Quality of Life and Management of Living Resources

Silvoarable Agroforestry For Europe (SAFE)

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CAPTION OF THE COVER PICTURES

Tree phenology may have a significant impact on light competition in silvoarable agroforestry: these two poplar clones in the Silsoe experimental plot have more than 10 days difference in spring for opening their buds.

The silvoarable farm of Claude Jollet in Poitou-Charentes (France) is a unique silvoarable enterprise with more than 60 ha of 25 year old intercropped walnut and wild cherry trees. This picture displays a very useful aspect: part of the tree plantations were done with forestry schemes (right) and allow the comparison with the agroforestry plots (left).

The landscape value of silvoarable agroforestry was often cited by French farmers among the positive aspects.

See Annexe 1 (INRA-UAFP)
Appendices

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at Les Eduts (Charente Maritime - FRANCE)

Contractor 1 : INRA UAFP

André Gavaland – INRA Toulouse FRANCE

Locating tree row

Record azimuth of the tree row from the tree trunk

Draw a vertical line (with paint) on the tree trunk, to locate the north, from the bottom to the top (if possible) of the tree; for performing this, it is necessary to decide what is the main tree axis.

Dendrometric measurements

Total height

Diameter of the trunk at 1.30 m above the ground

Diameter at ground level, at 0.50 m and 1m above the ground

Height up to the first big branch (= bole length)

Crown description

According to eight directions from the trunk, measure the crown projection (to the ground) radius and the height of the bottom of the crown at each of these eight locations.

Branch inventory

Write a number on each branch: give an increasing number from the bottom to the top of the tree crown (at the bottom of the branch, cut the bark to facilitate the inscription).

For each branch, measure:

insertion height

diameter at the insertion point on the trunk

branch azimuth

Hemispherical photographs

At 18 locations according to the SAFE protocol
Locate the camera at 1.50 m above the ground (on a camera foot) and 15 meters from the trunk

Record (from the tree trunk) the camera azimuth

Put a 3 meters graduated pole in front of the tree trunk

Take four photographs (according to directions different from the tree row direction in order to distinguish the crown of the observed tree from the crown of the other trees)

**Pruning lower branches**

To avoid that branch will be broken when the tree will fall down on the ground, it seems better to cut lower branches before to fell the tree

(Perform branch measurements as described below in &7)

**Felling the tree**

Cut the tree trunk between 0.50 m and 1m above the ground in order to keep the trunk section free from damages at these two latter levels for diameter measurement and trunk slicing.

Make the tree fall down out of the tree row to avoid likely damages on the neighbour trees—Finish painting the North line on the main tree axis up to the “top” of the tree (if its has not been done previously)

Separate the remaining branches from the trunk (at the insertion point on the trunk)

**Measurements after felling**

**ON THE TREE TRUNK**

Measure the total length (take into account the 1.30 m painted ring) to check tree height—Draw a mark on the main tree axis every 0.50 m (according to the marks previously painted at 0.50 and 1m point above the ground)

Measure tree diameter every 0.50 m from the bottom to the top of the tree (up to a near 3 cm diameter point)

Cut the trunk in several parts to allow carrying it for weighing (do not cut the trunk on the 0.50 m marks, neither than at the 1.30 m point to allow further slicing at these levels).

Weigh the entire trunk (main axis)

For ring analysis, cut 15 cm thick slices every 1m from the bottom to the top of the main tree axis and also another slice at the 1.30 m level

Write a number on the upper section of each slice (tree number + trunk level + arrow indicating the North direction)

Cut five other slices of about 5 cm thickness at different levels of the tree axis, for dry matter estimation
Weigh this 5 slices sample and put it in a referenced paper bag (the sample must weigh between 3 and 4 kilograms)

**ON THE BRANCHES**

**For every branches (of more than 3 cm basal diameter)**

Measure the branch length (+ check the basal diameter measured before pruning or felling)

Weigh the entire branch

**On five branches by tree:**

Identify a “main branch axis

Cut off the secondary axis of the branch

Measure branch diameter every 30 cm from the basal point to a near 3 cm diameter point

