AGFORWARD
Agroforestry for Europe

Lessons learnt: Iberian dehesa

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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 and Deliverable 2.5 which describes the lessons learnt from innovations within agroforestry systems of high natural and cultural value. Within the project, there were ten stakeholder groups focused on such systems (e.g. grazed forests, semi-open pastures, wood pastures, and bocage). This report focuses on a stakeholder group which focussed on the Spanish Dehesa, which together the Portuguese Montado dominates the most extended territory of Mediterranean wood pastures.

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 (Moreno et al. *2*013) and form one of the largest agroforestry system in Europe (der Herder et al. *2*017).

They are agrosilvopastoral systems originating from clearing of evergreen woodlands where trees, native grasses, crops, and livestock interact positively under specific management practices. The scattered tree layer is dominated by Mediterranean evergreen oaks (30–50 trees per ha, principal species *Quercus ilex* and *Q. suber*). Mature trees are regularly pruned with the aim of maximising acorn production providing leafy branches in summer and winter, when the herbage production is low, and wood fuel 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. More details are given in Moreno and Cáceres (2016), a thorough revision of the current knowledge about the structure and functioning of dehesas, the provision private goods and public environmental services, and the current threats (AGFORWARD project, Deliverable 2.4. "System report: Iberian dehesas"; Moreno and Cáceres 2016).

The importance of dehesas rests on both environmental and socio-economic values. First, dehesas play a prominent role in the economy of rural areas in southwestern Spain where high-quality food derived from livestock is produced (Campos et al. *2*013). In addition, dehesas have been valued at an international policy-making level for their biodiversity, aesthetic qualities and potential for tourism and recreation. Dehesas are included in the EU habitat directive as habitat with community-wide interest (Díaz et al. *2*013).

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 common agricultural policies (Plieninger et al. 2015). 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 vegetation, soil properties and hydrological processes (Schnabel et al. 2013); 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 (Diaz et al. 2013). In this context, the sustainability of the dehesa system has been seriously questioned (Moreno and Pulido 2009).

To help dehesa farmers overcome the current difficulties and threats, the University of Extremadura fostered the development of 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 proposals of innovations to be tested by the Participatory Research and Development Network in the course of the AGFORWARD project 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).

3 Innovations tested

The stakeholder group prioritized and agreed to focus on the following seven innovations, to be developed and evaluated in years 2015-2017.

1. Comparison of cost-efficient methods for tree regeneration including the study of nursery shrubs, artificial wire thorny shelters, natural protectors (pruned branches), and chemical organic repellents.
2. Evaluation of cultivars of triticale, a forage crop.
3. Search for forage legume species that perform well under tree shade conditions, grazing pressure and long dry periods.
4. Assessment of the feasibility of fast-intensive rotational grazing against regular grazing for livestock breeding in Iberian dehesas.
5. Explore the potential of multipurpose GPS collars to facilitate livestock management and to protect young tree regeneration.
6. Explore the consumer acceptance for agroforestry products and services, and
7. Evaluate the carbon sink strength of Iberian dehesas.

In October 2015 the experimental protocols to follow in the field test of these innovations were reported in the Milestone 4 (2.3) "Synthesis of the research and development protocols related to agroforestry of high nature and cultural value" (Moreno et al. 2015b, 2015c). This report presents the main findings concerning the innovations 1, 2, 3 and 6 (Sections 4 to 7).

The assessment of fast-intensive rotational grazing (nº 4), because of the complexity of implementing a new grazing scheme that involves reorganizing the farm and certain costs (new infrastructures and labour), progressed slower than expected and the scientific results are only now being produced. Nevertheless, as results of the work done within the stakeholder groups, in the last year four dehesa farms implemented new grazing schemes based on the idea of the fast-intensive rotational grazing, and two new projects will fund the monitoring for the following three years (LIFE project REGENERATE; and MAVA foundation project)[1].

With respect to the use of multipurpose GPS collars to facilitate livestock management and to protect young tree regeneration (nº 5), the studies did not progress beyond the lab design fabricated using the latest technologies in low-power electronics. Several features of this design allow the investigation of important open problems. For example, the modular design facilitates the testing of current and emerging radio technologies such as GPRS, SigFox, Lora or Neul. Also, a mechanism to stimulate the animal with electrical or ultrasound discharges is being tested in real conditions to elicit new precision grazing strategies. Finally, the collar is configured with different quantities of Lithium batteries to guarantee the required lifespan in each situation. The aim is to product low-cost collars to be used in a wide variety of experiments involving extensive livestock farming. Besides tracking, the collar has been designed to investigate several problems and situations occurring in the Dehesa, such us precision grazing for the removal of fences and optimization of pastures, protection of valuable tree regeneration for forest renewal, and selective water disposal for cattle to prevent the dissemination of tuberculosis from wild animals. In spite of the important progresses done in the design of the prototype, these were not sufficient enough to be implemented in real farms, especially because the duration of the battery, the current bottle-neck. The research is now focussed on the search of mechanism of battery auto recharge while the animal is wearing the collar. This research idea is now looking for additional funds to go forward, and we hope to run field experiments in real farms in the coming years.

Finally, although the stakeholder group of the dehesas has collaborated in the last three years in the progressive instrumentation of two dehesas for the monitoring of carbon fluxes, in collaboration with the project DEHESHyrE[2], data already collected are not sufficient to calculate reliable annual balances of carbon (and water) at ecosystem level. Fortunately the monitoring is guaranteed for the next few years and we expect to produce for the first time robust data on carbon balance in Iberian dehesas at different temporal scales (from daily to multiyear periods).

[1] http://en.mava-foundation.org/what-we-fund/strategy

[2] https://www.bgc-jena.mpg.de/bgi/index.php/Research/Deheshyre

4 Cost-efficient methods for tree regeneration

This section provides a summary of the results of a series of trials designed to test (i) the efficiency of repellents against rodents that consume sown acorns, (ii) the nursery effects of leguminous shrubs for oak seedlings, and (iii) the resistance of different natural and artificial plant shelters. They are all proposed options for the design of a menu of low-cost practices for the natural regeneration of dehesa tree cover at farm level. Results have been partially presented in the World Congress of Silvopastoral Systems hold at Évora (Portugal) in September 2016 (Cáceres et al. *2*016) and in the Spanish Congress of Forest Science hold at Plasencia (Spain) in June 2017 (Cáceres et al. *2*017). In addition, a peer-review article is in preparation to be submitted to the journal Applied of Vegetation Science. A stakeholder-oriented version of this article will be then prepared for the Spanish journal "19 lineas" (http://www.19lineas.es/).

4.1 Background

Dehesas and other wood pastures are facing several threats, especially the lack of tree recruitment accompanied by a gradual dieback of existing oak stands. Tree mortality has increased considerably over the past three decades due to the effect of the combined action of soil pathogens, xylophagous insects and adverse climate conditions (Brasier 1996). Indeed, the continuity of the dehesas could be threatened by the gradual decay of tree canopy. In fact tree regeneration ranks second in the list of innovation demands proposed by stakeholders (prevention of oak sudden death, a closely related issue, ranking first) (Moreno 2014).

Poor regeneration and high adult mortality have prompted the implementation of government-supported artificial regeneration programmes in areas where the tree population has declined or disappeared and in those dehesas with unbalanced tree age classes. Currently, the artificial regeneration in managed dehesas is too expensive because planted seedlings have low rates of survival, and replanting is frequently needed, and because young planted trees have to be fenced out or protected individually with costly wire shelters designed to avoid damage by livestock. Grazing exclusion or individual shelters need to be maintained for long periods (even for 20 years) due to the slow growth of oaks. Typically tree shelter cost ca. 30 € /unit, and must be at least 1.80 m high with 3 strong iron bars (Figure 1).


Figure 1. Conventional seedling shelters, combining Tubex and wire shelters (ca. 30 € /unit)

The benefits from artificial regeneration are thus outweighed by the high costs involved and therefore artificial regeneration methods have been increasingly identified as an inefficient method of tree establishment that cannot be afforded (Birch et al. 2010). For these reasons there is a growing demand for alternative, cost-effective methods to protect acorn or seedlings. Reducing the costs of such practices and testing different methods of shelters are essential to improve the restoration efforts. In general these alternatives are aimed at reducing the cost of the plant material (acorn/seedling), the protecting devices, or the labour while increasing plant survival in the long term.

Passive restoration methods that promote regeneration by mimicking natural processes may be more effective and efficient than artificial regeneration methods (Pulido et al. *2*010). Sowing acorns directly in the field for instance, has been shown to be a viable technique for restoring holm oak forests, for forestation on agricultural lands, or the diversification of forest species on a large scale at low costs (Navarro et al. *2*006; González-Rodríguez et al. *2*011; Moreno and Franco 2013). In Mediterranean environments, native shrubs contribute to tree recruitment, provide net facilitative effects for oak seedlings, which benefit from shade and protection from herbivores (Castro et al. *2*004; Gómez-Aparicio et al. *2*004, 2005a,b; Smit et al. *2*008; Rey et al. *2*009; Rolo et al. *2*013).

4.2 Objectives

This study has been designed to develop, based on knowledge on the processes that promote or prevent tree regeneration, an effective, low-cost approach to enhance tree regeneration in grazed dehesas. We test alternative low-cost methods of protection of sown acorns and emerged oak seedlings and saplings. Specifically, we tested in different field trial:

i. the survival of seedling planted (artificial regeneration) vs seedling emerged of sown acorns;
ii. the efficiency of repellents against rodents that consume sown acorns;
iii. the effectiveness of shade shelters (tubex) and anti-grass mesh (reducing the competition on seedlings) to increase the survival of planted seedling;
iv. the effectiveness of classic vs innovative shelters to protect seedlings and sapling against browsers (livestock and wild herbivores such a as red deer);
v. the nursery effects of leguminous shrubs for oak seedlings.

Overall, we want to respond to the following three questions:

1. Is the approach effective (able to result in a sufficient number of trees established)?
2. Is the approach cost-efficient (cost per tree established)?
3. Is the approach feasible? (can it be easily implemented by land owners and managers with their own resources and/or with minimal support?)

The underlying hypothesis is that the propensity of farmers to restore oaks without subsidies or with small investments increases when costs are reduced. In addition, the risk of introducing plant material infested with microbial diseases and/or mal-adapted to local conditions could be minimized by using acorns from local sources.

4.3 Methodology

4.3.1 Experiment 1. Comparison of shelters for seedlings and saplings

Ecological shelters for seeds or seedlings are a diverse array of techniques using natural materials and/or mimicking natural processes by which plant survival is increased. Here we compared three shelters that protect plants of herbivores, the classic shelter (standard wire shelter with thick iron fixers; Figure 2) and two alternative shelters (Figure 2), one built with branches coming from tree pruning, and another with thorny wire (http://protectorcactus.com/). Thorny shelters allow the use of thin fixers what saves money. Spatial coordinates of each planted seedling were recorded with a submetric GPS to allow the analysis of spatial effects on seedling survival.

Figure 2. Innovative eco-shelters proposed in this study: thorny wire shelter (left), small band of thorny shelter around a classical protector (right top), and natural shelter made with branches (right bottom).

Five farms with grazing cows (3 farms), sheep (3 farms), pigs (2 farms) and presence of red deer (1 farm) collaborated in this trial (details in Moreno et al. *2*015b, 2015c). Table 1 gives details on the treatments compared on each farm, and the number of replicates.

Table 1. List of treatments compared in each of the five dehesa farms

Farm Las Parras	Monteviejo	Atoquedo	Las Lebreras	Valdesequera
Control Control + thorny ring Thorny shelter Natural shelter	Control Thorny shelter Natural shelter	Control Control + thorny ring Thorny shelter Natural shelter	Control Thorny shelter	

4.3.2 Experiment 2: Nurse plants

Three potential nurse shrub species were tested (*Retama sphaerocarpa, Cytisus multiflorus* and *Lavandula stoechas*) with two control habitat, open pasture and pilled pruned branches. Locally available dog excrement was mixed with the acorns as a repellent against predators. Spatial coordinates of each planted seedling were recorded with a submetric GPS to allow the analysis of spatial effects on acorn survival. Details on sites, combined treatments, and repetitions are given in Table 2.

Table 2. List of treatments compared on each dehesa farms

<table>
<tr><th colspan="6">Experiment 2.1</th></tr>
<tr><th colspan="3">Farm “Dehesilla”, Valdehuncar</th><th colspan="3">Farm “La Parra”, Villa del Campo</th></tr>
<tr><td colspan="3">12 treatments (100 acorns per treatment)</td><td colspan="3">8 treatments (50 acorns per treatment)</td></tr>
<tr><td colspan="3">Retama sphaerocarpa + repellent
Retama sphaerocarpa - no repellent
Retama interspaces + repellent
Retama interspaces-no repellent
Cytisus multiflorus + repellent
Cytisus multiflorus - no repellent
Cytisus interspaces + repellent
Cytisus interspaces - no repellent
Piled branches + repellent
Piled branches – no repellent
Open pasture + repellent
Open pasture – no repellent</td><td colspan="3">Cytisus multiflorus-no repellent
Cytisus multiflorus + repellent
Retama sphaerocarpa –no repellent
Retama sphaerocarpa + repellent
Lavandula stoechas -no repellent
Lavandula stoechas + repellent
Open pasture (control) -no repellent
Open pasture (control) + repellent</td></tr>
<tr><th colspan="6">Experiment 2.2</th></tr>
<tr><th colspan="2">Farm Santi Spiritus</th><th colspan="2">Farm San Pedrillo</th><th colspan="2">Farm Valverdejo</th></tr>
<tr><td colspan="6">(10 repetitions; 10 acorns per repetition)</td></tr>
<tr><td colspan="6">Open – no repellents
Pruned branches – no repellents
Pruned branches + repellents</td></tr>
</table>

Acorns were collected from holm oak trees in December 2014 and kept at room temperature in cold and dry storage. On January 31 2015, acorns were sown (Figure 3). In each site, sown microsites were chosen following a random walk. Acorns were sown in shallow holes no more than 5 cm deep and covered with soil. The repellent was placed with the acorns in the dig out holes. Each sown spot were marked with two 25-cm long 6 mm thick iron bars nailed in. Sticks coloured in red were used to mark spots sown with repellent and blue sticks when no repellent was used.

Figure 3. Treatment with acorns sown under the nursery shrub (*Retama sphaerocarpa*)

4.3.3 *Measurements*

The measures carried out in the trials of seedling protections were:

1. Plant survival and size (height and stem diameter) after the 1st, 2nd and 3rd drought period (end summer 2015, 2016, 2017).
2. Evidence of shelter deterioration.
3. In addition, indicators of grazing intensity (based of pasture height, browsed shrubs, and density of livestock dungs) were recorded.

The measures carried out in the trials of acorn protections were:

1. One month after the establishment of the trial a visual inspection of the sowing spots to assess the level of acorn predation.
2. Seedling emergence before the summer period.
3. Seedling survival after the summer.
4. Seedling growth (diameter at root collar and height) in the first successive years.

4.4 Results

4.4.1 *Survival of planted vs sown seedling*

Pooling data of the different experiments, expectedly planted seedlings survived much better than the seedlings emerged from sown acorns (Figure 4), probably because acorns were sown too late and emerged seedling rooted unsatisfactorily. In a previous experiment, Moreno and Franco (2013) had demonstrated an inverse pattern (Figure 4), with emerged plants surviving clearly better than planted seedlings.

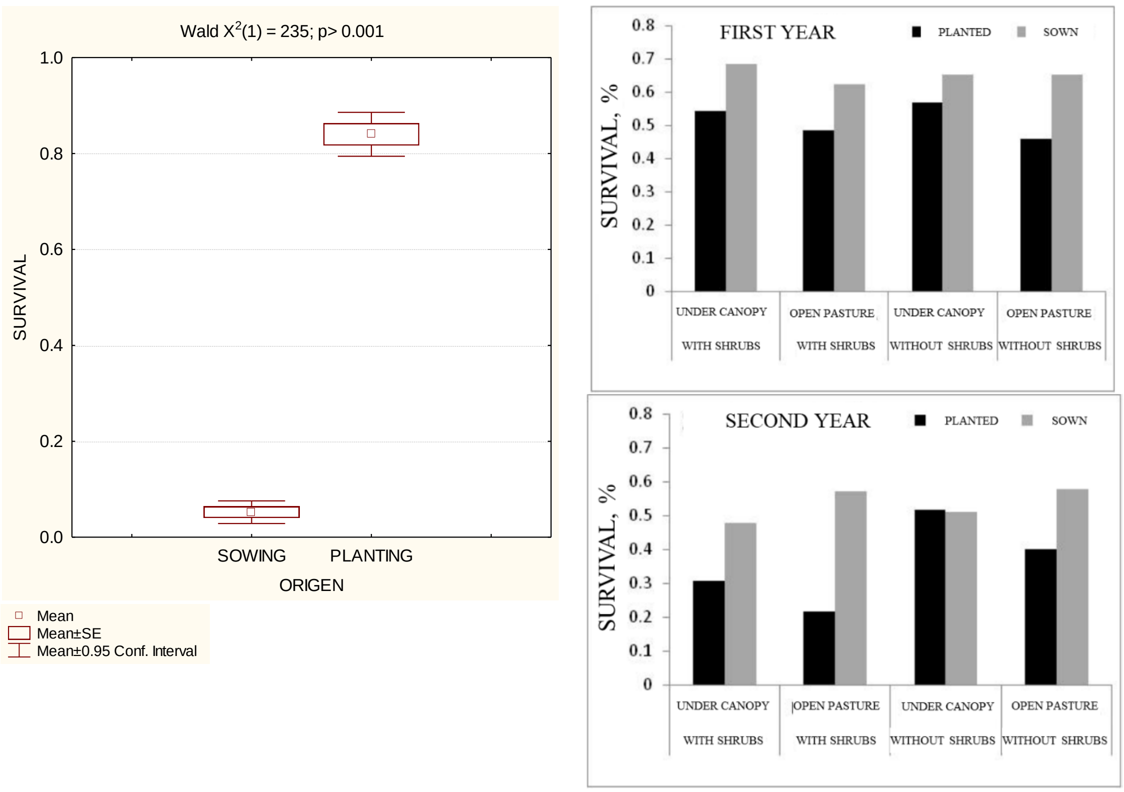

Figure 4. Survival rate of seedling planted and emerged after acorn sowing in different microhabitats, defined by the tree and shrub cover. On the left, mean values come from three different farms per treatment in the frame of AGFORWARD project. On the right, mean values come from a previous study done in the same study region by Moreno and Franco (2013).

In addition they show that the survival of planted and emerged seedlings depended on the microhabitat (shrub and tree cover). Planted seedlings survived better in plots without shrubs and beneath the influence of tree canopies, with rates slightly above 50% after the second summer drought. Out of the influence of the trees survival rate decreased to around 40%, while with the presence of shrubs seedling survival decreased to around 30 and 20% (beneath and out of tree canopy, respectively). For seeding emerged of sown acorns, survival rates were among 50 and 60% after the second summer drought, with best values in open pastures regardless the presence of shrubs.

Taking both studies together, it seems that sowing acorns a sufficient number of seedlings can be achieve at a very low cost, saving the costs of producing and planting seedlings. However, emergence of seedlings can be very low because rodents can consume most of the sown acorns and/or because in dry winters many acorns can die dehydrated. Moreno and Franco (2013) showed that burying acorns decreases the predation of acorns and the emergence of germinated acorns increases significantly (Figure 5).

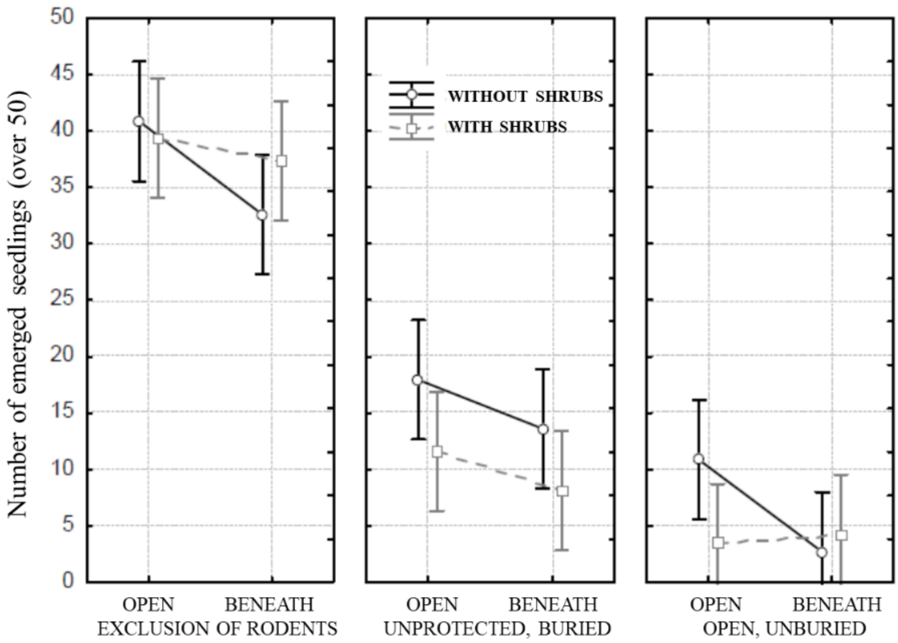

Figure 5. Mean values of oak seedlings emerged after sowing acorns under different schemes, protected against predation of rodents within an exclusion cages or unprotected, and these latter buried 3-5 cm depth or left in the surface. Error bars indicate confident intervals at 95%.

4.4.2 Efficiency of repellents against acorn predators

Apart of the benefit of burying acorns, repellents have been also proposed as a cheap strategy to reduce the consumption of acorns. In a previous experiment we had tested the efficiency of 4 repellents in two farms, founding that the more efficient was the cheapest and most accessible for farmers, the excrement of domestic dogs. Using this repellent, less than 10% of acorns were consumed and more than 50% germinated and emerged. Based on this experiment, an in-deep test focused on excrements of dogs of the farms was initiated, which showed a clear positive effect on protection of acorns against rodents in trial 1 (Table 3) and on the protection of acorns and emergence of seedlings in two out of three farms that participated of the trial 2 (Figure 6).

