno 2007a).

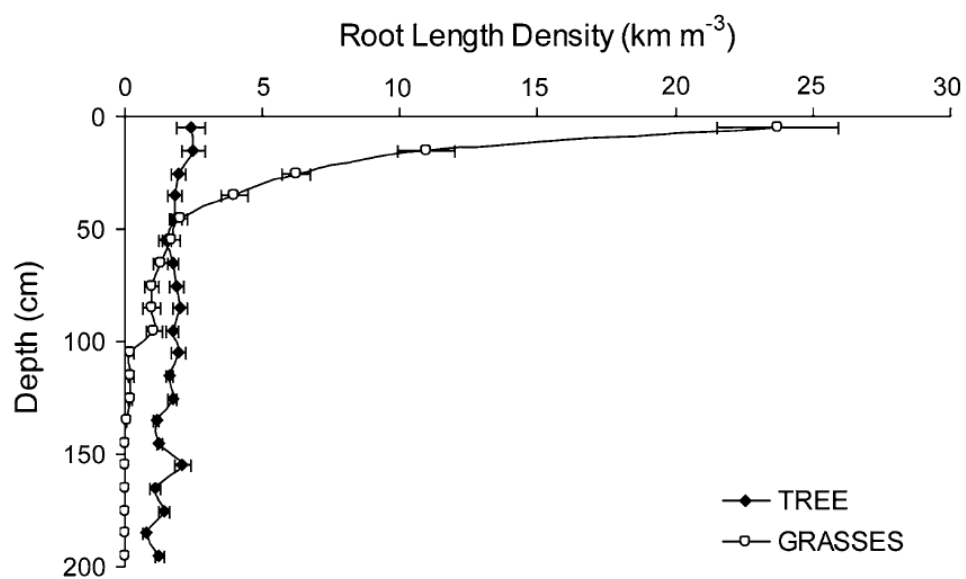


Figure 7. Rooting profiles of trees and native grasses in holm oak dehesa. Adapted from Moreno et al. (2005).



Table 3. Environmental conditions and components in the series of dehesa farms that participate of the AGFORWARD research network.

| Site name                                      | Las Parras   | Monteviejo   | Atoquedo  | Valdesequera  | Dehesilla   | Los Varales  | Casablanca   | La Higaleja  | La Casilla   | La Cabra   | Los Llanos  | Majadas   |
|--|--|--|---|---|---|--|--|--|--|--|---|---|
| Coordinates (N, E)                             | 40.1324<br>-6.5199   | 40.0312<br>-6.6326   | 39.7694<br>-5.9340  | 39.0598<br>-6.8516  | 39.8200<br>-5.5164  | 38.7720<br>-6.8536   | 40.1500<br>-6.1110   | 40.1635<br>-6.2875   | 39.4858<br>-7.1413   | 39.1908<br>-6.7055   | 38.9831<br>-5.0165  | 39.9403<br>-5.7746  |
| Area (ha)                                      | 24   | 3  | 275   | 6   | 1.5   | 5.5  | 15   | 2.5  | 100  | 6  | 6.5   | 50  |
| AMT (°)  | 15.4   | 16.0   | 15.8  | 16.6  | 15.8  | 15.9   | 15.2   | 15.0   | 15.8   | 14.9   | 15.6  | 16.1  |
| AMP (mm)                                       | 739  | 649  | 546   | 523   | 640   | 543  | 715  | 771  | 577  | 721  | 628   | 753   |
| Soil   | Haploxeralf<br>Xerochrept<br>Acid,<br>Very low SOC<br>Clay-Loam  | Xerochrept<br><br>Acid<br>Low SOC<br>Sandy-Loam  | Ochraqualf<br>Palaxeralf<br>Very acid<br>Moderate<br>SOC; Sand-<br>clay-loam                                | Ochraqualf<br>Palaxeralf<br>Mid acid<br>Moderate<br>SOC; Sand-<br>clay-loam           | Xerochrept<br><br>Very acid<br>Very low SOC<br>Sand-loam  | Haploxeralf<br>Rhodoxeralf<br>Neutral<br>Very low SOC<br>Sandy-clay-<br>loam       | Xerochrept<br><br>Very acid<br>Low SOC<br>Sandy-loam   | Xerochrept<br><br>Very acid<br>Moder. SOC<br>Sandy-loam  | Xerochrept<br><br>Mid acid<br>Low SOC<br>Sandy-loam                              | Xerochrept<br><br>Mid acid<br>Very low SOC<br>Sandy-loam                         | Xerochrept<br><br>Mid acid<br>Very low SOC<br>Sandy-loam  | Haplaquept<br>Ochraqualf<br>Very acid<br>Very low SOC<br>Sandy-clay-<br>loam                              |
| Tree<br>(Q. =<br><i>Quercus</i> )<br>(t= tree) | <i>Q. ilex</i><br>< 10 t ha <sup>-1</sup>  | <i>Q. ilex</i><br>< 10 t ha <sup>-1</sup>  | <i>Q. ilex</i><br>25 t ha <sup>-1</sup>   | <i>Q. ilex</i><br>20 t ha <sup>-1</sup>   | <i>Q. ilex</i><br>25 t ha <sup>-1</sup>   | <i>Q. ilex</i><br>20 t ha <sup>-1</sup>  | <i>Q. ilex</i><br>30 t ha <sup>-1</sup>  | <i>Q. pyrenaica</i><br>16 t ha <sup>-1</sup>   | <i>Q. ilex</i> (50%)<br><i>Q. suber</i><br>(50%)<br>???? t ha <sup>-1</sup>      | <i>Q. ilex</i><br>?? t ha <sup>-1</sup>  | <i>Q. ilex</i><br>10 t ha <sup>-1</sup>   | <i>Q. ilex</i> (90%)<br><i>Q. faginea</i><br>(8%) <i>Q.</i><br><i>Suber</i> (2%)<br>26 t ha <sup>-1</sup> |
| Understory                                     | Natural<br>pasture and<br>shrublands<br>with <i>Retama</i><br><i>sphaerocarp</i><br>a and <i>Cytisus</i><br>spp. | Natural<br>pasture   | Natural<br>pasture and<br>sown<br>pasture rich<br>in legumes  | Natural<br>pasture  | Natural<br>pasture and<br>shrublands<br>with <i>Retama</i><br><i>sphaerocarp</i><br>a                 | Natural<br>pasture and<br>cereal crops   | Natural<br>pasture   | Natural<br>pasture,<br>sown<br>pasture rich<br>in legumes &<br>shrublands<br>of <i>Cytisus</i><br>spp. | Natural<br>pasture and<br>sown<br>pasture rich<br>in legumes                     | Natural<br>pasture and<br>sown<br>pasture rich<br>in legumes                     | Natural<br>pasture and<br>sown<br>pasture rich<br>in legumes  | Natural<br>pasture  |
| Animal   | Cattle<br>0.5 LU ha <sup>-1</sup>  | Fighting bulls<br>0.45 LU ha <sup>-1</sup>   | 1.67 ewes<br>and 0.05<br>goat ha <sup>-1</sup>  | Sheep and<br>pigs   | Cattle,<br>0.4 LU ha <sup>-1</sup>  | Sheep and<br>pigs,<br>4 ewes and<br>0.5 pigs ha <sup>-1</sup>                      | 0.37 cows,<br>1.5 calves<br>and 0.25 pigs<br>ha <sup>-1</sup>                                  | Cattle   | Cattle   | Cattle   | Sheep   | Cattle<br>0.3 LU ha <sup>-1</sup>   |
| Contact  | Alfonso<br>García<br>Cobaleda<br><a href="mailto:sitocob@gmail.com">sitocob@gmail.com</a>                        | Victorino<br>Martín<br>García,<br><a href="mailto:oficina@victorinomartin.com">oficina@victorinomartin.com</a> | Enrique<br>Rodríguez-<br>Arias,<br><a href="mailto:enrique.r.arias@gmail.com">enrique.r.arias@gmail.com</a> | Angel<br>Rodriguez;<br><a href="mailto:agrodehesa@gmail.com">agrodehesa@gmail.com</a> | Victor Arroyo<br>Gubau,<br><a href="mailto:victorarroyo92@hotmail.com">victorarroyo92@hotmail.com</a> | Ángel<br>Albarrán<br>Liso,<br><a href="mailto:angliso@unex.es">angliso@unex.es</a> | Enrique Vega<br>Rubio,<br><a href="mailto:quiquevegar@hotmail.com">quiquevegar@hotmail.com</a> | Alejandro<br>Martín,<br><a href="mailto:info@asedagro.com">info@asedagro.com</a>                       | Alejandro<br>Martín,<br><a href="mailto:info@asedagro.com">info@asedagro.com</a> | Alejandro<br>Martín,<br><a href="mailto:info@asedagro.com">info@asedagro.com</a> | Miguel<br>Cabello<br>Cardeñosa,<br><a href="mailto:alydecabello@hotmail.com">alydecabello@hotmail.com</a> | Gerardo<br>Moreno<br><a href="mailto:gmoreno@unex.es">gmoreno@unex.es</a>                                 |

### 3.3 Components of the system

#### 3.3.1 Herbaceous pasture

Dehesa pastures are rich in annual plant species and exhibit a high temporal and spatial variability. The maximum production of the herbaceous pasture is obtained in spring (around 70%) and autumn, while pasture growth is at a minimum in winter and summer (Figure 8).

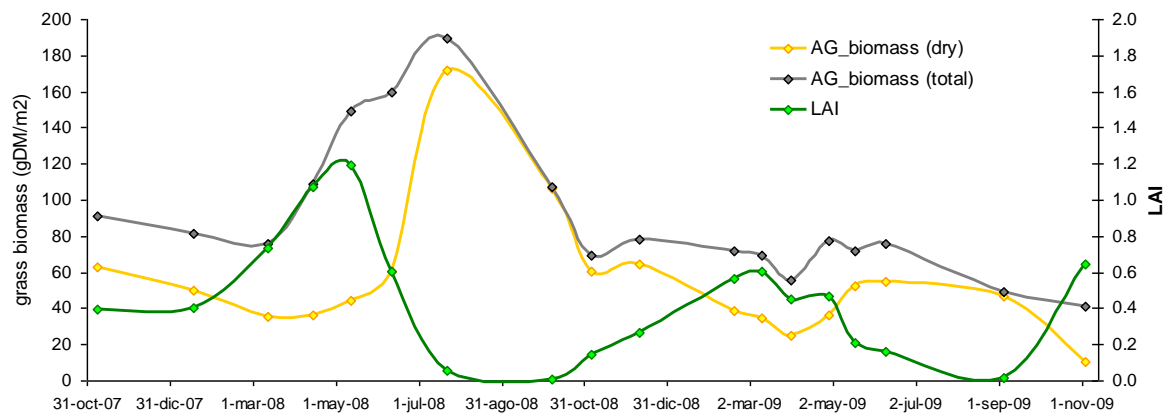


Figure 8. Seasonal evolution of green and dry pasture biomass in Majadas dehesa farm (Spain). Source: Unpublished data (Arnaud Carrara; CEAM, Valencia; Spain).

The most important natural pastures of the dehesa may be divided functionally in three groups. The first (*common annual pastures*) occupy the shallower/poorer soils of the dehesas, which usually covers most of the dehesa. This is composed almost exclusively of annual and short species that has been stabilized by grazing and/or by cultivation. Drying occurs prematurely at the end of spring. These are pastures with annual production of between 1000 and 2700 kg DM ha<sup>-1</sup> year<sup>-1</sup> depending on the site condition and year (López-Díaz et al. 2009).

The second type of natural pasture is known as *majadal*. This is a pasture composed of annual and very dense bi-annual species, small in size and usually of good nutritional quality, created by the intense and continuous action of the livestock, where the presence of gramineum *Poa bulbosais* and the legume *Trifolium subterraneum* is noticeable. Its creation was due to the traditional management of sheepfolds. This consists of concentrating the presence of the animals in one area for 2-3 consecutive nights so that the animals may fertilize it with their manure/dung. The dry matter production in the *majadal* (around 3000 kg ha<sup>-1</sup> year<sup>-1</sup>) is generally higher than the first type because this has a higher capacity of re-sprouting. Its palatability and nutritional quality is superior because the subterranean clover contributes to the increase in the protein content through the pasture. However, the *majadales* are not only important due to its productive qualities but above all, to its strategic value, that is determined by two features: in spring the subterranean clover dries lengthily and provides an important quantity of digestible matter when the animals' need for protein is higher because of lactation. In autumn, *Poa bulbosa* is the species that readily resprouts after the first rains and consequently determines the start of the autumn grazing period and the end of the artificial supplementation.

In the depressions of the dehesas located in poor substrate bases and where the phenomenon of seasonal abnormal existence of water or humidity in the soil or subsoil (not very prolonged and

ceases in summer) occur, a third type of natural pasture develops known as *vallicares*. These are mostly made up of bi-annuals that flower at the end of the spring and dries in the middle of summer with abundant tall gramineous and few legumes. Its pastoral value is average because although its productivity is high, its palatability and nutritional quality is not high as it lacks legumes. However it is the only grazing area that remains green during the long period of summer. That is why they may play an important contribution to shorten the summer scarcity of food and thus reduce the cost of the owner and increase the possibilities of self-sufficiency in the dehesa. The annual production of *vallicares* is usually between 1500 and 2500 kg DM ha<sup>-1</sup>.

Table 4. Major features of the dehesa natural pastures (Olea and San Miguel 2006)

|                  | Character                                     | Description  |
|------------------|---|--|
| Natural pastures | Major role                                    | Providing fodder for livestock   |
|                  | Communities                                   | Usually annual grasslands: <i>Helianthemetalia</i> , <i>Thero-Brometalia</i> , <i>Sisymbrietalia</i> . Edapho-hygrophilous perennial grasslands ( <i>Agrostietalia</i> ) grow on valley beds and wither in mid-summer. The optimum grassland community is the 'majadal' ( <i>Poetalia bulbosae</i> ), a dense sward of annuals and perennials with a rather high representation of legumes (protein) created and maintained by intensive and continuous livestock grazing.   |
|                  | Production                                    | 1000-2700 kg ha <sup>-1</sup> a <sup>-1</sup> (DM). Majadal pastures usually around 3000 kg ha <sup>-1</sup> a <sup>-1</sup> DM, with early growth start in autumn and late withering  |
|                  | Yearly distribution of the fresh fodder yield | Spring: 60-70%<br>Summer: 0%<br>Autumn: 15-20%<br>Winter: 5-15%<br>Highly variable due to a very high climatic variability   |
|                  | Management goals                              | Legumes are essential due to their protein supply and their nutritional quality is high enough for the maintenance requirements of livestock. Supplementary feeding can then be avoided or reduced (Olea et al. 1989; Olea and Viguera 1998).  |
|                  | Improvement                                   | Sustainable but intensive grazing aimed at increasing the pasture quality and at recycling limiting nutrients<br>P fertilization (25 to 35 kg P <sub>2</sub> O <sub>5</sub> ha <sup>-1</sup> during the first year and 18-25 thereafter) aimed at favouring legumes, whenever their abundance is high enough to ensure good results (Moreno et al. 1993, 1994). The available P level should be high enough: 8-12 ppm, Olsen method (Granda et al. 1991). Superphosphate is the usual product, but natural phosphates (ecological products) are also showing good results (Olea et al. 2005) |

Deciduous and evergreen oaks affect the production, species composition, chemical quality and phenology of the understory in Iberian dehesas (González Bernáldez et al. 1969; Alonso et al. 1979; Puerto et al. 1987; Calabuig and Gómez 1992; Moreno 2008; Gea-Izquierdo et al. 2009; Marañón et al. 2009; Fernández-Moya et al. 2011; Rivest et al. 2011a). This common feature is explained by the spatial heterogeneity of resources created by the presence of scattered trees in these systems. Grasses are dominant beneath the canopy, while legumes and forbs become more abundant in the

less fertile interspaces (Marañón 1986; Puerto 1992). This difference may be explained by the increased content of soil nitrogen and the nitrogen mineralization rate beneath oak canopy (Gallardo et al. 2000), which favours grasses as they need more soil nitrogen to thrive, while legumes and forbs are less dependent on soil nitrogen (Joffre 1990). The herbaceous understory has a higher content of some nutrients (mainly N and K) in plants beneath than outside the canopy (González-Bernáldez et al. 1969; Puerto 1992; Moreno et al. 2007a, b). However, the understory responds to increased nutrient availability mostly through increased growth and changes in botanical composition and not so much through increases in plant nutrient concentrations (Gea-Izquierdo et al. 2010; Rolo et al. 2012).

A longer growing season beneath the tree canopy, with an earlier start in winter and later drying in summer, is reported (Alonso et al. 1979; Puerto et al. 1987, 1990; Calabuig y Gómez 1992). Warmer temperatures beneath canopy would allow continued understory growth in winter compared to open pasture (Moreno et al. 2007a). Dominant grasses beneath a dehesa canopy dry out later in summer than forbs and legumes that are dominant outside of the canopy because grasses are capable of using water from deeper soil layers (Joffre et al. 1987; Figure 9.).

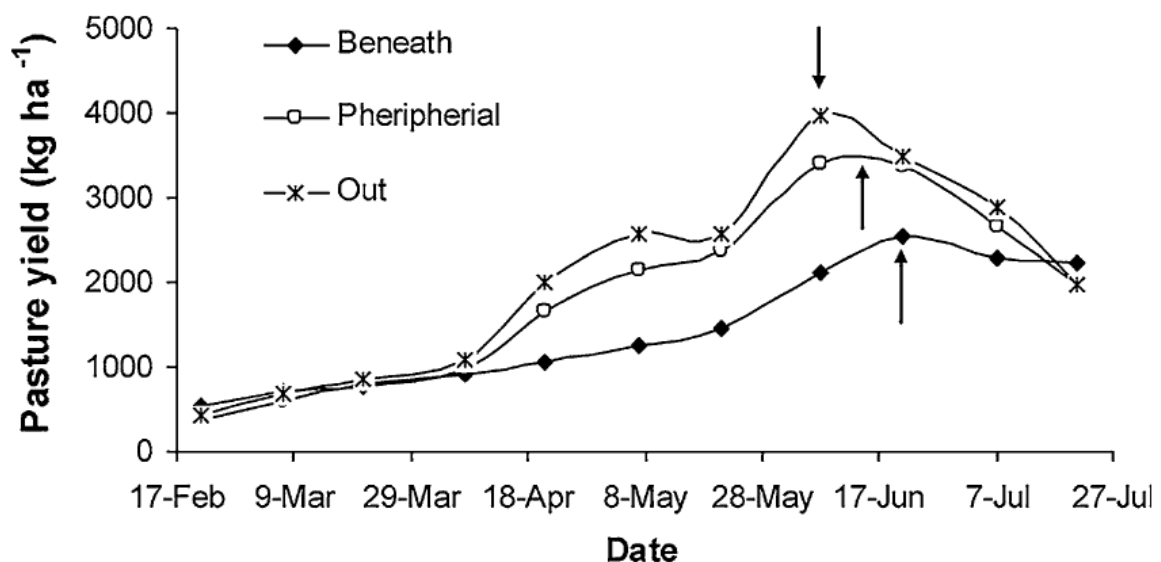


Figure 9. Temporal evolution of forage yield at three distances from holm oak trees. Note the decrease of pasture yield beneath the canopy, and the temporal difference for the maximum yield. Adapted from Puerto (1992).