Cut the main branch axis at the latter point (last diameter measurement)-Weigh the branch log

Cut five slices in this branch log for dry matter estimation

Weigh the five slices sample and put it in a referenced paper bag
ANNEXE 2. Tree phenology recording protocol

(Deciduous Tree Species)

Contractor 1 : INRA UAFP

André Gavaland – INRA Toulouse FRANCE

Based on a proposal by David Pilbeam

With suggestions by Christian Dupraz

Phenological stages documented

For the modelling validation of the tree module, we need to measure 4 dates on our experiments:

Budburst

Completion of short shoots elongation and corresponding leaf extension

Completion of long shoots elongation and corresponding leaf extension

Leaf shedding

Each stage will be characterised by a measurement on a fixed sample of designated trees.

Concurrently, as phenology is mainly related to temperature sums, recording of air temperature is strongly advised. If microclimatic conditions are strongly modified by tree crowns, two measurements may be necessary: within tree canopies, outside tree canopies. This will be very useful for validating the microclimatic module of Hi-SAFE.
<table>
<thead>
<tr>
<th>Phenological stage</th>
<th>Criterion</th>
<th>Comments</th>
<th>Measurement on designated trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budburst</td>
<td>“50% of the buds show bits of leaf lamina”</td>
<td>Should be possible even for highly pruned trees that are out of reach of the view: use binoculars?</td>
<td>Criterion : % of buds open 0 : no 1 : less than 50% 2 : more than 50% 3 : all</td>
</tr>
<tr>
<td>Short shoots completion</td>
<td>“All leaves of short shoots fully extended”</td>
<td>Very important for wild cherry, less for walnut or poplars</td>
<td>Criterion : % of short shoot completed 0 : no 1 : less than 50% 2 : more than 50% 3 : all</td>
</tr>
<tr>
<td>Long shoots completion</td>
<td>“All leaves of long shoots fully extended”.</td>
<td>After this stage, the leaf area of the tree is constant until leaf shedding, unless a second flush of shoot elongation occurs in late summer.</td>
<td>Criterion : % of short shoot completed 0 : no 1 : less than 50% 2 : more than 50% 3 : all</td>
</tr>
<tr>
<td>Leaf shedding</td>
<td>“50% of the leaves on the tree have been shed”.</td>
<td></td>
<td>Criterion : % of leaves shed 0 : no 1 : less than 50% 2 : more than 50% 3 : all</td>
</tr>
</tbody>
</table>
ANNEXE 3. Hemispherical photograph numbering

Contractor 1: INRA UAFP
(from 1 to 18)

NB: Photograph number 1 is always at the North side, even if the tree row direction is not North-South.
ANNEXE 4. Transmitted radiation percentage variation during the year for three black walnuts at Les Eduts

Contractor 1: INRA UAFP

“point by point” figures
ANNEXE 5. Farmer’s awareness on Agroforestry in Spain

Contractor 7 : UNEX

Maite Bellido Díaz

Gerardo Moreno Marcos

August 2004
INTRODUCTION

In Spain, traditional agroforestry systems are still common, although their importance has declined sharply in the last decades. Only dehesa, an agro-silvo-pastoral system is still relevant in term of surface (more than 3 millions ha in S-W of Iberian Peninsula).

However, very few experience on new agroforestry are found. Moreover, the term agroforestry is mostly unknown. Four main reasons are expected to contribute to a poor acceptance of agroforestry systems by farmers in Spain, (i) the general belief of the existence of a strong competence for water between trees and crops, (ii) a scant knowledge of the environmental consequences of many agriculture practices, (iii) the sharp decline of many different crop combinations in Spain in the second half of the twenty century, and (iv) the inexistence of modern agroforestry systems in Spain.

By contrast, the generalised low productivity of many herbaceous crops in Spain maintain farmers “eager” for new ideas and alternatives, which could contribute to increase the acceptance of agroforestry systems.

To know the farmers’ reaction to new silvoarable systems in Spain, 85 farmers have been interviewed. The study have been conducted in only three regions (Extremadura, Castilla-León and Castilla-La Mancha), among the seventeen existing in Spain. The total number of interviews foreseen for each region was 30, but in one of the region (Castilla-León), only 25 were realised.