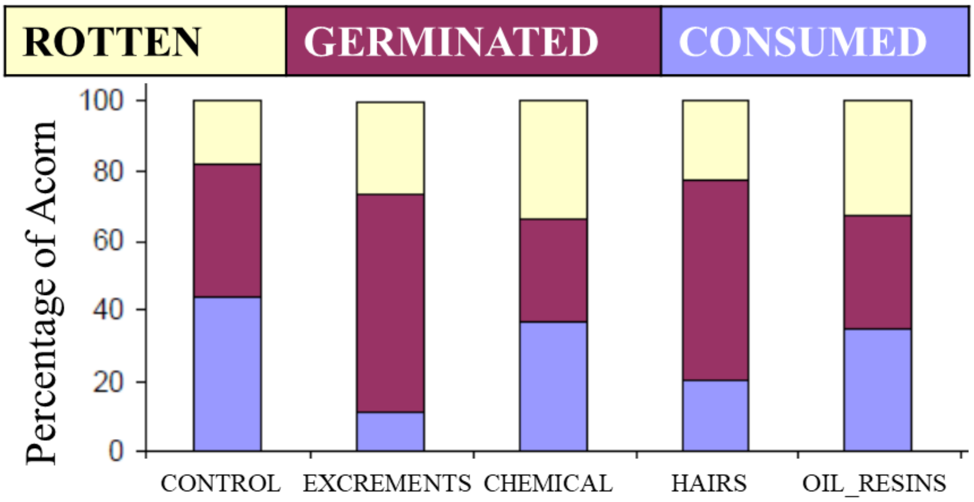

Figure 6. Efficiency of different repellents used with acorns sown in two dehesas of North of Extremadura (n = 240 acorns per treatment).

Table 3. Proportion of acorns consumed by rodents one month after sowing in the farm "Dehesilla" at Valdehuncar.

	Sheltered (piled pruned branches)		Unsheltered	
Treatment	Without repellent	With repellent	Without repellent	With repellent
Under Retama shrub	51	61	90	84
Under Cytisus shrub	69	33	84	39
Open pasture	36	22	55	16

Notes: The trial was established at the end of January, when no acorns are left in the field. High predation observed few days after sowing led us to consider the influence of the sowing date on predation. We hypothesize that sowing acorns earlier in December, when there are still plenty of acorns on the ground, available to predators, may result in a higher number of sown acorns left intact.

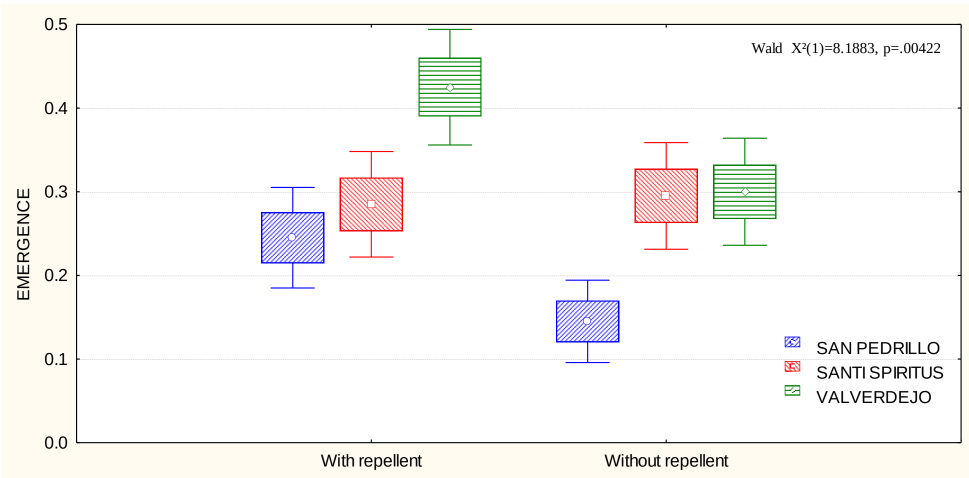

Figure 7. Efficiency of excrement of dogs as repellents against rodents that consume sown acorns in three dehesas of North of Extremadura (n=200 acorns per treatment and farm).

4.4.3 Effectiveness of shelters against browsers

We tested three kind of protectors alternative to the classical ones (Figure 8). The protector named Thorny is similar to the classical one but with prickly points to simulate a Cactus, and the one named Crown is based to a narrow band (10 cm height) of the Thorny surrounding the classical protector at mid height. The Natural protector is build up by pilling pruned branches around the planted seedling. Our results revealed very significant differences among the Natural protector, that performed the worst, and the three protectors made with metallic mesh (Chi-Square = 182.1, df = 3, p <0.001; Figure 8). Among the artificial protectors, the Thorny one performed the best which performed. This together with its lower cost respect to the classical one (lower size and lower demand of TMT iron bars).

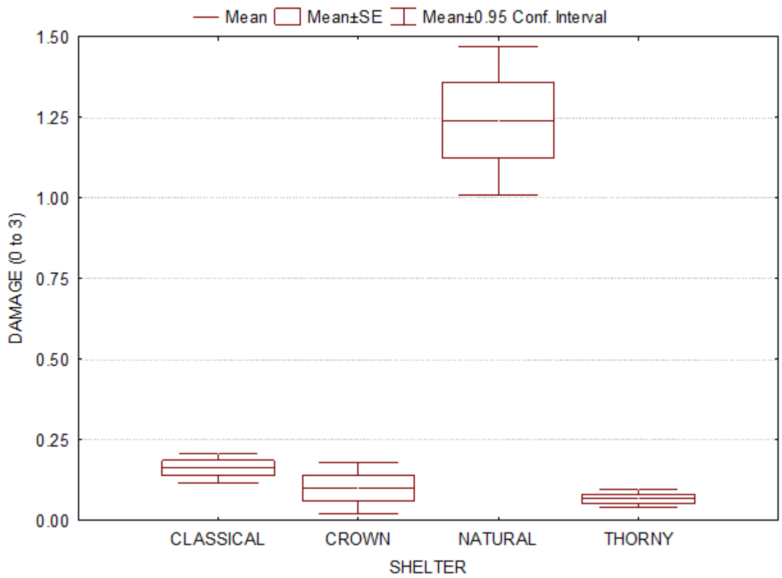

Figure 8. Efficiency of protectors for planted oak plants against livestock tested in five dehesas of North of Extremadura (in total, n = 425, 420, 100 and 150 plants for Classical, Thorny, Crown and Natural protectors, respectively). For the description of protectors see text above.

4.4.4 Nursery effects of leguminous shrubs

The proportion of seedlings alive was clearly higher under the leguminous shrubs than in the open pastures, where no plants were alive at the end of the second summer period (Figure 9). The use of shelters build with piled branches did not help. Plants in between shrubs plants initialled performed better that the ones born in the open pastures, but after two years they did not survived. Two years after the sowing of acorns, only few seedlings born beneath shrubs survived (4 and 3 out of 100 under Retama and Cytisus shrubs, respectively).

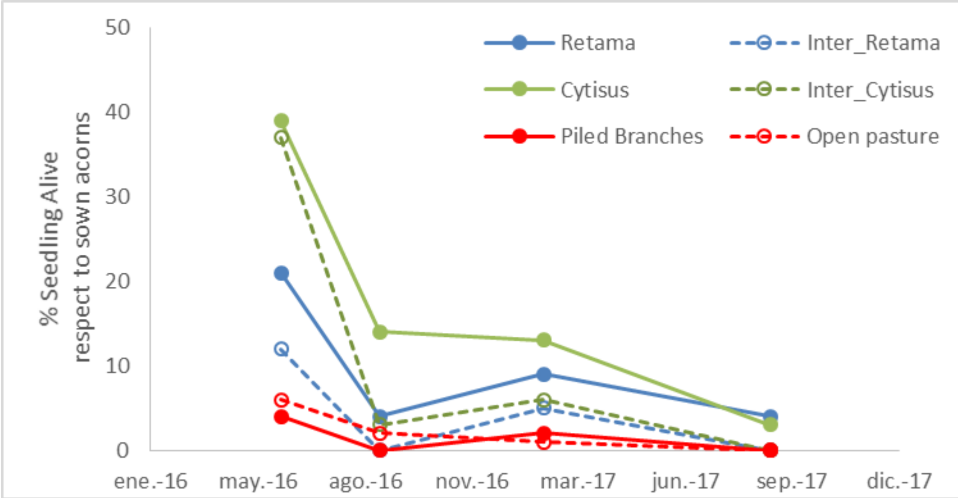

Figure 9. Mean of seedling survival planted in different microhabitats.

4.5 Discussion

The lack of tree regeneration is recognized as one of the most worrying issues for the sustainability of dehesas (Moreno and Pulido 2009; Pulido et al. 2010; Moreno et al. 2013). Seedling establishment and juvenile growth are critical periods in the life cycles of tree species, and morphological and physiological attributes during these periods are key factors for the recruitment and survival of the tree populations. Particularly important is the adaptability to water stress at the seedling stage because of the high mortality rate observed in the seedling establishment phase due to it has to thrive in competition with grasses, shrubs and mature trees for belowground resources (Mediavilla and Escudero, 2004). Pulido and Díaz (2005) have reported that most of the seedlings in dehesas (86%) die during the first summer of life by desiccation due to the water stress experienced in that season. This pattern of seedling mortality has been repeatedly observed in site within Mediterranean-climate regions. By contrast, mortality in the second summer was negligible, indicating that presumably seedling was using water too deep to be consumed by herbaceous plants (Moreno et al. 2013).

Browsers, such as cattle, sheep and red deer, can also heavily defoliate seedling shoots. Although seedlings are generally able to resprout, repeated browsing and soil compaction can kill most oak seedlings and impede natural regeneration (Pausas et al. 2012). Also the consumption of acorns by insects, rodents and large vertebrates (red deer, wold boar and livestock such as pigs, cows, sheep and goats) reduces the opportunities for the regeneration of dehesa trees. By end of winter, in open dehesa woodlands, most of the annual acorn crop below the parent trees is usually eaten by the various seed predators of all shape and sizes (Pulido and Diaz 2005; Pausas et al. 2012).

4.5.1 The advantages of sowing acorns instead planting seedlings

The intensity of the competition for water (and nutrients) between grasses and oak seedlings strongly determine the survival of seedlings and thus the oak recruitment in dehesas. Cubera et al. (2009; 2012) demonstrated that roots of *Quercus ilex* seedlings growing under unlimited conditions (loose, watered and fertilized soils) reached nearly 150 cm depth in six months. Unfortunately, no scientific data on rooting pattern of early stage of *Quercus* seedling growing in dehesas are available yet. Some evidence from studies done in Californian savannas indicate that under field conditions it may take 2-3 years to pass the maximum penetration depth of the roots of the herbaceous plants and thus reduce their competitive effects (Weltzing and McPherson 1997).

Moreno et al. (2005) reported that 95% of native grasses roots are located in the first 32 cm, with a maximum rooting depth of 80 cm, and Joffre et al. (1987) have reported that annual and perennial herbaceous plants of dehesas use water from the first 40-60 cm of depth, respectively. Hence, the capacity to develop a deep taproot system in dry soils would be essential for oak seedling survival in competence for water with native grasses. Navarro-Cerrillo et al. (2005) found that *Quercus ilex* survival increased 2.5 fold in the first summer after transplantation (reforestation with 1-year-old seedling with air pruned roots) when the grasses development was controlled.

The most common strategy followed to regenerate the tree cover in dehesas (and funded publicly) is the plantation of young seedlings (1-2 years old) with air root pruning at a maximum depth of approximately 20 cm. Outplanting these container-grown oak seedlings usually result in poor establishment and reduced field growth (Tsakaldimi et al. 2005). Root growth after planting is critical for ensuring seedling establishment (Grossnickle et al. 2005). Young and Evans (2005) reported that oaks grown from acorns had significantly greater survivorship than oaks planted from containers in non-irrigated plots because the former developed deeper taproots.

The initial costs of sowing acorns can be one-third to one-half the expense of planting bareroot seedlings, and a smaller fraction of the cost of planting container trees (Dey et al. 2008). Another advantage of direct seeding is that oak seedlings are able to develop natural root systems on the site what has particular advantages in regenerating oaks on shallow soiled sites, where planting large bareroot or container seedlings is difficult and expensive (Dey et al. 2008).

In our AGFORWARD trial the survival of seeded seedlings was very low, probably caused by the high pressure of rodents (which can consume even the cotyledons of germinated acorns) and the late seeding that could had compromise the adequate development of the taproot. Nevertheless in our previous experiments (Moreno and Franco 2013), the early survival was higher for oaks grown from seeded acorns than for planted seedlings, explained by the quick development of a deep taproot of in situ germinated plants (Cubera et al. 2009).

Moreno and Franco (2013) also found that the protection of acorns seemed essential to guarantee a sufficient seedling density. Germinated plants emerged more out of the canopy than beneath the canopy and much more when rodents were excluded. Seeding acorns out of the protection of the trees, and slightly buried, reduced the predation of acorns and the rate of acorns that produced seedlings increase up to near 20%. In spite of the low rate of acorn germinated, the further higher rate of survival of these plants could guarantee enough plant recruitment for the sustainable regeneration of the trees layer of dehesas. This together with the lower cost of seeding compared to planting, could justified the alternative of direct seeding instead of planting.

Nevertheless, failures in direct-seeded oak plantings are common, and causal factors are numerous. Dey et al. (2008) listed the following causes: poor quality seed, inadequate site preparation, improper species-site selection, improper depth of sowing, seeding when soil conditions are suboptimal, sowing too late to avoid summer drought, failure to control competing vegetation, and

high densities of small mammals and rodents, leading to high rates of seed predation and herbivory. Some of these factors affect all types of oak reproduction, but several are weaknesses of the direct seeding method alone.
The lack of efficient long-distance disperser of acorns in the dehesa is also a constraint (Morán-López et al. *2*015). So, dispersing manually or mechanically acorns far away of the trees, and burying them with a very shallow harrowing seem the cheapest approach to produce new oak plants. Protecting acorns with repellent against rodents and wild boar could be also advantageous, and then protecting emerged seedling against browser seem essential. These aspects are commented in the following sections.

4.5.2 The importance of repellents against acorn predators

The assisted regeneration of oaks can be achieved through seeding or planting. Whereas direct seeding of acorns has several advantages over planting nursery-grown seedlings, the problem of seed predation by mammals precludes its widespread application (Leverkus et al. *2*017). Indeed, the predation of acorns is usually very high (Sunyer et al. *2*013) and is a major bottleneck for oak self-regeneration in grazed Mediterranean dehesas (Benayas et al. *2*015; Leiva and Vera 2015).

We found that using cheap and easily available repellents (excrement of cats and dogs) could double the amount of emerged plants after acorn seeding. Although less efficient, using hairs of the same species also offered a positive effect. Rodents are prey of many mammals, and presumably rodents avoid to spend time consuming or hiding acorns where the presence of mammals is more probable (defecation areas) (Sunyer et al. *2*013). Rodents have an extraordinary olfactory acuity to avoid predators (Jedrzejewski 1993; Nolte et al, 1994; Herman and Valone 2000).

Although some chemical repellents, such as the oleoresin capsicum, are very efficient because the irritant effect for mammals mucosae (Nolte and Barrnett 2000), the effect is lost in few weeks (Willoughby et al. *2*011). Besides, in our study, this kind of oleoresins increased the rate for rotten acorns. Leverkus et al. (2017) tested the efficacy of diesel as repellent and found no reduction in acorn predation. On the other hand, the submersion in diesel hindered the germination of one in every four sown acorns regardless of submersion time.

Although plant secondary metabolites produced by higher plants have also potential as a tool for ecologically-based rodent management, a recent review (Hensen et al. *2*016) demonstrates inconsistent success across laboratory, enclosure, and field studies, which ultimately has led to a small number of currently registered PSM-based rodent repellents.

Leverkus et al. (2017) reported many failed attempts to protect acorns with chemical repellents and suggest that an effective, universally-abundant, inexpensive, and easy-to-apply acorn protector to enhance the success of seeding operations is yet to be found. Although our results with excrements of domestic animals were not fully satisfactory, they are promising especially by the own-application by farmers in a long-term (continuous) plan of dehesa tree regeneration. Burying treated or untreated acorns also helps a little to scape at least partly to the predation (Leverkus et al. 2013). Besides, in environments subject to high rodent predatory activity, early sowing of acorns during the seeding season (period of acorn-eaters satiation) should be considered in order to maximize the success of tree regeneration (Leiva and Díaz-Maqueda 2016). Moreover, current experiences with individual cheap "acorn shelter" are giving very promising results to prevent acorn predation by rodents after sowing, although the efficient against wild boar is not satisfactory yet (Leverkus et al. 2015) (Figure 10).

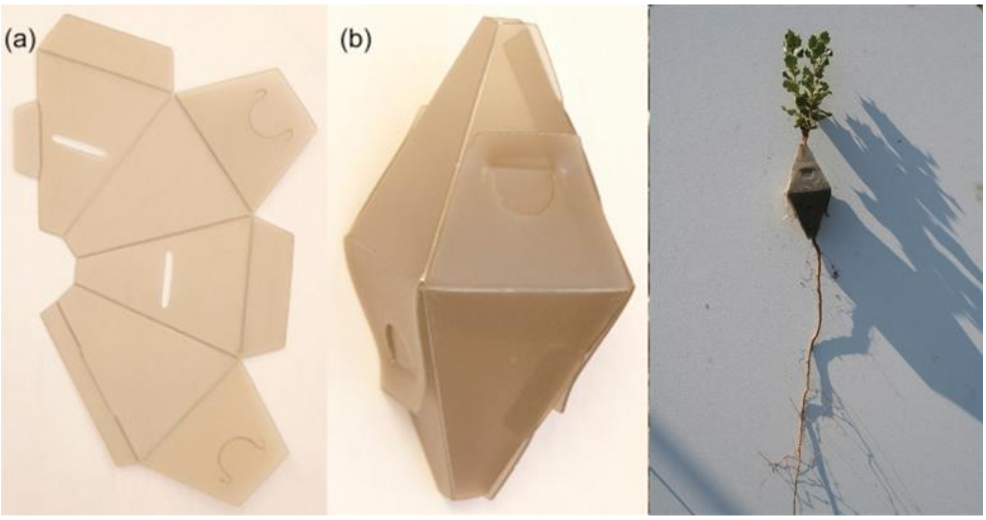

Figure 10. Acorn shelter against rodent predation (Leverkus et al. 2015)

4.5.3 Effectiveness of classic vs innovative shelters to protect young trees

Apart of acorn predation by wild animal and livestock, browsing of young trees by red deer and livestock also limits oak self-regeneration in grazed dehesas. Indeed the emergence of seedlings from acorns of Mediterranean oaks rarely limit recruitment, as germination rates are usually moderate to high (Pulido and Díaz 2005; Acàcio et al. *2*007; Pulido et al. *2*010). By contrast, exclusion of large herbivores increases the recruitment enormously (Pulido et al. *2*010).

To regenerate artificially the tree cover of the Iberian dehesas by planting nursery-grown seedlings, two approaches are usually followed to prevent browsers. The complete exclusion of grazing within the planted plot for 20 years or to keep the grazing and protecting individually each plant with strong shelters of wire mesh. The need of strong shelters become more important in dehesas grazed by cattle, and they are needed for 20 or more years give the slow-growth of the oak trees in dehesas. In both cases tree regeneration result very expensive and most of the regeneration projects are done under CAP (pillar II) payments. There is an urgent need to reduce the cost of protecting young trees to save money and more important to enable farmers to afford regeneration plans without the need of public support.

In our study the classical treeguard wire mesh worked very well and only a few trees were damaged by cattle. However the use of thorny protectors worked still better. Due to the pricking nature of these protectors, the need of iron bars is minimized saving costs. All included (plant, shelter and labour), the cost of plantation can be reduced from 25-30 to 15-20 € per plant when thorny protectors are used. Although data are not available, we also expect a reduction of maintenance costs in the following years, as animals avoid thorny shelters, while classical treeguards are frequently moved or damaged by the cows when scratching or with the horn when lifting the head.

The results of using “natural” shelters by stacking pruned branches were unsatisfactory, especially where cattle are present. Its efficacy against sheep was better. However, even in the optimal case where shelters were effective physical barriers against livestock, stacked branches were a refuge for small mammals such as rabbits and hares and most of the plants were consumed.

4.5.4 The nursery effects of leguminous shrubs

The net effect of shrubs on oak seedlings results from the balance of positive and negative effects of shrubs seedling performance and survival. Shrubs reduce direct radiation and evaporative demand of air, can improve microclimate and soil fertility, but they can also compete for soil nutrient and soil moisture (Rolo et al. *2*013). Frequently, shrub encroachment results in higher recruitment rates as compared with shrubless areas (Pulido and Díaz 2005; Pulido et al. *2*010; Rolo et al. *2*013). This pattern of recruitment is created by several non-exclusive mechanisms, such as disperser attraction, protection against seed predators and browsing herbivores, and amelioration of harmful effects of the Mediterranean summer drought (Retana et al. *1*999; Gómez et al. 2003; Gómez-Aparicio et al. *2*005a, b; Puerta-Piñero et al. *2*006; Rolo et al. *2*013). Indeed, Pulido et al. *(*2010) conducting a controlled experiment where acorns where seeded into an enclosure to prevent acorn depredation (mainly by rodents), showed a direct positive effect of shrubs on acorn germination and *Quercus ilex* seedling survival in Central-Spain dehesas. It seems that this facilitative phenomenon, named ‘nurse plants’, is widespread for Mediterranean *Quercus* species seedling growing in environments with a dry period (Castro et al. 2004 and 2006; Gómez-Aparicio et al. *2*004, 2005a, 2005b; Marañon et al. 2009).

Many studies have reported positive effects of shrubs on microclimate and soil physical properties that favoured oak seedling survival (Moro et al. *1*997; Cardillo and Bernal 2006; Gómez-Aparicio et al. 2006; Puerta-Piñero et al. 2006), although effects on the availability of soil nutrients and water depended on the shrub species and on the nutrient (Gómez-Aparicio et al. *2*005; Castro et al. *2*006; Quero et al. *2*006; Rolo et al. *2*013).

