Research and Development Protocol for Iberian Dehesas in Spain

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1 Context

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

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

This report mainly contributes to the second objective. It contributes to the initial research and development protocol (Milestone 4; (2.3)) for the participative research and development network focused on the use of agroforestry of high nature and cultural value (HNCV). Overall, the stakeholder group works:

- to propose management innovations that improve the productivity, sustainability, marketing of the products and governance of HNCV agroforestry systems,
- to identify ongoing innovation practices initiated by participants and organisations, and
- to establish a network of sites to test the proposed innovations.

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 (Opermmann et al. 2012) and form one of the largest agroforestry system in Europe (Eichhorn et al. 2006).

They are agrosilvopastoral systems originating from clearing of evergreen woodlands where trees, native grasses, crops, and livestock interact positively under specific management practices (Montero et al. 1998). Dehesa agroecosystems are characterized by the presence of an open tree layer mainly dominated by Mediterranean evergreen oaks (30–50 trees per ha, principal species *Quercus ilex* and *Q. suber*) with an understorey of croplands, grasslands, and shrublands where cattle, sheep, pigs, and goats are raised (San Miguel 1994).

Oaks have both direct and indirect value and are keystone species of the dehesa (Manning et al. 2006). 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 woodfuel for household use and sale. Trees also provide shelter from heat in summer, prevent soil erosion and desertification, enhance the vegetation and structural complexity of the ecosystem, provide habitat and resources for many species, and are an important food resource for livestock, especially for pigs.

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 (Escribano and Pulido 1998; Campos 2004; Pereira et al. 2004), because they occupy about 50% of grazing lands (Campos and Martín-Bellido 1997). In addition, dehesas are a fundamental component of regional identity,

and are the source of high-quality food products derived from livestock production. In addition, dehesas have been valued at an international policy-making level for their biodiversity, aesthetic qualities and potential for tourism and recreation. Dehesas support a large number of species and a high diversity of habitats, being listed in the EU habitat directive as habitat with community-wide interest (Diaz 2008).

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 (Moreno and Pulido 2009). Increased mechanisation and increase stocking rates, together with the oversimplification of the management practices (notably a lack of livestock herding), have increased at least three sources of environmental degradation: i) soil erosion rates due to changes in vegetation, soil properties and hydrological processes (Schnabel et al. 2014); 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. 2014). In this context, the sustainability of the dehesa system has been seriously questioned (Moreno and Pulido 2009), and a considerable debate concerning the long-term persistence of dehesas has emerged, because the current low economic profitability of most dehesa farms and because most stands have over-aged trees and saplings are extremely scarce.

To help dehesa farmer to overpass 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 (Moreno 2014). This report presents the motivation for each innovation proposed and describes the experimental protocol to be followed together with the objectives and outputs expected.

3 Innovations tested

A complete list of innovations proposed can be consulted in Milestone 2 (2.1) “Initial Stakeholder Meeting Report Dehesa farms in Spain” and Milestone 3 (2.2) “Report on Innovations for High Nature and Cultural Value Agroforestry”, reported by Moreno (2014) and Moreno et al. (2014), respectively. Here we focus on the following seven innovations, that were prioritized by the stakeholder group and that are going 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 of 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 collar 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.

Given the variety of innovations selected and the number of sites where they will be tested, the seven innovations are presented separately, following the same structure: i) motivation, ii) objectives, iii) experimental layout and iv) the parameters to be monitored. For innovation 7 (evaluation of carbon sink strength) the potential of further modeling is discussed. As several dehesa farms are involved in more than one innovation trial, the description of dehesa farms are given in Annex A. Table 1 summarize the sites where different trials are being conducted.

Table 1. List of trials designed by the Iberian dehesa stakeholder group, indicating the number of the farms where they are being carried out

Innovations			Farm number															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1Tree regeneration	Seedling protection	Thorny shelter	X	X	X	X	X											
		Pruned branches	X	X	X													
	Acorn protection	Nurse shrubs	X					X										
		Pruned branches						X										
		Repellents	X					X										
2 Cultivars of triticale					X							X					X	
3 Forage rich in legumes(shade adapted)	Multiple species comparison												X					
	Comparison of formulations													X				
	Long persistence				X										X	X		
4 Fast intensive rotational grazing	Feasibility												X					
	Benefits																X	
7 Carbon sequestration strength																		X

Note: Work on multipurpose GPS-collar and on the willingness of consumers are not linked to specific farms.
Note: Farm names are as follows: F1 (Las Parras), F2 (Monteviejo), F3 (Atoquedo), F4 (Magines), F5 (Valdesequera), F6 (Dehesilla), F7 (Santi Spiritus), F8 (San Pedrillo), F9 (Valverdejo), F10 (Los Varales), F11 (Casablanca), F12 (Higaleja), F13 (La Casilla), F14 (La Cabra), F15 (Los Llanos), F16 (Majadas).

4 Cost-efficient methods for tree regeneration

4.1 Motivation

Today the central problem for the continuity of the dehesas is the gradual decay of tree canopy due to the lack of tree regeneration. 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). Moreover tree regeneration is absent as a result on the one hand, of the intensification process suffered by dehesas in the last 50 years, and on the other hand, the abandonment and subsequent encroachment of pastureland by competing vegetation which increases the risks of fire (Plieninger and Wilbrand 2001). In fact tree regeneration ranks second in the list of innovation demands proposed by farmers in a recent AGFORWARD survey (prevention of oak sudden death, a closely related issue, ranking first).

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. These programmes have been, to some extent, successful even if the establishment of oak trees is difficult due to many factors including slow growth, low survival percentages, especially during the first summer drought and seedling damage by wild animals (Smit et al. 2008). However artificial regeneration in managed dehesas is too expensive, as planted seedlings have to be fenced out for long periods (at least 20 years) or protected individually with costly tree shelters designed to resist the action of cattle (a typical tree shelter must be at least 1,80 m high and consists of 3 corrugated iron bars that support a strong mesh wire; Figure 1).

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

This tree protection device is very expensive (ca. 30 euros per planted seedling). Besides, survival of planted seedlings is often poor, and successive seedling replacement are needed. 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. 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 (Birch et al. 2010). 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. 2006; González-Rodríguez et al. 2011). 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. 2002; Gomez et al. 2004; Padilla and Pugnaire 2006; Smit et al. 2008; Rey et al. 2009). This study, therefore, 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.

4.2 Objective of the trial

The aim of the trial is to test alternative low-cost methods of regeneration of dehesa oaks, based on oak seedling protection and on acorn sowing. The objective of the trial is to develop a cost-efficient and feasible approach to promote tree regeneration in grazed dehesas (low-cost method of seedling and acorn protection) as compared to the traditional reforestation methods. Key questions include:

1. Is the approach effective (i.e. 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? (I.e. can land owners and managers implement the approach 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 Experimental layout and trial design

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. They can be grouped into techniques relying on seeds or seedlings:

a) Seedling shelters

- Protecting seedlings with oak branches resulting from tree pollarding.
- Protecting seedlings with thorny wire shelters (http://protectorcactus.com/), combined with Tubex shelter and antigrass mesh to increase the survival of planted seedling.

b) Acorn shelters

- Protecting acorns under nurse shrubs

- Protecting acorns with oak branches coming from tree pollarding (acorns sown can be performed by animal dispersers using shelters).
- Treating acorn with natural repellents against vertebrate predators (olfactory or gustative).

4.3.1 Seedling shelters

Five farms with grazing cows (3 farms), sheep (3 farms), pigs (2 farms) and presence of red deer (1 farm) will be selected (Figure 1). Table 2 gives details on the treatments compared on each farm, and the number of replicates.

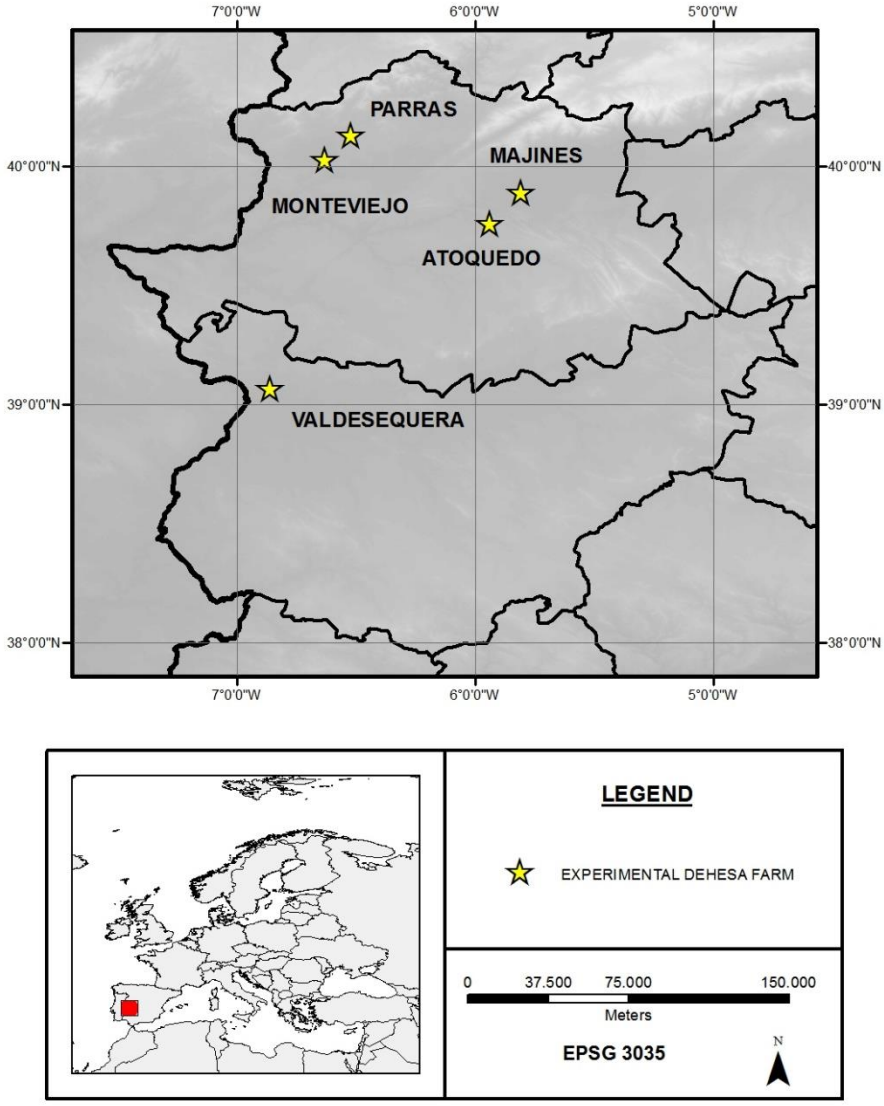

Figure 2. Location of the four farms where conventional plant shelter is compared with alternative shelters

The following treatments are compared.

- Control (standard wire shelter with thick iron fixers), with and without Tubex tree shelter, and with and without antigrass mesh.
- Thorny shelter (allowing thin fixers), with and without Tubex tree shelter, and with and without antigrass mesh.

- Natural shelter (made with pruned branches)

Spatial coordinates of each planted seedling were recorded with a submetric GPS to allow the analysis of spatial effects on seedling survival.

Figure 3. Innovative eco-shelters proposed in this study: thorny wire shelter (left), and natural shelter made with branches (right)

Table 2. List of treatments compared in each of the five dehesa farms

Las Parras (Figure 4)	Monte-viejo	Atoquedo (Figure 5)	Magines	Valdesequera
Control Control + thorny ring Thorny shelter: + Tubex + antigrass mesh + Tubex - antigrass mesh - Tubex + antigrass mesh - Tubex - antigrass mesh Natural shelter	Control Thorny shelter Natural shelter	Control Control + thorny ring Thorny shelter Natural shelter	Control Thorny shelter	

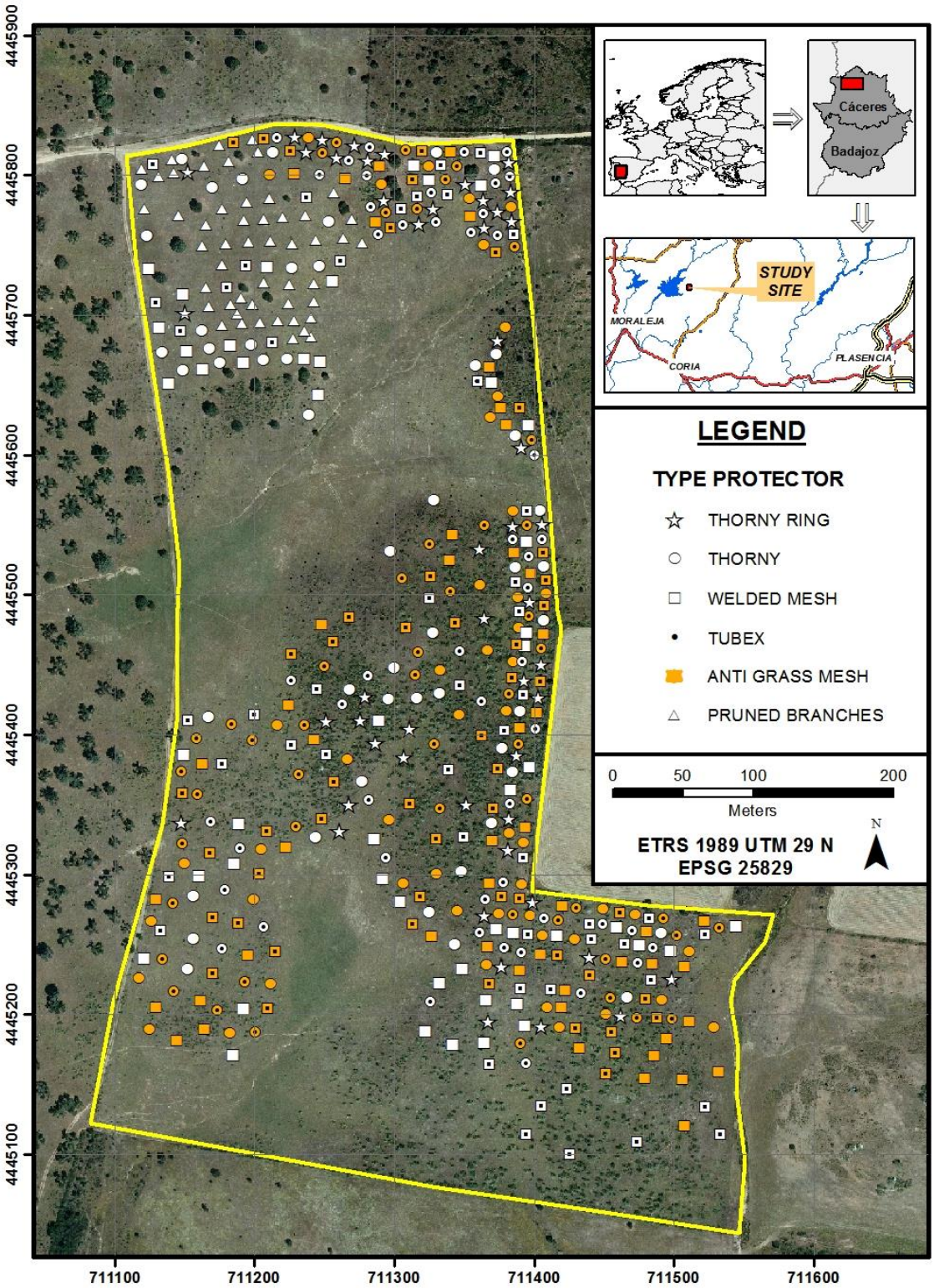

Figure 4. Location of the different methods of plant protection for regeneration of trees in dehesa "La Parra", Villa del Campo, Extremadura, Spain