Additionally, the interview was sent to several technical workers (extension services), but surprisingly, the respond was very poor, and insufficient to obtain any conclusion. Anyway, in personal talks they showed a high interest in the progress of our studies, and they found as possible the implementation of SAF if any type of subsidies is created.

OBJECTIVES

The aim of the study is to measure how farmers react to the proposal of establishing new silvoarable plots on their farms and to determine the conditions of acceptability of a silvoarable project in a farming system.

In this study, farmers should deliver standard information on the technical and economic aspects of introducing silvoarable systems on their farm, including their environmental value.

Questions we should explore include:

- determining in which situation, silvoarable systems can interest farmers and land owners
- finding what are the factors that can encourage or discourage the introduction of silvoarable systems at the farm scale
- listing the parameters that can impeded this introduction and finding what technical measures to adapt to solve these problems
• finding what fiscal aspects need to be solved to allow the development of silvoarable systems

• finding what level of subsidy or what other factors are needed for farmers to adopt new silvoarable schemes

**METHODODOLOGY**

**Selection of regions**

Three regions, among seventeen, were selected to conduct the study, according to three criteria: the existence of vast areas of cereal crops, the existence of some type of extant agroforestry in the region (this criteria was fulfill only in two regions), and the existence of some facilities (e.g. free lodgement) belonging to either University of Extremadura or FGN (our subcontractor in the SAFE project).

The selected regions were:

1. Extremadura: In this region exist almost one million ha of dehesas, probably the important traditional agroforestry system in Europe. Besides, in irrigated land are arising several plantations of high-quality wood species.

2. Castilla-León: The most important cerealistic region in Spain (35%, 49%, 76% and 28% of the wheat, barley, rye and maize in Spain, respectively).

3. Castilla-La Mancha: Very large regions with cereal monocrops, and also important areas with combination of olive trees with vineyards.

**Choice of the interviewed person**

In each regions 30 interviews were foreseen. The interviews are addressed to three different targets: non-farmer land-owners, and land-owning farmers and also leasing farmers. The common feature is that they don’t necessarily know anything about agroforestry and don’t necessarily have any agroforestry project on their land.

To select and contact the farmer, we were helped by the following organizations/organism: a landowner organisation (U.P.A: Unión de Pequeños Agricultores), a farmer associations (COAG: Coalición de Agrupaciones Agrarias), and the extension services of different counties. Previously, to facilitate their collaboration, we visit them to explain different aspect of the agroforestry systems, either in a formal speech or through personal talks. To this task, we prepared both a slide-show and a document reflecting some highlighting aspect of the agroforestry, including some illustrative pictures.

Farmers were selected in order to have a representative sample of the most common type of farms in each region, thus, in Extremadura, 30 farmers were selected all abroad the region, including both, irrigated and not irrigated areas, and both, cereal specialist farms and more complex farms (including dehesas). In Castilla-La Mancha were
included mainly herbaceous crops specialist, both irrigated and not irrigated, and olive specialist farms, from two different provinces. Finally, all the farmer selected in Castilla-León were cereal specialist in non-irrigated land in only one province (Figure 1).

![Figure 1. Localization of the interviews in three different Spanish regions, a) Extremadura, b) Castilla y León y c) Castilla-La Mancha.](image)

The interview takes place in two “rounds”: first presentation of agroforestry, and then interview with questionnaire. To achieve that, farmers were mainly contacted by telephone to establish personal or small-group meetings in the following days.

The interview used was the common for every partner of the SAFE consortium (after a general consensus). In general, the interview result very long for most of the farmer (around 1 hour), and in some case, the second part the interview was simplified by grouping questions or by deleting some of them (in some specific situations some questions had no sense).

A final “follow-up interview” should allow us to see how the message of agroforestry has changed in the mind of the interviewed people. However, due to the lacking of personnel, this second step have not been done.

**RESULTS**

**Characterization of the farms and farmers**

Interviewed people has been classified in function of several variables, which could affect the reaction of the people respect to the Afs. These variables have been: age, size of the farm, landownership, socio-politic activities, status of the farm and the existence of successor.