The trials carried out in the farms that collaborated in AGFORWARD were significantly positive with both shrub species (two legume species). In previous studies, comparing one of this species (*Retama sphaerocarpa*; (deep-rooted shrub that forms scattered populations) with a very competitive shrub species (*Cistus ladanifer*, a shallow-rooted shrub, forming dense populations, with reported allelopathic compounds) we found that both shrubs species had a positive effect at early recruitment stages (Rolo et al. *2*013). At later life stages, the effect weakened under *Cistus* whereas it strengthened under *Retama*. *Cistus* shrubs are effective in protecting seedlings physically against herbivores and facilitate early survival, but may compete with older stages of oak regeneration. In contrast, *Retama* shrubs (and other legume shrub species) exert stronger biological facilitation and guarantee long-term persistence of surviving seedlings. The improved understanding of the effectiveness of different nurse plants and their contrasting factors is of major interest for the conservation and restoration of degraded oak woodlands.

4.6 Conclusions

Dehesas and other wood pasture management have to make compatible grazing with tree recruitment. While undergrazed stands accumulate sufficient young plants to assure the future of

the dehesa structure, assisted regeneration, either by seeding or by planting, is recommended in normally grazed stands ($\geq$ 0.3 LU ha^{-1}).
Whereas direct seeding of acorns has several advantages over planting nursery-grown seedlings, the problem of seed predation by mammals precludes its widespread application. Seeding during the peak of acorn fall (end autumn) can reduce, by satiation, the acorn predation by rodents and wild boar. The use of natural, cheap and easily available repellents, such as cat and dog excrements, are efficient and recommended for small scales and/or multiyear plans of gradual afforestation/densification of trees in the dehesas. Also the use of cheap individual "acorn shelter" is recommended.

Irrespective of the origin of the plants (seeded of planted), young trees need to be fenced against ungulates (red deer and livestock). The use of wire mesh treeguards is a common established practice. While this classical protector worked well in our trials, and only few of them were damaged by livestock in the first three years, the artificial thorny protectors worked still better, with almost null damage. This cheap adaptation of the classic wire mesh is an efficient and long-lasting solution, that besides allow to save costs because the lower need of TMT iron bars.

Natural protection by stacking pruned brunches however decayed very quickly and its efficiency seems limited to the very short term with small ungulates such as sheep.

Shrubs species are also very efficient protecting young oaks against browsers and in many cases have been showed as very helpful nurse plant that foster the restoration of tree cover in grazed dehesas. Moreover, some legume shrub species show a positive biological facilitation of oak trees growth and survival.

5 Evaluation of forage crops: cultivars of triticale

This section provides a summary of the results of two years of experimentation with *Triticale* fodder cultivated in three private farms that participated in the AGFORWARD project. In the three farms three cultivars were tested to learn about the effect of trees on the productivity of the different cultivars. Preliminary results have been presented in the 55th and the 56th Congress of the Spanish Society for the Study of Grasslands (Santamaría et al. *2*016, 2017). Besides, a peer-review article entitled ”Influence of trees on the production and quality of different cultivars of Triticale cropped in Iberian dehesas as fodder crop” is in preparation to be submitted to the journal Grass and Forage Science.

5.1 Background

Natural pastures of dehesas have a low and very variable biomass productivity (on average 1440 kg dry matter (DM) ha^{-1} y^{-1}) and a low nutritive value (resulting forage contains 4-20% legume fraction, 9-12% crude protein, 44-59% neutral detergent fibre and 28-37% acid detergent fibre) (Olea et al. *2*006), as a consequence of the low and irregular rainfall of Mediterranean climate, poor soil fertility, inadequate livestock management and poor plant species composition (Vázquez de Aldana et al. *2*006). Under these conditions of low forage productivity, farmers need to purchase feed supplements that greatly increase production costs and that can reduce farm profitability. Traditionally management has focused on three aspects to improve productivity and reduce production costs (Rossiter 1966): low livestock grazing intensities, sowing of well-adapted and very productive pasture species or forage crops, and fertilizer application. In dehesa ecosystems, fodder crops often play a fundamental role in livestock feeding, as a complement to natural pastures, both in productivity and in quality (Joffre et al. *1*988).

Among forage crops, the cultivation of triticale, a high-productive cereal under Mediterranean conditions, is an interesting alternative because of its capacity to be grazed in winter and cut in late spring for hay (Garcia del Moral et al. 1995; Royo and Tribo, 1997; Kraiem et al. 1997; Delogu et al. 2002; Francia et al. 2006). The capacity to graze in winter provides triticale with an advantage over the traditional vetch-oat combination (Olea et al. *2*005), and its high productivity and protein content are of interest for farmers (Rodrigo et al. 2010). Under the dual-purpose use, the triticale crop can produce 3000-5000 kg ha^{-1} of a high-quality forage, providing an additional fodder offered for livestock rearing, especially in critical shortage periods, such as winter and summer, when the natural pasture production is very scarce in these areas. The defoliation provoked by the winter grazing produced a lost in the future grain yield of around 7% on average (Harrison et al. 2011).

Triticale cultivars used with this dual forage purpose have been developed to grow in areas free of trees with high solar radiation levels. The effects of trees on the productivity of fodder crops have been already studied for other species and regions (Pardini et al. 2010). These authors found that while pasture productivity was reduced to 75% beneath the trees respect to the open areas and the yield of wheat grain was almost halved. Reductions of around 25%, on average, by the presence of the trees was described by Moreno et al. *(*2007a) for oats grain in Iberian dehesas. However, these authors also reported slight increases of grain yield under trees in unfertilised poor soils. However, the suitability of the different cultivars of triticale, more usually used with forage purpose, to grow under tree cover remains also unknown.

5.2 Objectives

We studied three varieties of triticale of double use (grazed in winter and harvested as hay in early summer) in three dehesas that differ in soil fertility. In each of the three sites, each triticale variety was sown in 2 ha that include scattered mature oak trees. The aim of the research was to evaluate the effect of the tree cover on herbage production and nutritive value traits (crude protein, neutral and acid detergent fibre and acid detergent lignin) of three commonly used triticale cultivars.

5.3 Methodology

5.3.1 Study area and experimental layout

The trial took place in three dehesas of Extremadura, two in the province of Badajoz (dehesa Los Varales, Badajoz, and dehesa Los Llanos, Siruela) and one in the province of Cáceres (dehesa Atoquedo, Torrejón el Rubio) (Figure 11). In the three study dehesas, the tree layer was dominated by adult holm oaks (*Quercus ilex* subsp. ballota (Desf.) Samp.). Natural pasture covered 100% of the soil, with a high specie richness, mostly spontaneous annual species (e.g. *Helianthemetalia*, *Thero-Brometalia*, *Sisymbrietalia*) although perennials (e.g. *Agrostietalia and Poetalia*) were also present. Pasture productivity is usually low (1.5 – 2 t DM ha^{-1}), with strong seasonality (~ 80% production in spring) and interannual variability. Shrub species are frequently present by patches, mostly *Cytisus* spp. The main land use is the livestock rearing, being the two main species being cattle and sheep. All of them range freely grazing grasses but also browsing shrubs and trees and consuming acorns in autumn. The main characteristics of the study sites were presented in the report of Milestone 2.3 (Moreno et al. *2*015c).

On each dehesa, an experimental area of at least 5 ha was selected. The experimental area was divided in three plots, of at least 1.5 ha containing holm oak trees, to include each of the three triticale cultivars studied: cv 'Fronteira' (Portugal), cv 'Verato' (Spain) and cv 'Montijano' (Spain). Sowing was done in mid-autumn (approximately in November), at a seeding rate of 220 seeds m^{-2}. Conventional tillage was used to prepare a seedbed before sowing. All plots were fertilised by following the usual practices of each farmer. The first year, before sowing, four representative soil samples of 30 cm depth was taken from the experimental area of each dehesa studied and carried to the laboratory. Within each plot, four 4-8 homogeneous holm oak adult trees (4 repetitions) were selected in order to take samples under the same trees during the whole duration of the trial. The crop area under each tree was divided in four virtual sectors: one located close to the trunk, which was excluded for sampling because of the lack of plants due to mechanical seeding procedure, a second one located clearly under the tree, a third one located in the edge of the canopy projection, and a fourth one clearly out of the tree influence.

Figure 11. General view of triticale fodder intercropped in a dehesa of CW Spain. Los Llanos in February (left) and Los Varales in April (right).

The experimental areas were grazed at approximately January-February when plants were at the growth stage (GS) 31 of the Zadocks scale. Before the grazed period, one 0.25 m^2 herbage sample per sector of each tree was taken for measurements. The samples were taken with the same orientation: to the East of the tree. After the winter grazing period, the experimental areas were free of grazing until plants reach the growth stage 75-77 of the Zadocks scale (approximately in mid-May), when the crop were mowed for hay. Before mowing, a second set of herbage samples was taken by following the same procedure as explained above.

5.3.2 Measurements

In the laboratory, plant samples were air dried (70°C) until constant weight and then dry matter (DM) to record the herbage biomass production.

In 2016, for one farm (Atoquedo), samples were studied in details, by counting the number of spikes, and in a subsample of 20 plants per sample by counting the number of grains per spike and the mean weight of grains.

In one of the farm, Los Varales, the following parameters were analysed n samples of 2015 and 2016: total N content using the Kjeldahl method (Kjeltec™ 8200 Auto Distillation Unit. FOSS Analytical. Hilleroed, Denmark), crude protein (CP) by multiplying the biomass N x 6.25 (protein on average contains 16% N) as conversion factor (Sosulski and Imafidon 1990), neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) by means of a fibre analyser (ANKOM 8-98, ANKOM Technology, Macedon, NY), by following the official procedures (AOAC 2006).

5.4 Results

5.4.1 Forage biomass production

On average, the triticale production varied significantly among farms (F_{2-210} = 9.09; p< 0.001), with mean values ranging from 3063 (± 201 S.E.) kg DM ha^{-1} y^{-1} in 2016 in the farm Los Varales to 5572 ± 319 (S.E.) kg DM $ha-^{1}$ y^{-1} in 2015 in the farm Los Llanos. On average, the three cultivars produced similar amounts of biomass (F_{2-210} = 0.308; p < 0.735), which decreased significantly beneath the trees (F_{1-210} = 7.62; p < 0.006) regardless of the cultivar (non-significant Cultivar X Habitat interaction; F_{2-210} = 0.622; p < 0.538). Although barely significant, in some cases the biomass production was higher beneath the canopy than out of the canopy. This was the case of the three cultivars in 2016 in the farm Los Varales, the cultivar Montijano in 2015 in Siruela (Figure 12).

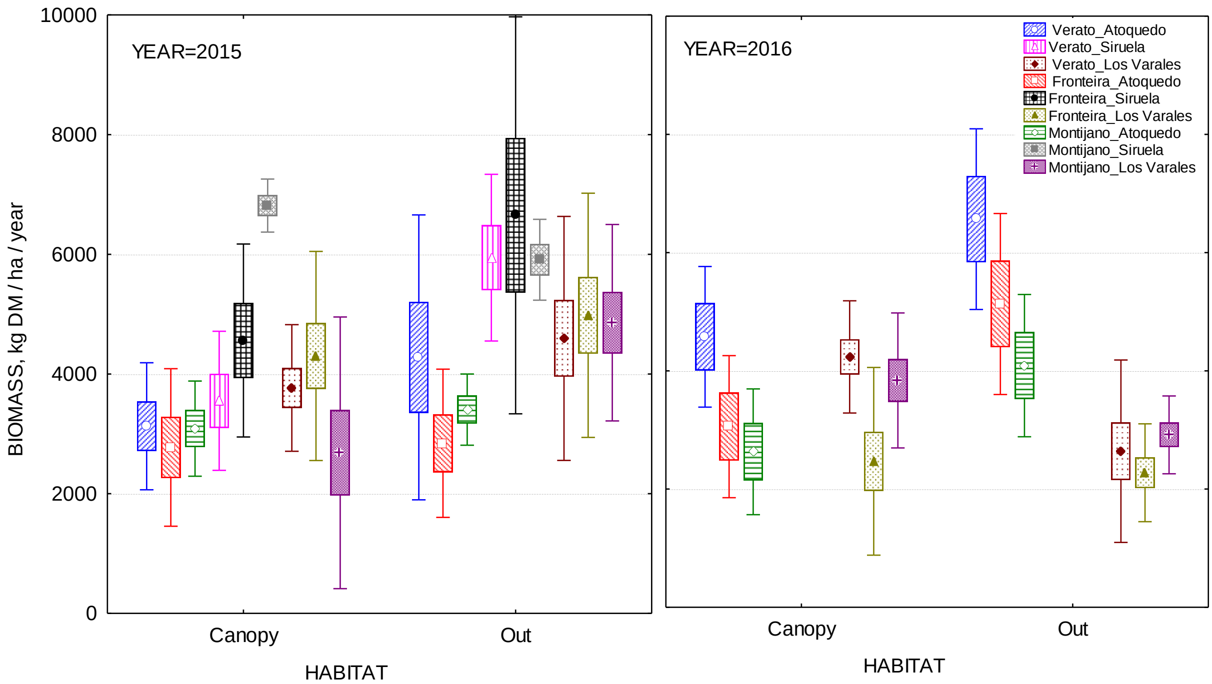

Figure 12. Mean values of biomass production of the three cultivars of triticale (Verato, Fronteira and Montijano) in the three farms and two years. Points indicate mean values, boxes the standard error and the whisker thee confident interval at 95%. Note that in 2016 there are not data for the farm Siruela.

The differences of biomass production among the two habitats, were also reflected, even reinforced, for the grain production (Table 4). On average, the grain yield was reduced to 27, 52 and 59% beneath tree canopy respect to the grain yield recorded out of the tree, for cultivars Fronteira, Montijano and Verato, respectively. The reduction of grain production was explained by the reduction on the number of spikes produced by surface unit, but also by the reduction in the number of grains per spike and the size of the grains.

Table 4. Mean values (± S.E.) for biomass and grain produced by three cultivars of triticale in two habitats (beneath and out of tree canopy) in the experiment of 2016 in the farm Atoquedo.

Farm	Habitat	Biomass, (kg /ha)	Spike number (0.25 m^{-2})	Grains per spike	Grain size (mg)	Grain yield, (kg/ha)
Fronteira	Canopy	5516 ±212	56 ±6	19.8 ±1.1	14.4 ±0.5	597 ±60
	Out	8074 ±536 ***	71 ±7 *	36.5 ±0.9 ***	20.2 ±0.4 ***	2188 ±216 ***
Montijano	Canopy	4159 ±222	65 ±11	20.5 ±1.1	23.1 ±1.4	1104 ±215
	Out	6053 ±464 *	70 ±6	26.7 ±0.8 ***	27.3 ±0.4 ***	2126 ±217 **
Verato	Canopy	6823 ±458	63 ±5	36.6 ±1.0	24.8 ±0.5	2328 ±178
	Out	9179 ±780 **	81 ±6 *	37.8 ±0.9	31.5 ±0.4 ***	3954 ±354 ***

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

As triticale cultivated as a fodder crop in the dehesa is also grazed in winter, we also determined the biomass production for that period in one of the farm (Los Varales) in two consecutive years (Figure 13). In 2016, biomass production was slightly higher beneath than out of the trees both in winter and in spring. Interestingly, in 2015, when biomass production was much higher out than beneath the canopy in spring, in winter biomass was significantly higher beneath the canopy. Overall, it seems that trees outcompete triticale in the second part of the growing season (flowering, grain formation and ripening), but during the first part, the trees seem to have a positive effect, probably associated with the warmer temperatures found beneath the trees in winter.

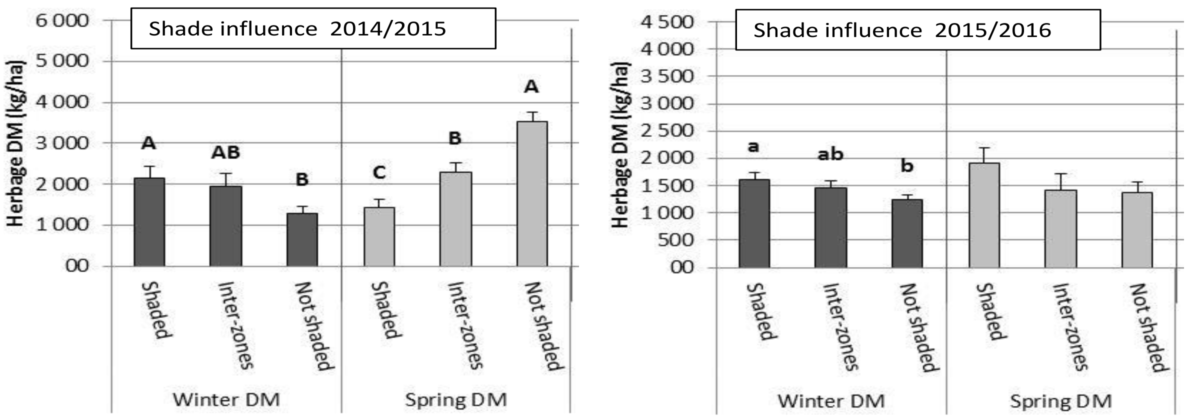

Figure 13. Mean values (± S.E.) of biomass production averaged for three cultivars of triticale in the farm Los Varales in two consecutive years. Data come from two different sampling periods (mid-Winter and end spring) in three distances from the tree. Different letters denote significant differences ($p < 0.05$).

5.4.2 Fodder quality

The presence of trees also affected significantly to the chemical quality of the forage (crude protein, fibre both acid and neutral detergent, and acid detergent lignin). Significant differences were also found among years, season and cultivars, with some interesting interactions (Table 5).

Table 5. F values and probability of a significant effect (p) in a comparison of mean values of quality-based chemical parameters of three cultivars of triticale sown in two consecutive years in the farm Los Varales, where data of biomass was recorded in two seasons (winter and spring) in two different habitats (beneath and out of the trees).

Factor and interaction	g.l.	Protein		NDF		ADF		ADL		Ash	
		F	p	F	p	F	p	F	p	F	p
Year (Y)	1	1.12	0.291	256.72	0.000	315.96	0.000	196.05	0.000	0.41	0.521
Season (S)	1	406.84	0.000	986.53	0.000	429.60	0.000	49.79	0.000	24.16	0.000
Cultivar (C)	2	12.28	0.000	22.64	0.000	7.88	0.001	1.41	0.249	3.73	0.027
Habitat (H)	2	21.44	0.000	2.12	0.125	1.00	0.372	3.17	0.046	2.25	0.110
Y x S	1	28.86	0.000	1.50	0.223	0.16	0.686	1.46	0.230	15.13	0.000
Y x C	2	0.54	0.586	5.12	0.008	7.02	0.001	0.29	0.751	5.33	0.006
S x C	2	0.84	0.435	25.25	0.000	11.73	0.000	5.02	0.008	1.27	0.286
Y x H	2	1.47	0.234	1.85	0.162	0.42	0.660	0.73	0.483	0.86	0.425
S x H	2	3.33	0.040	7.69	0.001	10.07	0.000	3.58	0.031	0.86	0.427
C x H	4	1.47	0.216	0.31	0.871	0.64	0.632	0.53	0.713	0.45	0.769

The response of the four parameters to trees depended significantly on the season (Figure 14). Trees had a positive influence on the protein content both in winter and spring samples, although differences were stronger in winter. Both types of fibres responded similarly, with higher values beneath trees in winter, shifting the differences in favour of 'beneath canopy' in spring (lower contents in fibres mean higher organic matter digestibility). The better digestibility of the triticale sampled beneath the trees is also confirmed by its lower content of lignin.

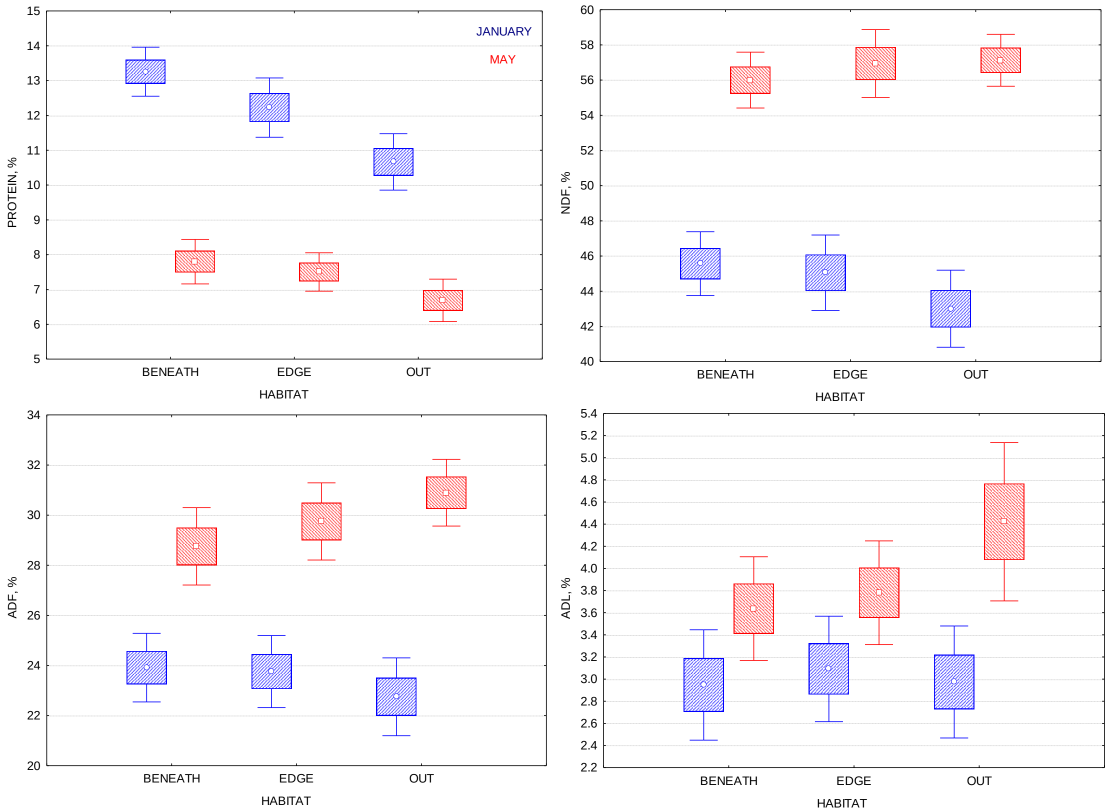

Figure 14. Variation of crude protein, fibre and lignin of triticale forage sampled at different distances of the tree in two different periods. Error bars denote standard errors.