The net effect of trees on understory production depends on the balance of positive, or facilitative effects and negative, or competitive effects (Marañón et al. 2009; Table 5). Studies reveal that the effect of trees on the understory in open oak woodlands is highly variable, ranging from decreased to increased production (see examples in Puerto 1992). The direction and magnitude of these effects depends on environmental factors like precipitation, soil type and fertility as well as biological factors like the species in the understory, the kind of oaks, amount of canopy cover, tree age, and the root architecture of the interacting plants in the community (Rivest et al. 2013). In a manipulative experiment conducted in three dehesas, Moreno (2008) found that pasture yield was higher beneath the canopy. But in fertilized and watered plots pasture yield was significantly higher



under artificial shade (50% full-sunlight) than under the canopy, showing that shade, despite the negative influence of reducing light for photosynthesis, probably played a greater positive role by reducing damage to photosynthetic apparatus from too much light (photoinhibition). Indeed, it has been pointed out that in a Mediterranean climate, maximum production of dehesa understory is obtained with around 30 % of overstory cover (Etienne 2005).

Table 5. Compilation of data on pasture production in dehesas comparing beneath canopy, in the peripheral area and out of the influence of the trees

| Source                       | Site                       | Year        | Production beneath trees (kg ha <sup>-1</sup> ) | Production in the peripheral area (kg ha <sup>-1</sup> ) | Production with no trees (kg ha <sup>-1</sup> ) |
|------------------------------|----------------------------|-------------|---|--|---|
| 1992 Puerto                  | Salamanca province         | 1982        | 2559  | 3495   | 3994  |
| 1992 Puerto                  | Salamanca province         | ?           | 3062.3  | 3074   | 3097.3  |
| 2009 López-Carrasco and Roig | Toledo province            | 2008        | 1492.7  | 1962.4   |   |
| 2009 Cubera et al.           | Herdade da Mitra, Portugal | 2001        | 313 ± 37  |  | 163 ± 43  |
| 2009 Cubera et al.           | Herdade da Mitra, Portugal | 2002        | 204 ± 30  |  | 121 ± 31  |
| 2009 Gea-Izquierdo           | North of the Extremadura   | 2004        | 3013  | 2479   | 1905,3  |
| 2009 Gea-Izquierdo           | North of the Extremadura   | 2005        | 977.3   | 958  | 841,5   |
| 2009 Gea-Izquierdo           | North of the Extremadura   | 2006        | 2594.7  | 2562   | 2013,8  |
| 2011 Fernández-Moya          | Toledo province            | 2008        | 1552.5  | 1973.5   | 2508  |
| 2011a Rivest et al.          | North of the Extremadura   | 2007        | 1800 ± 100                                      | 2200 ± 100   | 2500 ± 100                                      |
| 2011a Rivest et al.          | North of the Extremadura   | 2008        | 1400 ± 100                                      | 2000 ± 100   | 2600 ± 200                                      |
| 2011a Rivest et al.          | North of the Extremadura   | 2009        | 450 ± 50  | 500 ± 50   | 700 ± 50  |
| 2011a Rivest et al.          | North of the Extremadura   | 2010        | 1900 ± 70                                       | 1900 ± 70  | 1800 ± 70                                       |
| 2014 Dubbert et al.          | Lisboa, Portugal           | 2011        | 2880  |  | 2960  |
| 2015 Carranza et al.         | Estremoz, Portugal         | 2011 & 2013 | 4392.2  |  | 4278.3  |
| 2015 López-Carrasco et al.   | Oropesa, Toledo            | 2008        | 855   |  | 1043  |
| 2015 López-Carrasco et al.   | Oropesa, Toledo            | 2009        | 206   |  | 918   |
| 2015 López-Carrasco et al.   | Oropesa, Toledo            | 2010        | 1784  |  | 1687  |

Although a sparse canopy can produce more understory growth, trees do intercept a certain proportion of solar radiation that could be used for photosynthesis and take up water and nutrients, making them unavailable for understory plants. As a consequence, many cases of significant reduction of pasture yield beneath oak canopy compared to open pasture have been reported, especially with evergreen oaks (Puerto 1992; Nunes et al. 2005; Rivest et al. 2011a for holm oak). These studies confirm that trees compete for resources with the understory. In the three dehesa experiments conducted by Moreno (2008), when the main nutrient (N, P, K) limitations were

removed through fertilization, artificial shade produced a higher understory yield than tree shade, suggesting that negative effects, such as competition for soil water may limit production under the canopy. The stress gradient hypothesis has not been confirmed for dehesa. In fact, Moreno's (2008) experiment indicated the opposite. Understory yield beneath the canopy was higher than in the adjacent open grassland, but differences decreased with the aridity of the sites. Similarly, Gea-Izquierdo et al. (2009) reported a positive effect of oak canopy on dehesa pasture yield in average climatic years, but the interaction changed with increasing abiotic water stress. In a dry year, the higher fertility beneath the canopy could not be used for plant growth because of the lack of water and the effect of the oak canopy was neutral. The decreased positive effect of trees with aridity in Spanish dehesas indicates that competition for soil water is an outstanding factor in the balance of positive and negative effects of trees on pasture.

### 3.3.2 Forage crops

Some of the major features of dehesa crops and sown pasture are presented in Table 6.

Table 7. Major features of the dehesa crops and sown pastures (Olea and San Miguel 2006)

|       | Character                          | Major features of the crops and sown pasture in the dehesa  |
|-------|------------------------------------|---|
| Crops | Major role                         | Complementing the fodder yield of natural pastures, both in seasonal distribution and quality   |
|       | Types                              | Cereal crops: oat, barley, rye, wheat, triticale. They complement the fodder yield of natural pastures both in seasonal distribution (summer, late winter) and quality (energy). Grain is the most valuable product. It is usually collected, but it may also be harvested by direct summer grazing, since transhumance is no longer being carried out. Straw is also collected or grazed. Sometimes, there is a late winter grazing period of leafy biomass followed by a resting season until the summer grain harvest. Sown pastures are usually grazed or cut. In the first case, legumes are essential, so subterranean clover ( <i>Trifolium subterraneum</i> ) and other auto-reseeding legume species are the basis for permanent sown pastures (Olea et al. 2005). They complement the fodder yield of natural pastures in quality (protein) and, to a lesser degree, in seasonal distribution (air dry biomass and seeds). In the second case, vetch-cereal (oat, triticale, barley), with a 3:1 weight rate and conservation as hay, is the usual choice. However <i>Lolium multiflorum</i> and winter cereals are also a choice. Hay is used as summer and winter fodder. |
|       | Production (average climatic year) | Cereal crops: grain (1000-3000 kg ha <sup>-1</sup> ), straw (2000-5000 kg ha <sup>-1</sup> )<br>Sown pastures: legume rich permanent pastures: around 3000 kg DM ha <sup>-1</sup> ; vetch-cereal: 3000-6000 kg DM ha <sup>-1</sup>  |
|       | Management                         | Two-three tilling treatments before sowing (late winter, late spring, early autumn) followed by early autumn sowing. Fertilization: cereal crops: N-P-K usually 200-300 kg ha <sup>-1</sup> (8-24-8 or 15-15-15); legume rich permanent pastures: P (at least 35-40 kg P <sub>2</sub> O <sub>5</sub> ha <sup>-1</sup> before sowing)<br>Vetch-cereal: N-P-K usually 200-300 kg ha <sup>-1</sup> of 8-24-8; legume rich permanent pastures should be sown only when natural pastures show a very low abundance of legumes. In any other case, P fertilization becomes a better option.   |

The presence of periods with low or scarce production in the dehesa (summer and winter) frequently forces owners to plant pasture or fodder crops that may be used during these periods. These are planted on the best soils of the farms where the topography allows mechanization (and occasionally irrigation). Widely used cultivated forage in the dehesas include cereals like barley, oats and wheat (for the production of dried grains in summer), or rye (consumed green at the end of winter and spring). Typical production levels are 1000-3000 kg ha<sup>-1</sup> for grains and 2000-5000 kg ha<sup>-1</sup> for biomass. Other sown species include a mix of species of the genus *Vicia* (*Vicia sativa* or *Vicia villosa*) and *Avena sativa*, which can produce 3000-6000 kg ha<sup>-1</sup> of hay per year, and cultivated forages of annual grasses like *Lolium multiflorum* for hay production. Lastly, planted pasture mixes typically include a low content of grasses with diverse legumes that regenerate naturally, such as subterranean clover (*Trifolium subterraneum*). These pastures are grazed or harvested with annual production levels of around 3000 kg ha<sup>-1</sup>. These pastures are only sown when the proportion of the legumes in the original pasture is very low. If not, the fertilization with phosphorus would be sufficient (Olea and San Miguel 2006).

### 3.3.3 Tree layer

Trees, typically between 20 and 40 trees per hectare (10-50% canopy ground cover), are maintained not only to protect the soil and the herbaceous layer but also to provide diverse products to the system (fruits, fuel wood, cork, fodder) (Table 8). The most frequent species are holm oak (*Quercus rotundifolia*) and the cork oak (*Quercus suber*), both xerofitic evergreens. The holm oaks are in the interior regions and the cork oaks are present in more temperate and humid regions, with more Atlantic influence. The first are very good producers of fruits (low-tannins-content acorns or sweet acorns) while the second are very much appreciated for its production of cork. Other species present in the more humid dehesas are different oaks (*Quercus faginea* and *Q. pyrenaica*) and ash (*Fraxinus agustifolia*). These tree species are valued for fodder (branches are pruned for food in periods of pasture scarcity). Also present, although marginally, are various species such as chestnut (*Catanea sativa*), and junipers (*Juniperus* sp.) and pines (*Pinus* sp.). Conifers are generally only for protection purposes (Miguel et al. 2000).

The low density allows trees to survive and continue to produce even in severe drought conditions. Wider spacing between trees implies greater water availability for each tree, resulting in a reduction of the duration and intensity of tree water stress compared to trees growing in more closed forests of the same regions. Numerous authors report higher water potential and photosynthetic and transpiration rates at leaf and tree scales during the summer for holm and cork oaks in the dehesa, as compared to closed stands (Joffre and Rambal 1993; Infante et al. 2003; David et al. 2004; Moreno and Cubera 2008). Also the absence of shrub understory improves significantly the water potential and photosynthetic of dehesa trees (Rolo and Moreno 2011). The spacing of trees is more critical in the driest open woodlands. Moreno and Cubera (2008) reported that in dry dehesas (annual rainfall < 500 mm), both predawn and midday water potentials, CO<sub>2</sub> accumulation, and transpiration rates were significantly higher in trees growing in low tree density areas (20 trees ha<sup>-1</sup>) compared to those in high tree density areas (100 trees ha<sup>-1</sup>). By contrast, in humid dehesas (annual rainfall 700 mm), differences in both water potentials and CO<sub>2</sub> accumulation among tree densities were very small and emerged only at the end of the dry season (Figure 10.). Indeed, Joffre et al.

(1999) reported for Spanish dehesas that mean oak density increases with rainfall at a large geographical scale. Apart from the direct positive effect of low tree density on tree water status, Úbeda et al. (2004) reported a clear benefit of forest clearance on the leaf nutrient content in cork oak. As a result of the improved hydric and nutritional status of trees in dehesas the production of acorns was 10 times higher in a managed holm oak dehesa compared to a dense holm oak forest (Pulido and Díaz 2005).

Table 8. Major features of the dehesa tree layer and its management (Olea and San Miguel 2006)

|            | Character                      | Major features of the crops and sown pasture in the dehesa  |
|------------|--------------------------------|---|
| Tree layer | Major role                     | Stability, structure, landscape, climate, shelter, biodiversity, C fixation, cultural benefits, and fodder. Perennial sclerophyllous species might be fodder reserves for livestock and wildlife  |
|            | Species                        | <i>Quercus ilex rotundifolia</i> (= <i>Q. ilex ballota</i> ), <i>Q. suber</i> (sclerophyllous and perennial), <i>Q. faginea</i> , <i>Q. pyrenaica</i> (semi-deciduous) and other less important species.  |
|            | Density                        | (15) 20 – 100 (200) adult trees ha <sup>-1</sup>  |
|            | Crown                          | (5) 10 – 50 (70)%   |
|            | Basal area                     | 2 – 10 (15) m <sup>2</sup> ha <sup>-1</sup>   |
|            | Products:<br>Mean annual yield | Fuelwood: 800-5000 kg DM ha <sup>-1</sup> per rotation<br>Browse (pruning or direct browsing): 400-1500 kg DM ha <sup>-1</sup> from pruning.<br>Acorn: (100) 200 – 600 (800) kg ha <sup>-1</sup> , with inter-annual variations (Olea et al. 2004; López-Carrasco et al. 2005) Cork (only <i>Q. suber</i> ): 500-1500 (2000) kg ha <sup>-1</sup> per rotation<br>The importance of acorns usually increases with the age of the dehesa, while browsing decreases. |
|            | Silvicultural rotations        | Regeneration felling: tree senescence (150 years for <i>Q. suber</i> and 250-300 years for other species)<br>Pruning: 10-15 years; debarking: 9-12 years  |
|            | Threats                        | The lack or shortage of natural regeneration of trees in many dehesas is an important threat. This is exacerbated by the sudden dying-off of many trees known as 'seca'   |



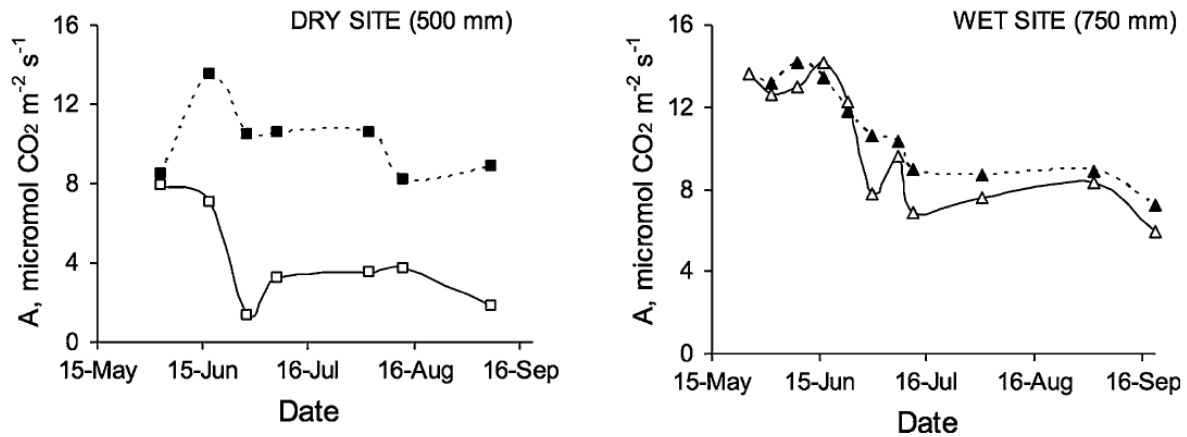


Figure 10. Mean values for CO<sub>2</sub> accumulation rates in mature holm oak growing in dehesa with a canopy cover below 20% (black square or triangle) and dense coppice with canopy cover above 90% (open square or triangle). Adapted from Moreno and Cubera (2008).

### 3.3.4 Tree layer productivity: browse and acorns

The typical fruit of the dehesa is the acorn, whose consumption by livestock is important in the areas with mild winters. The highest quality acorns are obtained from holm oak, followed by that of Portuguese oak (*Quercus faginea*), cork oak (*Quercus suber*) and pyrenean oak (*Quercus pyrenaica*). Acorn is a food source low in protein and rich in carbohydrates that are easily transformed into fat that is why they are given to fully developed animals for fattening (Escribano and Pulido 1998). Pigs are the best consumers of acorn in the dehesas, and the Iberian breed can eat them without supplements. For other livestock species, acorns can only be used to supplement a diet. Annual acorn production is highly variable in the dehesa, but a typical mean value for holm oak would be 500 kg ha<sup>-1</sup>, with values up to 800 kg ha<sup>-1</sup> in some cases (Table 8). Other studies predict long term production equivalent to 100 kg ha<sup>-1</sup> a<sup>-1</sup> (Figure 11). In cork oak, mean annual acorn production is around 400-600 kg ha<sup>-1</sup> or 18 -20 kg tree<sup>-1</sup>.