**Age of the farmer**

In general, the interviewed persons were rather aged farmers (Figure 2), but we did not found a higher predisposition to the AFs in younger people than in aged people (Figure 3).
Young people (< 35 y) is usually working with the parents in the same farming and most of them is still migrating towards the cities. Oldest people (> 65 y) are retired and usually their lands have been leased.

![Figure 2. Classification of the farmer by age classes.](image)

Figure 2. Classification of the farmer by age classes.

![Figure 3. Level of interest on agroforestry by farmer age classes.](image)

Figure 3. Level of interest on agroforestry by farmer age classes.

Size of the farm

Respect to the farm size, the variability was very high, from 4-5 ha till more than 1000 ha (only 3 farms), dominating the small to medium-size farms (Figure 4). We have found that farmers with medium-size farms are slightly more interested on Afs than other farmers (Figure 5).
Property

Near the half of the farmer are the owner of the whole farming, and in general, the percentage of the exploitation belonging to the farmer is very high (Figure 6), which could facilitate the decision-taking process to implement any AFs in the exploitation.
Figure 6. Percentage of farm surface in property.

Socio-Politics charges

A significant percentage of the farmer were involved in some social responsibility, mainly in cooperatives and society of farmers. Nevertheless, most of the farmer had not any social-political responsibility (Figure 7), which usually involves less informed and less open people respect to changes in the structure of the farming. However, the interest for AFs of the people with some type of responsibility was not very different to the interest of the rest of the farmer (Figure 8).

Figure 7. Classification of the farmers in function of their socio-political activities.
Figure 8. Level of farmer’s interest on agroforestry in function of their socio-political activities.
Status of the farming

There was a clear dominance of the single-owner farmers (Figure 9 and 10). 11% of the interviewed farmers would initiate an AF project in their own land, but they would contract people to develop the project. On the other hand, 7% of the interviewed ones would initiate an AF project in rented lands because they don’t have land in property.

Figure 9. Regime of the property of the farms where some type of Agroforestry project could be implemented.

Figure 10. Status of the farms.

Existence of successor

Only a third of the interviewed farmers expected to have a successor for the farm (Figure 11), which could hinder the implementation of a long, even medium-term project.
Previous knowledge of Agroforestry

Most of the farmers were positively impressed by the Agroforestry idea, mainly with the possibility of arranging trees in lines adapted to the present machinery, and with the possibility of growing high quality-wood trees. They showed a high curiosity for this type of systems because most of them had not heard before about agroforestry (73%). In fact, 60% of the interviewed defined agroforestry as afforestation of cropland.

Only 13% of the interviewed had a good knowledge about the agroforestry practices, although 47% of them realized easily and quickly the meaning of agroforestry once we showed them some pictures.

Respect to the existence of the trees in the farming, in a half of the farms there was no trees, even none in the borders (Figure 12). Some isolated trees, generally in the border, were presented in a third of the farm; in this cases, complete lines of trees were rare, except in the limit with streams and roads. Only 20% of the farms had a significant number of trees, dehesas in Extremadura and olive with vineyards in Castilla-La Mancha.

The reasons to maintain the trees in the farms were diverse:

a. Fruit production: acorn in dehesas, olive for oil, a other fruits in trees maintained in the border of the plots.

b. Shadow and protection for workers and for cattle.

c. Landscape amenity.

d. Microclimate (some farmers felt their lands are becoming as a desert).
Figure 12. Existence of trees into the farm.
Farmer’s Awareness on Agroforestry: Positive aspects

Agriculture profitability is very limited in many areas and situations all around Spain, thus the most quoted positive aspects for AFs were the wood productivity and the profitability of the whole system. The diversification of the rent was also highlighted (Figure 12).

More secondarily were quoted different environmental advantages of AFs, although most of the farmers realized the positive role of the trees in the environment conservation. Nevertheless, some farmers stressed the difficulty to grow trees in dry conditions, thus they preferred to plant trees with irrigation, even in rained lands.