5.5 Discussion

Triticale sowing is recommended to be carried out in late autumn, after the first autumn rainfall, by performing a slight tilling before, at a seeding rate of around 200 kg/ha. Depending on the initial mineral soil levels, N-P-K fertilization might be convenient to be carried out before or during sowing. The recommended crop management is as follows: The winter forage can be directly grazed by livestock, to meet the livestock food requirements of this period. The spring forage should be harvested and preserved as hay to be provided in summer to livestock. Optimizing the grazing intensity and period in winter is critical to obtain a good re-growth and consequently a good total forage yield. This grazing should not be very intense and be performed before plants reach the growth stage 30 of the Zadocks scale. The late-spring harvest should be made before the growth stage 73 of the Zadocks scale to obtain a good nutritive value forage. Due to the poor and shallow soil usually found in dehesa ecosystems, a yearly rotation in the crop area is highly recommended.

Under this management scheme, our experimental plots produced 3000-5000 kg/ha of a high-quality forage, providing an additional fodder offer for livestock rearing, especially in critical shortage periods, such as winter and summer, in which the natural pasture production is very scarce in the Mediterranean conditions of dehesa ecosystems in the Southwest of Spain.

The results showed that tree cover has a high and clear influence on the biomass yield and quality parameters of the triticale forage. Whilst the winter herbage production was enhanced by tree cover, the spring and annual productivity decreased around 30% under shade conditions. Similar results were reported by Moreno et al. *(*2007a) and Pardini et al. *(*2010) for oats and wheat cultivated as fodder crops under Mediterranean conditions.

The quality of the triticale forage was affected by the three factors analysed, cultivar, season and presence of the tree. The cultivar Montijano had the higher content on protein, probably because this cultivar develops later in the season (González et al. 2012), as it is well known, the protein content decreased along the season with the maturity of the plant (Santamaría et al. 2014). The most productive cultivars in each sampling showed the highest contents of fibre and lignin, although differences were rather slight.

The nutritive value parameters of the forage were also enhanced by tree cover in general terms. The protein content was also affected positively by the presence of the trees, especially in winter, where microclimatic conditions are better, both at soil and at atmospheric level (Moreno et al. *2*007b). The improved microclimatic conditions would facilitate the nitrogen absorption by plants (Pecio, 2010). The higher air temperature beneath trees also encouraged the formation of more leaves where nitrogen contents are high. The fibre content of the forage increases during the season (Santamaría et al. *2*014). As the forage develops faster beneath trees in winter, the fibre content was lower beneath trees in that season, while in spring when trees delay the ripening of triticale plants, the fibre content was higher beyond the trees.

5.6 Conclusions

Although the annual forage yield decreased in general terms under shade conditions, the tested cultivars of triticale could be considered as well-adapted to grow in these agroforestry systems. Yield differences, which were not very high, depended on the specific climatological conditions of the growing season. Likewise, the winter forage yield was higher under shade conditions, which is very interesting to meet livestock food requirements in this period.

Although the forage yield is widely variable between years due to the irregularity of the Mediterranean climate (especially rainfall), even in a low-rainfall year, the increase in the fodder yield of triticale, in comparison with that produced by natural pasture, offsets the cost of all cropping practices (tillering, sowing, harvesting, seeds, fertilizers). In addition, the quality of the forage (protein content and digestibility) was favoured by the presence of the trees.

This practice may allow farmers to reduce the high, and ever increasing, costs of the feeding supplements. In these generally farm systems of low commercial profitability, this cost reduction is important for their economic viability. To ensure adequate regrowth after winter grazing, grazing should be done before plants start the stem elongation (state 30 in the Zadocks scale). Due to the poor and shallow soil usually found in dehesa ecosystems, a yearly rotation in the crop area is highly recommended.

6 Evaluation of legume-rich forages

This section provides a summary of two manuscripts in preparation, one of them to be submitted to the journal Agroforestry systems (Are sown pastures rich in legumes effective allies for profitability and sustainability of Mediterranean dehesas?), and the other to the journal Biodiversity and Conservation (Sowing legume-rich pastures make compatible the increase of the production with the conservation of plant diversity of Mediterranean dehesas).

6.1 Background

Dehesa soil fertility is low, limited mainly by their shallow depth, and water and nutrients scarcity. In consequence, native pastures are poor in terms of productivity and quality. The necessity of making the dehesa a more competitive ecosystem while preserving ecosystem services and biodiversity is a challenge we must face.

Attending to the well-known N limitation in the dehesa, the increasing costs of inorganic N fertilizers and the harmful side effects of excessive N application (Canfield et al. *2*010) it is essential to find a N self-sufficiency strategy. Legumes appears to be the key strategy to maintain and increase the demanded current levels of production and protein self-sufficiency in a more sustainable way (Suter et al. *2*015). In fact, the inclusion of legumes in pastures management has been suggested as an important strategy for climate change mitigation in the agricultural sector (Smith et al. *2*008; Smith and Gregory 2013; Bustamante et al. *2*014). It is also important to highlight that, the majority of the commercial seed-mixtures are rhizobium-inoculated, and their potential to improve soil fertility with this nitrogen-fixation reinforcement has been proposed by different authors (Rodríguez-Echeverría and Pérez-Fernández 2005; Padilla and Pugnaire 2006; Thrall et al. *2*011; Vallés et al. *2*011)

In consequence, some farmers have sown pastures rich in legumes after noticing that fertilization alone was insufficient to reach satisfactory levels of grass productivity and animal feed quality (Teixeira et al. *2*015). These mixtures are specially designed taking physical and chemical soil conditions and local climate into account, thus, it is expected they should root successfully and show long term durability. These multi-specific pastures show high environmental plasticity. Each species can exploit different ecological niches, increasing the productivity, the production stability and also the pasture lifetime. Moreover, several studies (Texeira 2010; Teixeira et al. *2*011) also demonstrate an improvement in the soil organic matter (SOM) accumulation, indicating the sequestration of 3.5 million tons of CO_2 in the 94260 assessed hectares of improved pastures. However, it is still essential to improve our information about the persistence of legumes, both native and introduced, when dealing with the beneath-canopy-conditions in silvopastoral systems, such as Iberian Dehesas, moreover when most commercial seed mixtures were selected for full-sun conditions.

6.2 Objectives

The aim of this study is to evaluate the profitability of sowing legume-rich pastures in the dehesa from an environmental and productive point of view, raising the following research questions:

1. How do **soil nutrients** vary with the time after sowing legume-rich pastures? Total carbon, total nitrogen and mineral nitrogen are expected to increase progressively with years after sowing, and changes would be more important out than beneath the canopy.
2. How does **pasture production** is affected by sowing legume-rich pastures? How does pasture production evolve with time (years) after the sowing? Is this trend affected by the presence of

trees? We expect a progressive increment of pasture productivity as the soil fertility could improve with the presence of legumes, and we expect a stronger change out of the canopy than beneath canopy.

3. What is the behaviour of the different **plant functional groups,** especially legumes**,** along the time and with the shade imposed by trees? We expect a lower implantation of legumes beneath canopies as the higher soil N content under trees (Gallardo 2003) promotes the dominance of grasses (López-Carrasco et al. 2015). For same reasons, after the implantation of sown legumes, grass species would progressively replace legume species.
4. Is it the **diversity of the plant community** affected by sowing of a legume-rich mixture? We expect an initial decrease in the species richness but with time the original species richness is recovery. Changes are expected be smoothed by the presence of the trees.
5. Is the **nutritional status** of grasses and forbs improved by the cohabitee with sown legumes? It is assumed an indirect transference of nitrogen from legumes to the rest of the species of the pasture community.
6. Does the **implementation of sown pastures affect the trees**? It is not expected a significant effect on trees performance.

6.3 Methodology

6.3.1 Study area

The study area, as the general environment of the Spanish dehesa, is characterized by two fundamental features: The Mediterranean character of the climate (dry summers and cold winters; see Table 6) and the low fertility of the soil, particularly P and Ca. The soils are mainly acid varying among Eutric and Distric Cambisols and Luvisols. Topography is generally flat or hilly, but never with pronounced slopes. The plots and farms situation is represented in Figure 15. Lithology and soils FAO/USDA classification of the seven studied farms with their different year of sowing plots, municipality, elevations (m), geographic X and Y coordinates can be consulted in Moreno et al. (2015b).

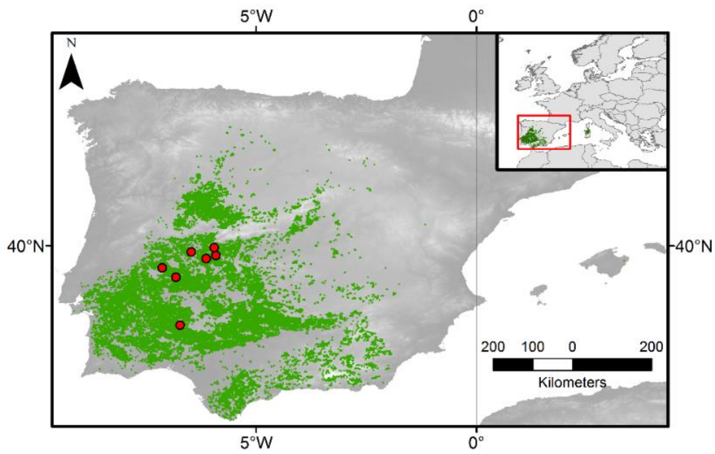

Figure 15. Geographical situation of the seven farms studied. Highlighted in green is reflected the dehesa distribution area in the Iberian Peninsula.

Table 14. Maximum, minimum and medium temperatures and annual, annual effective and spring precipitation

FARM	Nearest meteorological station (UTM coordinates and zone)	Year	Max. Tª mean (ºC)	Min. Tª mean (ºC)	Med. Tª mean (ºC)	Annual precipi-tation (mm)	Effective precip-itation (mm)	Spring precipi-tation (mm)
ATOQUEDO	CC-105 MIRABEL (X:738527, Y:4415189 Z-30)	2016	20.42	11.05	15.66	832	446	270
		2017	21.42	11.33	16.32	653	348	88
LAS CAÑAS	CC-106 ALISEDA (X:704113, Y:4349955 Z-30)	2016	22.86	8.67	15.85	575	239	269
		2017	23.88	8.22	16.17	408	204	77
LA CIERVINA	CC-105 MIRABEL (X:738527, Y:4415189 Z-30)	2016	20.42	11.05	15.66	832	446	270
		2017	21.42	11.33	16.32	653	348	88
LA CABRA	BA-05 JEREZ CABALLEROS (X:697969, Y:4239471 Z-30)	2016	24.09	8.33	15.88	711	354	319
		2017	24.88	7.51	15.83	490	249	126
CASILLAS	CC-104 ALCÁNTARA (X:680082, Y:4401750 Z-30)	2016	22.31	11.22	16.62	509	229	191
		2017	22.77	10.77	16.61	431	215	74
LA VILLA	CC-14 CORIA-P. ARGEME (X:204857, Y:4429511 Z-30)	2016	23.10	8.96	15.83	543	261	188
		2017	24.00	8.52	15.99	463	235	73
VALDELACASA	CC-10 VALDEÍÑIGOS (X:255705, Y:4427241 Z-30)	2016	23.09	8.48	15.77	720	367	223
		2017	24.20	8.19	16.06	507	267	60

6.3.2 Experimental layout

The experimental design was conducted in seven dehesa farms in Extremadura (West of Spain) where a mixture of forage legume seeds (20 kg seed ha^{-1}) had been sown in different years, following a chronosequence. In each farm, 3-5 ages (years of sowing) were identified besides of a control plot (parcel that has never been sown). In total 33 plots were monitored, covering a range for the year of sowing from 2002 to 2015. The plots were representative of the vegetation in the area in terms of botanical composition and phenology, and all the plots within each farm show topography.

For sowing, in November, a mixture of legume was sown. The mixture of *Rhizobium*-inoculated seeds provided by the Fertiprado company was composed of *Trifolium subterraneum* (61%) (different subspecies as *brachycalycinum* and *yaninnicum*) with other forage legumes: *T. michelianum var balansae* (7%), *T. vesiculosum* (3%), *T. resupinatum* (6%), *T. incarnatum* (8%), *Ornithopus sativus* (12%) and *T. glanduliferum* (3%). Superphosphate was applied as fertilizer in the sown parcels with different frequency among farms.

Two microhabitats were clearly defined in each of the 33 plots: beneath oak canopy and open areas. In each plot, 12 metallic cages (1 m x 1 m) were installed to exclude grazing, half of them beneath tree canopy and the rest beyond the canopy projection (> 20 m distance).

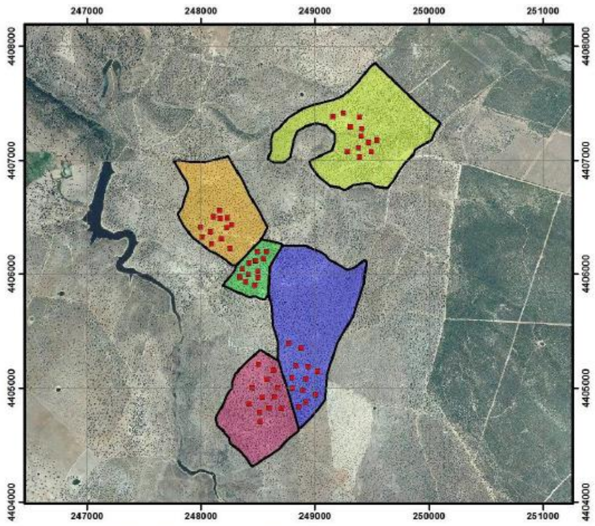

Figure 16. Map of the Atoquedo farm with the five plots sown since 2010. In red are marked the location of the exclusion cages used to study the pasture production. On the right, a view of legume-rich pasture, 6 months after sowing (spring 2016).

6.3.3 Sampling protocol and chemical analysis

Pasture production was estimated in 2015 and 2016 either in plots with delayed grazing (pasture was grazed after the growing season) or by using exclusion cages (plots where pasture was grazed during the growing season). Exclusion cages were installed prior to the growing season to prevent grazing. At the end of spring, coinciding with the end of pasture growth, all herbaceous species that were present in a 50 cm x 50 cm square quadrat were collected close to ground level. Herbaceous were air-dried and weighed to assess biomass. A total of six quadrats were monitored per age and microhabitat.

Botanical composition was determined with the Point Transect method (Southwood and Hendersen 2009), noting the species present every 100 cm in eight random 25-m transects, recording 208 plants per plot (104 beyond canopy and 104 beneath canopy). The inventory included 512 transects (7 seven farms (*33 plots) · 4 transects ·2 microhabitats*) and a total 6864 individual plants, per year. More abundant and ubiquitous species of grasses, forbs and legumes were air dried and stored in paper bags for further analysis.

Soil samples were taken in spring 2016 in the middle point of each botanical transect. With an auger of 8 cm of diameter, soil was sampled till 15 cm depth.

Foliar samples were taken in August 2016 (at leaf maturity) from 10 trees per age and farm. For each tree, four samples were taken at mid canopy-height to form a unique composite sample per trees. In these very open woodlands, branches at mid- height presented a similar growth to those located on the top of the canopy, and it can be assumed that sampled branches were representative of the actively growing branches of the canopy.

Chemical analysis of soil and plant (herbaceous species and tree leaves) focussed to N and C. Nitrogen was analysed by Dumas Method in a DUMATHERM® Gerhardt analyser. For plants, about

100 mg of dried and finely ground sample was used. A sample of 300 mg of 2-mm sieved and dried (60°C-48h) soil was used. Soil ammonia and nitrate was extracted with 1M KCl and analysed with a continuous segmented flow SEAL Auto Analyser.

6.3.4 Statistical analysis

Statistical analysis were performed with R Software (R Foundation for Statistical Computing, Vienna 2017). Differences with age among values for N of tree leaves and herbaceous plants, and for soil N and C, were compared by mixed effects models (LMMs), using the "nlme" package considering "farm" as random factor; besides of age, microhabitats and its interaction with age as fixed effects. Model selection was based on the Akaike information criteria (AIC) as a measure of the expected predictive performance of the different candidate models. Significance of changes in yield (kg/ha), considering habitat and age as independent variable was evaluated by two-way analysis of variance (ANOVA) and LSD Fisher´s test. The behavioural differences among the different functional groups coverage in percentage (% legumes, % grasses and % forbs) was assessed using curve fitting with linear and nonlinear regression.

6.4 Results

6.4.1 Pasture production

The positive effect of sowing legume-rich pastures in yield is clear for both pasture growing beneath tree canopy and for pasture growing in the interspaces. While mean values of pasture production for control plots were 1506 ± 157 $IC_{95\%}$ and 1618 ± 209 $IC_{95\%}$, (in kg DM ha^{-1}), for open and beneath canopy areas, respectively, the first year of sown pasture the pasture productivity was multiplied by around three (4543 ± 867 $IC_{95\%}$ and 5413 ± 890 $IC_{95\%}$ kg DM ha^{-1}, respectively). Production decreased gradually in the following years, although 8 years after the sowing, pasture production was still roughly 50% higher than in the unsown control plots (Figure 17). The positive effect of sowing of pasture productivity was stronger out than beneath tree canopies (Figure 17).

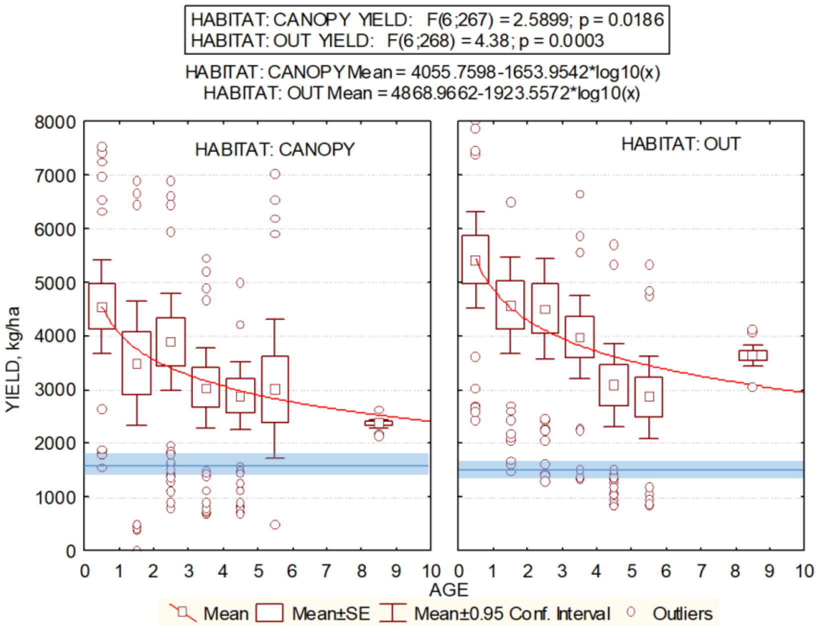

Figure 17. Evolution of the annual productivity of sown legume-rich pastures with age (years since the sowing) compared to control unsown plots (horizontal blue line, with band indicating 95% CI). Two microhabitats were considered, under canopy (left) and out of the canopy (right).

6.4.2 Plant functional groups

The mean coverage of the three functional plant groups (legumes, grasses and forbs) changed with age and habitats, following a unimodal curve, with maximum and minimum values (depending of the case) for mid ages (Table 7). In five out of six models the variability explained by the factors (R^2) was above or near 50%, with significant ($p < 0.05$) or marginal ($p < 0.10$) effects of age for legumes and forbs in 2016 and for grasses in 2017, and of habitat for grasses and legumes both in 2016 and 2017. The behaviour of the different groups varied with habitat. As expected, grasses dominated under the tree canopies and by contrast the legumes maintained higher proportions in the open areas.

Table 7. Significance (p) effects of generalized mixed model to explain the cover of three functional plant groups in two consecutive years. Fixed factors were Habitat (beneath and out of canopy), Age of sown legume-rich pastures (year from sowing) and their interaction (Age x Habitat), and Farm was included as a random factor (Age is nested in Farm). The model included a quadratic term.

Variable	Significance (p) fixed effects			R^2 Model
	Habitat	Age	Hab*Age	
Forbs 2016	0.238	0.053 *	0.214	0.603
Grasses 2016	0.078	0.209	0.330	0.603
Legume 2016	0.012 *	0.007**	0.402	0.687
Forbs 2017	0.665	0.209	0.079	0.264
Grasses 2017	0.034 *	0.085	0.483	0.716
Legumes 2017	0.004 **	0.197	0.666	0.471

In 2016, a very productive year, legumes, grasses and forbs showed very similar coverages in control unsown pastures (Figure 18), and much contrasted coverages in 2017 (dry spring, low productive year) when grasses were much more abundant (~70% of cover) that forbs (~17%), being legumes the less abundant (~13%). Sowing legume-rich pastures, as expected, altered the proportion of these three botanical groups: grasses, legumes and other forb. First years after sowing the coverage of legumes increased progressively, while the coverage of grasses and forbs decreased. Around the year 7-8 after sowing, legumes reached the maximum coverage, and grasses and forbs the minimum. While this trend seemed clear in the more productive year, 2016, for both microhabitats, beneath and out of the canopy, in 2017 the initial decrease of forbs was not observed and the decreased and increased coverage of grasses and legumes respectively seemed to persist longer. For instance, the maximum legumes coverages was found in plots that had been sown 15 years before.

Compared control plots with sown plots taken all together, the legumes cover increased from 18.7 ± 3.2 S.E. to 32.0 ± 1.6 S.E. The increase of legumes coverage in comparison with the control plots (control plots) was noticeable until eight years after the sowing. After that, the tendency starts to decrease but it remains over pre-sowing levels in the whole considered period.

In terms of the performance of legumes at the species level in the global context of the farms, the most abundant species was *Trifolium subterraneum*, with coverages around 12% in both habitats and years of sampling. Others legume species worth of mention in 2016 were *T. incarnatum* (13.5%) and *Medicago polymorpha* (11.5%) under canopy area and *T. michelianum* (14.2%) and *T. striatum* (12.0%) out of the canopy area. In 2017 were *Ornithopus sativus* (15.0%) and *M. polymorpha* (10.4%), and *T. stellatum* (8.8%) and *T. michelianum* (8.5%), respectively.