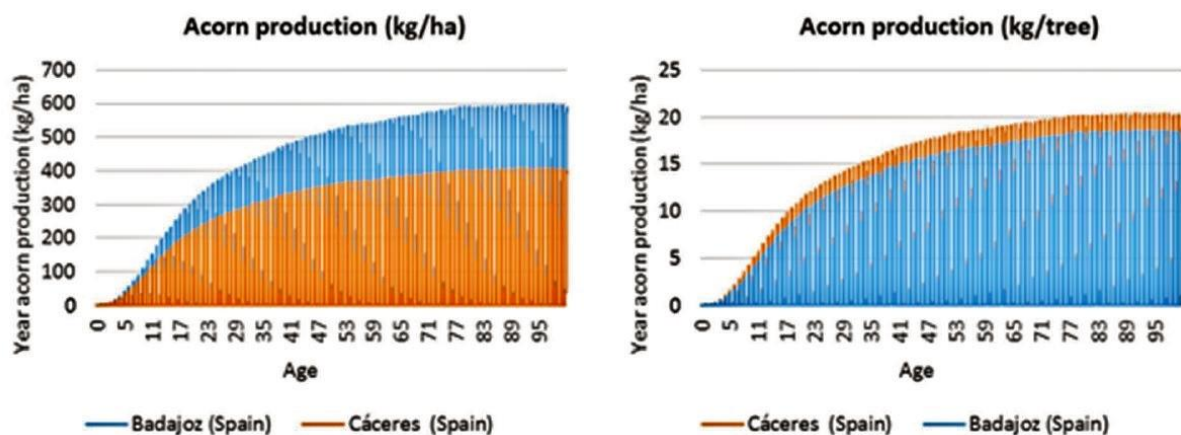


Figure 11. Yield-SAFE estimation of acorn production (cork oak) for Badajoz and Cáceres sites (Crous-Duran et al. 2015)

Table 9. Acorn production of Western Iberian holm oak woodlands according to different authors. Data are averages of several years and different stands. Pruning is not taken into account. Means of annual standard deviations (SD). Data compiled by Gea-Izquierdo et al. (2006).

| Source  | Species         | Site                     | Region      | System             | Stand density<br>(trees ha <sup>-1</sup> ) | Tree covers<br>(%) | Years     | Mean production      |                        |                          |                             |
|---|-----------------|--------------------------|-------------|--------------------|--|--------------------|-----------|----------------------|------------------------|--------------------------|-----------------------------|
|   |                 |                          |             |                    |  |                    |           | (g m <sup>-2</sup> ) | (kg ha <sup>-1</sup> ) | (kg tree <sup>-1</sup> ) | (Nº acorn m <sup>-2</sup> ) |
| 1971 Lossaint y Rapp  | <i>Q. ilex</i>  |                          |             |                    |  | 60                 |           | 278                  |                        |                          |                             |
| 1971 Lossaint y Rapp  | <i>Q. ilex</i>  |                          |             |                    |  | 75                 |           | 59.6                 |                        |                          |                             |
| 1980 Verdú et al.   | <i>Q. ilex</i>  |                          |             |                    |  | 100                |           | 14                   |                        |                          |                             |
| 1989 Zuleta and Canellas  | <i>Q. suber</i> | La Herguizuela           | Cáceres     | Dehesa             | 28.5                                       |                    | 1987      | 240.6                |                        |                          |                             |
| 1990, 1991 Vázquez et al<br>1993 Espárrago et al<br>1992 Cabeza de Vaca et al | <i>Q. ilex</i>  | Several sites            | Extremadura | Dehesa             | 35.3 ± 12.6                                |                    | 1990      |                      | 14.9 ± 0.9             |                          |                             |
| 1992 Bellot et al.  | <i>Q. ilex</i>  | Prades                   | Tarragona   | Dense forest       | 3952                                       |                    |           | 14.3 ± 11.0          |                        |                          |                             |
| 1992 Bellot al.   | <i>Q. ilex</i>  |                          |             |                    |  | 100                |           | 25.9                 |                        |                          |                             |
| 1998 Martín et al.  | <i>Q. ilex</i>  | Sierra Morena            | Andalusia   | Dehesa             | 23   | 10.2               | 1991-1998 | 285.8 ± 73.5         | 291.5 ± 75             | 25.3 ± 6.5               |                             |
| 1998 Martín et al.  | <i>Q. ilex</i>  | Sierra Morena            | Andalusia   | Dehesa             | 59.5                                       | 25.6               | 1991-1998 | 115.8 ± 31.5         | 296 ± 80.4             | 7.1 ± 1.9                |                             |
| 1998 Martín et al.  | <i>Q. suber</i> | Sierra Morena            | Andalusia   | Forest             | 93.7                                       | 27.6               | 1991-1998 | 58.2 ± 27            | 160.6 ± 74.6           | 4 ± 1.8                  |                             |
| 1998 Martín et al.  | <i>Q. suber</i> | Sierra Morena            | Andalusia   | Forest             | 140  | 42.4               | 1992-1998 | 19.5 ± 7.6           | 82.7 ± 32.2            | 0.6 ± 0.2                |                             |
| 1998 Martín et al.  | <i>Q. suber</i> | Sierra Morena            | Andalusia   | Dehesa. Encroached | 19.5                                       | 14.7               | 1992-1998 | 171.1 ± 90.3         | 250.9 ± 132.5          | 16.9 ± 8.9               |                             |
| 1998 Martín et al.  | <i>Q. suber</i> | Jerez de la Frontera     | Cádiz       | Forest             | 159.5                                      | 68.3               | 1992-1998 | 58.5 ± 21.8          | 399.2 ± 148.9          | 5.2 ± 2.5                |                             |
| 1998 Martín et al.  | <i>Q. suber</i> | Jerez de la Frontera     | Cádiz       | Forest             | 253.2                                      | 33                 | 1992-1998 | 51.1 ± 15.6          | 168.6 ± 51.3           | 3.2 ± 1                  |                             |
| 1998 Martín et al.  | <i>Q. ilex</i>  |                          | Sevilla     | Dehesa             | 23   |                    |           | 285.8 ± 194.5        |                        | 25.3 ± 6.5               |                             |
| 1998 Martín et al.  | <i>Q. ilex</i>  |                          | Sevilla     |                    | 60   |                    |           | 115.8 ± 83.2         |                        | 7.1 ± 1.9                |                             |
| 2002 Álvarez et al.   | <i>Q. ilex</i>  |                          | Salamanca   | Dehesa             | 25   |                    |           |                      | 479                    | 19                       |                             |
| 2003 Carbonero et al.   | <i>Q. ilex</i>  |                          | Córdoba     | Dehesa             | 60-78                                      |                    |           |                      |                        | 26.7 ± 5.1               |                             |
| 2004 Olea et al.  | <i>Q. ilex</i>  |                          | Badajoz     |                    | 20-45                                      |                    |           |                      | 674.3 ± 120.4          |                          |                             |
| 2005 García   | <i>Q. ilex</i>  | Cuatro Lugares           | Cáceres     | Dehesa. Cropped    | 14.7                                       |                    | 2002-2003 |                      | 571.1                  | 38.85                    |                             |
| 2005 García   | <i>Q. ilex</i>  | Cuatro Lugares           | Cáceres     | Dehesa. Grazed     | 11.7                                       |                    | 2002-2003 |                      | 280.8                  | 24                       |                             |
| 2005 García   | <i>Q. ilex</i>  | Cuatro Lugares           | Cáceres     | Dehesa. Encroached | 26   |                    | 2002-2003 |                      | 352.3                  | 13.55                    |                             |
| 2005 García et al.  | <i>Q. ilex</i>  | Several sites            | Extremadura |                    | 40   |                    |           |                      | 12.89 ± 6.54           |                          |                             |
| 2010 Tejerina et al.  | <i>Q. ilex</i>  | Villar del Rey - Badajoz | Badajoz     | Dehesa             |  | 30-50              |           |                      | 402.6 ± 32.32          |                          |                             |
| 2011 Alejano et al.   | <i>Q. ilex</i>  | Calañas                  | Huelva      | Dehesa             | 34.5                                       |                    | 2001-2006 | 136.6 ± 100.7        |                        |                          | 36.7 ± 29.6                 |
| 2011 Alejano et al.   | <i>Q. ilex</i>  | San Bartolomé            | Huelva      | Dehesa             | 36   |                    | 2002-2006 | 233.9 ± 191.0        |                        |                          | 58.4 ± 46.9                 |
| 2011 Carbonero  | <i>Q. ilex</i>  | Cardeña                  | Córdoba     | Dehesa             | 67   | 33.37              | 2001-2006 | 253 ± 253            |                        | 10.0 ± 19.4              |                             |
| 2011 Rolo   | <i>Q. ilex</i>  | Malpartida de Plasencia  | Cáceres     | Dehesa             | 43.5                                       | 8.4                | 2007-2009 | 68.3                 |                        |                          |                             |
| 2011 Rolo   | <i>Q. ilex</i>  | Malpartida de Plasencia  | Cáceres     | Dehesa             | 37   | 14.5               | 2007-2009 | 66.6                 |                        |                          |                             |
| 2011 Rolo   | <i>Q. ilex</i>  | Malpartida de Plasencia  | Cáceres     | Dehesa             | 50.6                                       | 14.3               | 2007-2009 | 138.3                |                        |                          |                             |
| 2011 Rolo   | <i>Q. ilex</i>  | Malpartida de Plasencia  | Cáceres     | Dehesa             | 40.1                                       | 11.7               | 2007-2009 | 95                   |                        |                          |                             |
| 2011 Rolo   | <i>Q. ilex</i>  | Malpartida de Plasencia  | Cáceres     | Dehesa             | 46   | 24.7               | 2007-2009 | 151                  |                        |                          |                             |
| 2011 Rolo   | <i>Q. ilex</i>  | Malpartida de Plasencia  | Cáceres     | Dehesa             | 45   | 14.5               | 2007-2009 | 164.8                |                        |                          |                             |
| 2011 Rolo   | <i>Q. ilex</i>  | Malpartida de Plasencia  | Cáceres     | Dehesa             | 42.4                                       | 5.7                | 2007-2009 | 245.5                |                        |                          |                             |

| Source                   | Species        | Site                    | Region  | System                | Stand density<br>(trees ha <sup>-1</sup> ) | Tree covers<br>(%) | Years     | Mean production      |                        |                          |                             |
|--------------------------|----------------|-------------------------|---------|-----------------------|--|--------------------|-----------|----------------------|------------------------|--------------------------|-----------------------------|
|                          |                |                         |         |                       |  |                    |           | (g m <sup>-2</sup> ) | (kg ha <sup>-1</sup> ) | (kg tree <sup>-1</sup> ) | (Nº acorn m <sup>-2</sup> ) |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 43.6                                       | 28.5               | 2007-2009 | 87.2                 |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 79.1                                       | 29.6               | 2007-2009 | 45.1                 |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 51.2                                       | 15.7               | 2007-2009 | 40.6                 |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 41   | 15.5               | 2007-2009 | 55.3                 |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 49.9                                       | 19                 | 2007-2009 | 92                   |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 46.6                                       | 16.8               | 2007-2009 | 115.4                |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 38.8                                       | 42.5               | 2007-2009 | 65.7                 |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Montehermoso            | Cáceres | Dehesa                | 62.5                                       | 19.6               | 2007-2009 | 66                   |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Plasencia               | Cáceres | Dehesa                | 48.3                                       | 13                 | 2007-2009 | 61.2                 |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Plasencia               | Cáceres | Dehesa                | 42   | 51.2               | 2007-2009 | 26.8                 |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 37   | 13.6               | 2007-2009 | 72                   |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 45.6                                       | 23.2               | 2007-2009 | 99.6                 |                        |                          |                             |
| 2011 Rolo                | <i>Q. ilex</i> | Malpartida de Plasencia | Cáceres | Dehesa                | 52.4                                       | 6.2                | 2007-2009 | 154.2                |                        |                          |                             |
| 2013 Koenig et al.       | <i>Q. ilex</i> | Several sites           | Spain   | Dehesa                |  |                    |           |                      |                        | 52.4 ± 27.3              |                             |
| 2013 Koenig et al.       | <i>Q. ilex</i> | Several sites           | Spain   | Forest                |  |                    |           |                      |                        | 124.4 ± 64.3             |                             |
| 2013 Martín-Pérez et al. | <i>Q. ilex</i> | San Bartolome           | Huelva  | Dehesa                | 36   |                    | 2006-2011 | 295.3 ± 120.5        |                        |                          |                             |
| 2013 Martín-Pérez et al. | <i>Q. ilex</i> | Huerto Ramirez          | Huelva  | Dehesa                | 73   |                    | 2006-2011 | 440,3 ± 186,4        |                        |                          |                             |
| 2015 Ferriz et al.       | <i>Q. ilex</i> | Pozoblanco              | Córdoba | Reforestation in 1995 | 300  |                    | 2011-2014 | 329 ± 0.89           |                        | 0.89 ± 0.35              | 145,5 ± 95,9                |
| 2015 Crous-Durán et al.  | <i>Q. ilex</i> | Majadas de Tietar       | Cáceres | Dehesa                | 20   |                    | 2003-2012 |                      | 182.8                  |                          | 365.7                       |

Martín et al. (1998) estimated in holm oak stands of low density (23 trees ha<sup>-1</sup>) had a higher mean production per tree (285.8 g m<sup>-2</sup> of canopy; 25.3 kg tree<sup>-1</sup>) but less per ha (291.5 kg ha<sup>-1</sup>) than stands with higher densities (59.5 trees ha<sup>-1</sup>; 115.8 g m<sup>-2</sup> of canopy; 7.1 kg tree<sup>-1</sup>; 296.0 kg ha<sup>-1</sup>). The same negative relationship was observed for cork oak stands in the same area: stands with lower density (20 trees ha<sup>-1</sup>) had a higher mean production per tree but lower per ha (171.7 g m<sup>-2</sup> of canopy; 16.9 kg tree<sup>-1</sup>; 250.9 kg ha<sup>-1</sup>) than stands with higher densities from 94 to 253 trees ha<sup>-1</sup> (Martín et al., 1998). The highest mean production per ha (58.5 g m<sup>-2</sup> of canopy; 399.2 kg ha<sup>-1</sup>) was obtained in the stand with 160 trees ha<sup>-1</sup>, which was located in the more humid and warmer area (Martín et al. 1998). Vázquez et al. (1996) studied three stands with densities 19, 56 and 133 trees per hectare. The stand of middle density averaged the highest acorn production per ha (21.3 ± 32.8 kg tree<sup>-1</sup>), and the stand with lower density the highest acorn production per tree (31.5 ± 3.4 kg tree<sup>-1</sup>). The third plot produced 2.3 ± 0.6 kg tree<sup>-1</sup>.

In woody pasture, there can be browsing of tree branches and shrubs and other products such as fruits, flowers and tree bark. The tree fodder of the dehesa may be obtained by the livestock directly (browsing) or indirectly through the fallen leaves due to pruning or cutting. The production of DM in these of browse may reach up to 350-550 kg DM ha<sup>-1</sup> a<sup>-1</sup> (López-Díaz et al. 2009).

### 3.3.5 Livestock

Livestock is both the main final product and a key component for the maintenance and improvement of the dehesa. Sheep are the most appropriate animal to make use of dehesa pastures; they are selective feeders consuming little browse. The typical breeds are traditional, like the *merina* which are mainly grown for meat and milk/cheese production. The stocking rate fluctuates between 1 and 4 sheep ha<sup>-1</sup>. It is usually necessary to supplement the diet with concentrates during the last month of gestation and lactations (Escribano and Pulido 1998; Olea and San Miguel 2006). Beef cattle are appropriate for the less dry dehesas which can support a stocking density of 1 LU (livestock unit = female dry of 500 kg of live weight) per 3-4 ha. The use of beef cattle has increased during recent years, because they require less management than sheep. Typical breeds include local breeds like *Retinta*, *Morucha*, *Avileña negra ibérica*, which are frequently cross-bred with more productive races such as Limousin and Charolais. Pigs have good future market potential and they make good use of acorns in the dehesas with moderate winters. The most common pig breed is the Iberian pig which is found in the dehesas from October to November at around 8 to 12 months of age and 60-80 kg. Pigs are taken out in January with 120-160 kg, normally without any supplement. The stocking rate is usually of 0.4-0.6 pigs ha<sup>-1</sup>. Before this, piglets are given feed after weaning. Another option is to use acorns and feeds at the fattening period. Goats are usually used with other animals to make better use of the woody fodder. Goats can be used for meat or milk production or mixed, with a typical stocking rate of 2-3 goats ha<sup>-1</sup>. Again supplementary feed is necessary during the last month of gestation and during the whole period of lactation. Horses can also be used to complement other animals. Aside from livestock, the presence of animals such as deer or rabbits associated with hunting is also common and hunting can increase the profitability of the dehesa. Unfortunately the effect of trees on animal welfare and nutritive demand of livestock have not been studied yet.



Table 10. Major features of the dehesa livestock

| Major features of the dehesa livestock |                           |   |
|--|---------------------------|---|
| Livestock                              | Major role                | The most important direct product   |
|  | Species (Breeds)          | <p><u>Cattle</u> breeds include Avileña-negra ibérica, Morucha, Retinta, lidia, Blanca cacereña, Berrenda en colorao, Berrenda en negro, and Atigrada de Salamanca,...</p> <p><u>Sheep</u> breeds include Merino, Ille de France, Fleischschaff, and Landschaff.</p> <p>Pigs breeds include Iberian pig breeds such as Negro lampiño, Negro entrepelado, and Colorado</p> <p>Goat breeds include Verata, Retinta, and Serrana</p> <p>Horse breeds: Español; Donkey breeds: Andaluz</p>  |
|  | Sustainable stocking rate | <p><u>Cattle</u>: 0.2-0.4 ha<sup>-1</sup>; <u>Sheep</u>: 2-4 ha<sup>-1</sup>;<br/> <u>Goat</u>: 2-3 ha<sup>-1</sup>; <u>Iberian pig</u>: 0.4-0.6 ha<sup>-1</sup></p> <p>Management usually includes several species, each one taking advantage of the optimal usage of specific natural resources (e.g. Iberian pig is preferred during autumn and early winter acorn yields) An even distribution of livestock is desired with the aims of reducing damage to the tree layer, increasing the efficiency of grazing ,and reducing the prevalence of parasites and diseases</p>  |
|  | Management                | <p>Periods of high nutritional requirements of livestock (late and lactation) pregnancy should coincide with seasons showing peaks of fresh fodder supply.</p> <p><b>Cattle</b>: desired calving season from November until March, depending on winter cold. Lactation: 5-6 months.</p> <p><b>Sheep-goat</b>: two systems. One lambing season each year: spring or autumn (better prices). Three lambing seasons every two years. Lactation: 45 days.</p> <p><b>Iberian pig</b>: two farrowing seasons per year: spring and autumn (LópezBote, 1998). Piglets born in autumn are fed for one year (to reach 90-110 kg live weight) and then they are fed on acorns and grass from October until January, gaining around 0.7 kg d<sup>-1</sup> (to reach 140-160 kg live weight)</p> |

## 4 Private goods and services

This section follows the categories proposed by the project RECAMAN<sup>1</sup> that recently has applied the green total income and capital accounting to the Andalusian dehesas (Campos and Ovando 2105). Most of the information reported here is based on this publication.

### 4.1 Natural pasture and acorns

Quantification of private commercial outputs and costs in the dehesa presents difficulties in the valuation of components, such as the acorns, and pasture consumption by livestock and wild animals. The consumption of pastures and acorns can be considered as intermediate commercial outputs, and the data from these outputs are known only from scientific research and not from official statistics. In Section 3.3 some data coming from partial scientific research are given.

### 4.2 Cork

Cork is exploited periodically throughout the life of cork-oak trees, and the mean production of cork per adult tree in each 9-year cycle varied from 5 kg (young trees) to 71 kg (mature trees) (Montero et al. 2003), i.e. 480 kg ha<sup>-1</sup> a<sup>-1</sup> (Pereira et al. 2004). Although the production of cork in the Spanish dehesas has been decreasing in recent decades; the economic potential of cork has increased since 2000 and thousands of hectares of arable and pastureland are being afforested with cork oaks. As long as the international markets continue to consider cork as the most efficient bottle-stopper, the future of cork-oak woodlands should be assured.