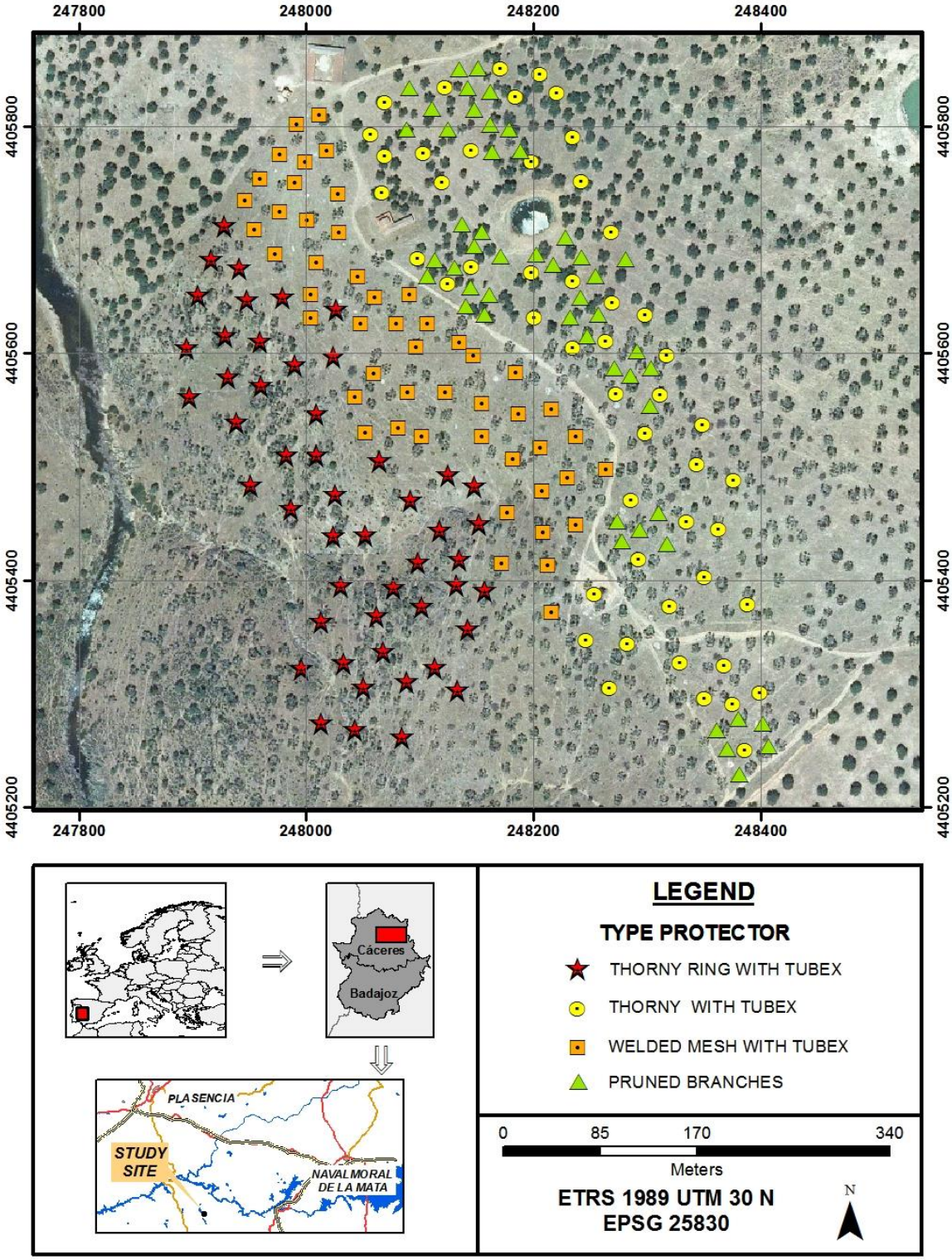

Figure 5. Location of the different methods of plant protection for regeneration of trees in dehesa "Atoquedo", Torrejón el Rubio, Extremadura, Spain

4.3.2 Acorn shelters

Experiment 1: effect of microhabitat and repellent

Three sites with different vegetation were selected for the trial: 1) Holm oak trees and Retama shrub; 2) Holm oak trees and Cytisus shrub; 3) Open pasture land. In these sites, acorns were sown in different microsites: under shrub canopy and in the open interspaces between shrubs for Retama and Cytisus sites, and under piled tree branches (natural shelter) and unprotected for the open pasture site. Locally available dog excrement was mixed with the acorns as a repellent against predators. Taking into account all the combinations, the trial consists of 12 treatments, with 50 sowing-points each and two acorns sown per point.

Table 3. List of treatments compared on each dehesa farms

Experiment 1	
Farm "Dehesilla", Valdehuncar	Farm "La Parra", Villa del Campo
12 treatments (50 repetitions; 2 acorns per repetition)	8 treatments (50 repetitions; 1 acorns per repetition)
Retama + repellent Retama-no repellent Retama interspaces + repellent Retama interspaces-no repellent Cytisus + repellent Cytisus-no repellent Cytisus interspaces + repellent Cytisus interspaces-no repellent Piled branches + repellent Piled branches - repellent Open + repellent Open - repellent	*Cytisus multiflorus*-no repellent *Cytisus multiflorus* + repellent *Retama sphaerocarpa* –no repellent *Retama sphaerocarpa* + repellent *Lavandula stoechas* -no repellent *Lavandula stoechas* + repellent Pasture land (control) -no repellent Pasture land (control) + repellent

Experiment 2		
Farm Santi Spiritus	Farm San Pedrillo	Farm Valverdejo
(10 repetitions; 10 acorns per repetition)		
Open – no repellents Pruned branches – no repellents Pruned branches + repellents		

Figure 6. Treatment with acorns sown under piled tree branches (left) and nursery shrub (*Retama sphaerocarpa*) (right)

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 at 40 microsites in each treatment. Twelve days later, on February 12, 10 additional microsites were sown in each treatment. 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 repellant 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 colored in red were used to mark spots sown with repellant and blue sticks when no repellant was used.

Experiment 2: effect of repellent and acorn quality

Three farms (Valverdejo, San Pedrillo and Santi Spiritus) were selected to test for the effect of acorn repellent and acorn quality on acorn survival under natural shelters made with pruned branches. On each farm 20 shelters were used and 10 acorns (5 dry and 5 fresh) were sown under their protection. Acorns in half the shelters were treated with repellent, with the remaining acorns being left as controls. Spatial coordinates of each planted seedling were recorded with a submetric GPS to allow the analysis of spatial effects on acorn survival.

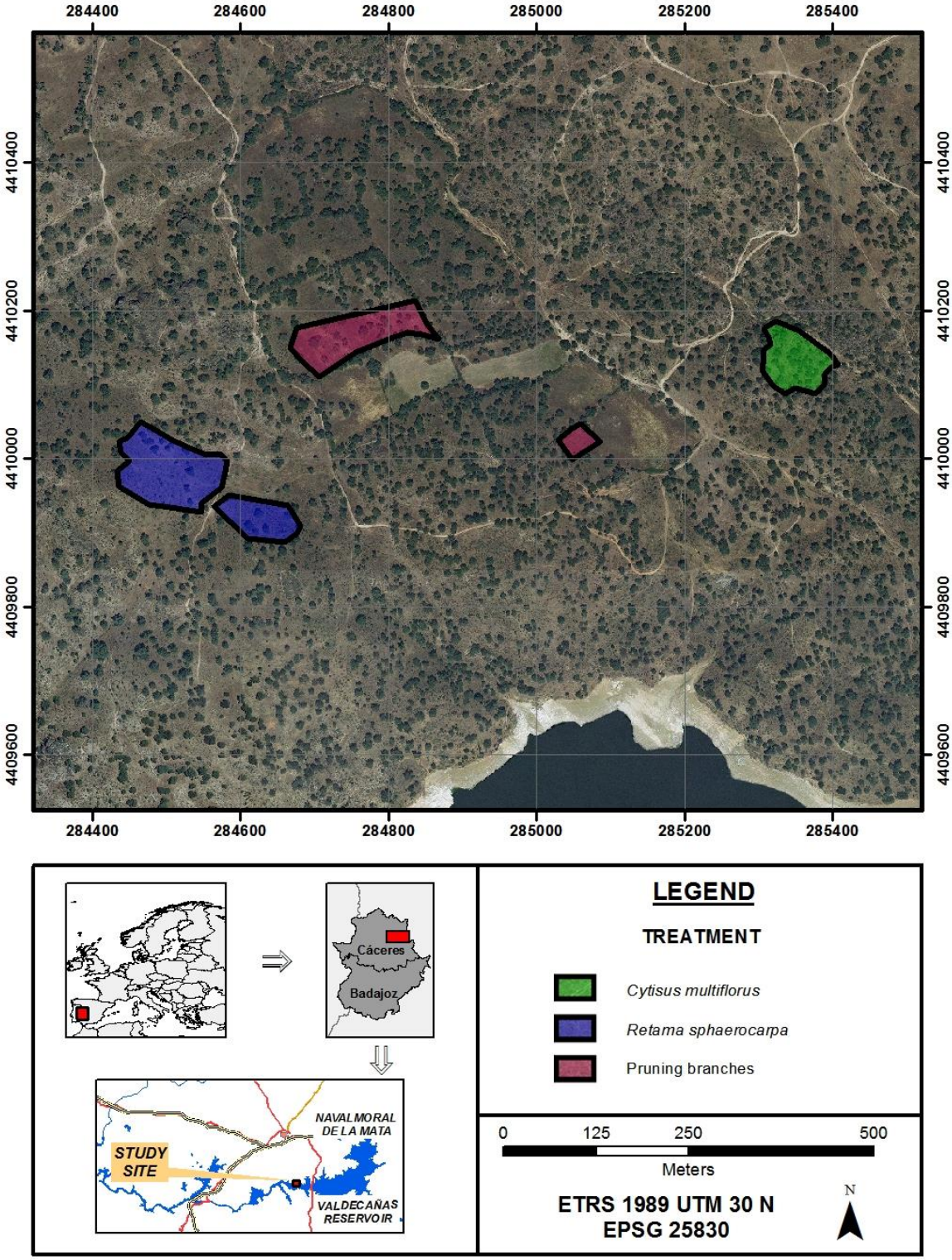

Figure 7. Map with the location of experimental sites in the farm "Dehesilla", in Valdehúncar, Extremadura, Spain

4.3.3 Measurements

The measures to be carried out in the trial of seedling protections are:

1. Plant survival and size (height and stem diameter) will be measured after the 1st, 2nd and 3rd drought period (autumn 2015, 2016, 2017)
2. Evidence of shelter deterioration will be noted.
3. In addition, monthly records of the spatial distribution of domestic herbivores within the plots will be gathered to test for association with shelter and seedling survival.

The measures to be carried out in the trials of acorn protections are:

1. One month after the establishment of the trial a visual inspection of the sowing spots to assess the level of acorn predation (Tables 1, 2 and 3) (Figures 4, 5 and 6).
2. Seedling emergence will be evaluated before the summer period (June 2015).
3. Seedling survival will be evaluated after the summer (October 2015).
4. Seedling growth (diameter at root collar and height) will be evaluated once a year for two years (October 2015-October 2017).

Figure 8. Predated acorn which had been sown without repellant under retama shrub (left) and with repellant in open pasture (right)

Table 4. Proportion of acorns consumed by rodents one month after the sown in the farm "Dehesilla" at Valdehuncar

	Sheltered		Unsheltered	
Treatment	Without repellent	With repellent	Without repellent	With repellent
Retama site	51	61	90	84
Cytisus site	69	33	84	39
Open pasture site	36	22	55	16

Notes: [1]Valdehuncár. Sheltered: under shrubs (Retama and Cytisus sites) or piled branches (Open pasture site). Unsheltered: Open interspaces (Retama and Cytisus sites) or open pasture (Open pasture site).
[2]The trial at La Dehesilla site 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.
[3]There is also a need to test other repellants (either commercial or home-made) as well as whether the use of pre-germinated acorns may repel predators. These tests can be easily down in the laboratory with live mice captured in the field.

5 High-productive forage crops: Triticale of double use

5.1 Motivation

Dehesas are grasslands with scattered trees and a well-developed herbaceous understorey used mainly for extensive rearing of sheep, cattle and pigs. Natural pastures in this area have low and very variable biomass productivity and low nutritive value as a consequence of low and irregular rainfall of Mediterranean climate, low soil fertility, inadequate livestock management and poor plant species composition (Vázquez de Aldana et al. 2006). Herbage yield is about 1440 kg dry matter (DM) per ha and year, and the resulting forage proportions are 4-20% legumes, 9-12% crude protein (Olea and San Miguel-Ayanz 2006), 44-59% neutral detergent fibre and 28-37% acid detergent fibre (Viguera et al. 2006).

Figure 9. View of the triticale sown in dehesa farm “Los Llanos”, in Siruela

Under these conditions of low forage productivity, farmers have the necessity of purchasing feeding supplements that greatly increase production costs, which can reduce farm profitability. Traditionally in this area to improve productivity and reduce then production costs, management has been focused in three aspects (Rossiter 1966): low livestock grazing intensity, sowing of well-adapted and very productive pasture species or forage crops, and fertilizer application. Among forage crops, the cultivation of triticale is becoming an increasingly interesting alternative due to its great capacity to be grazed in winter and then used again in late spring for hay production (double use). Triticale cultivars used with this dual forage purpose have been developed to grow in areas free of trees with a high insolation level. Hence, the use of these cultivars under tree cover, under different shadow regimes, is likely to affect biomass yield or quality traits of forage. However, how it can affect productivity and the intensity of this potential effect are aspects still poorly understood.

Likewise, 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

The aim of the present work is to evaluate the effect of the tree cover on the herbage production and nutritive value traits (crude protein, neutral and acid detergent fibre and acid detergent lignin) and discern if these effects depend on the triticale cultivars.

5.3 Experimental layout

The trial will take 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). The location of the dehesas is displayed in Figure 10. In the three study dehesas, the tree layer was dominated by adult holm oaks (*Quercus ilex* subsp. *ballota* (Desf.) Samp.). Natural pastures consisted of spontaneous annual species including *Helianthemetalia*, *Thero-Brometalia*, and *Sisymbrietalia*, although perennials such as *Agrostietalia* and *Poetalia* were also present. The main characteristics of the study sites are presented in Annex A.