![Figure 13](image.png)

**Figure 13.** Positive aspects of Agroforestry systems according to 85 interviewed farmers in Spain. Values are given as percentages of farmers referring to each aspect.

Farmer’s Awareness on Agroforestry: Negative aspects

Economical reasons were also placed as the most important difficulty to implement any AF project: the annual loss of rent and the long time needed to have money from the tree plantation (Figure 14). The present profitability of the cereal farm is rather low, and thus it is difficult to found farmer with enough money to start an expensive project. Finally, many farmers worry about the guarantee of the wood price in a long term. They propose that the administration should guarantee a minimum value for the future wood.
Other highlighted aspect have been the incompatibility with the irrigation systems, although pivot are not very common in many irrigated areas (Figure 15).

Figure 14. Negative aspects of Agroforestry systems according to 85 interviewed farmers in Spain. Values are given as percentages of farmers referring to each aspect.

Economical reasons were firstly quoted: reduction of agriculture rent and the long term of the tree productivity.

Complexity of the systems and mechanisation were also quoted for many farmers.

Biophysical conditions (dry climate, poor soils) were also highlighted

Figure 15. Number of farmer with each type of irrigation system.
Virtual project

Why an Agroforestry project

The profitability of the AFs would be the main reason to adopt this type of practice (Figure 16). Only if the overall profitability is higher than in the present monocrop, farmer would adopt AF projects.

Other reasons, as environment protection, diversification of the labour task, ... were placed in a very secondary position.

In some area, e.g. Tiétar valley in Extemadura, many farmer would adopt an agroforestry project only because the present herbaceous crop (tobacco) is threatened by a strong subsidy reduction.

![Figure 16. Reasons for the initiation of an Agroforestry project. Values expressed as percentage of farmers referring to each reason.](chart)

Where to implement an agroforestry project

Farmers would implement an agroforestry project mainly in their own land (91% of the interviewed people), in small plots (< 20 ha), involving no more than 20% of the total surface of the farm.

A foreseen modification of the law could limit the length of the contract to 5 years for renting land, which would imply a limitations for AF adoption in rented lands.

Agroforestry was considered interesting for small plots of irrigated lands and in marginal lands, where crops are maintained because of the subsidy (e.g. cereal in drylands and tobacco in
irrigated lands). In irrigated lands owner prefer fast-growth trees but they are worry about the possible lost of rent. In non irrigated lands owner wish plant trees but they are worry about the growth of the trees in dry conditions.

Figure 17. Percentage of farmers in function of the surface devoted to an agroforestry project

Figure 18. Percentage of farmers in function of the percentage of the farming devoted to an agroforest project
What to plant in an Agroforestry project

The most interesting combinations for Agroforestry projects:

a. Winter cereal with OAK, PINE, WALNUT, WILD CHERRY.

b. Vineyards with ALMOND TREE, OLIVE TREE.

c. Alfalfa, Ryegrass, Prairie with POPLAR.

d. Sunflower, Peas with WILD CHERRY, WALNUT.
Figure 20. Main trees and crops preferred by farmer to implement an Agroforestry project.
Design of an Agroforestry project

Farmers do not know what would be the optimum design for an Agroforestry plantation, e.g. the distance between tree lines. The main aspect affecting the decision are the irrigation system and the present profitability of the plot.

Machines is not a limiting factor to define the alley width because in Spain machines are usually small.
Figure 21. Distance between tree lines preferred by farmers for agroforestry projects.

18 m.

Figure 22. Scheme of tree-line distribution with watering by sprinklers.
Who should finance the Agroforestry projects

A third of farmers consider that they can invert between 1000-1600 Euros per ha, in small size AF project.

They usually prefer an annual subsidy than an initial grant. Nevertheless, in largest project (above 20 ha), the initial grant become more important.

A farmer proposed the co-property of the trees for farmer and forestry administration, and the farmer would refund the total of the subsidies to the administration when wood is sold; the rest of money will be the benefit for the farmer.