### 4.3 Tree products: browse, firewood and charcoal

The natural productivity of dehesas does not favour commercial timber silviculture. Dehesa trees are periodically pruned, and lopped branches are used for firewood or charcoal production and as fodder in winter. Pruning is carried out during the life of the oaks, traditionally performed in the year preceding arable cultivation to increase light availability for the crops. Due to the sclerophyllous evergreen nature of dehesa trees, they represent substantial fodder reserves for wildlife and livestock. An appropriate pruning event can yield 300–500 kg ha<sup>-1</sup> year<sup>-1</sup> of dry browse material (Cañellas et al. 1991). However, the economic costs of traditional light or moderate pruning are very high, and there are attempts to compensate these costs by obtaining income from firewood or charcoal. The forest management of the dehesas is also focussed to the production of fruits through periodically pruning. There is a traditional belief that pruning increases acorn production (San Miguel 1994; Gómez-Gutiérrez and Pérez-Fernández 1996) but a recent study has shown that, overall, pruning decreases acorn production (Cañellas et al. 2007). They found that pruning significantly decreased acorn production when production was above the average, whereas production was not affected by pruning the years that acorn yield was below the average. Hence, the effect of pruning in Mediterranean oak woodland is still controversial and more information based on research is needed to form an objective and rational opinion upon the response of trees to this important silvicultural practice (Cañellas et al. 2007).

There are no economic statistics on pruning and derived products, and scientific literature on the productivity of firewood and charcoal production in the dehesa are rare. A recent study done in the

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<sup>1</sup> Manufactured and environmental total incomes of Andalusian forest. [www.recaman.es](http://www.recaman.es)

Dehesa de la Luz (public dehesa of the municipality of Arroyo de la Luz, Extremadura) gives an indication of the importance of this product (Table 11). This study revealed an annual production of 100 kg of firewood per hectare.

Table 11. Estimation of main tree biomass parameters per diametric class in a typical holm-oak dehesa (Campos and Pulido 2015)

| Diameter class (cm) | Age <sup>1</sup> | Age <sup>2</sup> | Tree/ha | Wood volume (dm <sup>3</sup> ha <sup>-1</sup> ) | Firewood volume (dm <sup>3</sup> ha <sup>-1</sup> ) | Annual increment of wood <sup>1</sup> (dm <sup>3</sup> ha <sup>-1</sup> ) | Annual increment of wood <sup>2</sup> (dm <sup>3</sup> ha <sup>-1</sup> ) | Wood biomass (kg ha <sup>-1</sup> ) | Acorn yield (kg ha <sup>-1</sup> ) |
|---------------------|------------------|------------------|---------|---|---|---|---|-------------------------------------|------------------------------------|
| 5                   | 8.7              | 22.6             | 0.1     | 0.6   |   |   |   |                                     |                                    |
| 10                  | 18.5             | 30.5             | 0.4     | 11.7  | 0   | 0.8   | 0.9   | 8.8                                 | 0.5                                |
| 15                  | 30.2             | 39.0             | 0.9     | 41.7  | 10.2  | 2.0   | 2.8   | 43.2                                | 1.8                                |
| 20                  | 43.5             | 48.2             | 2.2     | 141.0   | 64.2  | 4.5   | 7.7   | 162.2                               | 5.1                                |
| 25                  | 58.2             | 58.2             | 3.0     | 267.2   | 159.9   | 5.8   | 11.1  | 313.8                               | 7.9                                |
| 30                  | 74.2             | 68.9             | 2.2     | 268.3   | 185.2   | 4.1   | 8.5   | 308.6                               | 6.4                                |
| 35                  | 91.4             | 80.6             | 1.8     | 289.3   | 215.6   | 3.3   | 7.1   | 324.7                               | 5.7                                |
| 40                  | 109.6            | 93.2             | 1.9     | 427.2   | 333.9   | 3.5   | 8.0   | 448.6                               | 6.9                                |
| 45                  | 128.8            | 106.9            | 1.6     | 460.7   | 367.7   | 3.0   | 6.8   | 466.0                               | 6.3                                |
| 50                  | 148.9            | 121.7            | 1.9     | 690.0   | 554.9   | 3.4   | 8.0   | 658.8                               | 7.9                                |
| 55                  | 169.9            | 137.7            | 2.5     | 1047.3  | 839.9   | 4.3   | 10.0  | 989.4                               | 10.7                               |
| 60                  | 191.8            | 155.0            | 2.0     | 1088.2  | 861.2   | 3.5   | 8.2   | 959.5                               | 9.4                                |
| 65                  | 214.4            | 173.7            | 1.8     | 1044.2  | 817.0   | 3.0   | 6.9   | 946.0                               | 8.5                                |
| 70                  | 237.8            | 194.0            | 2.2     | 1916.3  | 1397.8  | 3.7   | 8.3   | 1328.6                              | 10.9                               |
| 75                  | 262.0            | 216.0            | 1.8     | 1605.5  | 1171.1  | 3.0   | 6.7   | 1256.6                              | 9.6                                |
| 80                  | 286.8            | 239.7            | 1.5     | 1294.8  | 944.4   | 2.4   | 5.3   | 1135.4                              | 8.0                                |
| 85                  | 312.4            | 265.4            | 1.6     | 1450.1  | 1057.8  | 2.7   | 5.7   | 1415.2                              | 9.3                                |
| 90                  | 338.6            | 293.2            | 1.4     | 1243.0  | 906.7   | 2.3   | 4.7   | 1342.0                              | 8.3                                |
| 95                  | 365.4            | 323.3            | 0.8     | 673.3   | 491.1   | 1.2   | 2.4   | 799.9                               | 4.6                                |
| 100                 | 392.9            | 355.9            | 1.3     | 1191.2  | 868.9   | 2.2   | 4.1   | 1549.8                              | 8.5                                |
| 105                 | 421.0            | 391.2            | 0.5     | 466.1   | 340.0   | 0.8   | 1.6   | 661.3                               | 3.4                                |
| 110                 | 449.7            | 429.3            | 0.4     | 362.5   | 264.4   | 0.6   | 1.2   | 558.6                               | 2.7                                |
| 115                 | 479.0            | 470.6            | 0.5     | 414.3   | 302.2   | 0.7   | 1.3   | 690.9                               | 3.2                                |
| 120                 | 508.8            | 515.3            | 0.2     | 155.4   | 113.3   | 0.3   | 0.4   | 279.5                               | 1.2                                |
| 125                 | 539.2            | 563.7            | 0.0     | 0.0   | 0.0   | 0.0   | 0.0   | 0.0                                 | 0.0                                |
| 130                 | 570.1            | 616.0            | 0.0     | 0.0   | 0.0   | 0.0   | 0.0   | 0.0                                 | 0.0                                |
| 135                 | 601.5            | 672.6            | 0.1     | 51.8  | 37.8  | 0.1   | 0.1   | 114.9                               | 0.4                                |
| 140                 | 633.5            | 733.9            | 0.1     | 51.8  | 37.8  | 0.1   | 0.1   | 122.6                               | 0.5                                |
| Total               |                  |                  | 34.5    | 16653.5   | 12342.9   | 61.4  | 128.0   | 16884.9                             | 147.8                              |

<sup>1</sup> Estimated from allometric equations produced with 14 trees cut within the farm;

<sup>2</sup> Estimated from allometric equations produced with 60 trees cut out of the study area.

#### 4.4 Livestock production

Dehesas are mostly devoted to livestock breeding but in many different combinations. Indeed, the diversity of dehesas stems not only from the land cover (percentage of wooded area) but is fundamentally determined by the livestock species reared and the degree of intensification (Gaspar et al. 2007). In an economic analysis conducted by these authors 69 randomly selected dehesa farms in the Extremadura using technical and economic indicators to assess the profitability of livestock breeding, revealed that the two main determinants of dehesa profitability were whether or not pigs are present and the prevalence of ruminant species. They distinguished five types of farms: sheep farms at high and low stocking rates, beef cattle farms, wooded farms with mixed livestock, and

farms with a high level of cropping activity. The most profitable farms were those with either high overall livestock density or a high level of Iberian pig production. While high stocking density has historically attracted high levels of subsidy, production of Iberian pigs was profitable because of the high value of the product (Table 12). Mixed systems (beef cattle–sheep–Iberian pigs) have been found to be the most sustainable in general terms. The high–stocking rate sheep dehesas are the least sustainable, although at present, they are the most profitable (Gaspar et al. 2009). Mixed livestock dehesa farms are the closest to the traditional systems with a highly diverse production, an optimal use of the system's resources, and little dependence on external subsidies. In the present context, with uncertainties about European Union subsidies, this type of farm should be a goal for dehesa farmers (Gaspar et al. 2009)

Table 12. Mean values of variables considered for the economic analyses of 69 dehesa farms in Extremadura region (Gaspar et al. 2007). Group 1: low stocking rate sheep; Group 2: beef cattle farms; Group 3: high stocking rate sheep farms; Group 4: mixed beef cattle, sheep, and Iberian pig; Group 5: farms with significant crop growing activity.

| Variable  | Group 1<br><i>n</i> = 26 | Group 2<br><i>n</i> = 25 | Group 3<br><i>n</i> = 6 | Group 4<br><i>n</i> = 10 | Group 5<br><i>n</i> = 2 |
|---|--------------------------|--------------------------|-------------------------|--------------------------|-------------------------|
| Sheep stocking rate                             | 0.25                     | 0.23                     | 0.51                    | 0.27                     | 0.57                    |
| Pig stocking rate                               | 0.03                     | 0.03                     | 0.04                    | 0.1                      | –                       |
| Total stocking rate                             | 0.28                     | 0.37                     | 0.61                    | 0.47                     | 0.58                    |
| Cattle LU/ total LU                             | 0.1                      | 0.77                     | 0.06                    | 0.47                     | –                       |
| Sheep LU/total LU                               | 0.81                     | 0.21                     | 0.86                    | 0.33                     | 1                       |
| Pig LU/total LU                                 | 0.02                     | 0.02                     | 0.01                    | 0.2                      | –                       |
| Wooded area/Total UAA                           | 0.61                     | 0.65                     | 0.04                    | 0.98                     | 0.54                    |
| Cultivated area/Total UAA                       | 0.05                     | 0.08                     | 0.02                    | 0.02                     | 0.47                    |
| AWU/100 ha UAA                                  | 0.5                      | 0.6                      | 0.82                    | 0.94                     | 1.56                    |
| Temporary AWU/100 ha UAA                        | 0.05                     | 0.1                      | 0.03                    | 0.36                     | 0.65                    |
| Family AWU/100 ha UAA                           | 0.19                     | 0.19                     | 0.66                    | 0.27                     | 0.66                    |
| Pigs sold/ha UAA                                | 0.44                     | 0.42                     | 0.18                    | 2.01                     | –                       |
| Montanera pigs sold/ha UAA                      | 0.31                     | 0.24                     | –                       | 0.65                     | –                       |
| Land fixed capital                              | 4796.9                   | 5170.7                   | 3830                    | 6435.1                   | 6908                    |
| Buildings fixed capital                         | 420.1                    | 735.5                    | 360.5                   | 1058.8                   | 1983.5                  |
| Breeding Livestock fixed capital                | 129.23                   | 290.84                   | 261.5                   | 325.8                    | 229.5                   |
| Animal feedingstuffs/ha UAA                     | 67.70                    | 68.31                    | 180.23                  | 144.97                   | 123.12                  |
| Other goods and services/ha UAA                 | 9.62                     | 21.49                    | 13.09                   | 37.29                    | 87.89                   |
| Compensation of employees/ha UAA                | 40.66                    | 38.72                    | 20.34                   | 88.77                    | 109.12                  |
| Intermediate consumption/ha UAA                 | 123.97                   | 1138.75                  | 217.78                  | 254.94                   | 345.19                  |
| Consumption of fixed capital/ha UAA             | 30.06                    | 44.79                    | 24.90                   | 61.52                    | 126.77                  |
| Own account produced fixed capital goods/ha UAA | 22.80                    | 68.05                    | 53.25                   | 83.41                    | 36.10                   |
| Sales of livestock/ha UAA                       | 175.35                   | 178.27                   | 247.06                  | 594.05                   | 403.28                  |
| Subsidies/ha UAA                                | 67.48                    | 123.21                   | 144.87                  | 99.12                    | 206.39                  |
| Intra-unit consumption/ha UAA                   | 92.50                    | 99.70                    | 73.85                   | 124.08                   | 133.21                  |
| Gross output/ha UAA                             | 385.12                   | 483.10                   | 571.00                  | 921.75                   | 865.31                  |
| Net operating surplus/ha UAA                    | 193.10                   | 270.91                   | 315.64                  | 516.59                   | 284.23                  |
| Net value added at factor cost/ha UAA           | 233.76                   | 309.63                   | 335.99                  | 605.37                   | 393.35                  |
| Net entrepreneurial income/ha UAA               | 170.63                   | 249.76                   | 295.74                  | 511.38                   | 284.23                  |
| Profitability rate                              | 3.09                     | 3.93                     | 6.36                    | 6.24                     | 2.76                    |
| Sales/total income                              | 62.43                    | 52.70                    | 55.33                   | 83.46                    | 56.61                   |
| Subsidies/total income                          | 27.20                    | 40.17                    | 32.16                   | 13.88                    | 30.24                   |

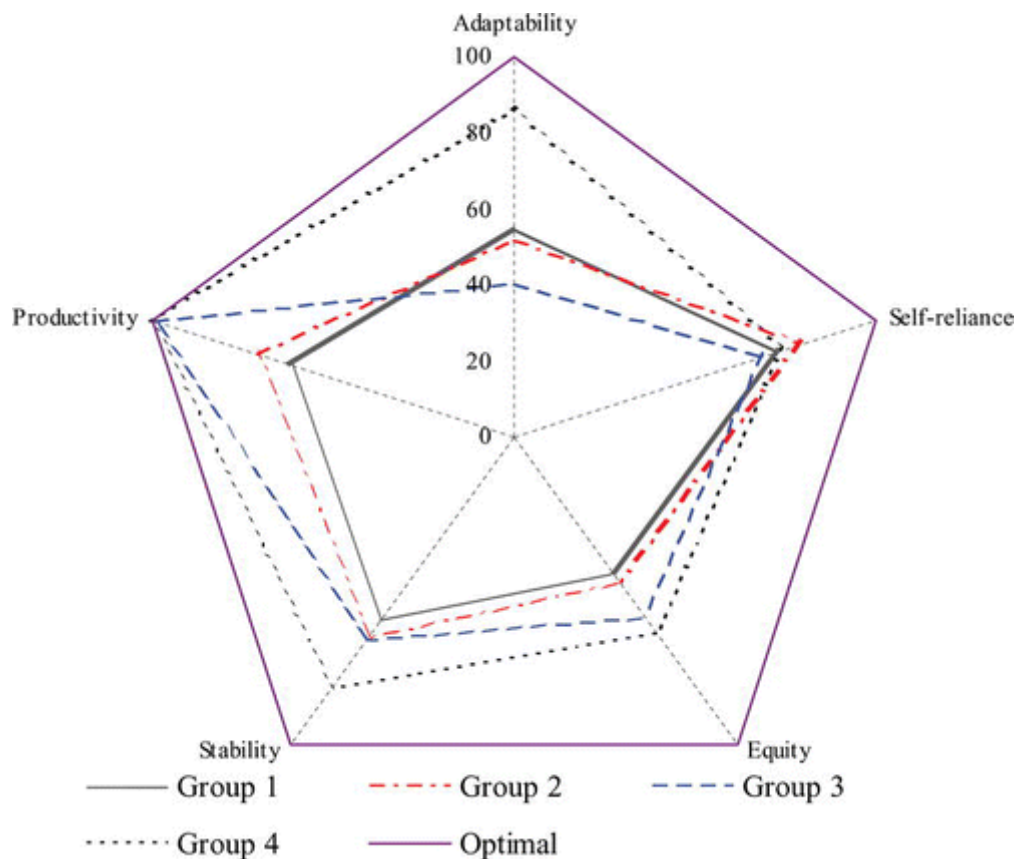


Figure 12. AMOEBA representation of the evaluation of sustainability in terms of its five attributes. The plotted values are the means of the indicators comprising each attribute. For definition of farm groups, see Table 12.

#### 4.5 Hunting

Hunting is a private economic activity in the dehesas, which is competing with livestock for the consumption of pasture and acorns. Big game has also great potential because it is a high quality product, compatible with dehesa conservation (Carranza et al. 1991; Vargas et al. 1995). Red deer ingest a high proportion of browse in summer during dry years (0.83% to 0.89% of total diet) and also in wet years (0.47%; Bugalho and Milne 2003). However, few attempts to quantify the effects of game on dehesa vegetation and sustainability have been carried out (Patón and Pulido 1999). Special attention should be given to the transformation of the vegetative cover, food supplementation, population structure and disease and genetic effects caused by the uncontrolled transference of animals between hunting estates (San Miguel 2005).

The capacity to hunt game explains why some farms are more valuable than farms with similar natural conditions but fewer animals for hunting. The hunting income of the owner is usually incorporated into the price of the land, something which does not occur with livestock income. There is a lack of official measures of recreational hunting services.

#### **4.6 Environmental services recognised by owners**

Owners of dehesa are aware that land prices include a component associated with the private use of environmental services. Many private dehesa owners appreciate both commercial and environmental benefits, where lower rates of profitability are accepted due to “lifestyle” benefits. Hence there is what may initially be seen as an economic paradox, i.e. properties of low financial profitability still achieve high land prices, is not a paradox if the private utility of the dehesa is estimated as the aggregate result of commercial and environmental benefits received by owners.

#### **4.7 Other private goods and services**

The Iberian dehesas produce a wide range of other individual minor private commercial products such as pine nuts and chestnuts, honey, wool, medicinal and edible herbs, mushrooms. New commercial initiatives in recent years include new acorn-derived products such as spirit drinks and beers, ice-creams, heart-healthy oils, gluten-free flavours, and natural tannins. Agrotourism represents an important growing source of income in dehesas, especially those located close to nature reserves, where recreation can account for a considerable proportion of total income (Campos 1998). The number of estates offering entertainment services is growing rapidly as a result of increasing demand by visitors, especially in naturally protected areas. In this way, the environmental values of dehesas will be increasingly internalized by landowners as a source of income values. Nevertheless, the commercialization of the dehesa recreational services, meals and accommodation is still in their infancy.

### **5 Public environmental goods and services**

#### **5.1 Net carbon balance**

Most of the carbon in dehesas is found in the soil as the tree density is very low. Within the soil, the amount of C stored beneath the canopy can be roughly twice that in open areas (Figure 9.).