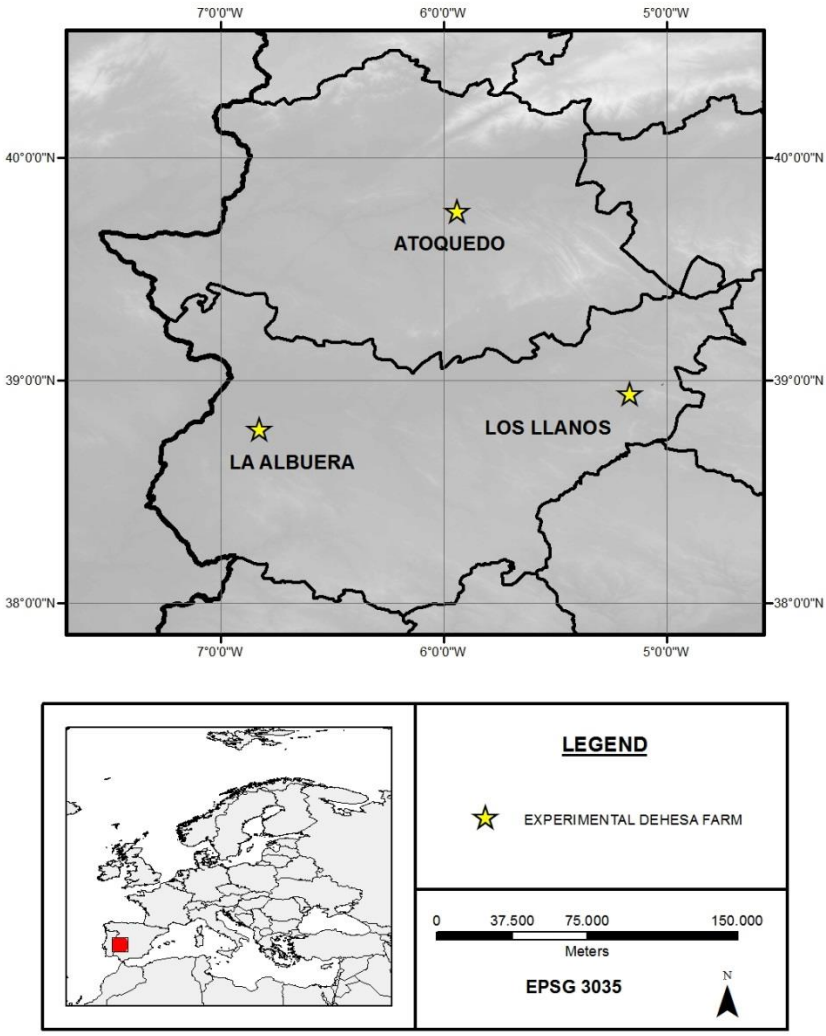

Figure 10. Location of the experimental dehesas: (a) La Albuera, (b) Los Llanos, and (c) Atoquedo

5.4 Trial design

On each dehesa, an experimental area of at least 5 ha will be selected. The experimental area will be 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 will be performed in mid-autumn (approximately in November), at a seeding rate of 220 seeds m^{-2}. Conventional tillage will be used to prepare a seedbed before sowing. All plots will be fertilised by following the usual practices of each farmer. Each year, before sowing, four representative soil samples of 30 cm depth will be taken from the experimental area of each dehesa studied and carried to the laboratory.

Within each plot, four 4 homogeneous holm oak adult trees (4 repetitions) will be selected in order to take samples under the same trees during the whole duration of the trial. The crop area under each tree will be divided in four virtual sectors (Fig. 11): one located close to the trunk (very dark green), which will be excluded to take samples because of the lack of plants due to mechanical seeding procedure, a second one located clearly under the tree (dark green), a third one located clearly out of the tree influence (very light green), and a fourth one in the edge of the canopy projection (light green). The experimental area will be grazed at approximately January-February when plants are 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 will be taken for measurements (with the exception of the very dark green sector, as explained above). Then, a total of 36 herbage samples will be taken per experimental dehesa in this first grazing period. The samples will be taken with the same orientation: to the East of the tree. After the grazing period, the experimental area will be free of grazing until plants reach the growth stage 75-77 of the Zadocks scale (approximately until mid-May), when the crop will be mowed for hay. Before mowing, a second set of herbage samples will be taken by following the same procedure as explained above.

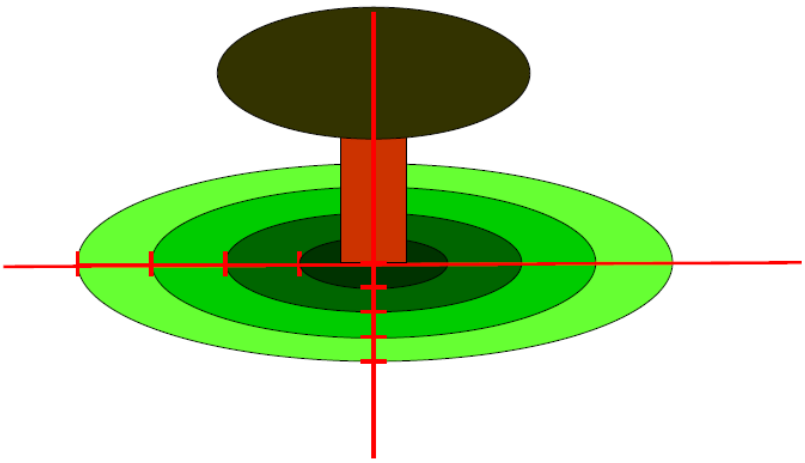

Figure 11. Virtual sectors performed under each selected trees. Herbage samples will be taken from each sector, excluding the one closest to the trunk

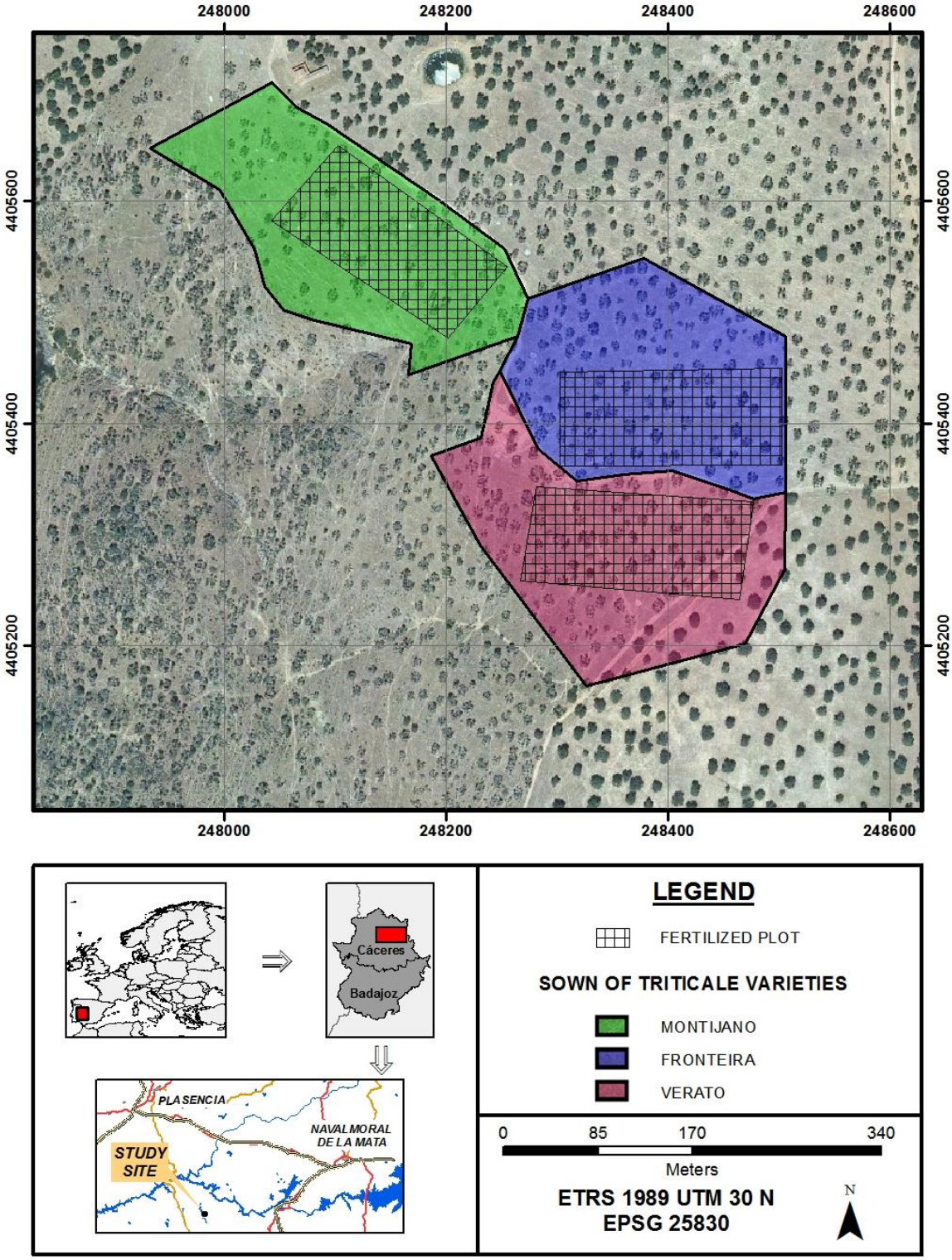

Figure 12. Aerial view of the trial with three cultivars of Triticale in Atoquedo dehesa farm. Grid shows the fertilized area (100 kg N as ammonium nitrate added in early April)

5.5 Measurements

5.5.1 Soil samples

Soil samples will be air dried (70°C) and sieved to < 2 mm using a roller mill. Texture will be determined gravimetrically. Soil pH will be determined using a calibrated pH meter (ratio 10 g soil: 25 ml deionized H_2O). Electrical conductivity (EC) will be determined using an EC-meter. Total N will be determined using the Kjeldahl method (Bremner 1996), with the aid of a Kjeltec™ K350 distillation Unit (Buchi Ltd., Flawil, Switzerland). Extractable P will be determined by the Olsen procedure, and Ca and K will be extracted with ammonium acetate (1N) and quantified by atomic absorption.

5.5.2 Herbage samples

In the laboratory, plant samples will be air dried (70°C) until constant weight and then dry matter (DM) of herbage biomass production will be recorded. From those herbage samples, the following parameters will be determined: 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 analyzer (ANKOM 8-98, ANKOM Technology, Macedon, NY), by following the official procedures (AOAC 2006).

6 Permanent pastures rich in legumes

6.1 Motivation

Livestock breeders are interested in increasing the quality of the feed as well as to diversify forage offer (mitigating seasonal shortages). Intercrops with leguminous forage species and accessions is a promising way to overcome seasonal shortages of forage. Some recent experiences in Portuguese *montado*, with the sowing of biodiverse permanent mixtures rich in legumes (Aguiar et al. 2011) and in Sardinian oak woodlands, with the sowing of mixtures of autochthonous pasture grasses and legumes (Franca et al. pers. comm.) highlight the need for a specific selection of seed mixtures suitable for silvopastoral purposes, where herbaceous plants have to cope with shade and competition imposed by trees. Marañon et al. (2009) report that the abundance of legume species decrease beneath tree canopy in dehesas, but the real cause, exclusion by shade or competition from deep rooting grasses (that beneath canopy find enough N to grow), remains unexplained.

Unfortunately most selection and breeding programmes have focussed for full-sunlight growing conditions, and studies focused on the selection of shade adapted legume forage species are rare. Houx III et al. (2009) reported some native species that grow and nodulate well under varying shade conditions in savannas of Midwest US. Similarly, Addison (2003) found that although root nodulation was strong and negatively affected by shading, he found a good number of shade-adapted or shade-tolerant species, suitable to be sown beneath tree plantations in seasonally dry tropics.

6.2 Objective of study

The aim of the study is to identify the best adapted legumes species and/or accessions suitable for implantation of permanent pastures rich in legume in Iberian dehesas. Key questions include:

- Do trees affect the grow, seed production and nodulation of legume plants?
- Are tree effects defined by shade or by soil resources availability?
- Do vary the effects of trees among legume species and accessions?

Alongside these key questions, a number of hypotheses can be developed:

- Trees hardly affect the growth of forage legume plants but could reduce significantly the production of seeds.
- The higher concentration of mineral N beneath trees reduces the potential for nodulation of legumes plants.
- The variability in terms of soil moisture imposed by dehesa trees will affect the persistence of legumes as a function of distance to the trees.
- We expect differences among species and provenances.

To respond the questions and assess the validity of the hypothesis, three parallels trials are designed, at three different scales and sites: i) assessment of the response of legume species to oak shade, ii) comparison of different forage crops rich in legumes, and iii) evaluation of the persistence in the long-term of legume species and cultivars in dehesas.

6.3 Assessment of response of legume species to oak shade

This trial aims to assess how tree affect the productivity, both in terms of biomass and seed production, of different legume species. Additionally we will evaluate the contribution of species to the enrichment of soil mineral-N and soil C both beneath evergreen oak (*Quercus ilex*) canopy and in the open areas.

6.3.1 Experimental design and Location

This study is located in the farm “Casablanca” (coordinates 40°08’55” N; 06°06’ 48” W, altitude of 400 m), owned by Enrique Vega, a cattle breeder based on Oliva de Plasencia, a small town 13 km north of Plasencia (Extremadura region). Mean annual rainfall is around 700 mm and mean annual temperature is around 16°C.

The study includes nine forage legume species contained in two mixtures: the mixture commercialized by the company FERTIPRADO, based in Portugal, and the mixture provided by ISPAM-CNR (Istituto per il Sistema Produzione Animale in ambiente Mediterraneo; Sassari, Sardinia, Italy). Species included in both mixtures are:

- FERTIPRADO: mix of *Trifolium subterraneum* (60.6%) with other forage legumes: *T. michelianum* var *balansae* (4.5%), *T. vesiculosum* (3%), *T. resupinatum* (3%), *T. incarnatum* (6.1%), *T. itsmocarpus* (1.5%), *T. glanduliferum* (1.5%), *Ornithopus sativus* (19.7%). For *T. subterraneum*, different subspecies (*brachycalycinum* (6.1%) and *yaninnicum* (3%)) and cultivars (early maturing (13.6%), mid-season (19.7%) and late-maturing (18.2%)). This mix was sown at a density of 20 kg seed ha^{-1}, buried around 0.5-1.0 cm.
- ISPAM: mix of Medicago polymorpha "Anglona", *Trifolium subterraneum* "Campeda" *and Lolium rigidum* "Nurra". This mix was sown at a density of 30 kg seed ha^{-1}, buried around 0.5-1.0 cm.

Both mixtures were fertilized with 144 kg ha^{-1} of monopotassium phosphate 52-34 before seeding.

The study followed a randomized block design, with n = 4 blocks. Each block include six 5 m x 3 m plots located in two different microhabitats, three plots beneath oak canopy and three in an adjacent open area. Each triplet includes a plot per mix (Fertiprado and ISPAAM) plus a control plot (native pasture). Finally, within the 8 plots located in the open areas with sown of mix of legumes, a 1 m x 1 m subplot was artificially shaded with a plastic mesh (50% of full sunlight). Figure 13 shows plots just after sowing, and Figure 14 illustrate the experimental design followed.