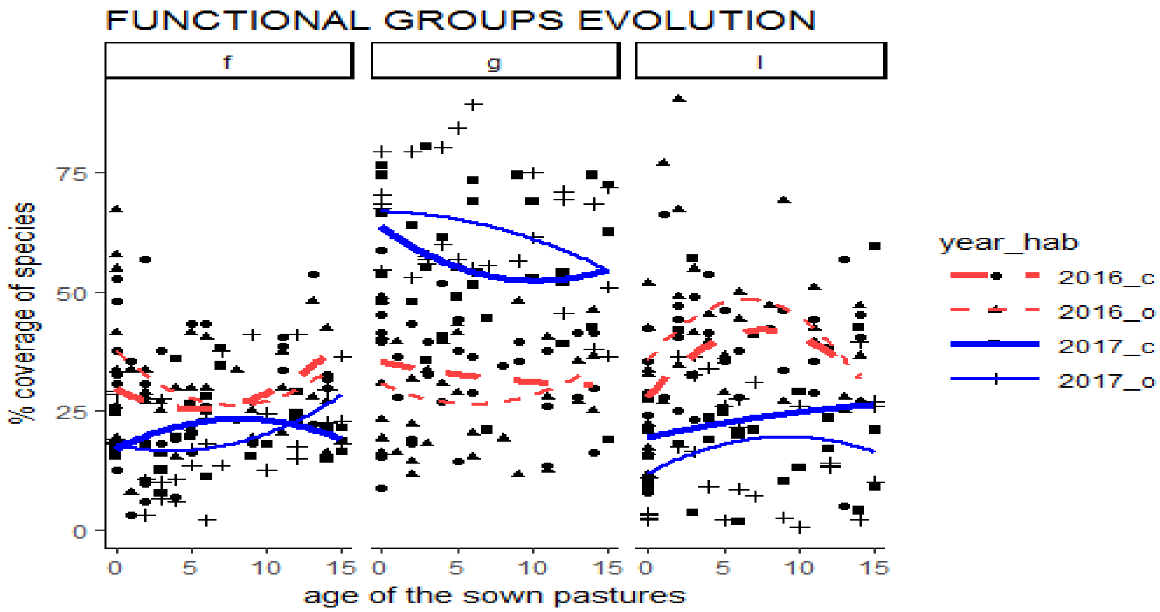

Figure 18. Evolution of coverage of plant functional groups (forbs (f), grasses (g) and legumes (l)) along the pastures chronosequence in two years of sampling 2016 and 2017. Two microhabitats were considered, under canopy (c) and out of the canopy (o). In the horizontal axis the age 0 indicates control unsown plots. Table 7 indicates the significance of different factors (Habitat, Age and their interaction) for the three functional groups of plant and the two years.

6.4.3 Plant diversity

The plant diversity of dehesas is usually high, and our results of control unsown plots confirm this statement. The mean number of species recorded in each sampling plot was near 50 species on average (α diversity) and the total number of species recorded per habitat (ϒ diversity) was above 150 species both beneath canopy and out of canopy, with species richness slightly higher in the latter habitat (Figure 19).

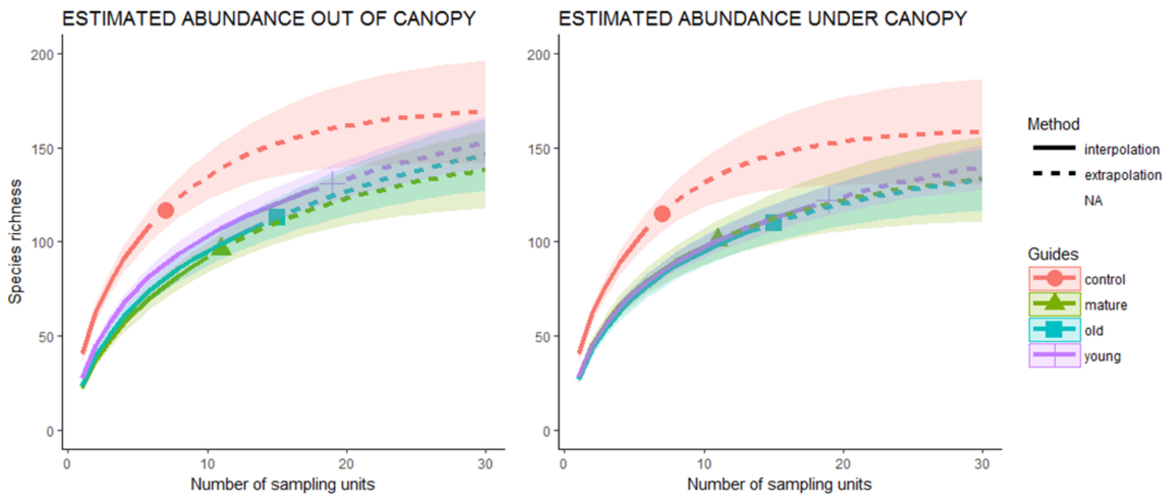

Figure 19. Estimated species richness by accumulation curves (±95 % C.I.) in native pastures (control) and legume-rich sown pastures of different ages (years from the sowing). Solid lines and symbols represent recorded data while dashed lines represent the species richness estimated following the extrapolation (prediction) approaches proposed by Chao (2005) and Colwell et al. (2012) to make comparable values produced with different sampling efforts.

After sowing rich-legume pastures (young pastures in Figure 19), mean species richness per sample decreased slightly both beneath and out of the tree canopy. This loss of α diversity persisted in mature (5-10 years after sowing) and old (> 10 years after sowing). However, species richness at higher spatial level (ϒ diversity) did not differed significantly for any of the age of the sown pastures respect to the control unsown pastures, indicating that the lost α diversity in sown pastures is compensate by the high β diversity.

6.4.4 Soil Carbon and Nitrogen

When referring to the soil fertility, we found that mean values of carbon and nitrogen (total and nitrate and ammonium as mineral forms) confirmed a significant increase with age resulting in higher contents of both, C and N, accumulated into the soils with the age of legume-rich pasture (Figure 20a to 20d). As these figures show, in all cases values fitted better to a lineal model, with significant effects of both Age and Habitats for the four parameters, and the interaction Age x Habitat for C and total N (Table 8).

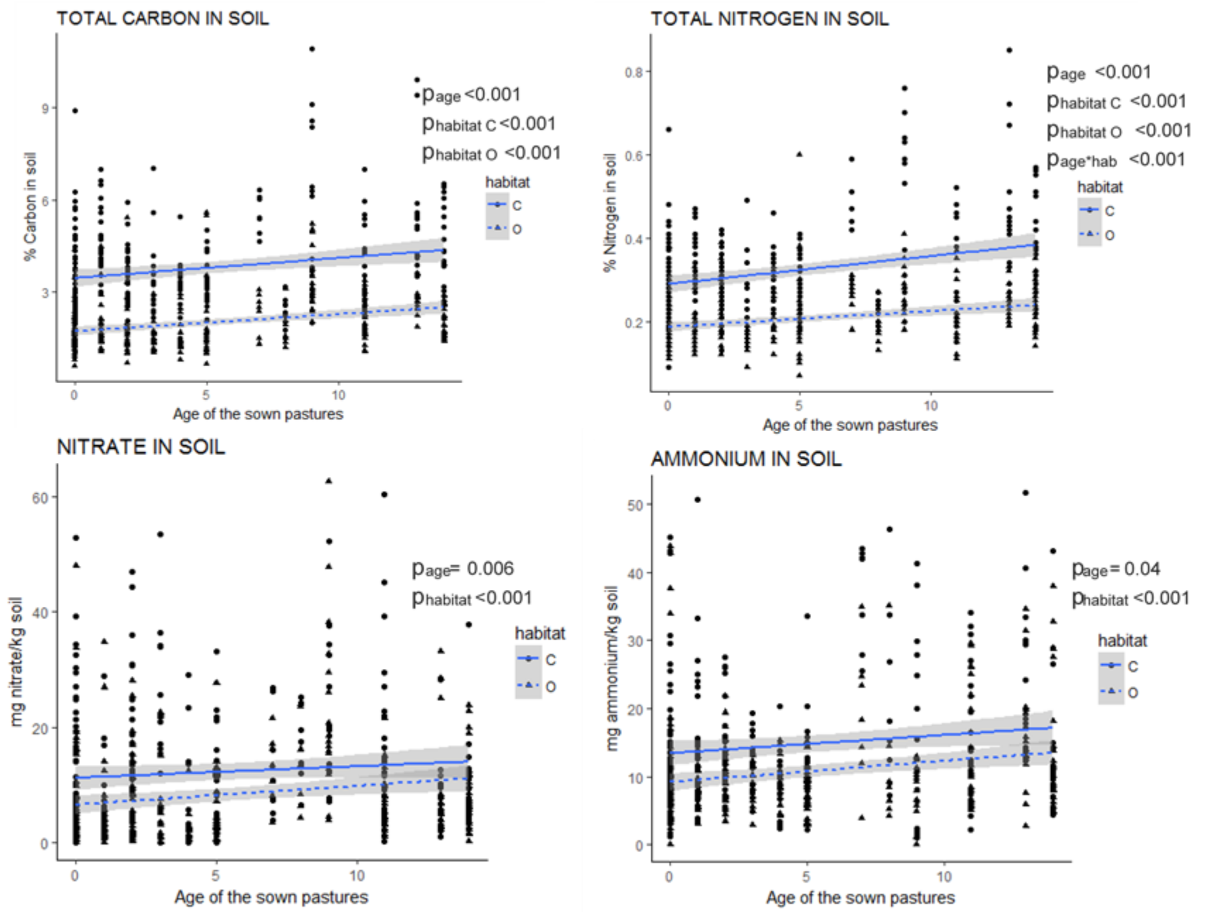

Figure 20. Evolution of the soil carbon, total nitrogen and mineral nitrogen (nitrate and ammonium) in soil in both habitats in the legume-rich sown pastures along the chronosequence. In the legend C represents the "beneath canopy situation" and O represents the "beyond canopy situation". In the horizontal axis, 0 represents the Control plots that have never been sown.

Table 8. Summary of the statistical factors considered in the mixed effect model (LMM) applied for analysis. C represents the "beneath canopy situation" and O represents the "beyond canopy situation". Values of the intercept (α) and slope (β) of the tendency lines represented on the different graphs are also given.

Variable	Significance (p) of fixed effects				Co-efficients of the Model			
	Habitat		Age	Hab* Age	Intercept (α)		Slope (β)	
	C	O			O	C	O	C
N in soil	<0.001	<0.001	<0.001	0.003	0.292	0.292 - 0.102	0.006	0.003
C in soil	<0.001	<0.001	<0.001	-	3.560	3.560 - 1.798	0.049	0.049
NO_3^- in soil	<0.001	<0.001	0.006	-	10.994	10.994 - 4.045	0.244	0.244
NH_4^+ in soil	<0.001	<0.001	0.04	-	17.745	17.745 - 0.275	0.275	0.275

6.4.5 Pasture nutritional status

In order to assess the influence of the sown legumes in the rest of the cohabitant pasture species (grass and forbs) we choose a selection of species based on their representativeness in the farms all along the chronosequence. These species were:

- Grass species: *Agrostis pourretii* Willd., *Brachypodium distachyon* (L.) P.Beauv., *Briza maxima* L, *Bromus madritensis* L, *Gaudinia fragilis* (L.) P. Beauv., *Hordeum murinum* L., *Lolium rigidum* Gaud. subsp. *rigidum*, *Vulpia ciliate* Dumort, *Vulpia geniculate* (L.) Link and *Vulpia myuros* (L.) C.C.Gmel.
- Forb species: *Anthemis arvensis* L, *Asperula arvensis* L, *Chamaemelum mixtum* (L.) All, *Crepis capillaris* (L.), *Hypochaeris glabra* L., *Plantago coronopus* L., *Plantago lagopus* L., *Silene gallica* L, *Tolpis barbata* (L.) Gaertn.

The analysis of nitrogen concentration in the cohabitant plants confirmed a significant increase with age (Table 9 and Figure 21) in both functional groups, finding enhanced nitrogen levels in grasses and forbs that grow plots sown with legume-rich pastures years before. Comparing their nitrogen baseline concentrations in the control plots with the concentration achieved 14 years after the sowing, improvements for grasses reached 49.8% under the canopy habitat, and forbs increase their N-level in 38% when analysed in the open areas.

Table 9. Summary of the statistical factors considered in the mixed effect model (LMM) applied for analysis. Values of the intercept (α) and slope (β) of the tendency lines represented on the different graphs are also given.

Variable	Significance (p) fixed effects				Co-efficients of the models			
	Habitat		Age	Hab* Age	Intercept (α)		Slope (β)	
	C	O			C	O	C	O
N in grasses	<0.001	0.04	0.01	-	1.463	1.463-0.25	0.035	0.0354
N in forbs	<0.001	0.06	0.02	-	2.061	2.061-0.234	0.0321	0.0321
N in oak leaves	-	-	0.86	-	1.395		0.0008	

6.4.6 Effects for trees

Regarding the effect of sown pastures on trees, a positive tendency with age of the sown pastures on the nitrogen content in the oak leaves was observed, however, the trends were not significant (Table 9, Figure 21).

Plotting the N content in forbs, grasses and oak leaves against soil nitrate we found a linear and significant relationship for grasses and marginally significant for oak trees (p= 0.051; Figure 21), indicating that the increase soil nitrate produced by the enrichment in legumes have a positive effect on the nutritional status of the dehesa vegetation.

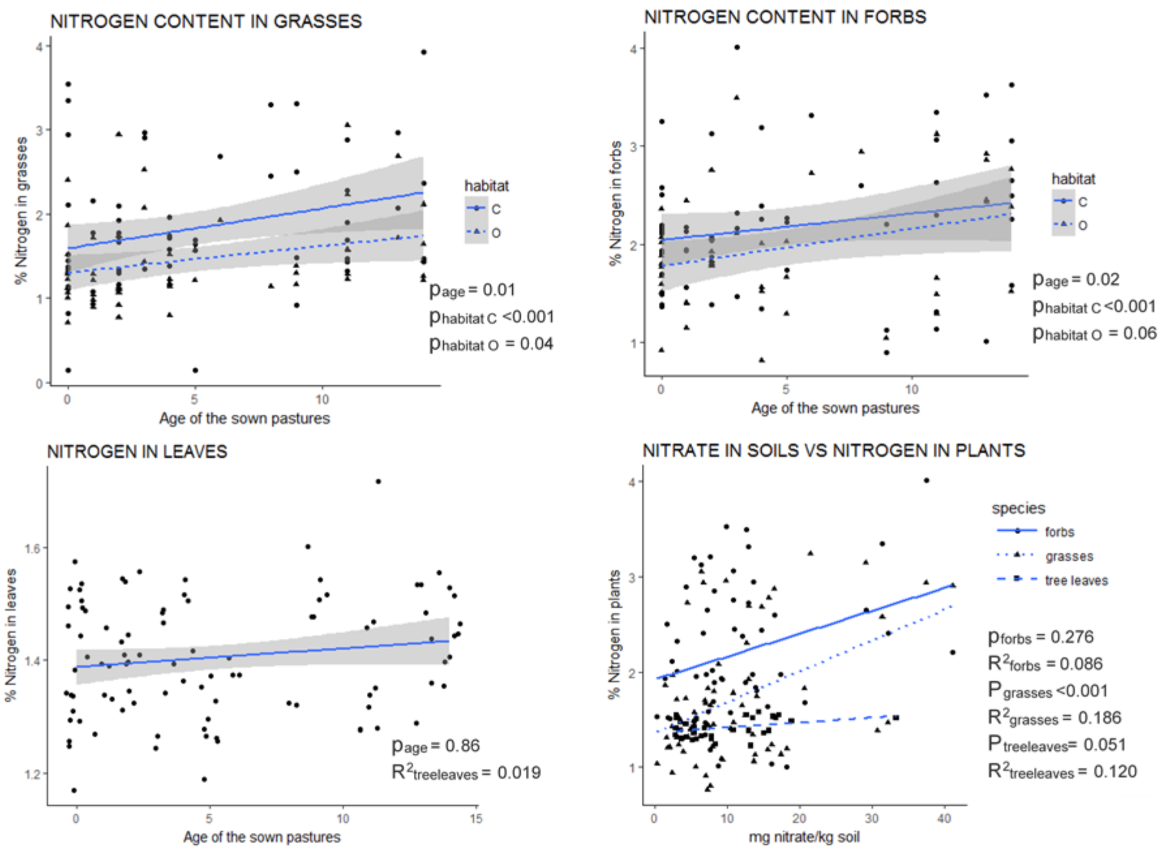

Figure 21. Evolution of the % of nitrogen in grasses, forbs and tree leaves along the chronosequence. In the legend C represents the "beneath canopy situation" and O represents the "beyond canopy situation". In the horizontal axis, 0 represents the Control plots that have never been sown. In the bottom right figure is represented the correlation among the mineral nitrogen in soil (nitrate) and the increase of nitrogen percentage in plants.

6.5 Discussion

6.5.1 Pasture production and legume cover

Considering the tree canopy cover fraction in our plots (20% on average), the increase in yield at plot level increased to the 217% of that of the control (1583 kg ha^{-1} in unsown plots vs. 3438 kg ha^{-1} in legume-rich pastures sown seven years before). We cannot fully explain the highly significant productive advantage of the sown pastures over natural pastures with the increment on the proportion of rhizobium-inoculated-N_2-fixing-plants. Previous research show that the Rhizobium N_2-

fixation is not the only factor that contributes to a higher yield, in fact, the importance of the interaction among N_2-fixing and non-fixing-plants are suggested to be more relevant (Li et al. 2007; Temperton et al. 2007; Kirwan et al. 2009; Nyfeler et al. 2009). As discussed in the next section, the total and mineral nitrogen of the soil also increases which is reflecting in a better nutritional status of grass species, and presumably in their productivity. Besides, the highly productive species and cultivars with hard seeds that sown pastures contains lead to a persistent seed bank and increase the viability of more persistent pastures (Crespo 2006; Teixeira et al. 2015). This long-lasting character together with the number of plant species with diverse functions contribute to higher yields (Fornara and Tilman 2009). As highlighted in previous research (Bullitta et al. 1989; Porqueddu and González 2011) when a natural seed bank of pasture legumes is present, as is in the case of dehesa, fertilisation repeated several years -without overseeding- may be sufficient to obtain satisfactory agronomic results. Our study shows, nevertheless, that sowing legume-rich pastures can be also an efficient way to increase the agronomy value of the pastures.

Previous comparisons of legumes and grasses have commented on habitat niches. Grasses fill a legume niche when the situation is adverse for them. Forbs seem to be less competitive with less evidence of variations in their coverage in the considered years. Focusing on the changes in the medium-long term, the biggest changes experienced in pasture composition relate to the legumes functional group. After 14 years of the sowing, legumes covered 30.8% and 25.7% of the soil under and out of the canopy, respectively, compared to the 18.9% and 18.6% in the unsown control plots. These covers represent total increments of 63.3% and 38.0% respectively. By contrast, grasses and forbs experienced slight decreases both beneath and beyond tree canopy.

Our results for legume cover are lower than the ones reported by Texeira et al. (2011). When sown pastures were installed, as expected, legumes proportion increased to reach almost 50% in the years after planting. Some researchers found the greatest development occurred in the first three years of establishment (Teixeira et al. 2011). We observed a sustained increase in the legumes percentage until the seventh year after the sowing. Regarding the stabilization stage, the percentage of legumes in the plant cover of a mature pasture (more than 5 years) tends to stabilize around 25–30% , as reported in some studies (Crews and Peoples 2004).

The response of the pastures to tree coverage depended on the climate. In 2017 pastures experienced unusually high temperatures in early spring and rainfall was scarce, and legumes were more abundant beneath the canopy, while in 2016, with a more favourable climate conditions, legumes were more abundant outside of the canopy. Given the increasing recurrence of heat/dry events in spring/growing season, this could be a support to the implementation of sown pastures rich in legumes in silvopastoral systems as dehesa, where scarce trees exert a “nurse” effect over the pastures, above all in climatologically adverse years.

To sum up, joining the increase in yield and legumes proportion in the farms, the sowing of legume-rich pastures seems to be well justified. The appropriateness of the commercial seed mixtures has received minimal attention by many authors because of their unsuitability to current climatic and management conditions (Olea and Viguera 1997) or their excessive competitiveness or invasive character (Driscoll et al. 2014). In contrast, our results indicate an unproblematic coexistence of both, native and cultivated legumes, supporting the observations of Proença el al. (2015). In fact, in our botanical inventory transects, we found some native *Trifolium* such as *T. striatum, T. stellatum and T. glomeratum* among the most abundant legumes in the assessed farms. The most persistent species under and beyond the tree canopy was *T. subterraneum*. All these species should be part of an "ideal" seed mixture created to be sown at the dehesas.

6.5.2 Increased nitrogen: a successful transfer from soil to plants

Our results show the enhancement of the nitrogen pools in all the studied farms along the chronosequence. These results are consistent with those of Gómez-Rey et al.(2012) and Texeira et al. (2015). We found soil N increases of 44.1% under canopy conditions and 11.6% beyond the trees with regard to the unsown plots in the whole studied period. Regarding the soil mineral N types, the nitrate increase was 52.3% beneath and 34.5% beyond the canopy. Ammonium was raised by 15.4% in the shaded area and 46.5% in the open areas.

There has been minimal previous general research to evaluate soil nitrogen variations after sowing legume-rich pastures in agronomic and intercropping mixtures (Vandermeer 1989; Federer 1999; Connolly et al. *2*001) and multispecies implementation research (Connolly et al. *2*001; Skinner et al. *2*004; Finn et al. *2*013; Teixeira et al. *2*015). Hence it is difficult to establish general rules due to, for example, the different considerations in species, legume densities, and local area. Looking at our results we affirm that the implementation of legume-rich pastures in dehesas produce a green manure effect (Tribouillois et al. *2*016). In other words, the permanent sown pastures rich in legumes may be considered a fertility building crop. Legumes maximize N acquisition through rhizobium symbiosis, accumulating a large amount of N and increasing soil N availability (Tonitto et al. *2*006). In a complementary way, species of grasses and forbs take up soil mineral nitrogen, in particular nitrate, decreasing N leaching (Meisinger et al. *1*991; Constantin et al. *2*010; Thomsen and Hansen 2014). Thus, we could say that implementing intercropped mixtures composed of legumes and a non-legume species maximize the benefits of each functional group due to the principle of niche complementarity (Jensen 1996). This principle is based, among other facts, in the differences in the root lengths of legume and non-legume species (Nyfeler et al. *2*011) and differences in their growth pattern across the season (Luscher et al. *2*005) or among years (Nyfeler et al. *2*009). This complementarity relies on the maintenance of an adequate level of legume species, over 30% to 50%, as found in the studied farms. This level proportion keeps the system in an optimal performance (Lüscher et al. *2*014). Operating beyond these limits could end up causing acidification by an excessive N mineralization and nitrate leaching with precipitations (Bolan et al. *1*991). However, these effects could be reduced by the increase on organic residues and the water and nitrate intake by oak roots.