#### **5.2 Water yield and quality**

Across their geographic range dehesas are found in areas of low precipitation and high evaporative demand. Rainfall is highly variable, with low amounts in summer coinciding with high potential evapotranspiration. Most dehesas are found in areas with climates ranging from semi-arid to dry sub-humid and water yield is usually very low. Unfortunately, studies comparing water yield in dehesa catchments compared with open pastures and forest landscapes are not available. In a case study, where mean precipitation during the 12 years of record was 517 mm, mean annual runoff amounted to only 57 mm, which was approximately 12% of the rainfall (Schnabel et al. 2013). The amount of water generated in dry years was small, constituting only 3.3 % of precipitation which means that more than 96% of rainfall is evaporated by plants and soils (assuming low deep drainage due to the nearly impervious rocks). Only during years of higher precipitation did the catchments generate higher volumes of runoff with values in excess of 100 mm (Figure 14.). This behaviour is typical for semi-arid areas, where most of the precipitation is lost to the atmosphere by evapotranspiration. These data illustrate the possible effects of climate change on water resources. Climate change models project a decrease in precipitation and an increase of rainfall variability for the western part of the Mediterranean area (IPCC 2013). The consequence of a rainfall decline on catchment hydrology would be a reduction of water resources in general terms and increased



rainfall variability would provoke more extreme droughts with little channel flow, alternating with humid periods of water flow of short duration.

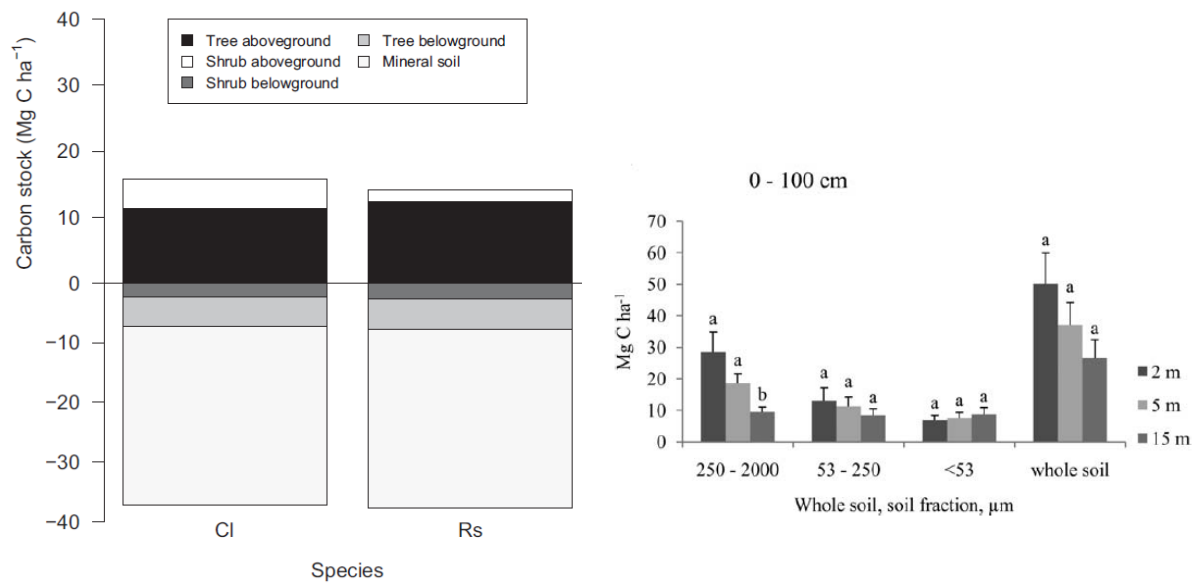


Figure 13. Left: Mean carbon stocks (Mg C ha<sup>-1</sup>) for two dehesa communities, both with *Quercus ilex* trees, one of them with an understory of *Cistus ladanifer* (CI) and the other with an understory of *Retama sphaerocarpa* (Rs). Right: Mean carbon storage (Mg C ha<sup>-1</sup>) in the whole soil and three soil fractions (2000–250 mm, 250–53 mm, <53 mm) to 1 m soil depth at three distances (2, 5, and 15 m) from individual cork oak trees (*Quercus suber*) in a dehesa of Extremadura, Spain. Source: Howlett et al. (2011) and Ruiz-Peinado et al. (2013).

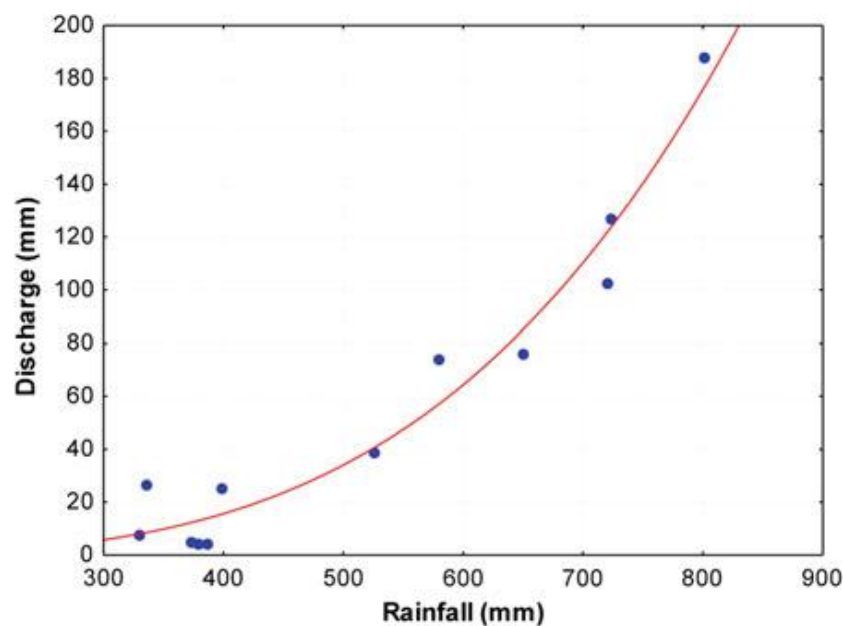


Figure 14. Rainfall-discharge relationship of two small dehesa catchments of Extremadura region for a 12-year period (Schnabel et al. 2013)

### 5.3 Biodiversity

Dehesas serve as the main habitat for several endangered species and for very high diversity of animals and plants. The Spanish imperial eagle (*Aquila adalberti* C. L. Brehm), the black vulture (*Aegypius monachus* L.), the black stork (*Ciconia nigra* L.) and the Iberian lynx (*Lynx pardina* Temminck) use dehesas as feeding habitats and adjacent forests and scrublands for breeding, and a noticeable fraction of their world populations depends on dehesas (Díaz et al. 1997). Many bird species, notably common cranes (*Grus grus* L.), use dehesas as their preferred winter habitat. As a consequence, a large proportion of the dehesa range has been included in the Natura 2000 European web for nature conservation, and dehesa grasslands are also a habitat to be protected by the EU Habitats Directive (Díaz et al. 2003).

In addition, dehesas sustain a high species richness of several contrasting taxonomic groups. For example with vascular plants, research has described 135 species in 0.1 ha in holm oak dehesas or 60–100 species per 0.1 ha in cork oak stands (Marañón 1986). Values of species richness of this and other taxa are much higher than those of other European man-made habitats. Also, diversity values of plants, birds and butterflies have been shown to be similar, or even higher, to those found in natural or semi-natural habitats located nearby (Díaz et al. 2003). As the only example available of a comprehensive biodiversity survey is from a 220 ha montado farm where, 264 fungi, 75 bryophytes, 304 vascular plants and 121 vertebrate species were recorded (Santos-Reis and Correia 1999).

Although high biodiversity values found in Iberian dehesas can be partly explained by the existence of a habitat dominated by scattered trees, the intimate mix of tree and treeless pastures has also a significant role. While at landscape scale the diversity of four biological groups (plants, bees, spiders and earthworms) was higher in wood pastures and other woody habitats, at plot scale they were more abundant and/or biodiverse in open pastures (Moreno et al. 2015). The low proportion of shared species among habitats and among plots within each habitat type, and the high proportion of species found in unique plots or habitats indicated that every habitat contributes to farm biodiversity. Marginal land uses and linear features, which occupy a low proportion of the dehesa area, harbored a good number of species that were not found in the main field of dehesas (Moreno et al. 2015). So, the main explanation for the diversity values found in dehesas is the intimate mixture of habitats at various scales.

First, at the very fine scale the presence of trees increases habitat heterogeneity and plant richness compared to treeless grasslands. Second, within the same management type (pasture, crop or shrubland), differences in tree density or age and topography determine local variations in animal and plant diversity, respectively. Third, the habitat mosaic generated by the combination of land-use units enhances farm-level diversity by favouring a combination of habitat specialists and generalists via the “hybrid habitat” hypothesis (Díaz et al. 2003). According to this hypothesis, bird diversity values have been shown to follow a nested pattern in dehesas, that is, the number of forest species increases with tree density while the number of grassland specialists remains unchanged. From these results, it follows that the anthropogenic maintenance of multi-scale habitat heterogeneity is crucial for biological diversity in dehesas (Tellería 2001; Díaz et al. 2003). Also, globally threatened species, which have large home ranges, are clearly favoured by landscape diversity, as they simultaneously exploit different habitat types (Donazar et al. 1997).

Nevertheless, the effect of dehesa land use on diversity remains a controversial issue that deserves further investigation. Thus, for example, the abundance of lizards increased when understorey bushy vegetation increased, while grasslands or cereal fields were scarcely colonised even if holm oak tree were present (Martín and López 2002). This and other less studied taxonomic groups may experience a reduction in species diversity as a result of forest clearance and grazing. Also, even if species diversity is enhanced by management, human practices may affect species which have a critical role in ecosystem function, as has been described for acorn dispersal on which oak regeneration relies (see Díaz et al. 2003; Pulido and Díaz 2005). Hence, the net effect of dehesas on diversity is not fully understood, and the assumed value of dehesa for the Mediterranean biota is more based on its importance for threatened species than on diversity values.

#### **5.4 Public environmental recreation services**

Although citizens visit dehesa territories for multiple provisioning services such as mushrooms, asparagus, flowers, salads, and even acorns and firewood, the primary reason includes recreational services such as outdoor sports (e.g. biking, running), fishing, hunting, bird-watching, and other cultural services (e.g. opportunities to appreciate local culture or a beautiful landscape or landmark). It can be argued that the current dehesa ownership regime, of mostly large private states, hampers the public use of these landscapes (Fagerholm et al, 2016). Where dehesas are publicly owned and open to public, they are typically preferred destinations that other forms of land use.

### **6 The low commercial profitability of Dehesa farms**

Dehesa is an extensive but labour-intensive land-use system. Thus increased labour costs in Europe threaten dehesa profitability and hence sustainability (Gómez-Gutiérrez 1992). Commercial profitability of direct dehesa products is usually low (Campos 2004). Applying the conventional net value added (NVA); dehesa profitability is very low and often negative (Escribano and Pulido 1998), with a range of -14.7 to 9.7 %. Only in some cases, e.g. for cork oaks with low livestock grazing and red-deer hunting, is commercial profitability clearly positive (Campos et al. 2001). However, according to the total economic value theory (Campos et al. 2001), economic analysis based only on NVA produces an incomplete assessment. Whenever there are multiple uses of renewable resources, a new operative approach called Agroforestry Accounting System (AAS) can be used to incorporate environmental goods and services (Campos et al. 2001).

In recent decades, land prices in the dehesas and montado have shown large capital gains; e.g. the price of dehesa land in Extremadura has increased at a real cumulative annual rate adjusted for inflation of 5%, (Campos 2004; see also Escribano and Pulido 1998). The constant rise of land prices of dehesas, at a time when commercial profitability of dehesa farming is declining, is thought to be largely due to the revaluation of self-consumed private environmental services (indirect products); in other words, 'leisure has become a product of the dehesa' (Pardal 2002; Campos 2004). Indeed, several studies carried in Spain showed that private environmental services used by landowners themselves account for 33–43% of the market price of land reported by landowners (Campos 2004). There is a consumptive value associated with ownership of rural land, reflecting innate desires to own land, live in a rural environment, obtain or maintain the lifestyle of a farmer, engage in outdoor recreation, get back to nature, and partake of any other real or perceived benefits of rural land ownership (Campos and Caparrós 2005).

As a result, economic analyses of dehesas usually use a discount rate of 4.5%, which is higher than that used for many European forests (around 2–3%; Campos et al. 2003). Considering both capital gains and direct product-included subsidies, which account for between 43% and 80% of the commercial income in a common dehesa (Calvo et al. 1999), the total private real profitability of dehesas is in the range of at least 3–5%, not including hypothetical incomes from public environmental services (Campos 2004). These public direct goods and services, and environmental functions are not fully incorporated to the present accounting systems (Escribano and Pulido 1998; Campos et al. 2003). It is arguable that because the capital accumulation depends on the capital appreciation of land prices, rather than farm income, there is little incentive to conserve the dehesa. Land owners are usually more interested in obtaining economic profit than in the rational long-term exploitation of dehesa resources. This attitude leads to a lack of capital to finance the management and improvements needed to develop sustainable production systems (Montero et al. 1998). Campos et al. (2003) argues that subsidies are needed to develop financially sustainable systems, and that these subsidies can be justified in terms of economic efficiency and social fairness.

Recently Campos and Ovando (2015) have reported the results of a comprehensive study based on the interviews to 843 forest owners and in-depth analysis of 58 forest farms (including dehesas). The study i) integrates commercial and non-commercial products in a consistent manner, ii) fully integrates a production account with a capital account, iii) clearly distinguishes between intermediate output and final output, allowing for the estimation of activity-level values and iv) provides spatially explicit results at micro-scales. Figure 14 summarizes the total income generated in 2010 by the different activities, separating labour, manufactured income and environmental income. Briefly, the results indicate that most of the total social incomes come from environmental incomes while the income from production hardly covers labour costs. Unfortunately disaggregated results for dehesas are not available yet, but the results appear to be in line with those presented in Figure 15 (Dr. Pablo Campos, personnel communication).

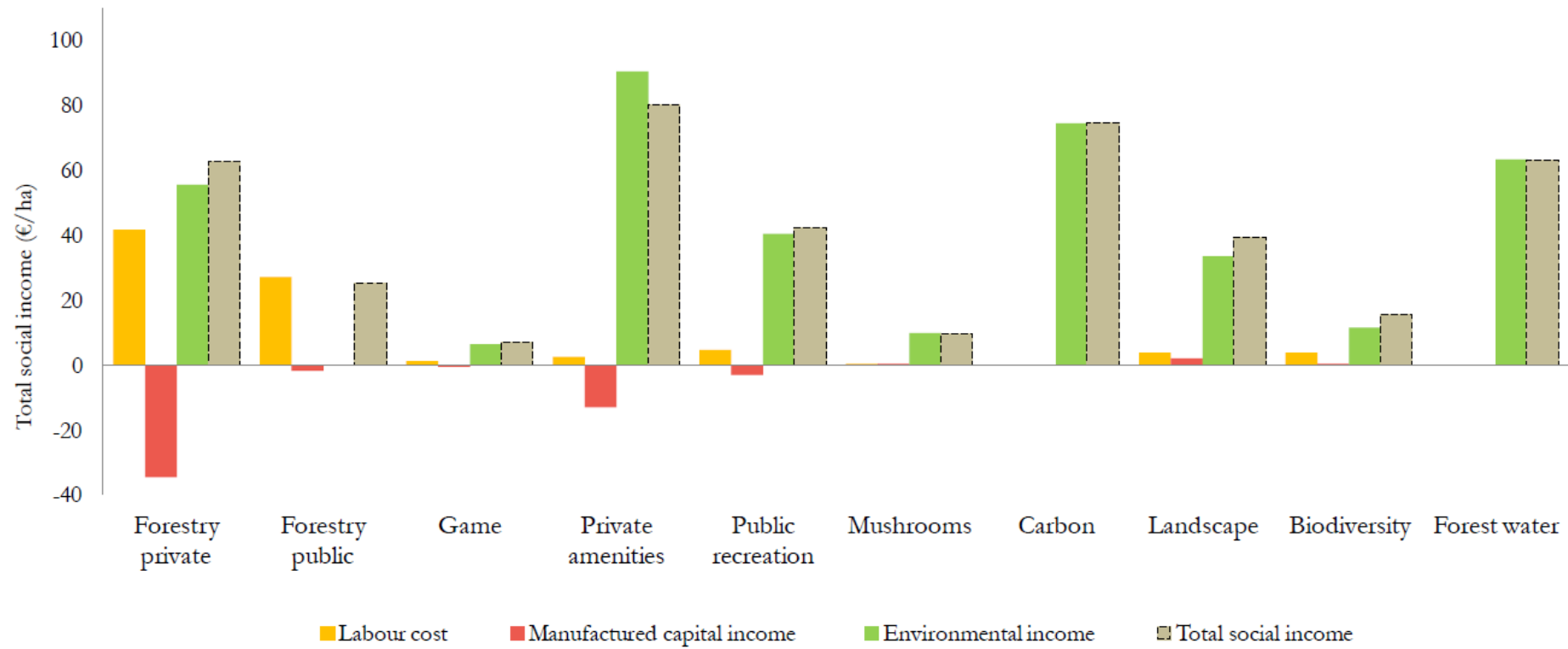

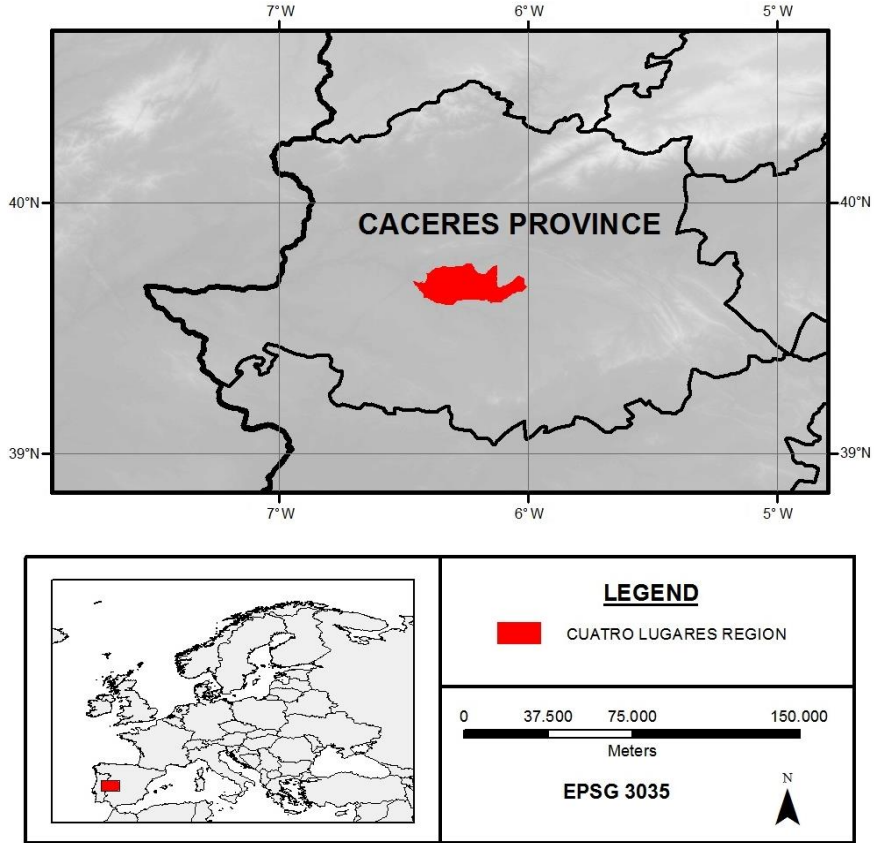


Figure 15. Total social income distribution for different activities in Andalusian forest in 2010 (Campos y OVando 2015)