Figure 13. View of the sowed plots beneath *Quercus ilex* canopy

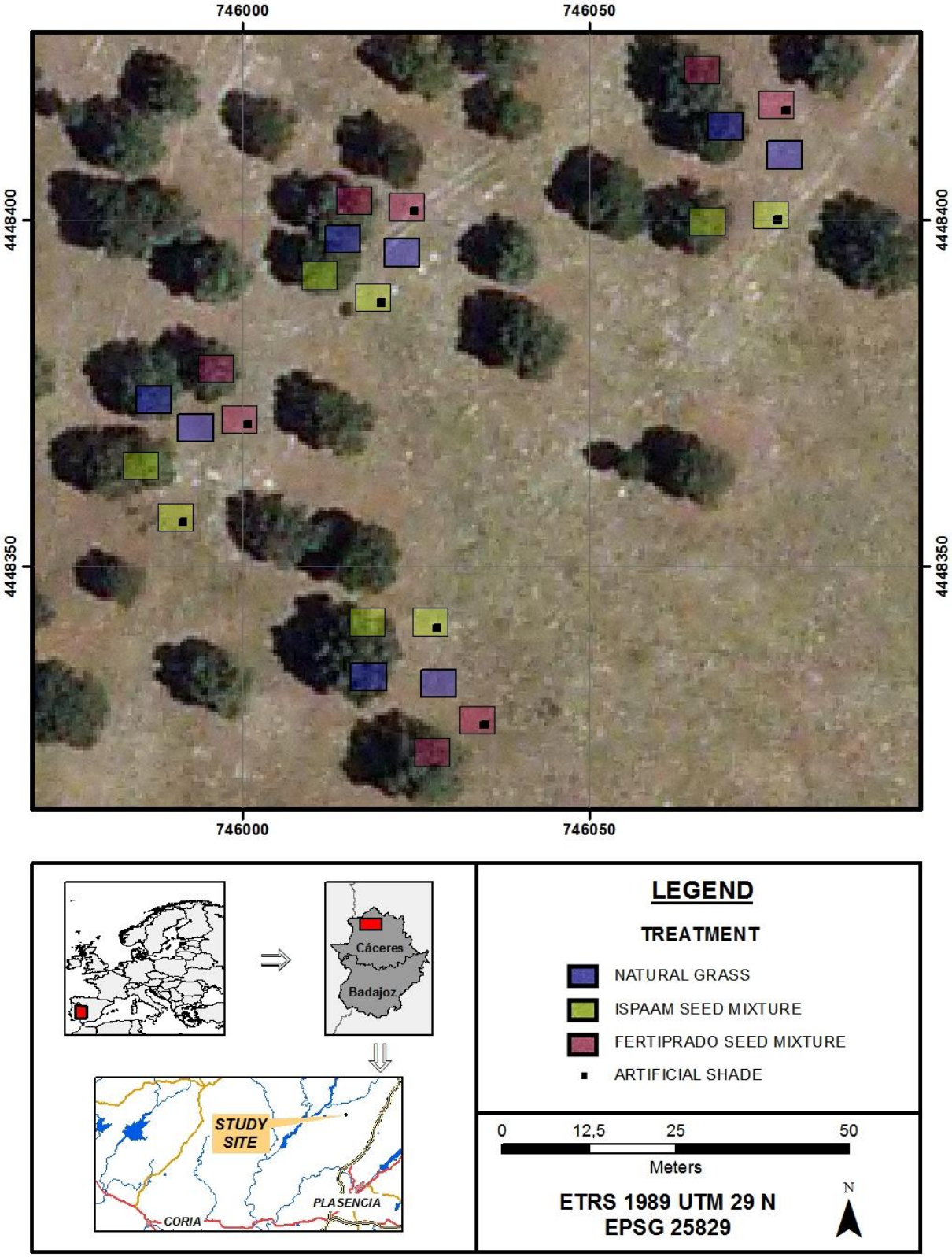

Figure 14. Experimental design followed in the dehesa farm "Casablanca" where the response of different legumes species (ISPAAM and FERTIPRADO mixture) to evergreen oak shade is studied

6.3.2 Parameter monitored

The study will include four categories of parameters (ecological conditions, aboveground biomass, root nodules and soil quality):

1. Two key factors will be measures to know the ecological conditions experienced by different plots. Light available will be modelled using hemispherical pictures, analyzed with the software ''Gap Light Analyzer'' (GLA 2.0; Frazer and Canham 1999). Pictures will be taken in April and irradiance will be integrated for the whole growing season. Measurements of soil moisture will be taken for each plot with a Thetaprobe Sensor (Delta-T Devices) that registered values of water volumetric percentage in the uppermost soil layer (10 cm). Measurements will be taken once by mid growing season (end April) in 4 points per plots.
2. Relative abundance per species and microhabitat, expressed in terms of green biomass and in terms of seed abundance. Plants will be sampled at maturity (end May) in 50 cm x 50 cm squares (n=4 square per plot, except for shaded subplots, with n=1). Samples will be store at 4°C (in the fridge) until botanical separation (to be done immediately in following days). For the quantification of seeds abundance, three full plants per species will be additionally sampled within each plot.
3. Nodule number quantification per species and microhabitat. The same plants sampled for seed quantification will be used for quantification of the intensity of nodulation (Lira and Smith 2000). Nodules number will be expressed by unit of root length, both nodule number and root length measured with WinRhizo software.
4. Mineral-N availability and soil carbon per micro-habitat. Soil cores of the uppermost soil (0-10 cm) will be taken in two different dates, at plant maturity (end May) and at the beginning of the following growing seasons (next fall and spring). Four samples will be taken per plot, and bulked in a single composite sample. Samples will be store in cold. Mineral N (nitrate and ammonium) and available P will be measured by colorimetry (continuous segmented flow analyzer, SEAL AA1). Both labile and non-labile organic will be measured by dry combustion. Labile fraction will be determine by difference between total and non-labile organic carbon, being the latter determined in sample treated previously with 333 mM potassium permanganate (Blair et al. 1995).

6.4 Comparison of different forage crops rich in legumes

This trial aims to compare the productivity of alternative formulations (mixture) of forage seeds, included the popular FERTIPRADO mixture rich in legumes, and their response to the presence of deciduous oak trees. The response of different species will be also determined here. Additionally, the short-term effect of different pastures on soil properties (N and C) will be assessed.

6.4.1 Experimental design and location

This study is located in the dehesa farm "La Higaleja" (coordinates 40°09'48" N 06°17'16"W, altitude of 430 m), owned by Juan Pareja-Obregón, a cattle breeder based on Aceituna, a small town 20 km north-west of Plasencia (Extremadura region). Mean annual rainfall is around 750 mm and mean annual temperature is around 15.5°C.

The trial follows a simple design with only one plot per forage type within a single block. Within each plots, two microhabitats are defined, beneath deciduous oak (*Quercus pyrenaica*) canopy and open areas. Each plot covers about 1000 m^2 and include ≥3 trees (Figure 15).

The trial compares 8 forage types:

Number	Description
T0	Native pasture
T1	Native pasture with phosphoric fertilization
T2	Simplified mixture of pasture legume seeds (15 kg ha^{-1} *Trifolium subterraneum* + 3 kg ha^{-1} *Ornithpus sativus* + 2 kg ha^{-1}*T. michilianum*)
T3	T2 + Ryegrass (10 kg ha^{-1})
T4	T2 + Triticale (50 kg ha^{-1})
T6	Mixture of short duration pasture legume species (8 kg ha^{-1} *Trifolium subterraneum* + 5 kg ha^{-1} *Ornithopus sativus* + 3 kg ha^{-1} *T. granduliferum* + 2 kg ha^{-1} *T. michilianum* + 2 kg ha^{-1} *T. vesiculosum*).
T7	Mixture FERTIPRADO I for permanent pastures (*Trifolium subterraneum* + *T. michilianum* + *T. vesiculosum* + *T. resupinatum* + *T. incarnatum* + *T. repens* + *O. sativus* + T. *isthmocarpum* + *Lolium multiflorum* + *Lolium perenne* + *Dactylis glomerata*).
T8	Mixture FERTIPRADO II for short duration pastures (*Trifolium suaveolens* + *T. michilianum* + *T. vesiculosum* +*Lolium multiflorum*).

Note: Treatments T3 to T8 were fertilized similarly to T1. Fertilizer was applied in November 2014 at the time of the sowing.

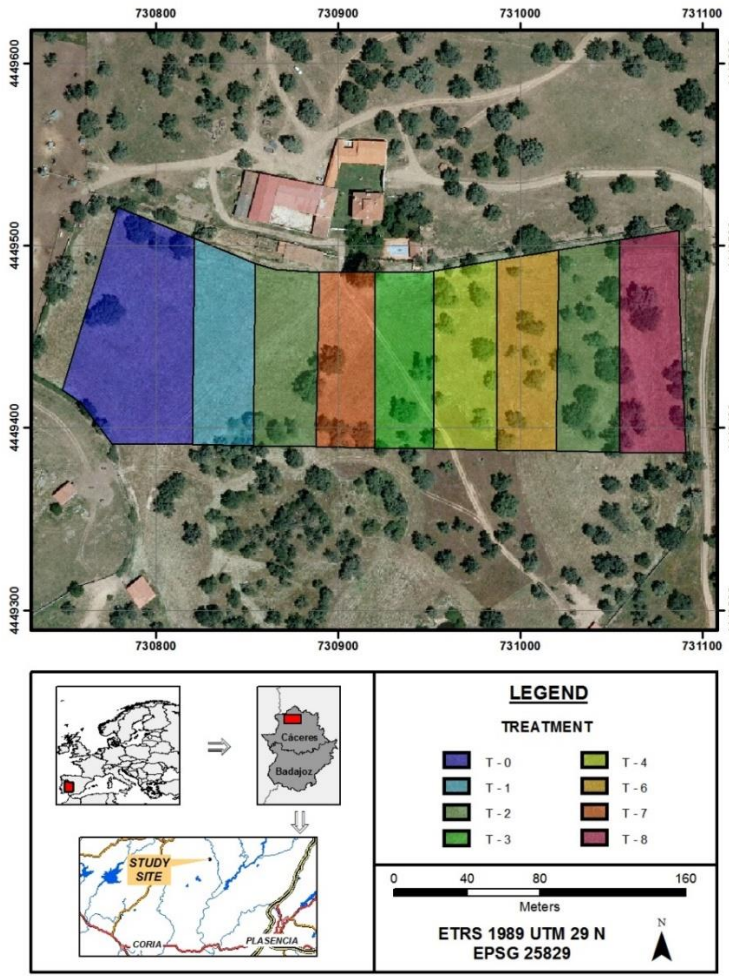

Figure 15. Experimental design followed in the dehesa farm "Higaleja", where eight pasture different were sown to compare their response to the presence of the tree (deciduous oak, *Quercus pyrenaica*)

6.4.2 Parameters monitored

The study will include three categories of parameters (ecological conditions, aboveground biomass, and soil quality):

1. Two key factors will be measures to know the ecological conditions experienced by different plots. Light available will be modelled using hemispherical pictures, analyzed with the software ''Gap Light Analyzer'' (GLA 2.0; Frazer and Canham 1999). Pictures will be taken in April and irradiance will be integrated for the whole growing season. Measurements of soil moisture will be taken for each plot with a Thetaprobe Sensor (Delta-T Devices) that registered values of water volumetric percentage in the uppermost soil layer (10 cm). Measurements will be taken once by mid growing season (end April) in 4 points per plots.
2. Aboveground biomass production. Samples will be taken at two different dates, in February before winter grazing, and in May at maturity. In each date four 50 cm x 50 cm squares per plot will be sampled. In winter, only overall dry biomass will be measured. In spring, relative dry mass will be given for each legume species. Samples will be store at 4°C (in the fridge) until botanical separation (to be done in the immediate following days).
3. Mineral-N availability and soil carbon per micro-habitat. Soil cores of the uppermost soil (0-10 cm) will be taken in two different dates, at plant maturity (end May) and at the beginning of the following growing seasons (next fall and spring). Four samples will be taken per plot. Samples will be store in cold. Mineral N (nitrate and ammonium) and available P will be measured by colorimetry (continuous segmented flow analyzer, SEAL AA1). Both labile and non-labile organic will be measured by dry combustion. Labile fraction will be determine by difference between total and non-labile organic carbon, being the latter determined in sample treated previously with 333 mM potassium permanganate (Blair et al. 1995).

6.5 Evaluation of persistence across years of legume species sown in dehesas

In this study, the persistence of sown pasture legume species will be assessed in a chrono-sequence. The persistence of different species beneath oak canopy (*Quercus ilex*) will be compared with their persistence in the open areas. The mid-term effects of legumes on soil nutrient availability and carbon sequestration will be also monitored.

6.5.1 Experimental design and Location

This study is replicated in three dehesa farms of Extremadura (CW Spain), each of them with a chronosequence of pastures rich in legumes sown in previous years. The location and characteristic of the three farms are summarized in Table 6, and their locations are shown in Figure 16.

Table 6. Main characteristic of the farms with chronosequence of pasture rich in legumes

Farms	Location	Town	Owner	Altitude (m)	Temp (˚C)	Rainfall (mm)	Ages (year old)
Atoquedo	39˚ 46’ 10” N 05˚ 56’ 03” W	Torrejón el Rubio	Enrique Rodríguez	360	16	550	1,2,3,4,5
Las Casillas	39˚ 29’ 24” N 07˚ 07’ 58” W	Valencia de Alcántara	Iñigo Oriol	420	15.5	494	3-10
La Cabra	38˚ 11’ 00” N 06˚ 42’ 32” W	Fregenal de la Sierra	Sociedad el Coto S.L.	690	14.8	740	1-6

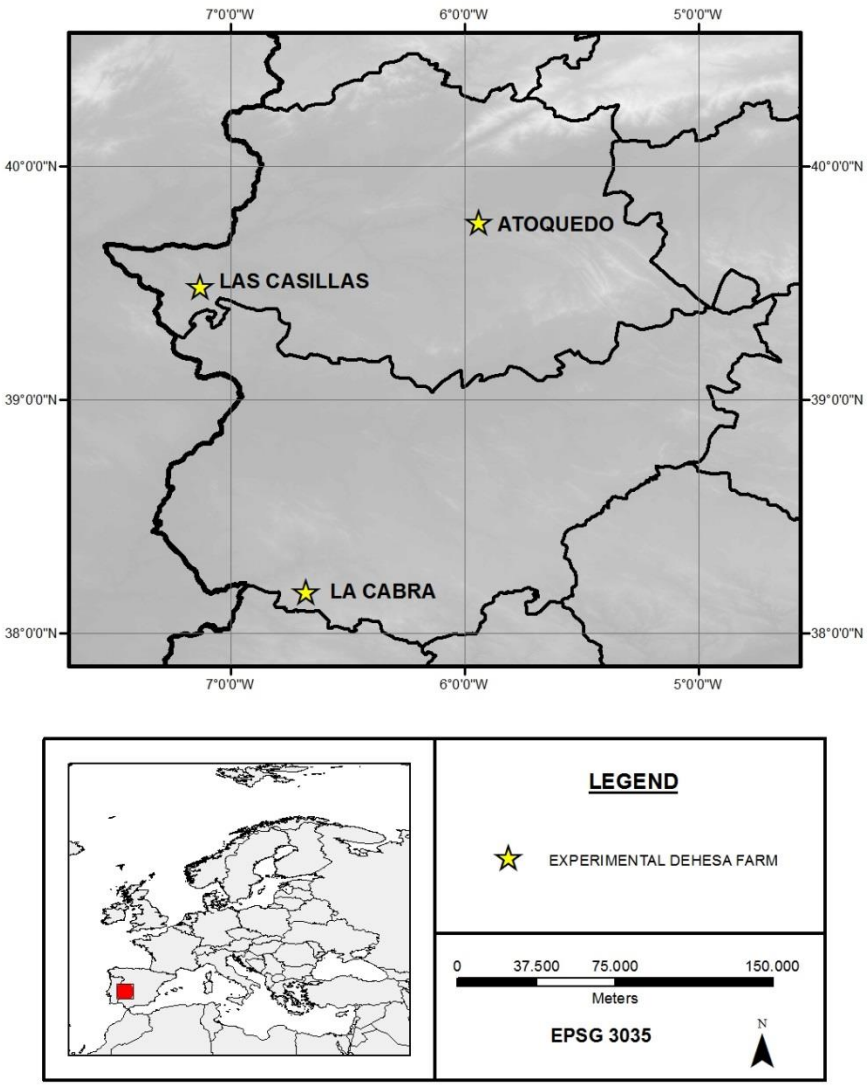

Figure 16. Location of the three dehesa farms with chronosequence of pastures rich in legumes sown in different years with the FERTIPRADO mixtures of legume seeds. Coordinates in Table 6

The trial follows a simple design with only one plot per age and farm. In all cases a commercial mixture of forage legume seeds was sown. The mixture of seed (FERTIPRADO company) is composed of *Trifolium subterraneum* (60.6%) with other forage legumes: *T. michelianum* var *balansae* (4.5%), *T. vesiculosum* (3%), *T. resupinatum* (3%), *T. incarnatum* (6.1%), *T. itsmocarpus* (1.5%), *T. glanduliferum* (1.5%), *Ornithopus sativus* (19.7%). For *T. subterraneum*, different subspecies (*brachycalycinum* (6.1%) and *yaninnicum* (3%)) and cultivars (early maturing (13.6%), mid-season (19.7%) and late-maturing (18.2%)). Seeds were sown at a density of 20 kg seed /ha, buried around 0.5-1.0 cm.