When looking at our data, both grass and forb species showed significant positive effects for N content, related to neighbouring legumes (Figure 21). The N concentration of plants in sown plots increased, under and beneath canopy, respectively, by 15.5% and 38.1% in forbs and 49.8% and 9.0% in grasses. These results comparing control plots with sown plots are similar with those reported by Nyfeler et al. (2011). They demonstrate the ability of both legumes and grasses to expand their acquisition for N from symbiotic sources when grown in mixture as compared to pure stands. Similar results in this transfer of legumes symbiotically fixed nitrogen to the rest of the plants were also found by Høgh-Jensen and Schjoerring (2000) and Gylfadóttir et al. (*2*007), To sum up, it is necessary to highlight that beneath the tree canopy the response to sown legumes in terms of soil and plant N was similar (mineral N and N content in forbs) or stronger (for total soil N and N concentration in grasses) than the response found out of the influence of trees. Thus, it confirms the benefits of sowing legume-rich pastures in Mediterranean silvopastoral systems as dehesa, where the enhancement of mineral-N production (and respective leaching) promoted by improved pastures can be counteracted by trees (Gómez-Rey et al. *2*012).

Further studies are needed to understand how it could positively or negatively affect trees, but our results show that scattered oaks are not really affected by the sown pastures in terms of nutritional status. As reported by Cubera et al. (2012), improved pastures can negatively affect young oak seedlings by competition for water, and thereby the recruitment and regeneration of thee tree cover of dehesas. However, the effects on mature trees could be different. Given the slow response of oak trees to fertilisation in dehesas (Pulido et al. *2*013), the indirect transference of nitrogen from legumes to trees via soil N can be expected over the medium-term.

6.5.3 Carbon fixation. Benefits for soil and strategy against climate–change

Soil organic matter (SOM) is the basis of the transformation and reactions within a soil (Lal 2004). There is ample evidence that silvopastoral systems have high potential to store more stable C in the soil compared with the treeless systems (Montagnini and Nair 2004; Sharrow and Ismail 2004; Haile et al. *2*010; Howlett et al. *2*011a,b; Tonucci et al. *2*011; Baah-Acheamfour et al. *2*014). Soil C stock is also reported to be influenced by species richness (Steinbeiss et al. *2*008; Cong et al. *2*014; Lange et al. *2*014) and tree density (Saha et al. *2*009). In fact, some research (Schmidt et al. *2*011), concludes that the persistence of soil organic carbon is primarily not a molecular property, but an ecosystem property. In other words, that carbon stability instead mainly depends on its biotic and abiotic environment.

When evaluating the accumulation of Organic-C (we equate the measures of Soil Total Carbon to SOC in our acidic soils) in the upper soil layer of open areas we obtained highly significant differences with the habitat (beneath and beyond canopy) and with the age of the sown pastures (Figure 20, top left). To quantify this, the increase in SOC percentage after 14 years of the sowing resulted in a 47% increase under the tree canopy and 26% beyond it. That can be explained through different considerations, such as the increase above and belowground dry matter production and the increase nitrogen in the system (Milne and Haynes 2004; Piñeiro et al. *2*010; Mcsherry and Ritchie 2013). Indeed, the C: N ratio is an important driver of soil carbon sequestration, and increasing the N produced over the medium-term results in a clear increase in the soil organic accumulated in the soil. As commented above, plant diversity (and functional diversity) is frequently associated with a higher rates of carbon sequestration. Indeed, Stockmann et al. *(*2013) found an enhance plant diversity and hence the quality of residue input and SOC pool after the implementation of legume-rich pastures . However in our study we did not find any increment on plant diversity after sowing legume-rich pastures, although an increment in the diversity and cover of legumes could be playing any positive role for the reinforce soil carbon sequestration.

6.6 Conclusions

The sowing of seed mixtures with high numbers of self-reseeding legume species produced a noticeable increase of the pasture productivity, a positive effect that last even more than one decade, irrespective of the microhabitat. The positive effect is also evidenced by a slight but long-lasting significant increase of legume cover in the sown pastures, both beneath and out of the canopy. In addition to the introduced species, native species also increased their presence, explained by the improved soil conditions caused by sown species and by possibly by the increased *Rhizobium* inoculation.

Delayed grazing is essential the first years to ensure a good establishment of the legume species. More persistent legumes species were *Trifolium subterraneum, T. michelanium, T. resupinatum, T. vesiculusum* and *Ornithopus compressus*. Among these species, some of them seemed better adapted to tree shade conditions e.g. *Trifolium stellatum* and *T. incarnatum* grew better beneath the oak canopy. Other species such as *T. subterraneum, T. glomeratum, O. compressus* and *Medicago polymorpha* grew similarly beneath and out of the canopy. All these species seem adequate for the seed formulation to improve pastures in Iberian dehesas.

The increase cover of legumes produced a significant increment of the soil mineral (nitrate and ammonium) and total nitrogen both beneath and out of the tree canopy. This enrichment resulted in significant increment of the nitrogen content of the rest of the plants, especially for grasses. As consequence, the sown of legumes caused an overall improvement on the quality of the pastures, both for the higher cover of legumes (rich in protein) and for the increase protein content of the non-legumes plant species. Although the sowing seemed to reduce slightly the α diversity of plant, the total species richness (ϒ diversity) was not affected significantly.

The content of carbon accumulated into the soil showed a positive and significant tendency with the age of the sown pasture, both under and beyond canopy, which enhances the importance of considering this kind of management practice to increase the resilience of these silvopastoral systems against climate change.

A reliable economic evaluation was not completed. According to the seven farmers that participated in the study, the improvement in the pasture quality and productivity was sufficient to offset the high cost of seed mixture and fertilizers. Nevertheless the profitability of sowing strongly depends on the persistence of the self-seeding legume species, for which delayed grazing is essential for at least the first years, to ensure the sufficient establishment of the legume species.

7 Explore the consumer acceptance for agroforestry products and services

This section provides a summary of the analysis of consumer preferences by agroforestry products and of the search of best strategies of branding agroforestry products. Results were partially presented in the 3rd European Agroforestry Congress hold in Montpellier in June 2016 (Gaspar et al. 2016a) and published in the scientific journal *Land Use and Policy* (Gaspar et al. 2016).

7.1 Background

Among the different alternatives to overcome the constraints that threaten agroforestry systems, one of the most promising is the development of brands which could help consumers identify those products generated in agroforestry systems of high nature and cultural value. The stakeholder group of the dehesa has stressed the need to explore new opportunities regarding product diversification and adaptation to market demands. It is considered that in this way agroforestry products would be valorised and therefore, it could be possible to increase the revenues for these systems (Moreno 2014).

We need to take into account that the main products provided by dehesa agroforestry systems are high quality meat and milk products produced in extensive conditions. Different livestock species are usually raised at the same time. According to the different livestock species the main products marketed are described below:

Cattle: the marketed product of the beef systems is the calf at weaning, with an age close to 6 months and 200 kg live weight. These animals are sold on for fattening away from the farm, and in most cases outside the region of dehesas.

Sheep: sheep farms in dehesa systems are basically devoted to meat production, but there are examples where artisanal cheese are also targeted. Meat production is lamb fattened on the farm, and slaughtered at 3 months and 23-25 kg live weight, depending on resource availability and market demand.

Goats: goat herds are mainly used to produce milk for local high quality artisanal cheeses.

Pigs: The product marketed in the case of pigs is highly varied and complex, depending principally on whether the predominant nutrition was mast or commercial feed. The main destination is the processing industry of cured meat products. The determining factor in the maintenance of a production system such as that of the Iberian pig is the high quality and market value of its products. Given the current systems of production of meat and meat products, the existence of an animal of this type with such a long productive cycle, and low prolificacy is only possible if the end product is of high market value. The quality of Iberian pig meat and its derivatives has been extensively proven in several studies (Serra et al. 1998; Cava et al. 2003; Estévez et al. 2003). It is a high quality product with market acceptance, and one that has to be located in areas of dehesa in order for the animal-food-ecosystem interaction to generate the optimal product.

Similarly, the production of ruminants complemented by Iberian pig will also have to be linked to products of quality, since in the dehesa they are range animals feeding freely on the natural vegetation, with low environmental impact. This type of production is fully coherent with the new trends of the Common Agricultural Policy such as quality production, respecting animal welfare, and generating environmental benefits for society.

However, it must be taken into account that agro-industrial development in dehesa regions is relatively young. Even though there are already many quality brands and an important organic livestock farming production in these regions, there remain major structural problems that impede the proper marketing of products. For example, there is little experience of farming associations and although there are brands with real quality they have little market penetration.

Within this context, management success at farm level is linked to the optimal use of farm resources by the different species that are raised. It is also essential to improve the utilization of other products currently considered by-products and also innovate in the development of novel products as a way to generate added value. It must not be forgotten that, in order to maximize added value for these products, it is essential to use appropriate marketing channels and to develop appropriate marketing strategies so that consumers can identify the products from these systems as high quality ones. In many cases they are commodities that consumers are not able to identify and therefore, are not able to valorise and pay a premium for. In this context, it was considered that the development of a brand for products from agroforestry systems could be a useful tool to reach the abovementioned objectives, taking as a first approach the Spanish dehesas.

Accordingly, empirical studies were carried out in order to analyze consumer behaviour towards products and services provided by Iberian dehesas. This protocol has been developed by the Agricultural and Food Economics Research Group in order to carry out these tasks. Due to the nature of this task, with different products covered and many subjective issues having to be considered, it was decided that the way to deal with this chore was a mixed and qualitative methodology, using discussion groups (focus groups) and projective techniques that would enable us to get a glimpse of the both of the inner concepts that such a brand should include and also of other general aspects that could be interesting for the consumers. These systems generate commercial and environmental values, which are not always perceived by the society.

7.2 Objectives

The purpose of this research was to find out the value society places on these agroforestry systems and their products and services. Three main objectives were afforded using different methodologies:

- to identify agroforestry derived products and services, new demands and emerging products,
- to assess the willingness to pay a premium price for products and agroforestry services, and
- to identify mechanisms to promote marketing of high value products and ecosystem services.

To achieve the objectives primary data were collected through focus groups, interviews and in-depth surveys. The process was organized with different types of stakeholders according to the methodology selected.

7.3 Methodology

The information has been obtained from two rounds of focus groups. In the first round, 4 focus groups organised in Badajoz and Caceres (Spain) in May/June 2015. The discussions involved 35 people with an even distribution of age and gender being sought for each group. Content analysis was applied and given the qualitative nature of the study and with the purpose of improving the validity of the results, the analysis was also carried out by means of triangulation. The purpose of this methodology is to improve the validity of the results by analysing them from various points of view.

Table 10. Structure of the focus group discussions

Section	Contents
1. Agroforestry systems and ecosystem-related services	Familiarity with the term “agroforestry system” Familiarity with the concept “ecosystem-related services” Identification of the ecosystem services supplied by the dehesa.
2. Users and consumers of products generated by the ecosystem	Identification of products generated by the ecosystem Factors causing an impact at the time of purchase of food products The impact that the origin of a product has on the purchase/ consumption decision Quality labelling associated to the agroforestry systems as a measure to increase the added value of by-products
3. Compensation to ecosystem services' suppliers	Subsidies to ecosystem services’ suppliers Compensation through the purchase of ecosystem products Ecosystem services and CAP

In the second round of focus groups, six focus group sessions with consumers were carried out in municipalities with different characteristics in Extremadura. Two of them were held in March 2017 in rural areas, two were held in May in medium-sized towns and finally two sessions were held in July in the largest cities of the region. In total 48 consumers participated, the main criterion for the selection of the participants being the willingness to participate in the study, since no special feature or previous knowledge about agroforestry or “dehesas” was required. The number of participants varied between 7 and 10 per session. The sociodemographic characteristics of the participants appear in Table 11.

Table 11. Characteristic of the participants

		Large-medium city	Small Town	Rural village	Total
Gender	Men	26.7%	37.5%	41.2%	35.4%
	Women	73.3%	62.5%	58.8%	64.6%
Age	18-35 years	20.0%	25.0%	35.3%	27.1%
	36-55 years	66.7%	50.0%	47.1%	54.2%
	> 55 years	13.3%	25.0%	17.6%	18.8%
Education	Primary/Secondary	40.0%	31.3%	52.9%	41.7%
	University	60.0%	68.8%	47.1%	58.3%

All sessions were led by an expert and recorded on video for later analysis. The total work time of each session was 120 minutes. The work sessions were developed following a common protocol which included different projective techniques (sentence completion and brand personification) within the discussions of the focus group.

Sentence completion: In sentence completion respondents are provided with incomplete sentences in the shape of sentences or dialogues and they are asked to complete them, usually with the first word or sentence that comes to mind (Eldesouky et al. 2015). It proves a useful technique when the time is limited (Donoghue, 2000), although it may lose part of the worth of the responses provided by the use of other techniques such as story completion.

Brand personification: In this technique participants were asked to attribute personalities to brands, and imagine them as if they were people or individuals. The intention is to evoke information and symbolic images associated to the brands. In this task, different brands were presented to the consumers: a dehesa brand, a sustainable production brand, a traditional food brand, and a socially responsible production brand. The objective was to get a comparison of the attributes assigned to the different concepts in order to identify those constraints associated to the agroforestry systems by themselves and those positive aspects linked to the other ideas but which are also related to dehesas.

7.4 Results

7.4.1 Citizen knowledge of products derived from dehesa HNCV

For citizens dehesa agroforestry systems generate a great variety of products with commercial value, both in terms of food and non-food services. In these regards, the participants were individually asked to indicate specifically the products and services derived from the dehesas they were aware of. Table 12 includes the products identified together with the number of times they were mentioned.

In addition to identifying typical products which are abundant in the ecosystem, other products were mentioned that are classified as emergent or with a development potential. Mushrooms and asparagus are considered as very interesting products; the commercialisation of these is currently very limited. Other products the participants were interested in were the acorn by-products and they gave examples such as acorn chocolates, acorn fruit drink, acorn ice-cream, acorn bread and acorn liqueur.

Table 12. Commercial-value products and services deriving from dehesas identified by focus groups

Consolidated products			
Food	**No. of times identified**	**Non-food**	**No. of times identified**
Pig: meat and by-products	35	Cork and by-products	31
Beef	34	Agritourism	16
Sheep: meat, milk and by-products	29	Acorn (fruit)	16
Goat: meat, milk and by-products	19	Firewood and by-products (oak coal)	13
Honey and by-products	19	Hunting tourism	10
Cereal	16	Timber	9
Game meat	14	Pasture	7
Fighting bull meat	7	Wool and furs	6
Poultry production	3	Active tourism, e.g. hiking, horseback routes, touristic cycling	3
Fish products (e.g. tench)	1	Bird watching	2
Products with a potential to develop			
Food	**Nº**	**Non-food**	**Nº**
Mushrooms and fungi	11	Medicinal plants and cosmetics	4
Asparagus	7	Aromatic plants (thyme, oregano)	3
Acorn liqueur	1	Herbs and herbal tea	1
Acorn beer	1	Crafts (cork, timber, etc.)	1
Acorn flour and other food by-products	1	Hydraulic resource	1
		Solar power	1

7.4.2 Consumer behavior towards products generated by dehesa HNCV

As one of the targets of this project was to identify the factors with an impact on the consumer behaviour towards the products deriving from the agrosystem, the discussion at this point was driven towards the consolidated food products, as they were mostly identified by all the participants. The aspects discussed were the role of the origin (geographic or production system origin) on selecting the products that had been previously identified. Another topic raised due to its potential was the use of quality brands used in order to add value to agroforestry system products. Table 13 summarizes the results related to these topics.

Table 13. Summary of questions, answers and verbatim comments arisen in the focus group sessions.

Questions raised by the moderator	Summary of answers	Verbatim comments made by the participants
Role played by product origin when choosing products	- Geographic origin is highly valued, although specially for certain types of products	*"On selecting between two products, if I see that one of them is locally produced, I buy that product…"* *"I like to know where the products come from. If I can find out, I look for it, but sometimes this information is not provided…"*
Influence of production system in consumer behaviour	- The production system used has a limited impact at the time of purchase - Participants are aware of the value of a product derived from a sustainable production system but recognise that their behaviour do not reflect this attitude	*"We should place importance on a product being originated in a dehesa system, but in reality we place the importance on the quality of the product"* *"In some cases the quality of a product is guaranteed by the fact that is has been produced in a dehesa"*
Opinion in development of quality brands	-The existence of a quality brand generates trust and guarantees the product -Many products that are designated by quality brands are not accessible due to high pricing -A quality brand must be accompanied by an adequate promotion policy	*"The quality brand is "dehesa", in this way it could be differentiated from other production systems"* *"A quality brand is not indicative of the sustainability of the system where it comes from"* *"The quality brand should be simple and get strong promotion to be successful"*

During the discussion a few proposals were raised to support the fact that the production system should become a key factor and that people should act responsibly at the time of purchase, rather than just focus on price and geographic area. The participants believed that there was a need to build citizen awareness and better and more advertising of the products in order to guarantee the sales as a way to increase their added value and improve prices.

Finally and regarding the development of quality brands, the participants generically stated that the presence of a quality brand is seen as a positive attribute in any food product. However, they also pointed out that a quality brand would not make them think that the production systems are more sustainable or better for the environment.

At the same time, they pointed out that the establishment of a brand identifying the dehesa must be clear. For example, the incorporation of the term agroforestry is not seen as particularly attractive, as it is an unfamiliar term. The main advantage of a dehesa brand to designate all the products would be the simplification of the current situation, as for the majority of the participants there are too many designations of origin that may even confuse the consumer.

7.4.3 Development of a brand for agroforestry systems

Table 14 shows the results of the Completion task. For this task, participants were asked to complete a sentence regarding them finding a food product in a supermarket labelled with a quality brand “Dehesa”.

Table 14. Categories identified in completion of sentences task

Question provided to the participants:
Please complete the following sentence: *If I am in a supermarket and I find a food product with a quality brand named "Dehesa" I ...*

Categories identified	Frequencies of mention (%)	Examples
I will buy it	25.6	*"I would buy it without hesitation. Although the price would be higher "*
I value it, but it is not decisive	23.1	*"It strikes me; You may buy it; I think it has more value (quality, environment) "*
I think about quality	17.9	*"I perceive that it has been prepared and processed in such an environment and therefore guarantees quality"*
I'm looking for more information	10.3	*"... I keep reading, who produces it, where it comes from ..."*
I value it but it is not determinant, it also price	10.3	*"I would try to buy it as long as it was not excessively expensive"*
I think "it's natural"	10.3	*"I understand that it has occurred naturally in the middle of the dehesa"*
I'm interested, it gives me additional guarantee	2.6	*"I'm interested; it offers me confidence; give me guarantees"*

As can be observed, a high percentage of participants (25.6 %) showed recognition towards a Dehesa brand and were favourably disposed to purchase it. However, as the comment shows, sometimes the Dehesa brand can be related with products having a high price. Likewise, 23.1 % of participants value the attributes of environment and quality that the brand can convey but they are not decisive factors in the purchase. Other aspects highlighted and related to the Dehesa brand were referred to the quality of products, while it was also stated that despite the brand, some consumers would seek more information about the product, as they would consider it as natural but with price as the most determining factor.

As it has been mentioned before, the feasibility of a brand encompassing the products of agroforestry systems was studied along the Focus Group by using brand personification. The participants were asked to attribute personality characteristics to four hypothetical brands that would gather the main features of agroforestry products in southwestern Spain. Participants were guided to define the aforementioned characteristics based on: age, sex, origin, hobbies, etc. Table 15 shows the main results of the brand personification study. As can be observed, when analysing the different aspects of the personality some brands complemented each other while others showed totally opposite aspects. This is an interesting finding to highlight, since the brand image should be attractive to as many consumers as possible. So much so that, for example, it was appreciated that while the dehesa or traditional product brands conveyed an image of mature-older people (47.6% in the dehesa brand and 83.4% in traditional product), this result was in contrast with the sustainability and socially responsible brands, whose images were fresher or oriented towards young consumers. On the other hand, the dehesa brand is related to the male gender in 60.9%, while the other brands are associated with women or are indifferent regarding gender.

Character and personality are similar in the four brands, while the physical appearance conveys a traditional and rural image in the first two brands, as opposed to sustainability which is associated with a dynamic, young and informal character, while at the same time serious and socially committed with the natural environment. These aspects are reinforced by the association of the first two brands with rural environments, as opposed to the sustainability and socially responsible brands, clearly considered as urban and cosmopolitan brands.

Finally, it can be seen that all the brands are closely linked with hobbies related to the natural environment and healthy life, which are element of great value when considering the development of a brand for agroforestry products.

7.5 Discussion

In spite of the citizens being unfamiliar with the term "agroforestry system", the dehesa - as the reference agroforestry system in the Iberian Peninsula - is accurately recognised and described. This reveals that it may become necessary to use terms that are more familiar if a specific system is intended to be placed in value.

The dehesa agroforestry system is mainly identified as a service supplier, specifically for high-quality animal-origin food products. The cultural services associated with the aesthetical and recreational value of the landscapes have also been recognised in social importance.

These services translate into products with a commercial value. The majority of them are products that are already consolidated in the market. Emerging products with little presence in the market were also described, but these were seen by the citizens as with development potential (for example, asparaguses, fungi and mushrooms, acorn beer, medicinal plants and cosmetics, herbs, and herbal tea).