## 7 Study Site: Cuatro Lugares

| Specific description of site |   |
|------------------------------|---|
| Site contact                 | Gerardo Moreno  |
| Site contact email           | <a href="mailto:gmoreno@unex.es">gmoreno@unex.es</a>  |
| Site                         | Cuatro Lugares country is situated in the autonomous community of Extremadura in southwestern Spain. This region is integrated for the municipalities of Monroy, Talaván, Hinojal and Santiago del Campo. There are four main farms within this region: “Cerro Lobato, CL”, “El Baldio, BA”, “El Sotillo, ST” and “Dehesa Boyal de Talaván, DB”.  |
| Area                         | 44,100 ha with around 48.8 % of the surface occupied by dehesas (Plieninger and Wilbrand 2001).   |
| Coordinates                  | 39°41'N - 6°13'W (39.68°N, 6.22°W)  |
| Example photograph           |  <p>Figure 16. View of the dehesas in Cuatro Lugares (Extremadura) by end June, with the pasture layer completely dry.</p>   |
| Management                   | <p>Cuatro Lugares country is primarily devoted to continuous grazing by cattle or sheep with scattered trees intercropped with cereal, natural grasses or an abundant understory. Areas with reduced grazing intensity have been encroached with shrubs. Cereals are mainly oat (<i>Avena sativa</i>) and wheat (<i>Triticum</i> sp.), grasses include annual species such as <i>Trifolium campestre</i>, <i>Medicago polymorpha</i>, <i>Anthemis arvensis</i>, <i>Geranium molle</i>, <i>Erodium cicutarium</i>, <i>Taraxacum obovatum</i>, <i>Lolium rigidum</i>, and <i>Silene psamitis</i>, and understory species are <i>Genista hirsuta</i>, <i>Cistus ladanifer</i>, <i>Retama sphaerocarpa</i>, <i>Lavandula stoechas</i>. Other marginal activities are firewood production and hunting.</p> <p>As a result of differing land-uses, the structure of vegetation found within</p> |



|                                       |  |
|---------------------------------------|--|
|                                       | <p>dehesas from Cuatro Lugares country varies between:</p> <ul style="list-style-type: none"> <li>- Oak trees and intercropped cereals (cropped).</li> <li>- Oak trees and native grass vegetation with livestock (grazed).</li> <li>- Oak trees with abundant understorey shrubs (encroached).</li> </ul>   |
| Map of system                         |  <p>Figure 17. Location of the Cuatro Lugares study area.</p>   |
| Modelling scenarios                   |  |
| Comparison                            | Technical and ecological analysis of management in the dehesa.   |
| Climate characteristics               |  |
| Mean monthly temperature              | 16.3 °C  |
| Mean annual precipitation             | 551 mm   |
| Details of weather station (and data) | <p>Data from 1981-2010 from the 3469A weather station at Caceres (39° 28' 17" N 6° 20' 20" W), accessed from website:</p> <p><a href="http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=3469A&amp;k=ext">http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=3469A&amp;k=ext</a></p> |
| Soil type                             |  |

According to the FAO classification, the soils are Chromic Luvisols (Cerro Lobato, Sotillo and El Baldío farms) developed over tertiary sediments and Eutric Leptosols (Dehesa Boyal farm) developed over precambrian slates with slopes between 2 and 4% (Moreno and Obrador 2007). Leptosols are underlain by parent material slightly weathered, thus this soil type normally shows depths on the order of 60 cm. Soil texture is predominantly sandy loam in Sotillo and El baldío, clay loam in Cerro lobato while this texture is loam in Dehesa Boyal.

Table 13. Main features of the soils of the four farms studied (Cubera and Moreno 2007)

| FARM         | SOIL TYPE       | Thickness of the layer (cm) | SAND (%) | SILT (%) | CLAY (%) | Water content (%)       |                        | Bulk density (g cm <sup>-3</sup> ) |
|--------------|-----------------|-----------------------------|----------|----------|----------|-------------------------|------------------------|------------------------------------|
|              |                 |                             |          |          |          | Field capacity (pF 2.5) | Wilting point (pF 4.2) |                                    |
| Sotillo      | Chromic Luvisol | 0 - 20                      | 51.8     | 30.3     | 17.9     | 15                      | 7.2                    | 1.49                               |
|              |                 | 20 - 40                     | 39.7     | 23.1     | 37.2     | 21.7                    | 11.8                   | 1.65                               |
|              |                 | 40 - 60                     | 38.8     | 23       | 38.2     | 21.9                    | 12                     | 1.43                               |
|              |                 | 60 - 80                     | 44.6     | 21.7     | 33.8     | 21                      | 11                     | 1.46                               |
|              |                 | 80 - 100                    | 48.6     | 5.8      | 45.6     | 27.3                    | 13.7                   | 1.53                               |
| Dehesa Boyal | Eutric Leptosol | 0 - 23                      | 34.4     | 46.4     | 19.2     | 12.2                    | 7.6                    | 1.45                               |
|              |                 | 23 - 35                     | 29.6     | 49.5     | 20.9     | 12.1                    | 8.1                    | 1.55                               |
|              |                 | 35 - 60                     | 32       | 55.6     | 12.4     | 8.6                     | 6.1                    | 1.6                                |
| Cerro Lobato | Chromic Luvisol | 0 - 20                      | 55.9     | 23       | 21.1     | 17.3                    | 7.9                    | 1.49                               |
|              |                 | 20 - 40                     | 37.2     | 26.1     | 36.7     | 20.9                    | 11.7                   | 1.65                               |
|              |                 | 40 - 60                     | 33.2     | 27.9     | 38.9     | 21.2                    | 12.2                   | 1.43                               |
|              |                 | 60 - 80                     | 44.5     | 19.3     | 36.1     | 22.1                    | 11.5                   | 1.46                               |
|              |                 | 80 - 100                    | 46.6     | 16.5     | 37       | 22.9                    | 11.7                   | 1.53                               |
| El Baldío    | Chromic Luvisol | 0 - 20                      | 58.3     | 15.5     | 26.2     | 20.1                    | 9.1                    | 1.49                               |
|              |                 | 20 - 50                     | 39.7     | 18.3     | 42       | 23.9                    | 12.9                   | 1.65                               |
|              |                 | 50 - 80                     | 38.5     | 18.5     | 43       | 24.1                    | 13.1                   | 1.45                               |
|              |                 | 80 - 120                    | 48.3     | 14.5     | 37.2     | 23.3                    | 11.7                   | 1.5                                |

### Management

The management of the land use in Cuatro Lugares has affected the properties of soil. Soil pH did not show differences due to land uses with values about 5.4. The soil organic matter (SOM) was low, according to the range of values reported for dehesas (Pulido-Fernández et al. 2013). The concentrations of SOM were slightly higher in encroached plots than in cropped and grazed plots. In general, some authors have reported that cropping dehesas contributed to an increase in most of the nutrient contents in the uppermost soil layer with respect to uncropped or grazed plots (Moreno and Obrador 2007). This increase could be produced by plough (soil aeration and increased mineralization), fertilization, and change in vegetation (Moreno et al. 2005). Overall, the studied soils showed moderately low concentrations of N and moderately high levels of P. Thus, lower nitrate content was found in cropped or grazed plots compared to encroached plots. This result agrees with the result for SOM; both N and SOM tendencies show a positive effect of the shrubs on the soil fertility. Available P and exchangeable base cations increased in cropped plots with respect to grazed areas.

Table 14. Summary of the main soil properties in different managements of the dehesa. Averaged for the four farms studied (compiled from Moreno et al. 2005a; Moreno et al. 2007a; Moreno and Obrador 2007; Cubera and Moreno 2007).

| SOIL PROPERTIES                           | CROPPED | GRAZED | ENCROACHED |
|---|---------|--------|------------|
| Organic matter (%)                        | 2.25    | 2.18   | 2.31       |
| pH (water)                                | 5.40    | 5.41   | 5.46       |
| CEC (meq/kg)                              | 135.8   | 132.5  | 132        |
| N ( $\text{g kg}^{-1}$ )                  | 1.02    | 0.88   | 1.11       |
| P ( $\text{mg kg}^{-1}$ )                 | 10.90   | 8.10   | 6.80       |
| K ( $\text{cmol+ kg}^{-1}$ )              | 0.159   | 0.136  | 0.161      |
| Ca ( $\text{cmol+ kg}^{-1}$ )             | 9.61    | 5.64   | 8.98       |
| Mg ( $\text{cmol+ kg}^{-1}$ )             | 2.70    | 1.86   | 2.34       |
| N-NH <sub>4</sub> ( $\text{mg kg}^{-1}$ ) | 22.63   | 19.5   | 19.08      |
| N-NO <sub>3</sub> ( $\text{mg Kg}^{-1}$ ) | 5.35    | 9.43   | 3.28       |
| Maximum soil moisture (% weight)          | -       | 23.97  | 17.05      |
| Minimum soil moisture (% weight)          | -       | 9.48   | 6.46       |

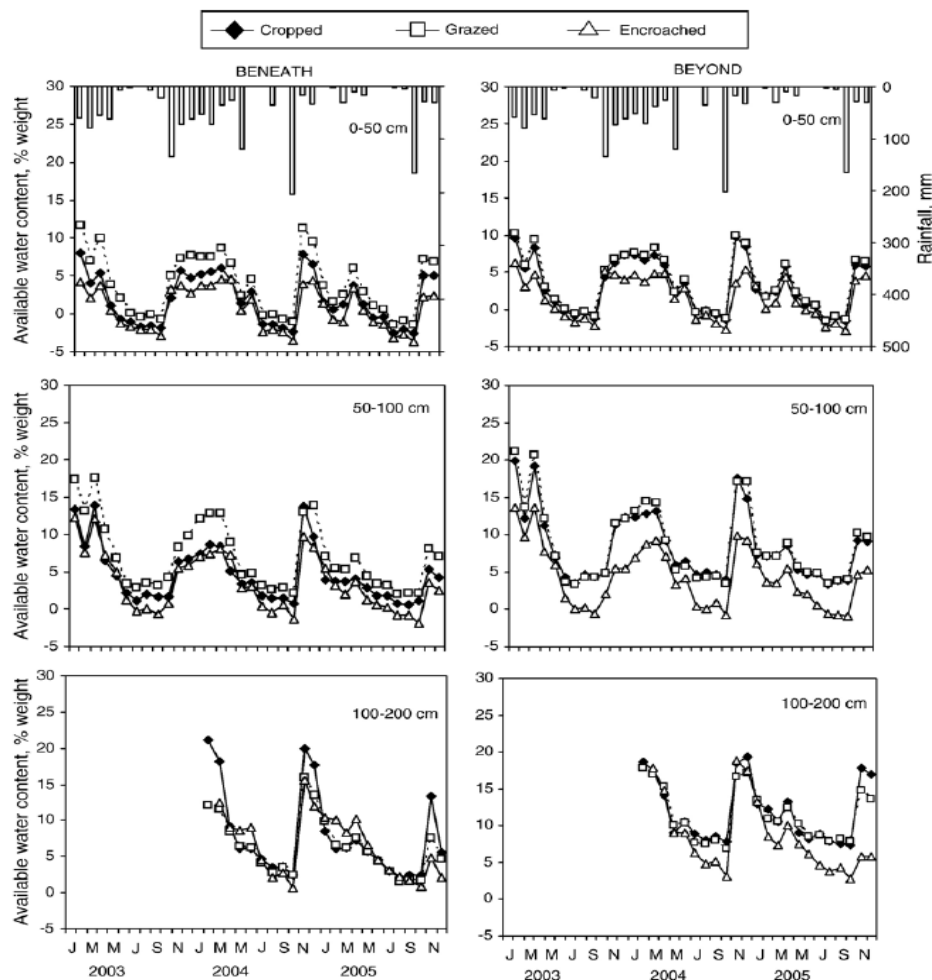


Figure 18. Variation of soil moisture at different depth with different understory management (Cubera and Moreno 2007).

| Dasometric characteristics   |  |   |             |                   |            |
|--|--|---|-------------|-------------------|------------|
| Species  | Holm-Oak ( <i>Quercus ilex</i> )   |   |             |                   |            |
| Comparison   | In Cuatro Lugares country, the management combines grazed, shrubby and cultivated open woodland and dense forest. Undergrazing encourages the invasion of various species of shrubs. The forest is normally devoted to big game hunting. |   |             |                   |            |
| <p>Dehesas result from a simplification, in structure and species richness, of Mediterranean forests and shrublands, and are attained by reducing tree density, eliminating matorral cover, and favouring the grass layer by means of grazing and crop culture (Montero et al. 1998). In Cuatro Lugares country, the density of the trees ranging from 5 to 40 trees per hectare (usually 10–25 trees per hectare) with 10–23 % canopy cover and average tree height of 6.5 m.</p> |  |   |             |                   |            |
| Table 15. Main dasometric features of the dehesas in Cuatro Lugares  |  |   |             |                   |            |
| SOURCE   | SITE   | Tree density<br>(trees ha <sup>-1</sup> ) | DBH<br>(cm) | Tree cover<br>(%) | Height (m) |
| Pulido et al. 2010   | Cuatro lugares   | 10.0-16.0                                 | -           | -                 | -          |
| Cubera & Moreno 2007   | Cuatro lugares   | 10.0-18.0                                 | -           | -                 | -          |
| Moreno & Obrador 2007  | Cuatro lugares   | 5 to 40                                   | 35 ± 4.1    | 10                | 6.2        |
| Montero et al. 2008  | Cerro Lobato and El Baldio   | 19 ± 6                                    | 35 ± 4.1    | -                 | 6.2 ± 0.3  |
| Moreno et al. 2005a  | Cerro Lobato and Sotillo   | 35  | 44.9        | 10.4              | -          |
| Moreno et al. 2007a  | Cerro Lobato   | 14.3 ± 3.2                                | -           | 13                | -          |
| Moreno et al. 2007b  | Cerro Lobato   | 18  | 46          | -                 | -          |
| Montero et al. 2004  | Cerro Lobato   | 15.5 ± 4.9                                | 41.5 ± 6.3  | -                 | 7.8 ± 0.8  |
| Moreno et al. 2007a  | Dehesa Boyal   | 10.3 ± 2.1                                | -           | 10.7              | -          |
| Moreno et al. 2007b  | Dehesa Boyal   | 8   | 61          | -                 | -          |
| Pulido et al. 2013   | El Baldio  | 20  | -           | -                 | -          |
| Moreno et al. 2007a  | El Baldio  | 21.2 ± 26.4                               | -           | 23                | -          |
| Moreno et al. 2007b  | El Baldio  | 11 ± 1.4                                  | 26.5 ± 9.2  | -                 | -          |
| Montero et al. 2004  | El Baldio  | 21.8 ± 9.7                                | 23.5 ± 5.5  | -                 | 4.7 ± 0.4  |
| 2007 Moreno et al. a   | Sotillo  | 16.5 ± 9.4                                | -           | 18.25             | -          |
| 2007 Moreno et al. b   | Sotillo  | 14  | 50          | -                 | -          |
| 2004 Montero et al.  | Sotillo  | 13.5 ± 3.5                                | 48.5 ± 3.5  | -                 | 7.9 ± 0.5  |

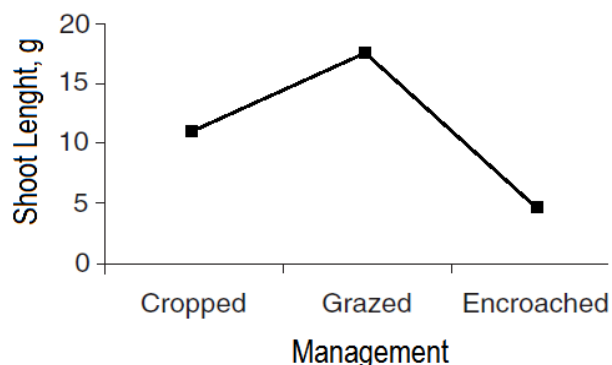
The variation in the density tree normally depends on its main use: lower densities occur in intercropped areas and higher densities in areas devoted to big game hunting (Montero et al. 1998). In Cuatro Lugares, lower densities were located in grazed areas while that higher densities was located in forest and encroached dehesas by shrubs.