Within each plot, two microhabitats are defined, beneath oak canopy (either *Quercus ilex or Q. suber*) and open areas. In each plot (age), 12 wire exclusion cages (60x60x60 cm; Image 6.2) were installed, one half beneath tree canopy and the other half beyond the canopy projection (> 20 m distance). An example of the experimental layout is given in figure 18 (Atoquedo dehesa farm).

Figure 17. Left: view of the exclusion cages installed to monitor the abundance and biomass of pasture legume species sown in the previous years. Right: view of pasture rich in legumes sown in November 2013 (picture taken in May 2014). Both pictures taken in plots grazed by sheep in the dehesa farm named “Atoquedo”, in National Park of Monfragüe (Torrejón el Rubio, Extremadura).

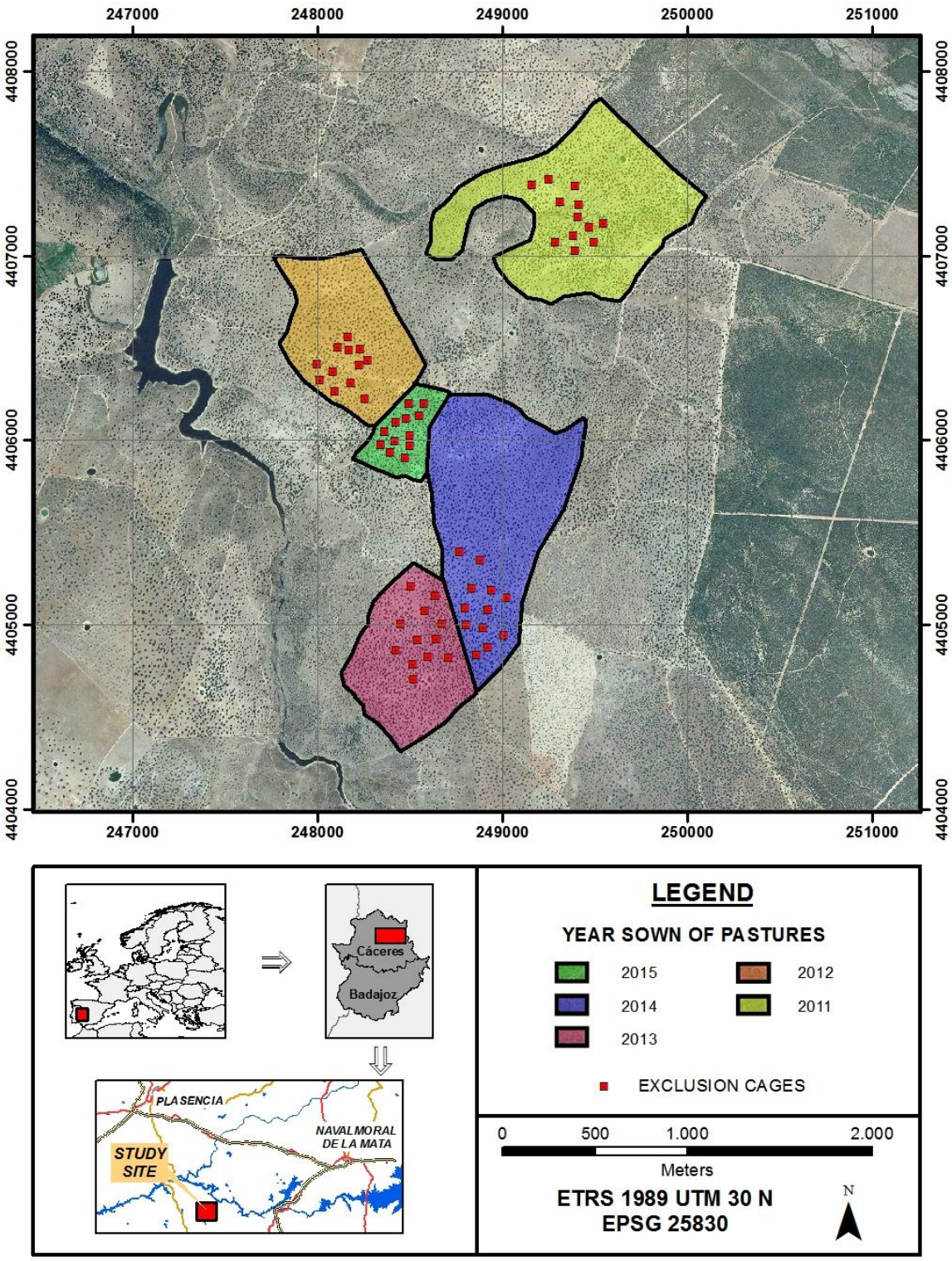

Figure 18. Experimental design followed in the dehesa farm "Atoquedo", where the persistence of sown pasture legume species is assessed by comparing a chronosequence of pastures sown in different years (five different ages). Pasture biomass is measured in exclusion cages located both beneath tree canopy (*Quercus ilex*) and out of the canopy (n=6 per plot and microhabitat).

6.5.2 Parameter monitored

The study will include two categories of parameters (aboveground biomass and soil quality):

1. Aboveground biomass production. Samples will be taken at in May (just before pasture becomes dry) in eight 50 cm x 50 cm squares per each microhabitat x plot (age) x farm combinations (30 plots x 6 repetitions). Samples will be store at 4°C (in the fridge) until botanical separation (only legume species) to be done in the immediate subsequent days.
2. Mineral-N availability and soil carbon per micro-habitat. Soil cores of the uppermost soil (0-10 cm) will be taken at the time and points of plant sampling. The six soil samples within each plots will be pooled to have a composite sample per plot (30 soil samples). Samples will be store in cold. Mineral N (nitrate and ammonium) and available P will be measured by colorimetry (continuous segmented flow analyzer, SEAL AA1). Both labile and non-labile organic will be measured by dry combustion. Labile fraction will be determine by difference between total and non-labile organic carbon, being the latter determined in sample treated previously with 333 mM potassium permanganate (Blair et al. 1995).

7 Fast-intensive rotational grazing

7.1 Motivation

The most important economic activity of dehesa is the extensive livestock farming. Therefore, natural pastures, as the main source of fodder for livestock, are an essential component of the system. The management of natural pastures is aimed at increasing their quality (legumes: protein, minerals) and quantity. As a consequence, that management is based on three fundamental issues: livestock management, legume introduction, and phosphoric fertilization (Olea and San-Miguel Ayanz 2006).

In the past dehesas formed a vital part of the transhumance migrations, though today the vast majority of dehesas are under continuous grazing regimes what is threatening the long persistence of the system (deficient tree regeneration and soil degradation). A sustainable livestock management could imply important improvements in the dehesa ecosystem such as preventing colonization of pastures by invading shrubs, improving grassland quality, ameliorating soil fertility and quickening the nutrient cycle (Montero et al. 1998).

Fast-intensive rotational grazing (FIRG), such as holistic management, is being promoted as a possible solution to their deterioration and desertification. With FIRG, high densities of large herding animals graze for brief periods at appropriate intervals rotating across plots (Savory and Butterfield 1999). Although this approach has been developed in different countries and ecosystems reporting an enhancement of ecosystem process, biodiversity, economic profitability and quality of life (Joyce 2000; McCoster 2000; Stinner et al. 1997), there is a lack of scientific studies that evaluate the effects of FIRG approach in dehesa ecosystems and other seasonally dry wood pastures.

7.2 Objective of trial

The aim of the trial is to assess the adaptability of holistic grazing management to the Iberian oak savannah woodlands. We propose an experimental project based on time-controlled grazing systems. With a holistic management grazing approach, based on short grazing periods and adequate pasture rest, we expect an improvement in ecosystem functions and therefore an enhancement of economic profitability.

A vegetation cover restoration could enhance the infiltration rate and the holding water capacity. The soils properties also could be enhanced, increasing organic matter, nutrient and biological activity. We also expect an increase in pasture biodiversity and tree recovery. Key questions include:

- How do short grazing periods and adequate pasture rest affect vegetation cover and pasture yield?
- How does the holistic management approach influence pasture biodiversity and tree regeneration?
- How do this approach relate to soil properties?

Our hypothesis is that holistic management, not only increases productivity but also implies ecosystem improvements: improving soil properties (soil structure, amount of organic matter, water efficiency, and availability soil nutrients), pasture species cover and composition, and tree regeneration.

7.3 Experimental layout

Two different experiments are planned, the first one to assess the feasibility of the holistic grazing in dehesa, where forage resources are seasonally available, and the second one to compare the potential of holistic grazing to improve pasture quality with respect to conventional methods of pasture improvement (sown and fertilization).

7.3.1 Feasibility of holistic management

The study is carried out in a 21 ha plot of Casablanca dehesa farm, dominated by open savanna woodlands with *Quercus ilex and Q. suber.* For the experiment, we will use a herd of 15 steers of +12 months of age and around 300 to 350 kg.

The plot will be split using electric fencing in a control area of 7 ha (C.M.) managed with continuous grazing with 5 steers (1.4 ha per animals), and 15 paddocks of 1 hectare (C.M.1 - C.M.15) under holistic grazing management, with 10 steers per paddock (1.5 ha per animals) for periods of 3-4 days (animals will move from North to South (C.M.1 to C.M. 15), every Tuesday and Friday of the week (Figure 19).

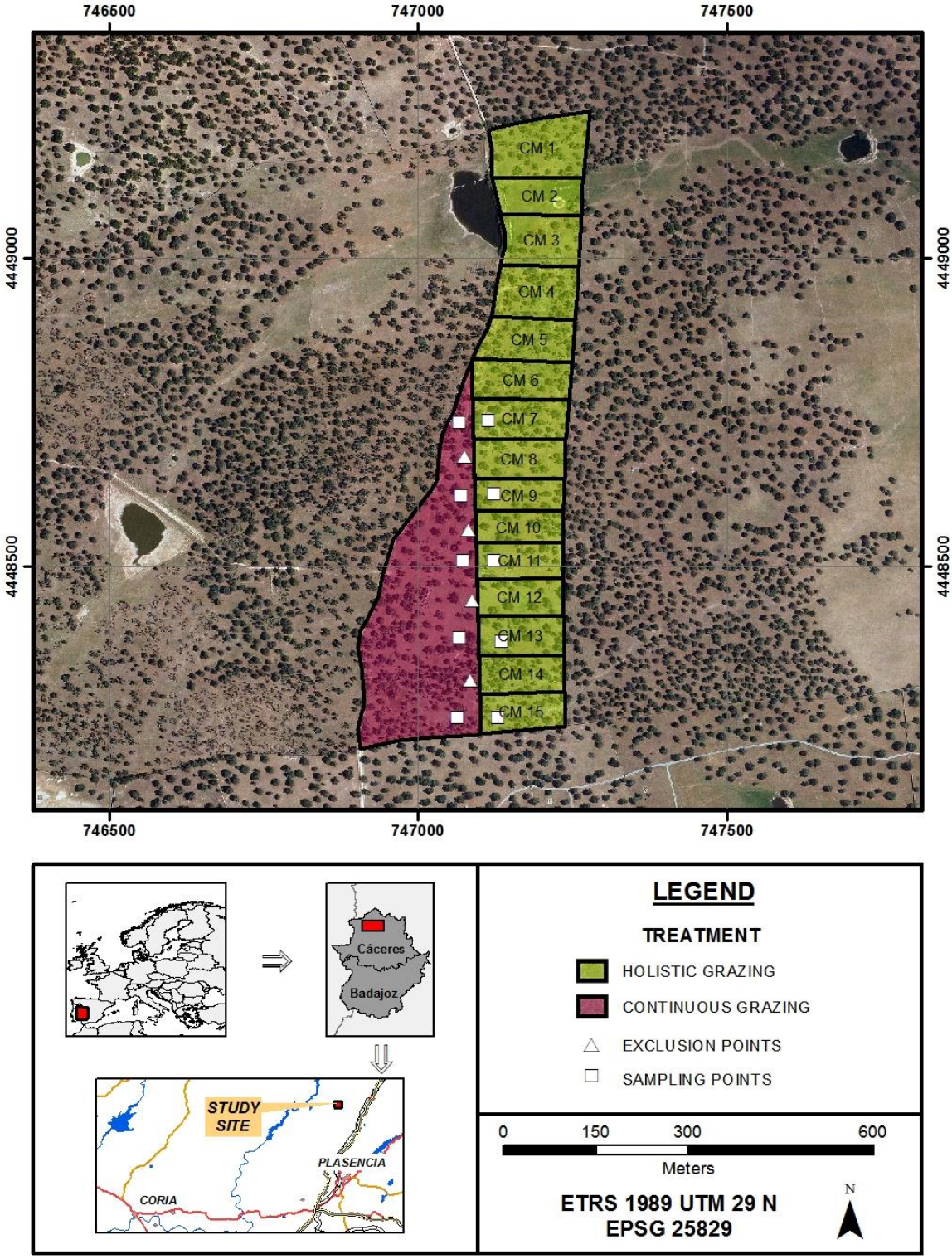

Figure 19. Comparison of traditional grazing scheme (Control: 0.7 steers/ha continuously) vs fast-intensive rotational grazing (Holistic grazing; CM 1 to CM15: 10 steers/ha for 3 days every 45 days, 0.67 steers/ha around the year).

Table 7. Summary of animal movements, stock density and grazing regime as depicted in a standard holistic management fact-sheet.