Table 15. Proportion of respondents (%) identifying brand personification activities

	Brand dehesa		Brand sustainability		Brand traditional product		Brand socially responsible production	
Age	Less than 30 yo	9.52	Less than 30 yo	37.50	Less than 30 yo	4.88	Less than 30 yo	36,84
	30 - 40 yo	2.38	30 - 40 yo	32.50	30 - 40 yo	4.88	30 - 40 yo	34.21
	40 - 50 yo	35.71	40 - 50 yo	22.50	40 - 50 yo	4.88	40 - 50 yo	7.89
	More than 50 yo	47.62	More than 50 yo	5.00	More than 50 yo	85.37	More than 50 yo	15.79
	Indifferent	4.76	Indifferent	2.50	Indifferent	100.00	Indifferent	5.26
Gender	Male	60.87	Male	13.79	Male	31.58	Male	19.44
	Female	13.04	Female	41.38	Female	44.74	Female	47.22
	Indifferent	26.09	Indifferent	44.83	Indifferent	23.68	Indifferent	33.33
Job	Farmer	47.06	Farmer	35.48	Farmer	52.63	Farmer	10.71
	Shepherd	23.53	Environmental professional	38.71	Craftman.Businessman	28.95	Liberal professional, civil servant	64.29
	Other rural jobs	11.76	Entrepreneurs and service	19.35	Other	18.42	Entrepreneurs	17.86
	Entrepreneurs & service sector	17.65	sector			0.00	Oher	7.14
			Other	6.45				
Character and personality	Quiet, kind and nice	53.49	Cheerful, kind, nice and enthusiastic	40.00	Cheerful, kind, noble	52.63	Cheerful, kind, nice and enthusiastic	44.74
	Lonely	2.33	Commited, ethical and with environmentally conscious	37.14	Rude, traditional	28.95	Commited, ethical and with environmentally conscious	28.95
	Serious, enterprising and determined	44.19	Serious, enterprising and determined	22.86	Professional	18.42	Serious, enterprising and determined	26.32
Physical appearance	Traditional, rural	48.57	Young and informal	37.84	Traditional, rustic, tough	52.78	Traditional, rustic, tough	44.83
	Ethnic	20.00	Serious and informal	45.95	Intellectual, serious, caring	47.22	Intellectual, serious, caring	55.17
	Well dressed, young, modern, cosmopolitan	31.43	Sporty and muscular	13.51				
			Indifferent	2.70				
Origin	Extremadura, other dehesa areas	29.03	Rural	30.77	Rural	96.77	Rural	12.50
	Rural	58.06	Urban	61.54	Urban	3.23	Urban, cosmopolitan, European	56.25
	Urban	12.90	Indifferent	7.69	Indifferent	0.00	Indifferent	31.25
Hobbies	Landscaping and ornithology	48.15	Walking in the countryside, landscaping	66.67	Family and hobbies linked to the environment	64.00	Walking in the countryside, landscaping, reading	33.33
	Hiking and sports in nature	22.22	Hiking and sports in nature	22.22	Hiking and sports in nature	12.00	Hiking and sports in nature	33.33
	Activities with friends in rural settings and in the city	29.63	Activities with friends	11.11	Activities with friends, reading, other	24.00	Activities with friends	33.33

Citizens see quality brands as reliable tools to place a value in products and in general they see the creation of brands associated to the agroforestry production systems as a positive measure, provided that suitable training and promotion mechanisms are articulated. In order to become effective, these brands must emphasise the production system, which is a secondary attribute in the eyes of the consumer.

Although the participants agreed that certain mechanisms should be established in order to compensate ecosystem service suppliers (e.g. land owners and farmers), they were unable to specify the tools to be used. The most intuitive idea for the participants was that the compensation should be made through the prices of products that are originated by the agrosystems (although they took it for granted that the price would usually be considered more determining than quality during the product purchase process), which leaves aside products that are socially beneficial but have no commercial value. In this sense, the payment for ecosystem services become essential tools for these systems to stay operational and keep offering the services and products being demanded by society, as they cannot compete in productivity terms with the most intensive systems.

It may be concluded that public policies, both those directed to the promotion of quality products and to the compensation of ecosystem services (with and without commercial value) are necessary so that the agrosystems may stay and keep providing a service to society. Notwithstanding the above, citizen awareness is key so that their perception and evaluation of these systems may be more positive.

7.6 Conclusions

Public policies, both those directed to the promotion of quality products and to the compensation of ecosystem services are necessary so that the agroforestry systems may stay and keep providing a service to society. Notwithstanding the above, citizen awareness is key so that their perception and evaluation of these systems may be more positive. Public policies design in order to increase this awareness have also to be implemented.

The results revealed a lack of citizen familiarity with the agroforestry system, as well as of the services it supplies, besides those that are purely associated to food production. Other key findings were the low importance given by the consumers to the item’s “production system” - a key aspect in order to place a value on the products derived from these systems - as well as the difficulty perceived by the citizens in compensating the providers of these systems as suppliers of ecosystem-related services.

In order to become effective, quality brands must emphasise the production system, which is a secondary attribute in the eyes of the consumer. Citizens see quality brands as reliable tools to place a value in products and in general they see the creation of brands associated to the agroforestry production systems as a positive measure, provided that suitable training and promotion mechanisms are articulated.

8 Lessons learnt

The participatory research carried out by the stakeholder group of Spanish dehesas primarily focused on i) the search of alternative low cost shelters and practices for the regeneration of the trees of the dehesa, ii) the evaluation of commercially available protein-rich fodder crops and self-seeding pastures to assess how they perform under dehesa conditions, and iii) the study of the consumer acceptance for dehesa products and services. The key lessons learnt are outlined below.

8.1 For the regeneration of dehesa trees

- Tree regeneration of dehesas should be an integrated part of regular management practices instead of sporadic pulses of artificial afforestation. A rotational stage of grazing exclusion per plot could be included in the farm management plan to guarantee the continuous renewal of the tree cover. Nevertheless, some assistance could be needed to make grazing compatible with tree regeneration, especially in areas with very low tree density.
- Assisted regeneration can be based either on seeding acorns or on planting nursery-grown seedlings.
- For direct seeding, acorns need to be protected against predators (rodents and wild boar). Cat/dog excrements can be recommended for small scale and/or multiyear plans of gradual reforestation. Also the use of cheap individual “acorn shelters”, made of a degradable material are worth testing. Seeding during the peak of acorn fall (end autumn) can reduce, by satiation, the acorn predation by predators.
- Young plants need to be fenced against livestock (and red deer) for years. The use of refuges done by stacking pruned branches can help for a couple of years, but then (if not from the beginning) the use of treeguards wire mesh is essential. The thorny protectors, a cheap adaptation of the classic wire mesh, is an efficient and long-lasting solution that saves costs because of the lower need of TMT iron bars.
- Combining direct seeding with protected acorns and fencing new plants with thorny protectors is recommended as a cost-effective and feasible method of tree regeneration.
- Shrubs frequently act as nurse plants for oak species, and thorny plants can be very helpful to foster the restoration of tree cover in grazed dehesas. Hence, the conservation of certain cover should be also promoted (especially in the more open areas) and not penalise by CAP payments.

8.2 To gain fodder autonomy

- Given the large seasonal limitation of dehesas to provide enough forage and the increasing costs of feeding supplements, practices to increase the fodder autonomy of the farms are recommended. High productive and protein-rich fodder such as triticale and legume-rich self-seeding pastures are recommended in view of the satisfactory results found in our monitoring.
- Although the biomass and grain production of triticale generally decreases with the presence of trees, the cultivars Montijano, Fronteira and Montijano can be considered as well-adapted to grow in dehesas. Forage yields in winter were higher under trees, compared to beyond trees, which is very interesting to meet livestock food requirements in this period. Also the quality of the forage (protein content and digestibility) was favoured by the presence of the trees.
- To assure the adequate regrowth of triticale after winter grazing, grazing should be done before plants start the stem elongation (state 30 in the Zadocks scale). Due to the poor and shallow soil usually found in dehesa ecosystems, a yearly rotation in the crop area is highly recommended.

- Although the biomass production of triticale is widely variable between years due to the irregularity of the Mediterranean climate (especially rainfall), even in low-rainfall years, the increase in the forage biomass in comparison with that produced by natural pasture, offsets the cost of all cropping practices (tillering, sowing, harvesting, seeds, fertilizers).
- The sowing of legume-rich self-reseeding pasture can produce a noticeable increase of the pasture productivity and quality for at least a decade, irrespective of the presence of the trees. Delayed grazing is essential the initial years to ensure a good establishment of the legume species.
- The cover of legumes increases for years (relative to a control), with the native species becoming progressively dominant to the detriment of the sown species. The most persistent legumes species were *Trifolium subterraneum, T. michelanium, T. resupinatum, T. vesiculusum* and *Ornithopus compressus. Trifolium stellatum* and *T. incarnatum* grow better beneath the oak canopy. Nevertheless, a selection program of shade adapted genotypes is still needed.
- The increased cover of legumes produces a significant increase in soil nitrogen that indirectly results in a significant increase in the quality (protein content) of the rest of the plants, especially grasses. As consequence, the sowing of legumes caused an overall improvement on the quality of the pastures, both for the higher cover of legumes (rich in protein) and for the increase in the protein content of the non-legume plant species.
- The content of carbon accumulated into the soil showed a positive and significant tendency with the age of the sown pasture, both under and beyond canopy, which enhances the importance of considering this kind of management practice to increase the resilience of this silvopastoral systems against climate change. Although the sowing seems to reduce slightly the α diversity of plants, the total species richness (ϒ diversity) was not affected significantly.
- A reliable economic evaluation has not been completed. According to the seven farmers that participated in the study, the improvement in the pasture quality and productivity offset the high costs of the seed mixture and fertilizers.

8.3 For better branding

- Among the different alternatives to overcome the constraints that threaten Spanish dehesas, one of the most promising is the product diversification, adaptation to market demands and development of brands which could help consumers identify those products generated in dehesas and eventually to pay a premium for public ecosystem services provide by this high nature and cultural value system.
- In spite of the citizens being unfamiliar with the term “agroforestry system”, the dehesa - as the reference agroforestry system in the Iberian Peninsula - is well-recognised and described. This reveals that it may become necessary to use terms that are more familiar if a specific system is intended to acquire value.
- The dehesa agroforestry system is mainly identified as a service supplier, specifically for high-quality animal-origin food products. The cultural services associated with the aesthetical and recreational value of the landscapes have also been recognised in social importance.
- These services translate into products with a commercial value. The majority of them are products that are already consolidated in the market. Emerging products with little presence in the market were also described, but these were seen by the citizens as with development

potential (for example, asparagus fungi and mushrooms, acorn-based products, medicinal plants and cosmetics, herbs and herbal tea).

8.4 More research needed

- New technologies to ease herding and improve pasture use do not seem ready for the wide use by livestock breeders but results with the multipurpose GPS collar are promising and encouraging for further research.
- Assessment of the feasibility of fast-intensive rotational grazing against regular grazing for livestock breeding in Iberian dehesas.
- Preliminary results of the carbon fluxes monitoring in the dehesa of Majadas, indicate a slight positive annual carbon balance (~ 0.5 t C ha^{-1}), a noticeable C-sequestration strength given that the mean value estimated for European grasslands is ~ 0.15 ± 0.07 t C ha^{-1} (Chang et al. 2015). This carbon sequestered in trees and soil organic matter of dehesas could offset sufficiently the emission of other greenhouse gases (GHG) associated with livestock rearing. Nevertheless, the balance of GHG in dehesas deserve more studies in order to get reliable estimation of the C footprint of dehesa products.

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10 References

Acácio V, Holmgren M, Jansen PA, Schrotter O (2007). Multiple recruitment limitation causes arrested succession in Mediterranean cork oak systems. Ecosystems, 10(7), 1220-1230.

Benayas JMR, Martínez-Baroja L, Pérez-Camacho L, Villar-Salvador P, Holl KD (2015). Predation and aridity slow down the spread of 21-year-old planted woodland islets in restored Mediterranean farmland. New Forests, 46(5-6), 841-853.

Birch JC, Newton AC, Alvarez Aquino CA, Cantarello E, Echeverría C, Kitzberger T, Schiappacasse I, Tejedor TN (2010). Cost-effectiveness of dryland forest restoration evaluated by spatial analysis of ecosystem services. PNAS vol. 107 (50): 21925–21930.

Bolan NS, Hedley MJ, White RE (1991). Processes of soil acidification during nitrogen cycling with emphasis on legume based pastures. Plant Soil 134:53–63.

Bullitta P, Bullitta S, Roggero PP (1989). Agronomic methods to increase pastureland production in Mediterranean marginal areas. In: Proceedings of the XVI International Grassland Congress. pp 1591–1592

Bustamante M, Robledo-Abad C, Harper R et al. (2014). Co-benefits, trade-offs, barriers and policies for greenhouse gas mitigation in the agriculture, forestry and other land use (AFOLU) sector. Glob Chang Biol 20:3270–3290.

Baah-Acheamfour M, Carlyle CN, Bork EW, Chang SX (2014). Trees increase soil carbon and its stability in three agroforestry systems in central Alberta, Canada. Forest Ecology and Management, 328, 131-139.

Cáceres Y, Pulido FJ, Juárez E, Moreno G (2016). Evaluation of cost-efficient shelters to regenerate trees in silvo-pastoral systems. World Congress Silvo-Pastoral Systems 2016. Silvo-Pastoral Systems in a changing world: functions, management and people. 27-30th September 2016. Évora, Portugal.

Cáceres Y, Pulido FJ, Moreno G (2017). Regeneración artificial en dehesas con diferente manejo de ganado: evaluación de la eficiencia y optimización del costo. Congreso Forestal Nacional. Sociedad Española de Ciencias Forestales. 26-30th June 2017, Plasencia, Spain. Artículo 7CFE01-334, 10 pp.

Campos P, Huntsinger L, Oviedo JL, Starrs PF, Diaz M, Standiford RB, Montero G (Eds.) (2013). Mediterranean Oak Woodland Working Landscapes. Dehesas of Spain and Ranchlands of California. Series: Landscape Series, Vol. 16, Springer.

Canfield DE, Glazer AN, Falkowski PG (2010). Review: The evolution and future of Earth's nitrogen cycle. Science (80-) 330:192–196.

Cardillo E, Bernal CJ (2006). Morphological response and growth of cork oak (*Quercus suber* L.) seedlings at different shade levels. Forest Ecol Manag 222:296–301.

Castro J, Zamora R, Hódar JA (2006). Restoring the forest of *Quercus pyrenaica*. Appl Veg Sci 9:137–142.

Castro J, Zamora R, Hódar JA, Gómez JM (2004). Benefits of using shrubs as nurse plants for reforestation of Mediterranean mountains: a 4-year study. Restor Ecol 12:352–358.

Cava R, Estévez M, Ruiz J, Morcuende D (2003). Physicochemical characteristics of three muscles from free-range reared Iberian pigs slaughtered at 90 kg live weight. Meat Science, 63, 533-541.

Chang J, Ciais P, Viovy N, Vuichard N, Sultan B, Soussana JF (2015). `Global Change Biology 21, 3748-3761.

Cong WF, Ruijven J, Mommer L, De Deyn GB, Berendse F, Hoffland E (2014). Plant species richness promotes soil carbon and nitrogen stocks in grasslands without legumes. Journal of Ecology, 102*(*5), 1163-1170.

Connolly J, Goma HC, Rahim K (2001). The information content of indicators in intercropping research. Agric Ecosyst Environ 87:191–207.

Constantin J, Mary B, Laurent F et al. (2010). Effects of catch crops, no till and reduced nitrogen fertilization on nitrogen leaching and balance in three long-term experiments. Agric Ecosyst Environ 135:268–278.

Crespo DG (2006). The role of pasture improvement on the rehabilitation of the montado/dehesa system and in developing its traditional products. In: Ramalho Ribeiro, J.M.C.; Horta, A.E.M.; Mosconi, C. and Rosati, A. (Eds.) - Animal Products from the Mediterranean area. The Netherlands Academic Publishers, pp 185–197.

Crews TE, Peoples MB (2004). Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs. 102:279–297.

Cubera E, Nunes JM, Madeira M, Gazarini L (2009). Influence of *Quercus ilex* trees on herbaceous production and nutrient concentrations in southern Portugal. J Plant Nutr Soil Sci 172:565–571.

Cubera E, Moreno G, Solla A, Madeira M (2012). Root system of Quercus suber L. seedlings in response to herbaceous competition and different watering and fertilisation regimes. Agroforestry Systems, 85(2), 205-214.

Delogu G, Faccini N, Faccioli P, Reggiani F, Lendini M, Berardo N, Odoardi M (2002). Dry matter yield and quality evaluation at two phenological stages of forage triticale grown in the Po Valley and Sardinia, Italy. Field Crops Research, 74, 201–215.

den Herder M, Moreno G, Mosquera-Losada RM, Palma JH, Sidiropoulou A, Santiago Freijanes JJ, Crous-Duran J, Paulo JA, Tomé M, Pantera A, Papanastasis VP, Mantzanas K, Pachana P, Papadopoulos A, Plieninger T, Burgess PJ (2017). Current extent and stratification of agroforestry in the European Union. Agriculture, Ecosystems and Environment, 241, 121-132.

Dey DC, Jacobs D, McNabb K, Miller G, Baldwin V, Foster G (2008). Artificial regeneration of major oak (Quercus) species in the eastern United States—a review of the literature. Forest Science, 54(1), 77-106.

Díaz M, Tietje WD, Barrett RH (2013). Effects of management on biological diversity and endangered species. Mediterranean Oak Woodland Working Landscapes. Springer Netherlands, 2013. 213-243.

Donoghue S (2000). Projective techniques in consumer research. Journal of Consumer Sciences, 28(1).

Driscoll DA, Catford JA, Barney JN et al. (2014) New pasture plants intensify invasive species risk. Proc Natl Acad Sci 111:16622–16627.

Eldesouky A, Pulido AF, Mesias FJ (2015). The Role of Packaging and Presentation Format in Consumers' Preferences for Food: An Application of Projective Techniques. Journal of Sensory Studies, 30(5), 360-369.

Estévez M, Morcuende D, Cava R (2003). Physical-chemical characteristics of m. Longissimus dorsi from three lines of 90 kg live-weight iberian pigs free-range reared and commercial pigs: a comparative study. Meat Science, 64, 499-506.

Federer WT (1999). Statistical Design and Analysis for Intercropping Experiments.

Finn JA, Kirwan L, Connolly J et al. (2013). Ecosystem function enhanced by combining four functional types of plant species in intensively managed grassland mixtures: A 3-year continental-scale field experiment. J Appl Ecol 50:365–375.

Fornara DA, Tilman D (2009). Ecological mechanisms associated with the positive diversity-productivity relationship in an N-limited grassland. Ecology 90:408–418.

Francia E, Pecchioni N, Li Destrii Nicosia O, Paoletta G, Taibe L, Franco V, Odoardi M, Stanca AM, Delogu G (2006). Dual-purpose barley and oat in a Mediterranean environment. Field Crops Research, 99, 158–166.

Garcia del Moral LF, Boujenna A, Yanez JA, Ramos JM (1995). Forage production, grain yield, and protein content in dual-purpose triticale grown for both grain and forage. Agronomy Journal, 87, 902–908.

Gaspar P, Escribano M, Mesias FJ (2016b). A qualitative approach to study social perceptions and public policies in dehesa agroforestry systems. Land Use Policy, *58*, 427-436.

Gaspar P, Escribano M, Mesías FJA (2016a). Participatory approach to develop new products that social valorization of agroforestry systems. 3rd European Agroforestry Conference – Montpellier, 23-25 May 2016 Productivity and economic performance of agroforestry. Book of abstracts, pp 156-158.

Gómez JM (2003). Spatial patterns in long-distance dispersal of Quercus ilex acorns by jays in a heterogeneous landscape. Ecography 26:573–584

Gómez-Aparicio L, Gómez JM, Zamora R, Boettinger JL (2005a). Canopy vs. soil effects of shrubs facilitating tree seedlings in Mediterranean montane ecosystems. J Veg Sci 16:191–198

Gómez-Aparicio L, Valladares F, Zamora R, Quero JL (2005b). Response of tree seedlings to the abiotic heterogeneity generated by nurse shrubs: an experimental approach at different scales. Ecography 28:757–768.

Gómez-Aparicio L, Zamora R, Gómez JM, Hódar JA, Castro J, Baraza E (2004). Applying plant facilitation to forest restoration: a meta-analysis of the use of shrubs as nurse plants. Ecol Appl 14:1128–1138.

Gómez-Rey MX, Garcês A, Madeira M (2012). Soil organic-C accumulation and N availability under improved pastures established in Mediterranean oak woodlands. Soil Use and Management 28: 497-507.

González F, Gil A, Llera F, González JA, Maya V (2012). Catálogo de variedades de semillas obtenidas en el Centro de Investigación la Orden-Valdesequera. Gobierno de Extremadura, Mérida.

González-Rodríguez V, Navarro-Cerrillo RM, Villar R (2011). Artificial regeneration with Quercus ilex L. and Quercus suber L. by direct seeding and planting in southern Spain. Annals of Forest Science 68:637–646. DOI 10.1007/s13595-011-0057-3.

Grossnickle SC (2005). Importance of root growth in overcoming planting stress. New Forests, *30*(2-3), 273-294.

Gylfadóttir T, Helgadóttir Á, Høgh-Jensen H (2007). Consequences of including adapted white clover in northern European grassland: Transfer and deposition of nitrogen. Plant Soil 297:93–104.

Haile SG, Nair VD, Nair PKR (2010). Contribution of trees to carbon storage in soils of silvopastoral systems in Florida, USA. Glob Chang Biol 16:427–438.

Harrison MT, Evans JR, Dove H, Moore AD (2011), Recovery dynamics of rainfed winter wheat after livestock grazing 1. Growth rates, grain yields, soil water use and water-use efficiency. *Crop & Pasture Science*, 62, 947-959.

Herman CS, Valone TJ (2000), The effect of mammalian predator scent on the foraging behaviour of Dipodomis merriami. Oikos, 91, 139–145.

Howlett DS, Moreno G, Mosquera Losada MR, Nair PKR, Nair VD (2011). Soil carbon storage as influenced by tree cover in the Dehesa cork oak silvopasture of central-western Spain. Journal of Environmental Monitoring 13: 1897-1904.

Howlett DS, Mosquera-Losada MR, Nair PKR, Nair VD, Rigueiro-Rodríguez A (2011). Soil carbon storage in silvopastoral systems and a treeless pasture in Northwestern Spain. Journal of Environmental Quality 40: 825-832.