Table 16. Tree density for different managements of the dehesa of Cuatro Lugares country

| SOURCE              | SITE         | Cropped | Grazed | Encroached (Shrub) | Forest |
|---------------------|--------------|---------|--------|--------------------|--------|
| Montero et al. 2004 | Sotillo      | 16      | -      | -                  | -      |
| Moreno et al. 2007b | Sotillo      | 12      | 11     | 31                 | -      |
| Moreno et al. 2007b | Dehesa Boyal | 8       | 11     | 12                 | -      |
| Moreno et al. 2007b | El Baldio    | 11      | 11     | 10                 | 75     |
| Montero et al. 2004 | El Baldio    | 19      | 10     | 39                 | -      |
| Montero et al. 2004 | Cerro Lobato | 19      | 16     | -                  | -      |
| Moreno et al. 2007b | Cerro Lobato | 18      | 13     | 12                 | -      |

## Livestock management

| Livestock species     | Main species: sheep and cattle<br>Other species: goats, pigs and horses  |           |           |           |           |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |
|-----------------------|--|-----------|-----------|-----------|-----------|--------|--------|----------------------|------------|-----------|-----------|-----------|-----------|----------------------|------|------|------|------|------|-----------------------|------|------|------|------|------|----------------------|---|------|------|---|---|---------------------|---|-------|---|------|---|-----------------------|---|-------|-------|------|---|
| Livestock densities   | <p>Livestock densities vary considerably between farms with values from 1.6 to 3.5 ewe per ha, clearly higher than the low values of the traditional system that are estimated as 0.7 or 1 ewe equivalent per ha (Plieninger and Wilbrand 2001).</p> <p>Table 17. Main characteristics of some representative livestock farms in Cuatro Lugares, Spain (Elaborated from Plieninger and Wilbrand 2001)</p> <table><tr><th></th><th>Farm 1</th><th>Farm 2</th><th>Farm 3</th><th>Farm 4</th><th>Farm 5</th></tr><tr><td>Size (ha) - % dehesa</td><td>857 - 99,6</td><td>798 - 100</td><td>547 - 100</td><td>366 - 100</td><td>241 - 100</td></tr><tr><td>Sheep (heads per ha)</td><td>1.84</td><td>1.98</td><td>1.46</td><td>1.59</td><td>2.07</td></tr><tr><td>Cattle (heads per ha)</td><td>0.12</td><td>0.03</td><td>0.17</td><td>1.41</td><td>0.05</td></tr><tr><td>Goats (heads per ha)</td><td>0</td><td>0.24</td><td>0.33</td><td>0</td><td>0</td></tr><tr><td>Pigs (heads per ha)</td><td>0</td><td>0.004</td><td>0</td><td>0.02</td><td>0</td></tr><tr><td>Horses (heads per ha)</td><td>0</td><td>0.001</td><td>0.004</td><td>0.02</td><td>0</td></tr></table> |           | Farm 1    | Farm 2    | Farm 3    | Farm 4 | Farm 5 | Size (ha) - % dehesa | 857 - 99,6 | 798 - 100 | 547 - 100 | 366 - 100 | 241 - 100 | Sheep (heads per ha) | 1.84 | 1.98 | 1.46 | 1.59 | 2.07 | Cattle (heads per ha) | 0.12 | 0.03 | 0.17 | 1.41 | 0.05 | Goats (heads per ha) | 0 | 0.24 | 0.33 | 0 | 0 | Pigs (heads per ha) | 0 | 0.004 | 0 | 0.02 | 0 | Horses (heads per ha) | 0 | 0.001 | 0.004 | 0.02 | 0 |
|                       | Farm 1   | Farm 2    | Farm 3    | Farm 4    | Farm 5    |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |
| Size (ha) - % dehesa  | 857 - 99,6   | 798 - 100 | 547 - 100 | 366 - 100 | 241 - 100 |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |
| Sheep (heads per ha)  | 1.84   | 1.98      | 1.46      | 1.59      | 2.07      |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |
| Cattle (heads per ha) | 0.12   | 0.03      | 0.17      | 1.41      | 0.05      |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |
| Goats (heads per ha)  | 0  | 0.24      | 0.33      | 0         | 0         |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |
| Pigs (heads per ha)   | 0  | 0.004     | 0         | 0.02      | 0         |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |
| Horses (heads per ha) | 0  | 0.001     | 0.004     | 0.02      | 0         |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |
| Grazing systems       | The flocks of livestock are now kept in enclosures year round. Moreover in the farms has increased livestock numbers. These factors intensify the grazing pressure and therefore tree regeneration is less and soil degradation is greater. Only some goat shepherds practice the traditional livestock movements (Plieninger and Wilbrand 2001).  |           |           |           |           |        |        |                      |            |           |           |           |           |                      |      |      |      |      |      |                       |      |      |      |      |      |                      |   |      |      |   |   |                     |   |       |   |      |   |                       |   |       |       |      |   |

| Oak tree competitive effects |  |             |         |        |            |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
|------------------------------|--|-------------|---------|--------|------------|--------|------|--------|---------|--------|------------|--------------------|----------------|-----------|------|-------|-------|------------------------|----------------|-----------|-------|-------|-------|-------------|-------|-------|-------|---------------------|-----------|-----------|-------|-------|-------|-------------|------|-------|-------|---------|-----------|------|------|---|--------------|-----------|-------|-------|
| Tree species                 | Holm-Oak ( <i>Quercus ilex</i> )   |             |         |        |            |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
| Cereal species               | Oat ( <i>Avena sativa</i> )  |             |         |        |            |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
| Comparison                   | Grow trees in dehesas with different management practices  |             |         |        |            |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
|                              | <p>Trees exert a series of positive effects on dehesa resources, but trees can also compete for resources (light, nutrients, and water) with understory vegetation or cereal cropping. Moreno et al. (2007) have shown that dehesa management affected significantly to the physiological status, growth and productivity of trees.</p> <div></div> <p>Figure 19. Effect of the dehesa management on tree growth in Cuatro Lugares country (Moreno et al. 2007)</p>   |             |         |        |            |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
| Comparison                   | Leaf water potential of trees in dehesas with different management practices   |             |         |        |            |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
|                              | <p>Irrespective of land-use, pre-dawn water potential (<math>\Psi_d</math>) values were lower during summer than in spring in Cuatro Lugares. Encroached plot trees showed <math>\Psi_d</math> values significantly lower than trees in cropped and grazed plots. The increased soil water depletion in the encroached plots suggests either that shrubs compete with trees for water resources, or that shrubs use soil water resources not available for trees (Cubera and Moreno 2007).</p> <p>Table 18. Effect of the dehesa management on predawn leaf water potential measured (<math>\Psi_d</math>, -MPa) in current-year shoots during the summer and spring</p> <table><tr><th>Source</th><th>Site</th><th>Period</th><th>Cropped</th><th>Grazed</th><th>Encroached</th></tr><tr><td>Pulido et al. 2010</td><td>Cuatro lugares</td><td>March-May</td><td>-0.4</td><td>-0.65</td><td>-0.94</td></tr><tr><td rowspan="2">Cubera and Moreno 2007</td><td rowspan="2">Cuatro lugares</td><td>March-May</td><td>-0.33</td><td>-0.35</td><td>-0.45</td></tr><tr><td>June-August</td><td>-0.45</td><td>-0.44</td><td>-0.54</td></tr><tr><td rowspan="4">Montero et al. 2004</td><td rowspan="2">El Baldio</td><td>March-May</td><td>-0.26</td><td>-0.22</td><td>-0.24</td></tr><tr><td>June-August</td><td>-0.4</td><td>-0.43</td><td>-0.55</td></tr><tr><td>Sotillo</td><td>March-May</td><td>-0.8</td><td>-1.1</td><td>-</td></tr><tr><td>Cerro Lobato</td><td>March-May</td><td>-0.49</td><td>-1.01</td><td>-</td></tr></table> |             |         |        |            | Source | Site | Period | Cropped | Grazed | Encroached | Pulido et al. 2010 | Cuatro lugares | March-May | -0.4 | -0.65 | -0.94 | Cubera and Moreno 2007 | Cuatro lugares | March-May | -0.33 | -0.35 | -0.45 | June-August | -0.45 | -0.44 | -0.54 | Montero et al. 2004 | El Baldio | March-May | -0.26 | -0.22 | -0.24 | June-August | -0.4 | -0.43 | -0.55 | Sotillo | March-May | -0.8 | -1.1 | - | Cerro Lobato | March-May | -0.49 | -1.01 |
| Source                       | Site   | Period      | Cropped | Grazed | Encroached |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
| Pulido et al. 2010           | Cuatro lugares   | March-May   | -0.4    | -0.65  | -0.94      |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
| Cubera and Moreno 2007       | Cuatro lugares   | March-May   | -0.33   | -0.35  | -0.45      |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
|                              |  | June-August | -0.45   | -0.44  | -0.54      |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
| Montero et al. 2004          | El Baldio  | March-May   | -0.26   | -0.22  | -0.24      |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
|                              |  | June-August | -0.4    | -0.43  | -0.55      |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
|                              | Sotillo  | March-May   | -0.8    | -1.1   | -          |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |
|                              | Cerro Lobato   | March-May   | -0.49   | -1.01  | -          |        |      |        |         |        |            |                    |                |           |      |       |       |                        |                |           |       |       |       |             |       |       |       |                     |           |           |       |       |       |             |      |       |       |         |           |      |      |   |              |           |       |       |



### Light distribution in dehesas

|              |   |
|--------------|---|
| Crop species | Holm-Oak ( <i>Quercus ilex</i> )  |
| Comparison   | Light distribution in dehesas with different management practices (pruned-unpruned) |

The pruning in the holm-oak increased the percent of light transmitted only in the vicinity of the trunk. Thus, the pruned increases the light availability under tree.

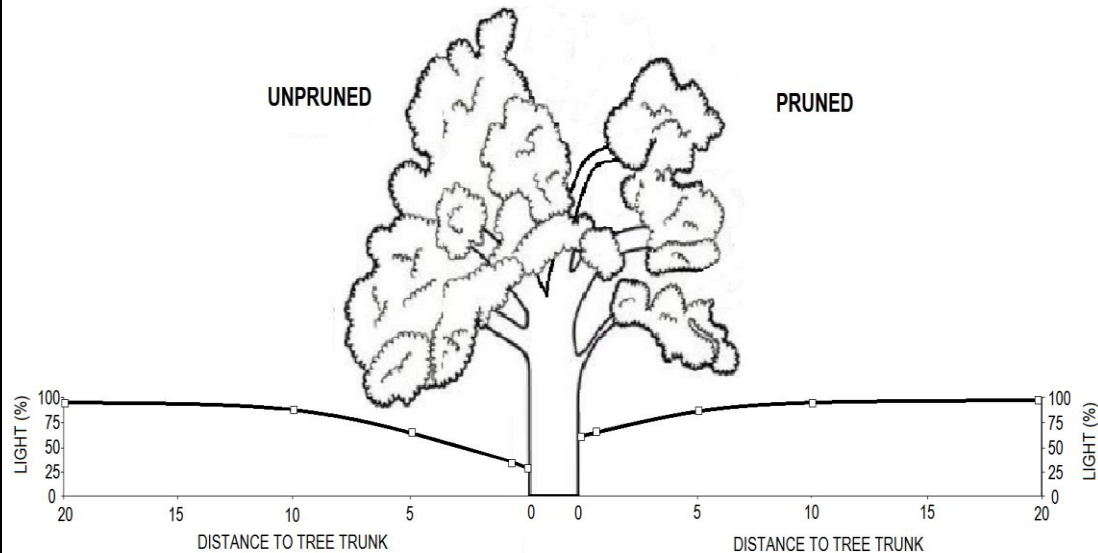


Figure 20. Effect of light transmitted in pruned and unpruned Holm-oaks in dehesas from Cuatro Lugares country (Cerro Lobato farm) (Montero et al. 2008)

### Root characteristics

|              |   |
|--------------|---|
| Crop species | Holm oak ( <i>Quercus ilex</i> )  |
| Comparison   | Root length density of herbaceous plants and holm oak with different management practices (grazed and cropped). |

Root length density of herbaceous plants was much lower in grazed plots (native grasses) than in intercropped plots (oats + weeds). Root length density of tree was however very similar in both types of management.

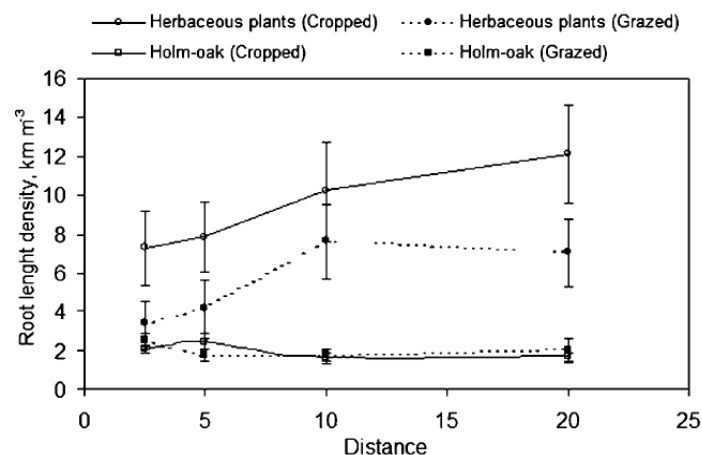


Figure 21. Distribution of the root length density of tree and herbaceous plants at different distances on two different types of dehesa management (Moreno et al. 2005)

| Crop production  |   |
|--|---|
| Crop species   | Holm oak ( <i>Quercus ilex</i> )                                |
| Comparison   | Crops with or without fertilization                             |
| <p>Crop yield in the dehesa shows a huge spatial variation and temporal variation. Furthermore, crop yield normally increases in fertilised areas. Thus, in Cuatro Lugares, without fertilization plots showed lower biomass production (<math>3136 \pm 1344</math> dry matter kg ha<sup>-1</sup>) compared with fertilization plots (<math>1136 \pm 491</math> dry matter kg ha<sup>-1</sup>). Besides, without fertilisation crop yield was higher beneath the canopy than in the open spaces, while it was higher beyond the canopy in fertilised crops.</p>  |   |
| <p><b>a)</b></p> <p>Crop biomass (dry matter Kg ha<sup>-1</sup>)</p> <p>Distance to tree (m)</p> <p>Legend for (a):<br/>     - Cerro Lobato - Fertile (solid line, open squares)<br/>     - Cerro Lobato - Unfertile (dotted line, open circles)<br/>     - Dehesa Boyal - Fertile (solid line, filled squares)<br/>     - Dehesa Boyal - Unfertile (dotted line, filled circles)<br/>     - El Baldio - Fertile (solid line, open circles)<br/>     - El Baldio - Unfertile (dotted line, open circles)<br/>     - Sotillo - Fertile (solid line, filled circles)<br/>     - Sotillo - Unfertile (dotted line, filled circles)   </p> <p><b>b)</b></p> <p>Crop biomass (dry matter Kg ha<sup>-1</sup>)</p> <p>Distance to tree (m)</p> <p>Legend for (b):<br/>     - Cuatro Lugares - Unfertile (dotted line, filled triangles)<br/>     - Cuatro Lugares - Fertile (solid line, filled triangles)   </p> |   |
| <p>Figure 22. Variation of mean values of crop biomass (aboveground dry matter of oat plants, in kg ha<sup>-1</sup>) around Holm-oak trees with different management plot. The fertiliser was of 150 kg NPK 9/18/27 + 75 kg 46% urea in “El Baldio” and 200 kg NPK 7/12/7 in “Sotillo”, “Cerro Lobato” and “Dehesa Boyal (Moreno et al. 2007b)</p>   |   |
| Acorn production   |   |
| Crop species   | Holm oak ( <i>Quercus ilex</i> )                                |
| Comparison   | Acorn production in dehesas with different management practices |
| <p>A study reported by Moreno et al. (2007b) shows that the cropped dehesa had a positive effect on acorn production (Kg acorns per tree). However, Moreno et al. (2007a) determined that the grazed plots showed higher values of production than cropped plots (g acorn per m<sup>2</sup> canopy). Both studies determined that shrub encroaching caused a slight decrease as compared to grazed or cropped sites. Thereby, a positive effect of tree clearance (by cropped or grazed) on the acorn productivity of the trees is observed.</p>   |   |

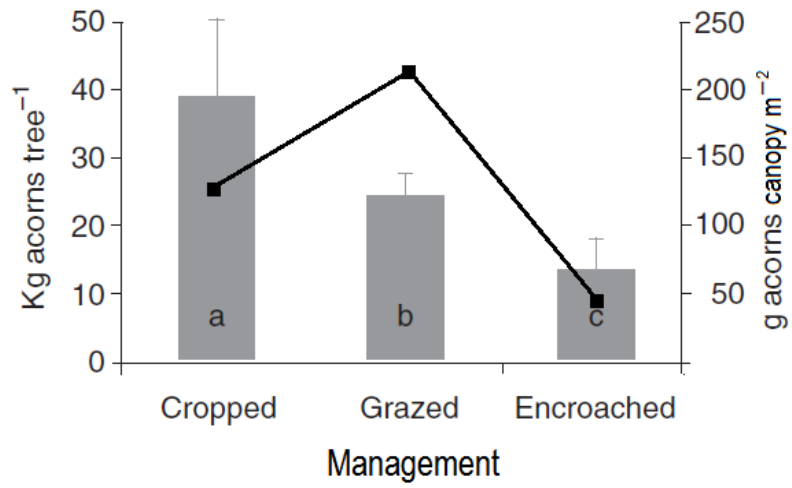


Figure 23. Effect of the dehesa management on acorn production (Moreno et al. 2007a).