STUDY AREA NAME:	***Cerco de Maxi***				
Herd code:	***M.1.M.***				
Reference code	**Surface area in Ha**	**Number of animals**	**Entry date**	**Grazing days**	**Grazing regime:**
Control C.M.	7	5	31/10/14	46	Continuous grazing
C.M.1	1	10	31/10/14	4	H.G.M.
C.M.2	1	10	04/11/14	3	H.G.M.
C.M.3	1	10	07/11/14	4	H.G.M.
C.M.4	1	10	11/11/14	3	H.G.M.
C.M.5	1	10	14/11/14	4	H.G.M.
C.M.6	1	10	18/11/14	3	H.G.M.
C.M.7	1	10	21/11/14	4	H.G.M.
C.M.8	1	10	25/11/14	3	H.G.M.
C.M.9	1	10	28/11/14	4	H.G.M.
C.M.10	1	10	02/12/14	3	H.G.M.
C.M.11	1	10	05/12/14	4	H.G.M.
C.M.12	1	10	09/12/14	3	H.G.M.
C.M.13	1	10	12/12/14	4	H.G.M.
C.M.14	1	10	16/12/14	3	H.G.M.
C.M.15	1	10	19/12/14	4	H.G.M.
Movement of 10 steers to:	C.M.1	10	23/12/14	46	

*Note: Proper holistic grazing management is a complex process that is determined by a number of key factors, such as the characteristics of each paddock, the recovery periods of individual grass species and the holistic context established beforehand for each area. However, these parameters have been simplified for study purposes. Therefore, the paddocks under holistic grazing management have been set at 1 hectare and the animal movements for Tuesday and Friday of each week.

7.3.2 Pasture yield under fast-intensive rotational grazing

A factorial experimental project has been designed (4 treatments x 2 sites). Four different managements (fast-intensive rotational grazing (FIRG), continuous grazing, sown pasture rich in legumes, and phosphate fertilization) will be implemented in two different sites (plots of 1 ha each). The FIRG approach will be developed through high animal density in a short grazing time period and an adequate pasture rest.

Figure 20. View of sown pasture rich in legume and native pastures managed with continuous grazing, in the dehesa farm “Los Llanos”, in Siruela, Extremadura

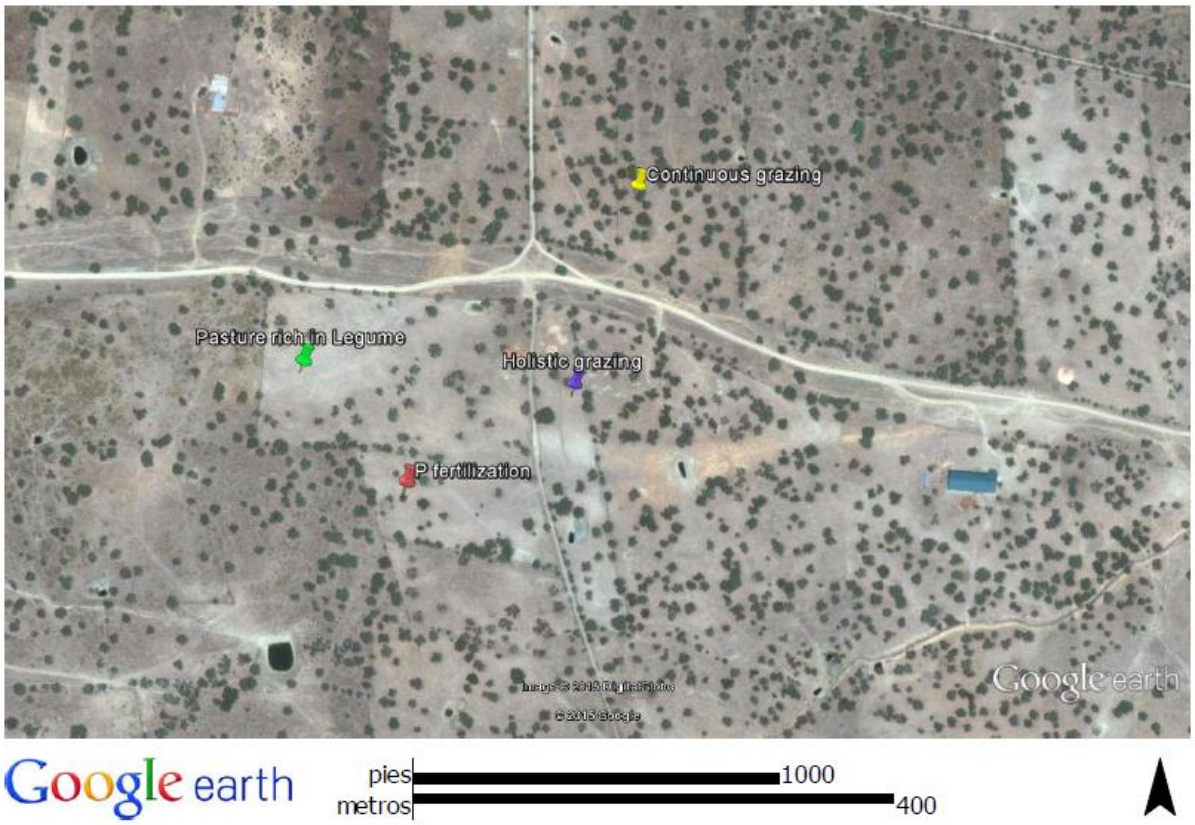

Figure 21. Location of the four treatments compared in one of the sites of the dehesa farm “Los Llanos”, in Siruela, Extremadura

7.4 Measurements

The effects of these treatments will be compared by monitoring different ecosystem indicators. Table 8 below shows the variables that will be monitored. In autumn 2015 and during the upcoming three years we will apply the different proposed managements in the experimental plots.

Table 8. Soil and vegetation indicators, sample sizes (N) and methods

Soil Indicators	N	Method
Compaction	90	Soil penetrometer
Water infiltration rate	27	Infiltrometer
Mineral N and available P	54	Ion-exchange resin membrane
Soil organic matter	54	Wet oxidation
Bulk density	54	Soil cores of 192.42 cm^3
Soil respiration	54	Portable soil respiration system measuring soil CO2 flux

Vegetation Indicators	N	Method
Productivity	27	Exclusion cage and biomass weight
Functional diversity	27	15 m transect
Vegetation cover	27	15 m transect
Tree recovery	27	30 m transects

8 Livestock management assisted by GPS collar

8.1 Motivation

A large portion of European rural land, especially in northern, eastern and southern Europe, is devoted to livestock husbandry on wood pastures and other rangelands facing environmental and economic threats. Since the second half of the last century, extensive shepherding has suffered significant reductions as people have moved out of rural areas. This situation has forced a process of simplification in management and a progressive trend towards monocropping. These changes are compromising the persistence of the efficient use of wood pastures and rangelands and the conservation of silvopastoral systems of high natural value. These semi-natural systems produce high quality goods in biodiversity rich territories that are threatened by environmental and economic marginality.

To increase competitiveness, rangelands need to promote a more efficient use of critical resources, especially livestock, pastures and water. In addition, the risk of catastrophic events associated with environmental marginality, such as livestock and tree diseases, need to be minimized to increase whole-system resilience. Information and communication technologies can provide a reliable assistance to this complex situation by helping to improve the efficient use of the available natural resources and reducing the risks of further degradation. Livestock husbandry plays a critical role in this scenario and information technology has today the potential to transform the way herds will be managed by future farmers.

8.2 Objective of the trial

The aim of the trial is to improve substantially the efficient use of natural resources in dehesa rangelands while reducing biotic risks and management costs. This end is to be achieved by devising new advanced livestock wearable devices and collars that will extend the virtual fencing paradigm with new, high-value uses, such as the prevention of contagious diseases from wildlife to livestock and the protection of scattered saplings in semi-natural rangelands facing environmental and economic threats.

8.3 Expected benefits

- Virtual fencing eliminates the need of artificial separations among pastures, significantly reducing the number and extension of wire and barber wire fences. This action will result in a cleaner, safer and reduced management cost of silvopastoral systems.
- The continuous acquisition of knowledge about livestock displacements, along with the capacity of remote shepherding, will improve the management of current pastures increasing the profitability of rangelands.
- The collar, in combination with inexpensive RFID (Radio Frequency IDentification) tags can be used to preserve the livestock from visiting or feeding in selected places. This functionality will be used to protect scattered saplings necessary for the reforestation of endangered silvopastoral systems.
- Additionally, an urgent and devastating problem in many places in Europe where wild ungulates and animals such as wild pigs cohabit with livestock, is the transmission of tuberculosis. One of the most effective solutions is to keep the domestic animals from drinking in the same ponds as the wildlife. The collar, in combination with RFID tags, can be used to virtually mark ponds as

forbidden areas and, at the same time, allow the livestock to drink from controlled access points that will provide water only to electronically identified animals.

- Animal reproductive males without human supervision is also a demanded functionality provided by the collar, since matings will be detected, recorded and transmitted to a remote server storage.

8.4 Technological challenges

While the needs raised by a representative fraction of silvopastoral ranchers are clear, no technological device is currently available to satisfy their demands. Experimental developments and a few commercial GPS trackers provide only limited autonomous operation, substantially below the six months required, and lack an open hardware and software architecture that could be expanded to add the required new uses. The overall challenge is to adapt and improve commercial GPS-collar devices for dehesa conditions. The objectives are:

- To design, develop and validate a new wearable device capable by itself of keeping the livestock inside virtual fences and outside singular spots for periods over six months.
- This collar will be able to interact harmlessly with the animal using negative stimuli, i.e. ultrasound, in order to locally modify its behavior. This actions will be triggered by an intelligent controller running in the collar's embedded computer and following a remotely loaded spatial plan.
- Also, the collar will communicate directly or through other collars with the internet to send position and other sensor data, and to receive reprogramming instructions. To allow this, a rapid deployment framework will be developed to adapt the firmware of the devices to the rangeland particular conditions of Global System for Mobile Communications (GSM) and Global Position System (GPS) coverage, or the availability of ground antennas supporting ZigBee triangulation technology.
- The self-recharging of the onboard batteries is a major challenge that will be researched using locally available sources including photoelectric, thermoelectric, piezoelectric and kinematic forms of transducing energy.
- A new generation of embedded software controllers for the collars will be created with the necessary local intelligence to manage a changing and unreliable communications network, optimise energy storage by opportunistic harvesting from unsteady available sources and apply a behavior modification program to shepherd the livestock.
- Global models of intelligence will be devised to integrate herd management wearing these cyber-collars, with existing digital models of the silvopastoral bio-dynamics. Livestock wearing these devices are a powerful source of environmental data that can be fused with traditional remote sensing sources such as airborne and satellite images to facilitate the construction and updating of more detailed and better calibrated models of a large-scale ecosystem.

8.5 Expected returns

- Significant improvement of livestock and semi-natural land management in extensive rangelands of the European Union devoted to livestock husbandry.
- The development and extensive testing in real heterogeneous conditions of these devices will provide a proof of concept for a commercially viable product. Start-up initiatives will be explored with SME partners in order to analyse production and marketing potential.

- Recovery of endangered areas by a more rational and sustainable exploitation of their natural resources. A measurable economic return is widely expected from the introduction of information technologies in this primary sector, especially in rangeland areas.
- Stimulation of rural activity and repopulation.

8.6 Technological program

The design and construction of a collar with these requirements is a considerable challenge that will confront combined technological, ethological and land management problems. To maximise the probabilities of success we have devised an ordered sequence of experiments that should validate each step of the development process. The main technological challenges that have to be solved are:

- A minimum of six months energy supply, provided either by standalone batteries, or using some auxiliary energy harvesting technology, such as flexible solar panels o piezoelectric generators. Six months is a usual time span for sanity control of the animals.
- Reliable data transmission using the General Packet Radio Service (GPRS) or GSM to a designated server. In order to reduce the cost of the collar, herding behaviour can used to design simpler collars with Wi-fi or zigbee connectivity that would transmit to a more expensive router-collar carrying mobile communications and extra battery. Data does not have to be uploaded to the server in real time, since the collars have all data they need to perform virtual fencing and active avoidance.
- Reliability for a flawless working during the unattended period supported by the batteries. This is a difficult challenge since time is scarce and special care will need to go into the design to minimize unexpected failures.
- A low final cost is extremely important since cattle owners are reluctant to big investments without proven guarantees. Using the router/slave variations, the majority of the cost in the slave collars goes to the GPS module and the batteries.

8.7 Experiment planning

To unfold this technological program we have devised a carefully planned schedule of experiments and milestones. Each step leads to the next one and contemplates alternative situations when a dead end is encountered.

1. Selection of valid technology for embedded computation, communications, energy, GPS, discharge generation and GSM/GPRS.
    - Trade-off between ultra low-cost potentially unreliable technology and high quality devices.
    - Trade-off between modularity and integration.
    - Nominal energy consumption of components.
    - Computational model of consumption for the whole system.
2. Testing current intensity and discharge frequency with remote controlled dog collars in controlled environments.
    - Response to direct stimulation. Minimum threshold determination.
    - Virtual fence experiment. Definition of a discharge gradient.
    - Set of valid parameters to be translated to the collar.
3. Test of GPRS/GSM and intra-herd transmission reliability and reach in laboratory conditions.

- Real transmission reach and robustness of communications with very low cost Wi-Fi/zigbee radios.
- Reliability of GPRS/GSM transmission with sleep/wake up cycles
- Evaluation of dynamic local network creation/break up and router behaviour.

4. Test of energy consumption in laboratory conditions
   - Setup for microamperes measurement in real operation cycles of individual modules.
   - System integration and testing.
5. Test of energy consumption with GPRS/GSM transmission with a selected animal in controlled conditions.
   - The collar is carried by a selected animal during short periods of time and all relevant variables are recorded.
   - Analysis of data and re-evaluation of current design.
6. Test of energy consumption with intra-herd transmission with selected animals in controlled conditions.
   - The collar is carried by a selected animal during short periods of time and all relevant variables are recorded.
   - Analysis of data and re-evaluation of current design.
7. Test of intra-herd communications through the router-collar getaway with selected animals in controlled conditions.
   - The collar is carried by a selected animal during short periods of time and all relevant variables are recorded.
   - Analysis of data and re-evaluation of current design.
8. Experiments in open field for increasing periods of time. At this point of the development process most of the technology should be validated. Longer term experiments will show additional aspects to be corrected to approach a pre-industrial prototype.

9 Consumer acceptance of agroforestry products and services

9.1 Motivation

Among the long list of ideas and innovations that were proposed to widen the opportunities for dehesas regarding their conservation and profitability, most participants of the meeting (carried out in Plasencia the 30 May 2014), stressed the need for studies to explore new opportunities for dehesas within the AGFORWARD project related to product diversification and market demands. Participants mostly demanded research focused in the enhancement of integration of management and exploitation of the dehesas through diversification of productive activities and the valuation of their different products.

We need to take into account that the main products provided by dehesa agroforestry systems are animal products raised in livestock farms in extensive conditions. Different livestock species are usually raised at the same time producing high quality meat and milk products. 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 other sheep products 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: the main production of goat herds is milk for the local manufacture of high quality artisanal cheeses.

Swine: 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. Furthermore, the pig is a perfect complement to ruminants, so that its addition improves the profitability of sheep and/or beef holdings.

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, etc. 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.

In 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 byproducts 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.

These points of view (among others) were shared by the stakeholders throughout the initial meeting. Several ideas were also proposed at the meeting that were later prioritised according to the methodology designed by the team at the University of Extremadura in order to establish innovations that could be tested in the AGFORWARD project.