Høgh-Jensen H, Schjoerring JK (2000). Below-ground nitrogen transfer between different grassland species: Direct quantification by 15N leaf feeding compared with indirect dilution of soil 15N. Plant Soil 227:171–183.

Jedrzejewski W, Rychlik L, Jedrzejewska B (1993). Responses of bank voles to odours of seven species of predators: experimental data and their relevance to natural predator-vole relationships. Oikos, 68, 251–257.

Jensen ES (1996). Grain yield, symbiotic N_2 fixation and interspecific competition for inorganic N in pea- barley intercrops Grain yield, symbiotic N2 inorganic N in pea-barley. Source Plant Soil Plant Soil 182:46–25.

Joffre R, Leiva Morales MJ, Rambal S, Fernández Alés R (1987). Dynamique racinaire et extraction de l’eau du sol par des graminées pérennes et annuelles méditerranéennes. Acta Oecol: Oec Plant 8:181–194.

Joffre R, Vacher J, LLanos C, Long G (1988). The dehesa: an agrosilvopastoral system of the Mediterranean region with special reference to the Sierra Morena area of Spain, Agroforestry Systems, 6:71-96.

Kirwan L, Connolly J, Finn JA, et al. (2009). Diversity-interaction modeling: Estimating contributions of species identities and interactions to ecosystem function. Ecology 90:2032–2038.

Kraiem K, Majdoub A, Ben Abbes S, Moujahed N (1997). Effects of the level of supplementation with concentrate on the nutritive value and utilization of oats hay cut at three maturity stages. Livestock Production Science, 47, 175–184.

Lal R (2004). Soil carbon sequestration to mitigate climate change. Geoderma 123:1–22.

Lange M, Eisenhauer N, Sierra CA, Bessler H, Engels C, Griffiths RI et al. (2015). Plant diversity increases soil microbial activity and soil carbon storage. Nature Communications, 6, 6707.

Leiva MJ, Díaz-Maqueda A (2016). Fast-growing seeds and delayed rodent predatory activity in the seeding season: A combined mechanism to escape and survive rodent predation in Quercus ilex subsp. ballota L. acorns and seedlings. Forest Ecology and Management, 380, 23-30.

Leiva MJ, Vera M (2015). Effect of artificial shelters of dead branches on acorn survival and dispersal in shrub-lacking Mediterranean dehesas. New Forests, 46(5-6), 965-978.

Leverkus AB, Carrión M, Molina-Morales M, Castro J (2017). Effectiveness of diesel as a mammal repellent for direct seeding of acorns. Forests, 8(8), 276.

Leverkus AB, Castro J, Puerta-Piñero C, Benayas JR (2013). Suitability of the management of habitat complexity, acorn burial depth, and a chemical repellent for post-fire reforestation of oaks. Ecological Engineering, 53, 15-22.

Leverkus AB, Rojo M, Castro J (2015). Habitat complexity and individual acorn protectors enhance the post-fire restoration of oak forests via seed sowing. Ecological Engineering, 83, 276-280.

Li L, Li S-M, Sun J-H et al. (2007). Diversity enhances agricultural productivity via rhizosphere phosphorus facilitation on phosphorus-deficient soils. Proc Natl Acad Sci 104:11192–11196.

Luscher A, Fuhrer J, Newton PC (2005). Global atmospheric change and its effect on managed grassland systems. In: Grassland - a Global Resource. pp 251–264

Lüscher A, Mueller-Harvey I, Soussana JF et al. (2014). Potential of legume-based grassland-livestock systems in Europe: A review. Grass Forage Sci 69:206–228.

Marañón T, Francisco I, Pugnaire, Callaway RM (2009). Mediterranean-climate oak savannas: the interplay between abiotic environment and species interactions. Web Ecology 9: 30-43.

McSherry ME, Ritchie ME (2013). Effects of grazing on grassland soil carbon: a global review. Global Change Biology, 19(5), 1347-1357.

Mediavilla S, Escudero A (2004). Stomatal responses to drought of mature trees and seedlings of two co-occurring Mediterranean oaks. Forest Ecol Manag 187:281–294.

Meisinger JJ, Hargrove WL, Mikkelsen RL et al. (1991). Effects of cover crops on groundwater quality in cover crops for clean water. Soil Water Conserv Soc 57–68.

Milne RM, Haynes RJ (2004). Soil organic matter, microbial properties, and aggregate stability under annual and perennial pastures. Biol Fertil Soils 39:172–178.

Montagnini F, Nair PKR (2004). Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agroforestry Systems, 61(1), 281-295.

Morán-López T, Alonso CL, Díaz M (2015). Landscape effects on jay foraging behavior decrease acorn dispersal services in dehesas. Acta Oecologica, 69, 52-64.

Moreno G (2014). Initial Stakeholder Meeting Report Dehesa farms in Spain. Milestone 2.1 (MS 2) for EU FP7 Research Project: AGFORWARD 613520. 19 pp. http://www.agforward.eu/index.php/en/dehesa-farms-in-spain.html.

Moreno G, Aviron S, Berg S, Bertomeu M, Bustos P, Cáceres Y, Escribano M, Franca A, Gaspar P, Hartel T, Juárez E, Lind T, Mantzanas K, Mesías FJ, Mirck J, Pacheco Faias S, Palma J, Pantera A, Papadopoulos A, Papanastasis V, Paulo J, Popa R, Porqueddu C, Pulido F, Rákosy L, Seddaiu G, Thenail C, Tomé M, Tsonkova P, Upson M, Valinger E, Varga A, Viaud V, Vityi A, Burgess P (2015c). Synthesis of the Research and Development Protocols related to High Nature and Cultural Value Agroforestry. Milestone 2.3 (MS 4) for EU FP7 research project: AGFORWARD 613520. 22 pp. http://agforward.eu/index.php/en/synthesis-of-the-research-and-development-protocols-related-to-high-nature-and-cultural-value-agroforestry.html.

Moreno G, Berg S, Burgess PJ, Camilli F, Crous-Duran J, Franca A, Hao H, Hartel T, Lind T, Mirck J, Palma J, Paula JA, Pisanelli A, Seddaiu G, Thenail C, Tsonkova P, Upson M, Valinger E, Varga A, Viaud V, Vityi A (2015a). Innovations to be examined for High Nature and Cultural value Agroforestry. Milestone 2.2 (MS 3) for EU FP7 Research Project: AGFORWARD 613520. 20 pp. http://www.agforward.eu/index.php/en/innovations-to-be-examined-for-high-nature-and-cultural-value-agroforestry.html.

Moreno G, Cáceres Y, Juárez E, Bertomeu M, Pulido F, Gaspar P, Mesías FJ, Escribano M, Bustos P (2015b). Research and Development Protocol for Iberian Dehesas in Spain. Milestone 2.3 (MS 4) for EU FP7 research project: AGFORWARD 613520. 71 pp. http://www.agforward.eu/index.php/en/dehesa-farms-in-spain.html.

Moreno G, Cáceres Y. (2016). System report: Iberian Dehesas, Spain. Deliverable 2.4. for EU FP7 research project. Contribution to Deliverable 2.4: Detailed system description of a case study system. AGFORWARD 613520. 60 pp. http://www.agforward.eu/index.php/en/dehesa-farms-in-spain.html

Moreno G, Bartolomew JW, Gea-Izquierdo G, Cañellas I (2013). Overstory-understory relationships. In: Campos P, Huntsinger L, Oviedo JL, Starrs PF, Diaz M, Standiford RB, Montero G (Eds.) Mediterranean Oak Woodland Working Landscapes. Dehesas of Spain and Ranchlands of California. Series: Landscape Series, Vol. 16, Springer. 145-179.

Moreno G, Obrador J, García A (2007a). Impact of evergreen oaks on soil fertility and crop production in intercropped dehesas. Agriculture, Ecosystems & Environment 119: 270-280.

Moreno G, Obrador JJ, Cubera E, Dupraz C (2005). Fine root distribution in Dehesas of Central-Western Spain. Plant Soil 277:153–162.

Moreno G, Obrador JJ, García E, Cubera E, Montero MJ, Pulido FJ, Dupraz C (2007b). Driving competitive and facilitative interactions in oak dehesas with management practices. Agroforestry Systems 70: 25-40.

Moreno G, Pulido FJ (2009). The functioning, management, and persistente of dehesas. In: Agroforestry Systems in Europe. Current Status and Future prospects. Riguero-Rodriguez, A., Mosquera-Losada, M.R., McAdam, J. (eds.). Advances in Agroforestry Series, Springer Publishers. pp. 127-161.

Moreno G, Granco MD (2013). Efecto diferencial de la jara (*Cistus ladanifer*) en la supervivencia de plántulas emergidas y plantadas de encina (*Quercus ilex*). 6º Congreso Forestal Español (SECF). Vitoria. 10-14 junio 2013. Comunicación 6CFE01-109, 12 pp.

Moro MJ, Pugmaire FI, Haase P, Puigdefábregas J (1997). Effect of the canopy of Retama sphaerocarpa on its understory in a semiarid environment. Funct Ecol 11:425–431

Navarro Cerrillo RM, Fragueiro B, Ceaceros C, Campo A, Prado R (2005). Establishment of *Quercus ilex* L. subsp. ballota [Desf.] Samp. using different weed control strategies in southern Spain. Ecol Eng 25:332–342.

Navarro FB, Jimenez MN, Ripoll MA, Fernandez-Ondoño E, Gallego E, De Simón E (2006). Direct sowing of holm oak acorns: effects of acorn size and soil treatment. Ann. For. Sci. 63 (2006) 961–967.

Nolte DL, Barnett JP (2000). A repellent to reduce mouse damage to longleaf pine seed. International Biodeterioration & Biodegradation 45: 169-174.

Nolte DL, Mason JR, Eppel G, Aronov E, Campbell DL (1994). Why are predator urines aversive to prey? Journal of Chemical Ecology, 20, 1505–1516

Nyfeler D, Huguenin-Elie O, Suter M et al. (2009). Strong mixture effects among four species in fertilized agricultural grassland led to persistent and consistent transgressive overyielding. J Appl Ecol 46:683–691.

Nyfeler D, Huguenin-elie O, Suter M, et al. (2011). Grass – legume mixtures can yield more nitrogen than legume pure stands due to mutual stimulation of nitrogen uptake from symbiotic and non-symbiotic sources. Agriculture, Ecosyst Environ 140, 155–163.

Olea L, Viguera F (1997). Dehesa ecosystem: production and preservation. In: 9th Meeting of FAO-CHIEAM, Dynamics and sustainability of Mediterranean pastoral systems. Badajoz (Spain). pp 239–246

Olea L, Lopez-Bellido RJ, Poblaciones MJ (2005). European types of silvopastoral systems in the Mediterranean area: Dehesa. In: Mosquera-Losada M.R., McAdam J., Rigueiro-Rodriguez A. (eds), Silvopastoralism and Sustainable Land Management, CABI Publishing, Wallingford, UK, pp 30–35.

Olea L, San Miguel-Ayanz A (2006). The Spanish dehesa. A traditional Mediterranean silvopastoral system linking production and nature conservation. Grassland Science in Europe, 11: 3-13.

Padilla FM, Pugnaire FI (2006). The role of nurse plants in the restorationof degraded environments the restoration of degraded environments. Front Ecol Environ 4:196–202.

Padilla MF, Pugnaire IF (2006). The role of nurse plants in the restoration of degraded environments. Front Ecol Environ 4(4): 196–202.

Pardini A, Mori S, Rigueiro-Rodríguez A, Mosquera Losada MR (2010). Efecto del arbolado en la producción de pasto y trigo (*Triticum aestivum* L.) Ecológicos en la Maremma Toscana (Italia central). *Pastos*, 40, 211-223.

Pausas JG, Marañón T, Caldeira M, Pons J (2012). Natural Regeneration. In: Aronson J, Pereira JS, Pausas JG (Eds.). Cork Oak Woodlands on the Edge: Ecology, Adaptive Management, and Restoration. Island Press. pp. 115-126.

Pecio A (2010). Productivity of triticale affected by nitrogen fertilization and weather conditions. Fertilizer and Fertilization, 40, 101-116.

Piñeiro G, Paruelo JM, Oesterheld M, Jobbágy EG (2010). Pathways of grazing effects on soil organic carbon and nitrogen. Rangeland Ecology & Management, 63(1), 109-119.

Plieninger T, Rolo V, Moreno G (2010). Large-scale patterns of *Quercus ilex, Quercus suber*, and *Quercus pyrenaica* regeneration in Central-Western Spain. Ecosystems, 13(5), 644-660.

Plieninger T, Hartel T, Martín-López B, Beaufoy G, Bergmeier E, Kirby K et al. (2015). Wood-pastures of Europe: geographic coverage, social–ecological values, conservation management, and policy implications. Biological Conservation, 190, 70-79.

Porqueddu C, González F (2011). Role and potential of annual pasture legumes in Mediterranean farming systems. Pastos 36:125–142.

Proença V, Aguiar C, Domingos T (2015). Highly productive sown biodiverse pastures with low invasion risk. Proc Natl Acad Sci U S A 112:E1695.

Puerta-Piñero C, Gómez JM, Zamora R (2006). Species-specific effects on topsoil development affect Quercus ilex seedling performance. Acta Oecol 29:65–71

Pulido FJ, Díaz M (2005). Recruitment of a Mediterranean oak: a whole-cycle approach. Ecoscience 12:99–112.

Pulido FJ, García E, Obrador JJ, Moreno G (2010). Multiple pathways for tree regeneration in anthropogenic savannas: incorporating biotic and abiotic drivers into management schemes. J Appl Ecol 47:1272–1281.

Pulido F, Moreno G, García E, Obrador JJ, Bonal R, Díaz M (2013). Resource manipulation reveals flexible allocation rules to growth and reproduction in a Mediterranean evergreen oak. Journal of Plant Ecology, 7(1), 77-85.

Quero JL, Villar R, Marañón T, Zamora R (2006). Interactions of drought and shade effects on seedlings of four Quercus species: physiological and structural leaf responses. New Phytol 170:819–834.

Retana J, Espelta JM, Gracia M, Riba M (1999). Seedling recruitment. In: Rodà F, Retana J, Gracia CA, Bellot J (eds) Ecology of mediterranean evergreen Oak forests. Springer, Berlin

Rey JP, Siles G, Alcántara MJ (2009). Community-level restoration profiles in Mediterranean vegetation: nurse-based vs. traditional reforestation. Journal of Applied Ecology 46: 937–945.

Rodrigo S, Poblaciones MJ, Pinheiro N, Maças B, Olea L, Santamaría O, García-White T, Coutinho J (2010). Dry matter yield and quality evaluation at different growth stages of Triticale forage in S.W. of the Iberian Peninsula. 13th Meeting of the FAO-CIHEAM sub-network on mediterranean pastures and fodder crops, Alicante.

Rodríguez-Echeverría S, Pérez-Fernández MA (2005). Potential use of Iberian shrubby legumes and rhizobia inoculation in revegetation projects under acidic soil conditions. Appl Soil Ecol 29:203–208.

Rolo V, Plieninger T, Moreno G (2013). Facilitation of holm oak recruitment through two contrasted shrubs species in Mediterranean grazed woodlands: Patterns and processes. J Veg Sci 24:344–355.

Rossiter RC (1966). Ecology of Mediterranean annual-type pastures. Advances in Agronomy, 11, 1-56.

Royo C, Tribo F (1997). Triticale and barley for grain and for dual-purpose (forage plus grain) in a Mediterranean-type environment. 2. Yield, yield components, and quality. Crop Pasture Science, 48, 423–10 432.

Santamaría O, Rodrigo S, Albarrán A, Moreno G, Olea L (2016). Producción y calidad del forraje de variedades de Triticale cultivadas en condiciones de sombra para su utilización en sistemas agroforestales. En: Innovación Sostenible en Pastos: hacia una agricultura de respuesta al cambio climático. Baez M.D. et al. *(*Eds). 55ª Reunión Científica de la S.E.E.P. Lugo-Coruña, 26-29 April 2016. pp 331-337.

Santamaría O, Rodrigo S, Albarrán A, Moreno G and Poblaciones MJ (2017). Influencia del arbolado sobre la producción y claidad del forraje en diferentes variedades de Triticale en sistemas agroforestales. En: Renaturalización vs Re-farming. Bartolomé J, Albanell E, Milán MJ, Serrano E, Broncano MJ, Manuelina CL (Eds). 56ª Reunión Científica de la S.E.E.P. Barcelona, 25-28 April 2017. pp 46-51.

Santamaría O, Rodrigo S, Poblaciones MJ, Olea L (2014). Fertilizer application (P, K, S, Ca and Mg) on pasture in calcareous dehesas: effects on herbage yield, botanical composition and nutritive value. Plant, Soil & Environment, 60, 303-308.

Schnabel S, Dahlgren RA, Moreno G (2013). Soil and water dynamics. In Mediterranean Oak Woodland Working Landscapes (pp. 91-121). Springer Netherlands.

Schmidt MWI, Torn MS, Abiven S et al. (2011). Persistence of soil organic matter as an ecosystem property. Nature 478:49–56.

Serra X, Gil F., Pérez-Enciso M, Oliver MA, Vázquez JM, Gispert M, Díaz I, Moreno F, Latorre R, Noguera, JL (1998). A comparison of carcass, meat quality and histochemical characteristics of Iberian (Guadyerbas line) and Landrace pigs. Livestock Production Science, 56,215-223.

Sharrow SH, Ismail S (2004). Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. Agroforestry Systems, *60*(2), 123-130.

Skinner RH, Gustine DL, Sanderson MA (2004). Growth, water relations, and nutritive value of pasture species mixtures under moisture stress. Crop Sci 44:1361–1369.

Smit C, den Ouden J, Díaz M (2008). Facilitation of *Quercus ilex* recruitment by shrubs in Mediterranean open woodlands. J Veg Sci 19:193–200

Smith P, Gregory PJ (2013). Climate change and sustainable food production. Proc Nutr Soc 72:21–28.

Smith P, Martino D, Cai Z, et al. (2008). Greenhouse gas mitigation in agriculture. Philos Trans R Soc B Biol Sci 363:789–813.

Southwood TRE, Henderson PA (2009). Ecological Methods. John Wiley & Sons.

Steinbeiss S, Bessler H, Engels C, Temperton VM, Buchmann N, Roscher C, ... Gleixner G (2008). Plant diversity positively affects short-term soil carbon storage in experimental grasslands. Global Change Biology, 14(12), 2937-2949.

Stockmann U, Adams MA, Crawford JW, Field DJ, Henakaarchchi N, Jenkins M ... Wheeler I (2013). The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, Ecosystems & Environment, 164, 80-99.

Sunyer P, Munoz A, Bonal R, Espelta JM (2013). The ecology of seed dispersal by small rodents: a role for predator and conspecific scents. Functional Ecology, 27(6), 1313-1321.

Suter M, Connolly J, Finn JA, et al. (2015). Nitrogen yield advantage from grass-legume mixtures is robust over a wide range of legume proportions and environmental conditions. Glob Chang Biol 21:2424–2438.

Teixeira R, Domingos T, Costa APS V, et al. (2011). Soil organic matter dynamics in Portuguese natural and sown rainfed grasslands. Ecol. Modell. 222:993–1001.

Teixeira RFM, Proença V, Crespo D et al. (2015). A conceptual framework for the analysis of engineered biodiverse pastures. Ecol Eng 77:85–97.

Temperton VM, Mwangi PN, Scherer-Lorenzen M et al. (2007). Positive interactions between nitrogen-fixing legumes and four different neighbouring species in a biodiversity experiment. Oecologia 151:190–205.

Texeira RFM (2010). Sustainable Land Uses and Carbon Sequestration: The Case of Sown Biodiverse Permanent Pastures Rich in Legumes. 173.

Thomsen IK, Hansen EM (2014). Cover crop growth and impact on N leaching as affected by pre- and postharvest sowing and time of incorporation. Soil Use Manag 30:48–57.

Thrall PH, Laine AL, Broadhurst LM et al. (2011). Symbiotic effectiveness of rhizobial mutualists varies in interactions with native Australian legume genera. PLoS One. doi: 10.1371/journal.pone.0023545

Tonitto C, David MB, Drinkwater LE (2006). Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agric Ecosyst Environ 112:58–72.

Tonucci RG, Nair PK, Nair VD, Garcia R, Bernardino FS (2011). Soil carbon storage in silvopasture and related land-use systems in the Brazilian Cerrado. Journal of Environmental Quality, 40(3), 833-841.

Tribouillois H, Cohan JP, Justes E (2016). Cover crop mixtures including legume produce ecosystem services of nitrate capture and green manuring: assessment combining experimentation and modelling. Plant Soil 401:347–364.

Tsakaldimi M, Zagas T, Tsitsoni T, Ganatsas P (2005). Root morphology, stem growth and field performance of seedlings of two Mediterranean evergreen oak species raised in different container types. Plant and Soil, 278(1-2), 85-93.

Vallés SM, Gallego Fernández JB, Dellafiore C, Cambrollé J (2011). Effects on soil, microclimate and vegetation of the native-invasive Retama monosperma (L.) in coastal dunes. Plant Ecol 212:169–179.

Vandermeer JH (1989). The Ecology of Intercropping, Cambridge.

Vázquez De Aldana BR, García-Ciudad A, García-Criado B (2006). Biomass production and protein content of semiarid grasslands in western Spain over a 20-years period. Grassland Science in Europe, 11, 547-549.

Weltzin JF, McPherson GR (1997). Spatial and temporal soil moisture resource partitioning by trees and grasses in a temperate savanna, Arizona, USA. Oecologia, 112: 156-164.

Willoughby IH, Jinks RL, Morgan GW, Pepper H, Budd J, Mayle B (2011). The use of repellents to reduce predation of tree seed by wood mice (*Apodemus sylvaticus* L.) and grey squirrels (*Sciurus carolinensis* Gmelin). European Journal of Forest Research, 130(4), 601-611.

Young TP, Evans RY (2005). Initial mortality and root and shoot growth of valley oak seedlings outplanted as seeds and as container stock under different irrigation regimes. Native Plants journal, 6(1), 83-90.

Zadoks JC, Chang TT, Konzak CF (1974). A decimal code for the growth stages of cereals. Weed Research, 14, 415-421.