## 8 Study Site: Majadas

### 8.1 Description of the site

| Site characteristics       |  |
|----------------------------|--|
| Area (ha)                  | 670 ha   |
| Co-ordinates:              | 39°56'25.1"N; 5°46'28.7"W (WGS84 Ellipsoid)  |
| Altitude                   | 237 - 283 m.a.s.l.   |
| Slope                      | 3.6% (range 0.7 - 29.4)  |
| Site contact:              | Majadas City Council, Extremadura, Spain   |
| Site contact email address | <a href="mailto:informacion@ayuntamiento-majadas.es">informacion@ayuntamiento-majadas.es</a> |

| Soil characteristics             |   |
|----------------------------------|---|
| Soil type (WRB classification)   | Dystric Cambisol over Pliocene-Miocene alluvial deposits  |
| Soil depth                       | Unlimited   |
| Soil texture                     | 0-20 cm: 3.9% clay, 20.3% silt, 75.8% sand<br>20-40 cm: 10.2% clay, 23.9% silt, 65.8% sand<br>40-60 cm: 17.6% clay, 30.6% silt, 51.9% sand  |
| Soil pH                          | 0-20 cm: 5.61-5.15  |
| (open pasture – beneath canopy)  | 20-40 cm: 5.73-5.12<br>40-60 cm: 5.90-5.05  |
| Soil Bulk Density                | Open pasture: 1.51 g cm <sup>-3</sup> ; Beneath canopy: 1.38 g cm <sup>-3</sup>   |
| (10–30–40–75–100–125–175 225 cm) | 1.49 – 1.56 – 1.50 – 1.52 – 1.62 – 1.65 – 1.73 – 1.70 g/cm <sup>3</sup>   |
| Soil organic carbon              | Open pasture: 38.9 mg g <sup>-1</sup> ; Beneath canopy: 13.6 mg g <sup>-1</sup><br>0-10 cm: 11.5 (range 4-24) mg g <sup>-1</sup><br>10-20 cm: 4.9 (range 2-8) mg g <sup>-1</sup><br>20-50 cm: 3.0 (range 2-4) mg g <sup>-1</sup><br>50-100 cm: 1.5 (range 1-2) mg g <sup>-1</sup> |
| Soil nitrogen (total)            | 0-10 cm: 1.05 (range 0.50-1.50) mg g <sup>-1</sup><br>10-20 cm: 0.52 (range 0.30-0.80) mg g <sup>-1</sup><br>20-50 cm: 0.40 (range 0.35-0.45) mg g <sup>-1</sup><br>50-100 cm: 0.28 (range 0.20-0.35) mg g <sup>-1</sup>  |
| Available O (Olsen)              | 0-20 cm: 11.0-11.0 mg g <sup>-1</sup>   |
| Open pasture – beneath canopy    | 20-40 cm: 11.6-12.7 mg g <sup>-1</sup><br>40-60 cm: 10.1-9.2 mg g <sup>-1</sup>   |

| Tree characteristics             |   |
|----------------------------------|---|
| Tree species                     | <i>Quercus ilex</i> ( <i>Quercus suber</i> + <i>Quercus faginea</i> ; <5%)      |
| Tree density                     | 24.8 tree ha <sup>-1</sup> (range 19.7 - 25.7)                                  |
| Fraction of canopy cover         | 19.75% (range 18.7 - 20.9)  |
| Basal area                       | 3.25 - 3.53 m <sup>2</sup> ha <sup>-1</sup>                                     |
| Tree age                         | 120 years (range 105-120)   |
| Tree height                      | 8.1 ± 1.3 m   |
| DBH                              | 44.9 ± 6.4 m  |
| Aerial Wood biomass              | 2.64 kg DM m <sup>-2</sup>  |
| Coarse root biomass              | 0.996 kg DM m <sup>-2</sup>   |
| Specific Leaf Area               | 45.95 cm <sup>2</sup> g <sup>-1</sup>   |
| LAI (crow and surface level)     | 1.5 (range 1.22-1.92) – 0.30 (range 0.24 – 0.38) m <sup>2</sup> m <sup>-2</sup> |
| Tree leaf N (new and old leaves) | 14.8 – 12.8 mg g <sup>-1</sup>  |
| Tree leaf P (new and old leaves) | 1.0 – 0.8 mg g <sup>-1</sup>  |

| Pasture                   |   |
|---------------------------|---|
| Forbs – Grasses - Legumes | $45.5 \pm 5.6\%$ - $45.4 \pm 6.7\%$ - $9.1 \pm 6.0\%$                       |
| Leaf N - Leaf P - Leaf C  | $20 \text{ mg g}^{-1}$ - $2.71 \text{ mg g}^{-1}$ - $420 \text{ mg g}^{-1}$ |
| Leaf N (Forbs – Grass)    | $25.7 - 26.5 \text{ mg g}^{-1}$   |
| Leaf P (Forbs – Grass)    | $2.9 - 2.8 \text{ mg g}^{-1}$   |
| Leaf N/P (Forbs – Grass)  | 8.9 – 9.4   |
| LAI (seasonal max)        | $1.5 \text{ m}^2 \text{ m}^{-2}$ (see picture 4)                            |

| Livestock characteristics |   |
|---------------------------|---|
| Species                   | Cattle  |
| Stocking density          | $0.3 \text{ LU ha}^{-1}$ (Extensive grazing with feeding supplementation) |

| Climate data                |   |
|-----------------------------|---|
| Mean monthly temperature    | $16.7^\circ \text{C}$                               |
| Mean annual precipitation   | 677 mm  |
| Annual rainfall 2004 - 2012 | 719 – 622 – 809 – 576 – 645 – 604 – 965 – 684 - 470 |
| Details of weather station  | In the experimental plot                            |



Figure 24. View of the soil profile in Majadas dehesa farm. Excavated down to 300 cm

## 8.2 Monitoring program

At the public dehesa farm of Majadas de Tiétar (Extremadura) an exhaustive monitoring program is currently running under the international network FLUXNET (<http://fluxnet.ornl.gov/site/440> and <http://www.ceam.es/carboredes/metadatos.htm#MAJADAS>). This experimental station is currently supported and managed by Max Planck Institute for Biogeochemistry (Jena, Germany), Centro de Estudios Ecológicos del Mediterráneo (Valencia, Spain), Centro de Ciencias Humanas y Sociales-CSIC (Madrid, Spain) and University of Extremadura (Plasencia, Spain). The aim of the monitoring program is the continuous measurements of the CO<sub>2</sub> and water vapor fluxes to assess the consequences of the climate change on the functioning of semi-arid wood pastures. Since 2014, the monitoring program incorporate additional measurements to assess components productivity in order to model i) the effects of trees on pasture understory production and ii) the effects of tree carbon sequestration, under different scenarios of nutrient availability and water availability.

The monitoring program includes four plots, one managed as Control, while one of them was fertilized with N (100 kg N ha<sup>-1</sup> applied as ammonium nitrate), one of them was fertilized with P (50 kg P ha<sup>-1</sup> applied as triple superphosphate), and the last one fertilized with N+P. Figure 18 shows the location of the four treatments and Table 19 shows the data available.

Table 19. List of measurements and data available

| Component    | Description of measurements   |
|--------------|---|
| Climate      | Air temperature and humidity, wind speed, solar radiation (global and diffuse)  |
| Soil         | Temperature (until 30 cm depth), Moisture (until 120 cm depth), Nutrient content (both beneath tree canopy and out of the canopy), Carbon, Respiration  |
| Tree         | Sap flow, Phenology, Leaf production, LAI, Leaf nutrient content, Stem growth, Acorn production.  |
| Pasture      | Evapotranspiration (automatic lysimeter), CO <sub>2</sub> exchange, Production (both beneath tree canopy and out of the canopy), LAI, Phenology, Consumed herbaceous pasture (grazed), Botanical composition of pasture |
| Whole system | gas exchange (CO <sub>2</sub> and water vapour) measure in three eddy covariance towers   |



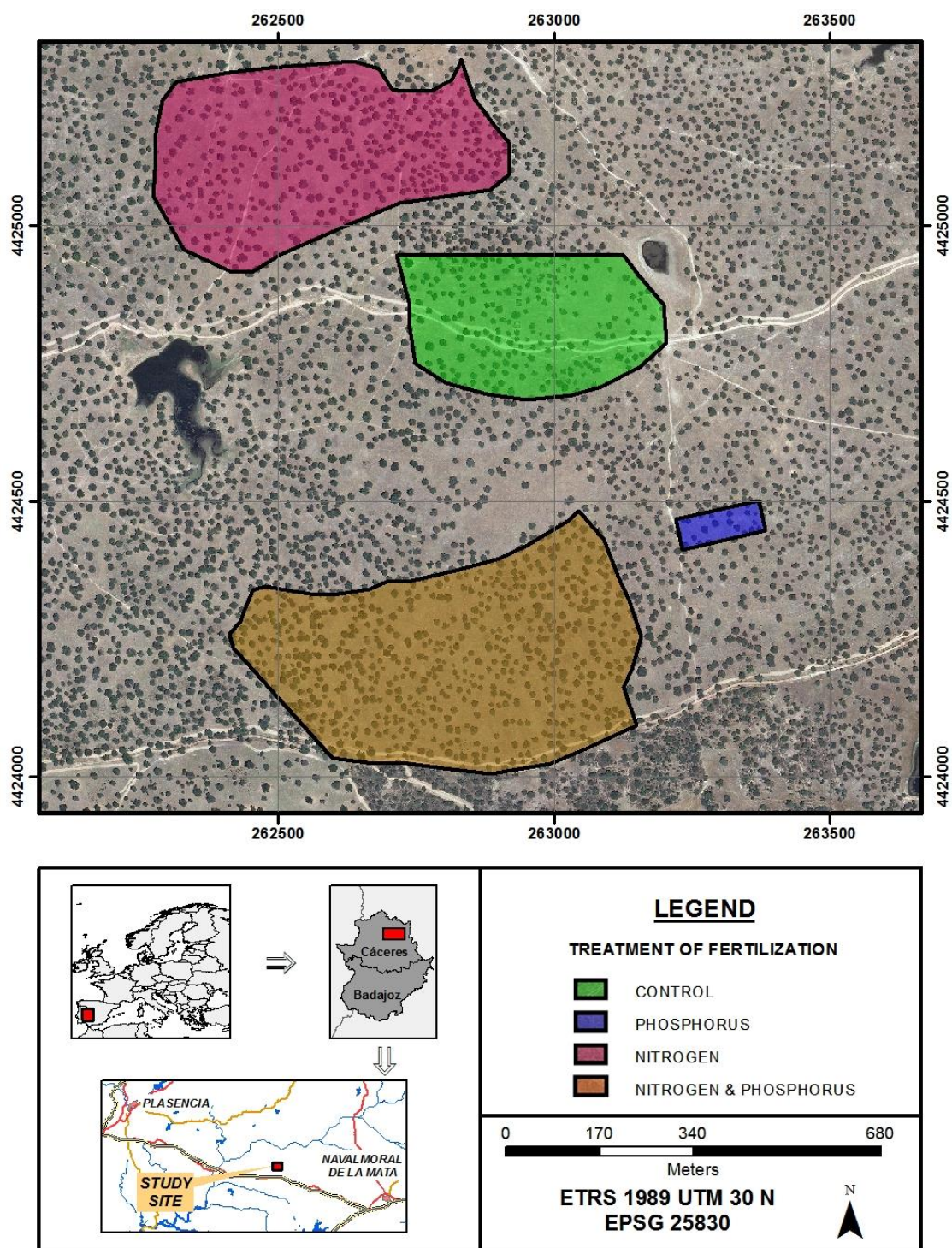


Figure 25. Location of the four fertilization treatments in Majadas dehesa farm





Figure 26. View of the litterfall traps used monitor litter and acorn production tree leaf area index (LAI)



Figure 27. View of dendrometer and sap flow probe installed in tree stem



Figure 28. View of the exclusion cages used to monitor pasture production and grazing intensity

### 8.3 Some initial results (the study is on-going)

Some initial results representative of the information already available are presented below. The measurements are on-going.

#### Pasture production

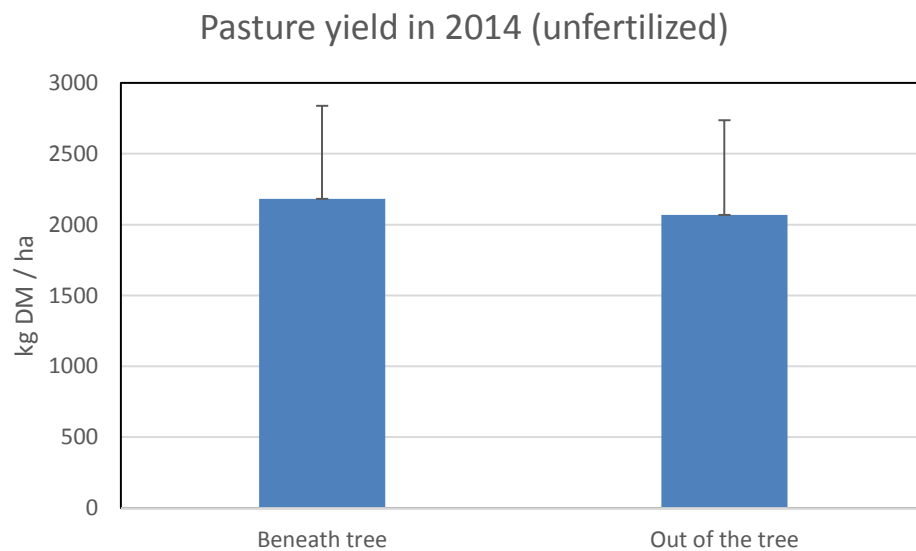


Figure 29. Production of pasture comparing two microhabitats, beneath the tree canopy and out of the trees (> 20 m distance from the tree trunk)



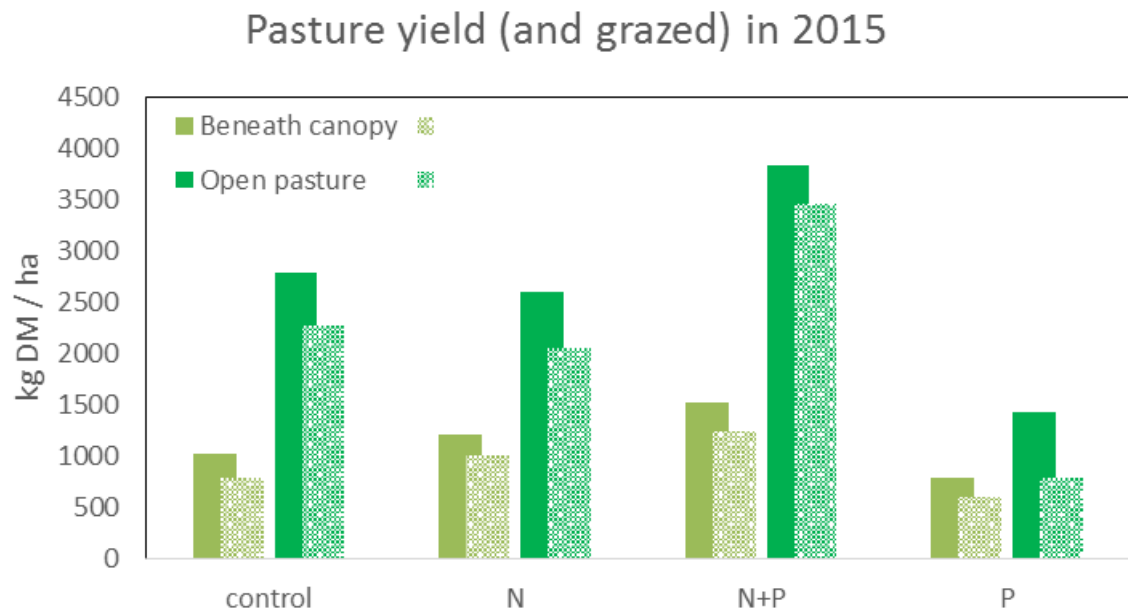


Figure 30. Production of pasture comparing two microhabitats, beneath the tree canopy and out of the trees (> 20 m distance from the tree trunk) and four treatments of fertilization. Data show the total production (full colour) and the amount consumed by cattle (colour weft).

#### Acorn yield

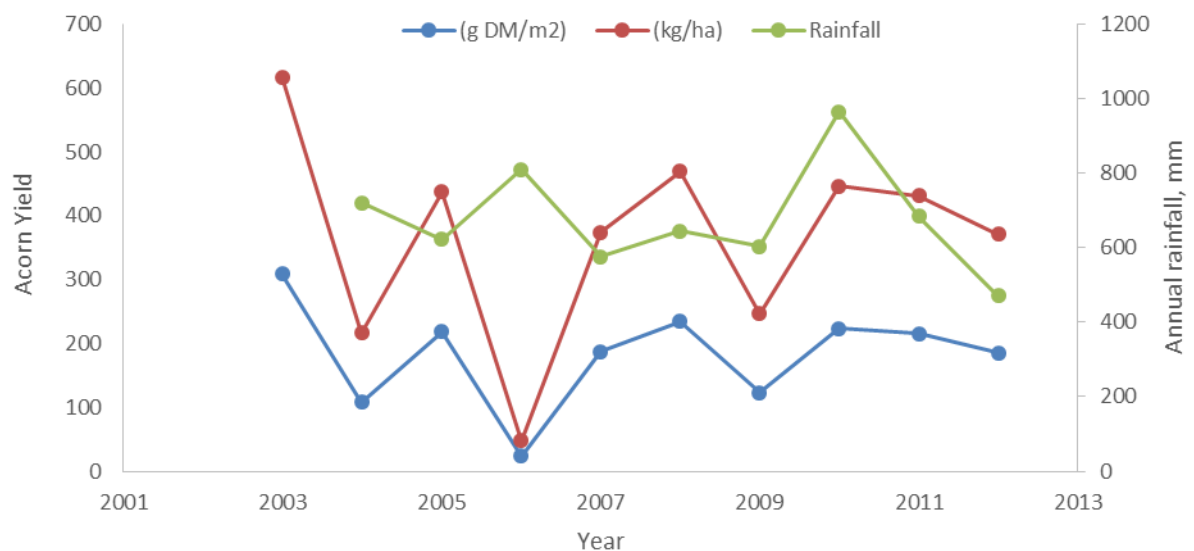


Figure 31. Temporal series of acorn production in unfertilized plot

### System functioning: Net CO<sub>2</sub> exchange

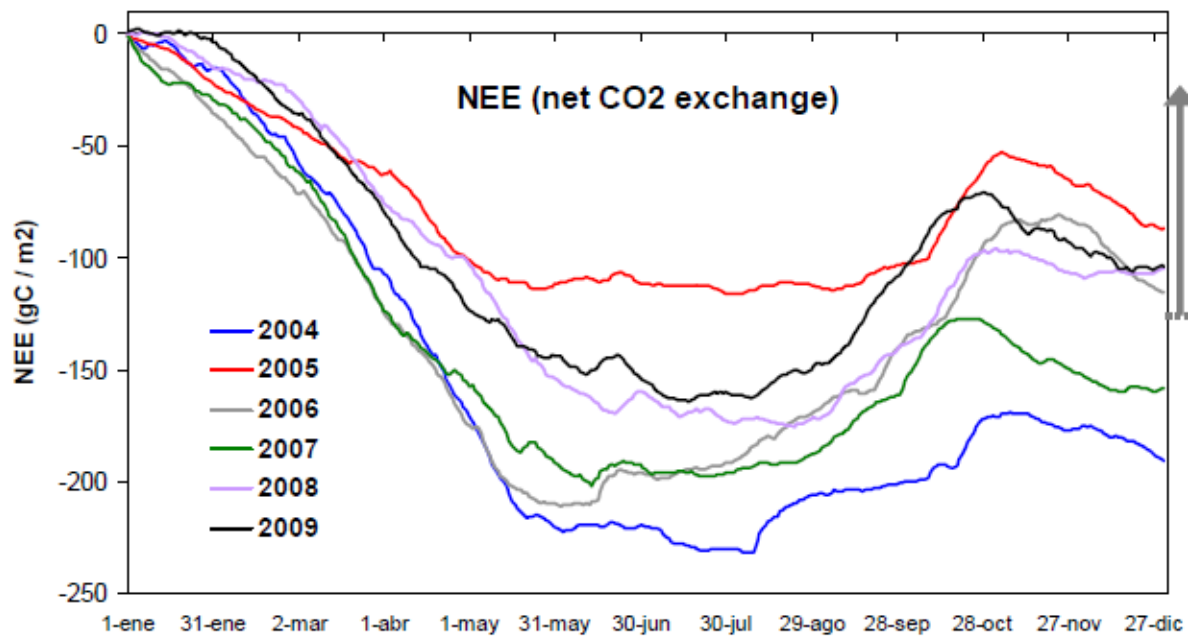


Figure 32. Annual course of net ecosystem exchange of CO<sub>2</sub> for six consecutive years, with annual rainfall of 719, 622, 809, 576, 645 and 604 mm, respectively

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