These ideas were organized in a list that was created taking into account the conclusions of the meeting. A total of 54 proposals, grouped in 11 thematic blocks were generated. The groups of proposals were:

Forage autonomy and Improvement of pastures		Soil protection
Pastoral management	Protection of the trees	Ecosystem services
Livestock productivity	Productivity of the trees	Governance
New products	Market	Policy

Starting from this list, empirical studies will be carried out in order to analyze consumer behavior towards products and services provided by Dehesa Agroforestry Systems. This protocol has been developed by the Agricultural and Food Economics Research Group in order to carry out these tasks.

9.2 General objective of trial

According to the above mentioned conclusions of the initial stakeholder meeting, three main objectives will be analyzed using different methodologies. Experiments will be developed in the area of influence of the “Dehesa” Agroforestry System, mainly in Extremadura Region. The objectives are:

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

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

9.3 Task 1: Identification of agroforestry derived products and services

The objective of this task is to undertake a qualitative study in order to identify consumers' extent of knowledge about agroforestry systems, with a special focus on "Dehesa ecosystems" and the benefits they generate. This exploratory study will serve as a basis for subsequent quantitative phases, because it can identify products (currently marketed or with potential of development) that could have a market added value for citizens.

Some of the Innovative Proposals brought up in previous steps of the Project and that will be dealt with within this task are:

- Valuation of new and old products from dehesas and other similar agroforestry systems of high natural and cultural value.
- Using sweet acorn oak genotypes (with low tannin content) to produce high quality foods such as gluten-free flavors, cakes, ice-creams, horchata (vegetal milk), and oils rich in unsaturated fatty acids,
- Silviculture for highly regarded edible mushrooms as King bolete (*Boletus edulis* and others), Caesar's mushroom (*Amanita caesarea*), *Amanita ponderosa*, and *Terfecia arenaria* which grow commonly in dehesas.
- Managing and valuation of other dehesa products such as oak honey (bees fed with oak honeydew), manufactured cork, aromatic and medicinal plants, and natural tannins and dyes.

9.3.1 Methodology

This task of the project will use "focus groups", a qualitative research technique suitable for the initial stages of an exploratory research. Focus groups are generally composed of 8 to 12 people who are unfamiliar to one another and who are selected because of sharing certain characteristics relevant to the study's questions. In this study, four focus group sessions will be carried out with around 40 participants.

Participants will be selected by means of a convenience sampling, a non-probability method commonly used in qualitative research when the aim is to obtain an approximation to a specific topic (Kinnear and Taylor 1993). Willingness to participate in the sessions will be main criteria used to recruit the participants in the study. The four sessions will be held in facilities preferably located in the University of Extremadura. Participants are volunteers and receive no monetary incentive for their participation. The sessions will be recorded on audio for later analysis.

After each focus group, a report reflecting the main points of interest will be produced. The audio recordings of the focus groups will be transcribed and analysed. This process will be performed four times, comparing different focus groups discussions and the responses of different participants until central themes emerge. Data will be analyzed using content analysis (Stewart and Shamdasani, 1990).

9.4 Task 2: Consumer behaviour towards previously identified products and willingness to pay for agroforestry derived products and services

Once the products and services have been identified the next step is:

- to determine the degree of knowledge of the products derived from agroforestry systems by consumers,
- to identify the relevant attributes in the product purchasing process (to find out if related environmental services are relevant), and
- to know the willingness to pay for agroforestry products and services.

9.4.1 Methodology

The methodology will use "projective techniques" to determine the degree of knowledge, perception of new products, attributes identification and association with agroforestry. "Choice experiments" will be used to estimate willingness to pay and the importance of each of the attributes identified by consumers

Projective techniques

Due to the nature of the study, the target population will be citizens of different areas of Extremadura (residents in small, medium and large towns of the autonomous community). Initially, and in order to contrast the questionnaire to be used, a pre-test will be performed with 10-20 individuals. Those questions that receive ambiguous answers or are difficult to understand by the participants will be corrected.

The final sample will consist of 150-200 individuals, who will present different socio-demographic characteristics (sex, age, education). We will contact respondents in public places (university campuses, shopping malls and urban areas), choosing them according to their interest and availability to participate in the study. It can be considered, therefore, that a sample of convenience (not probabilistic method) will be held.

A printed questionnaire will be delivered to participants in the study and will include: i) questions about socio-demographic variables, ii) questions about the degree of knowledge of agroforestry systems, iii) questions for the association of words and, iv) completion of sentences. The surveying will be performed by a specialist or contracting directly with interviewers in each area. Data analysis will be performed using one of the programs available on the market for qualitative data analysis (NVIVO, ATLAS.ti or similar).

Choice experiments

Choice experiment is a useful tool to estimate the effect of different attributes which constitute the structure of consumer preferences. Due to its potential, it has been widely used in the food sector. A choice experiment is characterized by the inclusion of several options of the same product carrying different attributes, with the subject selecting the option which better reflects his preferences. This procedure is more similar to the typical shopping decision of consumers when buying products in the real markets (Van-Loo et al. 2011), and therefore it can provide useful information for the producers to define their marketing strategies (Mauracher et al. 2013).

An online survey can be utilized for data collection. It is considered that the most appropriate will be hiring a professional panel to generate a representative sample based on their email addresses databases. It is estimated that the sample should have a size of about 400 people by geographic area if we want to get results at regional level (or reach 1000 surveys if the study is done at project level).

9.5 Task 3: Identifying strategies to encourage the marketing of agroforestry derived products

For this purpose, a study of new marketing channels will be carried out through a Delphi study with experts from different backgrounds.

9.5.1 Methodology

The Delphi method basically involves a process aimed at establishing a consensus among representative experts, and can be summarized in the following phases:

- Expert Panel Selection
- Development of the Delphi first round: Design and delivery of the first questionnaire
- Summary of responses from the first round and analysis
- Design and delivery of the second questionnaire and setting of initial probabilities
- Delphi Second Round
- Summary of responses of the second round, data analysis and determination of final probabilities

The experts selected should not communicate with each other, and their opinions are usually obtained through email or through web tools for online data collection.

In our case the goal is to contact a group of 20-30 stakeholders linked to different areas of expertise: agroforestry areas, product marketing and valuation of ecosystem services. Technicians, researchers, independent experts, representatives of producer organizations and members of environmental organizations will be contacted. Based on previous experience of the research group, we consider that by developing two Delphi rounds we can achieve a satisfactory degree of consensus among the participants.

10 Carbon sink strength of Iberian dehesas: the role of tree and pasture

10.1 Motivation

During the past 20 years, there has been an increasing appreciation of the extent of the negative externalities associated with livestock production, either as grazed ruminants or animals such a pigs and poultry (Burgess and Morris 2009). The key negative externalities include methane production by ruminants, ammonia and nitrous oxide production by all forms of livestock production and emissions related to feed production. Recently it was estimated that Europe's meat and dairy consumption was responsible for 14% of the increase in global warming potential of emissions in the EU (Weidema et al. 2008), and livestock production is seen as a key driver of global land use changes, with resulting impacts on climate change and biodiversity.

The integration of trees with livestock is seen as one method to mitigate ammonia emissions, and to store carbon as an offset for methane and nitrous oxide production (Hristov et al. 2013). The contribution of trees to the build-up of the soil carbon pool has been repeatedly reported (Mosquera-Losada et al. 2011) and comparison among pastures and silvopastures show that C pool is significantly higher in the latter ones (Nair 2012). Long-term effects of improved pasture establishment in Portuguese montados caused higher organic-C than those under unmanaged pasture, and the effects were stronger in the presence of oak trees (Gómez-Rey et al. 2012). Howlett et al. (2011a) and Howlett et al. (2011b) reported good examples for Atlantic and Mediterranean oak silvopastures of Spain. In these studies, soil C was almost doubled beneath tree canopies compared to open pastures. The higher inputs of residues generated by trees in silvopastures than in tree-less systems may cause high soil C sequestration potential and C could be stored deeper and for longer, what need to be more explored.

10.2 Objective of trial

The objective of this study is to monitor the carbon balance at ecosystem level and for each of their components (trees and pastures) with a high-temporal resolution and under different scenarios of nutrient availability in order to assess if dehesas are currently sequestering carbon and the extent to which trees contribute to carbon balance.

Key questions include:

- are trees contributing substantially to increase the strength of the system to sequester carbon?
- do trees contribute to buffer the temporal variability imposed by high seasonal and inter-annual variability of Mediterranean climate?
- can the alteration of the soil N/P ratio alter the functioning of the system and the carbon balance?

Alongside these aims, a number of hypotheses can be developed:

- trees have a net effect on pasture productivity dependent of soil moisture availability
- trees contribute to smooth the temporal variability of pasture productivity
- trees contribute highly to carbon sequestration of the dehesa ecosystems, both by accumulation in biomass and by accumulation in soil.
- the expected increased N deposition from the atmosphere to the dehesa hardly will alter the carbon balance given the water shortage experienced by the ecosystem.

10.3 Experimental layout

At the public dehesa farm of Majadas de Tiétar (Extremadura) there are three Eddy covariance station of the international network FLUXNET (http://fluxnet.ornl.gov/site/440 and http://www.ceam.es/carboredes/metadatos.htm#MAJADAS). This experimental station is currently supported and managed by Max Planck Institute for Biogeochemistry (Jena, Germany), Centro de Estudios Ecológicos del Mediterráneo (Valencia, Spain) Centro de Ciencias Humanas y Sociales-CSIC (Madrid, Spain) and University of Extremadura (Plasencia, Spain).

These stations register continuously the fluxes of CO_2 and water vapour exchanged by three typical dehesa stands (footprint around 25 ha for each of them). One stand is used as Control, while one of them was fertilized with N (100 kg N ha^{-1} applied as ammonium nitrate) and the third one was fertilized with N+P (100 kg N ha^{-1} applied as ammonium nitrate + 50 kg P ha^{-1} applied as triple superphosphate). Additionally, a 1-ha plot was fertilized only with P (without eddy covariance tower nor other automatized measurements). Figure 22 shows the location of the four treatments. The control tower is operating since 2003 and has accumulated a huge database of C and H_20 fluxes, together with other ancillary data regarding tree growth and pasture productivity (see below). Treatments and two additional towers started in 2014.

10.4 Measurements

- Ecosystem-scale eddy covariance tower (15 m height). Measure C and water vapour exchange (produced by roughly 25 ha of wood pasture) for the system (tree + pasture). Besides rainfall, air temperature and humidity, wind speed, solar radiation (global and diffuse) are recorded. In the control area, an additional tower placed a 1.5 m height records gases exchange for pasture layer.
- Other automatic measures. Soil temperature (until 30 cm depth), soil moisture (until 120 cm depth), tree sap flow, stem tree growth, tree and pasture phenology, pasture evapotranspiration (automatic lysimeter).
- Ancillary measures. Tree leaf production, tree LAI, acorn production, nutrient content in tree leaves and pasture, pasture production (both beneath tree canopy and out of the canopy), pasture LAI, consumed herbaceous pasture, soil nutrient content (both beneath tree canopy and out of the canopy), soil + pasture respiration and photosynthesis, botanical composition of pasture.
- Remote and proximal sensing. Detailed fine scale spectral observations using hyperspectral optical as well as thermal and Lidar sensors and the analysis of remote sensing data provided by airborne and satellite sensors.

10.5 Modeling proposal

The complete monitoring of Majadas dehesa farm, including different scenarios of nutrient availability give us an optimal situation for modelling exercises in AGFORWARD. Two specific questions could be modelled:

- the effects of trees on pasture understory production under different scenarios of nutrient availability and water availability, and
- the effects of tree carbon sequestration under different scenarios of nutrient availability and water availability.

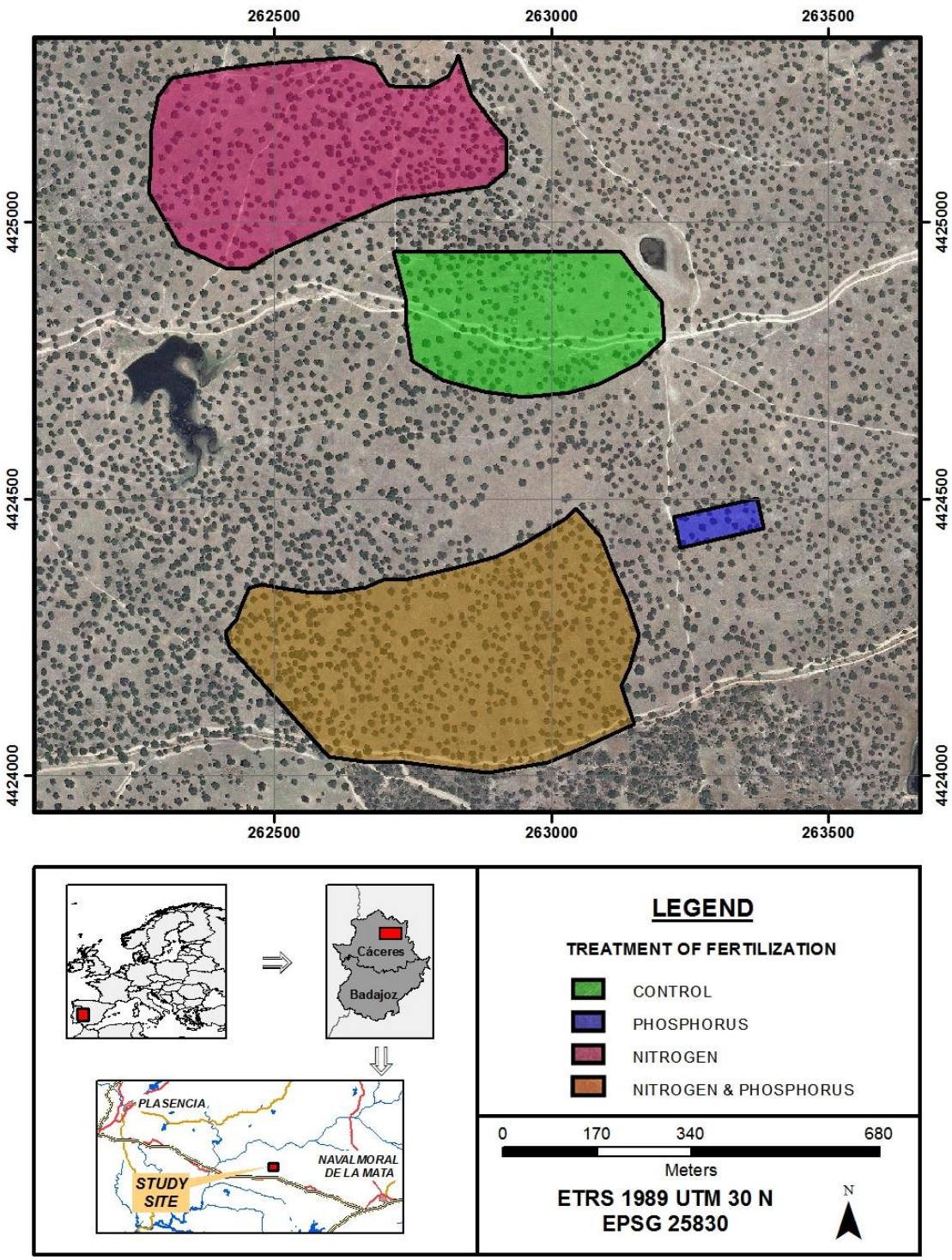

Figure 22. Location of the four fertilization treatments in Majadas dehesa farm, a FLUXNET station for the monitoring the effects of climate change on terrestrial ecosystems

Figure 23. View of the control and N+P fertilized eddy-covariance towers in Majadas FLUXNET station

Figure 24. View of the pasture-scale eddy-covariance in Majadas FLUXNET station (control site)

Figure 25. View of the close chamber to measure gases exchanges at soil-pasture scale

Figure 26. View of the lysimeters installed to monitor water evapotranspiration by soil-pasture system (control site)

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

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

Figure 29. View of the litterfall traps used monitor litter and acorn production tree leaf area index (LAI)

Figure 30. View of the soil profile in Majadas Control site

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ANNEX A. Description of the study sites

FARM 1. LAS PARRAS

Private dehesa with an approximate area of 1,900 ha used mainly for cattle production. The farm has a relatively flat topography, with a few rolling hills of gentle slopes (< 15 %). In the center of the farm can find the Reservoir of Borbollon. Vegetation consists of holm oak (*Quercus ilex*), cork oaks (*Q. suber*), and pasture. In some areas there is oakwood forests (*Q. pyrenaica*) and the shrub layer is dominated by *Retama sphaerocarpa* L. Average tree density is between 20 to 30 trees ha-1 although in the study area this density is lower. Tree regeneration is low with only few scattered young trees in those areas less accessible to cattle.

Table A.1. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Seedling protection UTM coordinates: 29N, X = 711300 m; Y = 4445400 m Plot Size: 24.0 ha Field test (2): Tree regeneration - Acorn protection UTM coordinates: 29N, X = 711350 m; Y = 4445650 m Plot Size: 2.5 ha
Co-ordinates:	Villa del Campo, Caceres province, Extremadura, Spain
Site contact:	Alfonso García Cobaleda
Site contact email address	sitocob@gmail.com

Soil characteristics (on productive forest land)	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	3-4 trees ha-1; Young & Adult (20-80 yr-old)

Livestock characteristics	
Species	Cattle
Stocking density	0.5 LU ha-1 (Extensive grazing with feeding supplementation)

Climate data	
Mean monthly temperature	15.4°C
Mean annual precipitation	739 mm
Details of weather station	

FARM 2. MONTEVIEJO

Monteviejo is a private dehesa located in the municipality of Moraleja, Cáceres. It has an area of 700 has and it is used mainly for fighting bulls, with 500 individuals. Local topography is flat, with some undulation (<5 %). Vegetation consists of holm oak (*Quercus ilex*) and pasture. Average tree density is between 20 to 25 trees ha-1 although in the study area this density is lower. The crown cover of vegetation varies from 10-20%. Tree regeneration is absent.

Table A.2. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Seedling protection UTM coordinates: 29N, X = 702000 m; Y = 4433900 m Plot Size: 3.0 ha
Co-ordinates:	Moraleja, Caceres province, Extremadura, Spain
Site contact:	Victorino Martín García
Site contact email address	oficina@victorinomartin.com

Soil characteristics (on productive forest land)	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	26 trees ha^{-1} (>100 yr-old)

Livestock characteristics	
Species	Fighting bulls
Stocking density	0.45 LU ha^{-1} (Extensive grazing with feeding supplementation)

Climate data	
Mean monthly temperature	16.0°C
Mean annual precipitation	649 mm
Details of weather station	

FARM 3. ATOQUEDO

Atoquedo is a private dehesa of 800 has. The farm has two distinct areas: a mountainous area with 200 has and a flat area with 600 has. The mountainous area is protected as a national park. There is not livestock but there is many deer. Vegetation consists of cork oak (*Quercus suber*) and shrubs dominated by *Cistus ladanifer*. The flat area is used mainly for sheep production with 1,000 individuals. There is also a small livestock of goats (27 individuals). Vegetation consists of holm oak (*Quercus ilex*) and pasture. Average tree density is between 20 to 30 trees ha-1 and crown cover varies from 20-30%. Tree regeneration is almost absent.

Table A.3. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Seedling protection UTM coordinates: 30N, X = 248200 m; Y = 4405800 m Plot size: 6.0 ha Field test (2): Forage rich in legume UTM coordinates: 30N, X = 249000 m; Y = 4406000 m Plot size: 275.0 ha Field test (3): Cultivars of triticale UTM coordinates: 30N, X = 248100 m; Y = 4405600 m Plot size: 6.0 ha
Co-ordinates:	Torrejón el Rubio, Caceres province, Extremadura, Spain
Site contact:	Enrique Rodríguez-Arias
Site contact email address	enrique.r.arias@gmail.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	24-26 trees ha^{-1} (60-80 years-old)

Livestock characteristics	
Species	Sheep and goats
Stocking density	1.67 ewes and 0.05 goat ha^{-1} (Extensive grazing with feeding supplementation)

Climate data	
Mean monthly temperature	15.8°C
Mean annual precipitation	546 mm
Details of weather station	

FARM 4. MAGINES

Table A.4. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Seedling protection UTM coordinates: 30N, X = 259900 m; Y = 4419500 m Plot size: 3.5 ha
Co-ordinates:	Toril, Caceres province, Extremadura, Spain
Site contact:	Juan Manuel Durán Torres
Site contact email address	juanmanuel.monfrague@gmail.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	34 trees ha^{-1} (60-80 years-old)

Livestock characteristics	
Species	Cattle and sheep
Stocking density	Not provided; extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	16.2°C
Mean annual precipitation	664 mm
Details of weather station	

FARM 5. VALDESEQUERA

Table A.5. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Seedling protection UTM coordinates: 29N, X = 685000 m; Y = 4405800 m Plot size: 6.0 ha
Co-ordinates:	Villa del Rey, Badajoz province, Extremadura, Spain
Site contact:	Miguel Angel Pitarch
Site contact email address	Responsible Angel Rodriguez; Agrodehesa Gestión S.L. agrodehesa@gmail.com)

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	

Livestock characteristics	
Species	Sheep and pigs
Stocking density	Not provided; extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	16.6°C
Mean annual precipitation	523 mm
Details of weather station	

FARM 6. DEHESILLA

The Dehesilla is a private dehesa with an area of 650 ha, used mainly for cattle production, with 260 individuals, and hunting activities (wild boar, red deer and roe deer). Local people have access to fishing and other recreational activities in the area. Local topography is undulating, with gentle to rolling slopes (3-18%). Vegetation consists of holm oak (Quercus ilex. L) (and few cork oaks), and pasture. In some areas a shrub layer is dominated by *Retama sphaerocarpa* L. and *Cytisus multiflorus* (L'Her) Sweet. Average tree density is between 25 to 35 trees ha^{-1} and crown cover varies from 20-30%, although in some areas tree density may be as high as 200 trees ha^{-1}. Tree regeneration is almost absent with only few scattered young trees in those areas less accessible to cattle.

Table A.6. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Acorn protection UTM coordinates: 30N, X = 244800 m; Y = 4410200 m Plot size: 1.5 ha
Co-ordinates:	Valdehuncar, Caceres province, Extremadura, Spain
Site contact:	Victor Arroyo Gubau
Site contact email address	victorarroyo92@hotmail.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	25 trees ha^{-1} (20-60 years-old)

Livestock characteristics	
Species	Cattle
Stocking density	0.4 LU ha^{-1}; extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.8°C
Mean annual precipitation	640 mm
Details of weather station	

FARM 7. SANTI SPIRITUS

Table A.7. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Acorn protection UTM co-ordinates: 29 N, X = 744900 m; Y = 4429000 m Plot size: 1.5 ha
Co-ordinates:	Plasencia, Caceres province, Extremadura, Spain
Site contact:	Antonio Gamonal Adámez
Site contact email address	agrotea@hotmail.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	29 trees ha^{-1} (60-80 years-old)

Livestock characteristics	
Species	Cattle
Stocking density	0.36 LU ha^{-1}; extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.0°C
Mean annual precipitation	739 mm
Details of weather station	

FARM 8. SAN PEDRILLO

Table A.8. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Acorn protection UTM co-ordinates: 29N, X = 741800 m; Y = 4435800 m Plot size: 2.5 ha
Co-ordinates:	Plasencia, Caceres province, Extremadura, Spain
Site contact:	José Maria Cid Delgado
Site contact email address	ppillo_60@hotmail.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	26 trees ha^{-1} (60-80 years-old)

Livestock characteristics	
Species	Sheep and cows
Stocking density	4.5 sheep and 0.6 cows ha^{-1}; extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.8°C
Mean annual precipitation	674 mm
Details of weather station	

FARM 9. VALVERDEJO

Table A.9. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Tree regeneration - Acorn protection UTM co-ordinates: 29N, X = 741800 m; Y = 4435800 m Plot Size: 2.5 ha
Co-ordinates:	Plasencia, Caceres province, Extremadura, Spain
Site contact:	José Maria Cid Delgado
Site contact email address	ppillo_60@hotmail.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	34.4 trees ha^{-1} (80-100 years-old)

Livestock characteristics	
Species	Cattle
Stocking density	1.34 cows ha^{-1}; extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.2°C
Mean annual precipitation	696 mm
Details of weather station	

FARM 10. LOS VARALES

Table A.10. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Cultivars of triticale UTM co-ordinates: 30N, X = 686864 m; Y = 4293812 m Plot size: 5.5 ha
Co-ordinates:	Badajoz, Badajoz province, Extremadura, Spain
Site contact:	Ángel Albarrán Liso
Site contact email address	angliso@unex.es

Soil characteristics	
Soil type (WRB classification)	
Soil depth	>90 cm
Soil texture (sand%, silt%, clay%)	Sandy-clay-loam
Other comments	Alkaline pH, low C_{org}, total N and K, very low P_{Olsen}, and high levels of total Ca and Mg. Without salinity problems and CEC and C/N ratio were normal

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	20 trees ha^{-1} (60-80 years-old)

Livestock characteristics	
Species	Sheep and pigs
Stocking density	4 ewes and 0.5 pigs ha^{-1}; extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.9 °C (± 0.44 SD)
Mean annual precipitation	543 mm (± 148 SD)
Details of weather station	

FARM 11. CASABLANCA

Casablanca has 450 hectare of open savannah woodlands dominated by Holm and Cork Oak trees (*Quercus ilex, Q. Suber*), known locally as 'Dehesas'. Soils are sandy loams and support mostly grazing, with some cropping on the river flats. The ranch has produced certified organic beef since the mid 1990's, and has recently opened a butchering operation to serve its direct sales costumers in the nearby town of Plasencia. Two herds are managed separately, a Limousine herd which is sold through conventional organic industry lines, and a black Avileña herd (antique breed) which serves direct sales consumers wanting specialty cuts or better quality, more flavourful beef. In those years with average or better acorn production, the famous black footed iberian pigs are also run on certain parts of the farm. New enterprises being introduced or considered are farm tours and picnics, and 'Grass-fed beef' production lines. One of the objectives of this study is to determine whether the grass-fed model is a viable option.

Table A.11. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Forage rich in legume UTM co-ordinates: 29N, X = 746000 m; Y = 4448350 m Plot size: 1.0 ha Field test (2): Fast-intensive Rotational Grazing UTM co-ordinates: 29N, X = 747000 m; Y = 4448500 m Plot size: 15.0 ha
Co-ordinates:	Oliva de Plasencia, Caceres province, Extremadura, Spain
Site contact:	Enrique Vega Rubio
Site contact email address	quiquevegar@hotmail.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	28-31 trees ha^{-1} (60-80 years-old)

Livestock characteristics	
Species	Cattle and pigs
Stocking density	0.37 cows, 1.5 calves ha^{-1} and 0.25 pigs ha^{-1}; extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.2 °C
Mean annual precipitation	715 mm
Details of weather station	

FARM 12. HIGALEJA

Table A.12. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Forage rich in legume UTM co-ordinates: 29N, X = 730900 m; Y = 4449400 m Plot size: 2.5 ha
Co-ordinates:	Santa Cruz de Paniagua, Caceres province, Extremadura, Spain
Site contact:	Alejandro Martín
Site contact email address	ASEDGRO; info@asedagro.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Pyrenean oak (*Quercus pyrenaica*)
Tree density	16 trees ha^{-1} (>100 years-old)

Livestock characteristics	
Species	Not reported
Stocking density	Extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.0 °C
Mean annual precipitation	771 mm
Details of weather station	

FARM 13. LA CASILLA

Table A.13. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Forage rich in legume - Long term persistence UTM coordenates: 30N, X = 248200 m; Y = 44200 m Plot Size: 100 ha
Co-ordinates:	Valencia de Alcántara, Badajoz province, Extremadura, Spain
Site contact:	Alejandro Martín
Site contact email address	ASEDGRO; info@asedagro.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	
Tree density	

Livestock characteristics	
Species	Not reported
Stocking density	Extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.8 °C
Mean annual precipitation	577 mm
Details of weather station	

FARM 14. LA CABRA

Table A.14. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Forage rich in legume – Long term persistence UTM co-ordinates: 30N, X = 248200 m; Y = 44200 m Plot size: 6.0 ha
Co-ordinates:	Fregenal de la Sierra, Badajoz province, Extremadura, Spain
Site contact:	Alejandro Martín
Site contact email address	ASEDGRO; info@asedagro.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	
Tree density	

Livestock characteristics	
Species	Not reported
Stocking density	Extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	14.9 °C
Mean annual precipitation	721 mm
Details of weather station	

FARM 15. LOS LLANOS

Table A.15. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Cultivars of triticale UTM co-ordinates: 6.5 ha Plot size: 30N, X = 325000 m; Y = 4317000 m Field test (2): Fast-intensive rotational grazing UTM co-ordinates: Plot size: not reported
Co-ordinates:	Siruela, Caceres province, Extremadura, Spain
Site contact:	Miguel Cabello Cardeñosa
Site contact email address	alydecabello@hotmail.com

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	Holm oak (*Quercus ilex* subsp. *ballota*)
Tree density	

Livestock characteristics	
Species	Not reported
Stocking density	Extensive grazing with feeding supplementation

Climate data	
Mean monthly temperature	15.6 °C
Mean annual precipitation	628 mm
Details of weather station	

FARM 16. MAJADAS

Table A.16. Description of the site, with soil, tree, understorey, livestock, and climate characteristics

Site characteristics	
Area (ha):	Field test (1): Carbon sequestration strength UTM coordenates: 30N, X = 262500 m; Y = 4425000 m Plot Size: 50.0 ha
Co-ordinates:	Majadas de Tiétar, Caceres province, Extremadura, Spain
Site contact:	Majadas City Council
Site contact email address	informacion@ayuntamiento-majadas.es

Soil characteristics	
Soil type (WRB classification)	
Soil depth	
Soil texture (sand%, silt%, clay%)	

Tree characteristics	
Tree species	90% holm oak (*Quercus ilex* subsp. *ballota*), 5 % pyrenean oak (*Quercus pyrenaica*) and 5 % portuguese oak (*Quercus faginea*)
Tree density	26 trees ha^{-1} (60-100 years-old)

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

Climate data	
Mean monthly temperature	16.1 °C
Mean annual precipitation	753 mm
Details of weather station	