![Pie chart showing tree-line distribution with watering by sprinklers]

Figure 23. Scheme of tree-line distribution with watering by sprinklers

CONCLUSION

On overall, farmer’s awareness on agroforestry was very positive (Figure 24), all more than 50% of them could be interested in implementing an agroforestry project (Figure 25) irrespectively of the region. In fact, there were very few structural difficulties for the implementation of the AF projects:

- machinery is usually medium-small size, which is an advantage to manage between trees.
- irrigation by pivot is not generalised (AF in Spain was found specially interesting in irrigated areas with crops in crisis, like tobacco).
Farmers are usually the owner. Nevertheless, when the land are rented, the contract will be 5 years long as maximum (a new regulation), which could difficult the implementation of AF project in rented lands.

Moreover, many interviewed found the low profitability of the present crops in vast areas of Spain as an additional reason to favour AF projects in Spain. Nevertheless, in some case, the crop profitability was so low that the farmer could prefer to plant just trees, that is to initiate a forestry project.

Most interesting areas for Agroforestry implementation (target areas) were:

- Irrigated lands with crops in crisis, mainly menaced by a sharp reduction of subsidies.
- Semiarid lands, non-irrigated, with low productive cereal crops.

On the other hand, there are some very important flaws in the regulations, to implement AF project.

- The only available money for planting tree is devoted for the afforestation of set-aside agriculture lands, where cropping and grazing are forbidden.
- In some regions (e.g. Extremadura), the presence of trees in cropped plots involves a substantial reduction of the payments for annual crops (around the double of the surface per trees is discounted).
- Many farmers think that with the future single payment many cropland (less productive ones) probably will better for forestry than for agroforestry plantations.

In fact, interviewed farmers were very cautious and expecting respect to the economical studies on the profitability of the AgroForestry Systems (Afs). In fact, the most reluctant aspects for the implementation of the AFS were, in this order, the lost of the annual income, the uncertainty of the productivity, the long-term profitability (versus the rapid incomes in agriculture crops), and the lack of knowledge of AFSs management practices.

The most demanded questions by farmers to initiate in AF practices were:

- Technical advice for the implementation. Which trees species and which combination would be adequate for each situation, ... and also for bureaucracy.
- technical formation for the management. In fact, different farmer association showed their interest in this subject.
- economical studies, considering tree growth and future price for wood.
- Evidently, all the farmers decision would depend to the level of the subsidies. Afforested land should be allowed to be cropped, with o without an specific reduction
of the agriculture grants, and to allow the maintenance of the agricultural status of the lands. The agri-environmental grants could be helpful to compensate the lost of agricultural rent.

Finally, to point out that many interviewed farmer found critical this moment because it should be necessary to profit the next PAC modification to give an specific status for AFs. Agroforestry system could avoid the undesirable abandonment of the cropland with the single-payment.

![Figure 24. Valuation of the Agroforestry System (0 – 10 ).](image)

![Figure 25. Farmers interested in introducing an agroforestry project in their farm.](image)
SCENARIOS TO BE CHECKED BY HI-SAFE MODEL.

1. Scenarios at plot level

- A farmer who wants to plant high quality-wood trees with cereal and leguminous as fodder complement for cattle in a 10-ha plot in an unfertile soil. Tree lines would be irrigated by drop. The harvester for cereal is 6 m width.
  - To study the profitability and the labour cost along time. To compare with a forestry project.

- The present crop will be granted only till 2006. Then, the farmer will be obligate to change of use. The farm has an irrigation system compatible with trees.
  - To compare different tree densities and tree species.
  - When should be more interesting to plant trees, in 2006 or before.
  - To compare the profitability of maize monocrop, pimento monocrop, these crops in combination with trees or only trees, with o without subsidies.

- A farmer wants to improve the profitability of a plot with a low productive cereal crop.
  - To compare different tree densities and tree species.
  - Is it interesting to invert in a irrigation system? Should that decrease the labour cost?
  - Should be the AF project profitable with contracted worker?

- A farmer Intend. To diversify the production of an irrigated (aspersion 18x18) plot, which is usually cropped with maize.
  - To do an economical study with different tree densities.
  - To study different alley widths considering that the machine is 6 m width.

- A farmer intends to initiate an 33-ha AF project irrespective of the subsidies, but he is worry about the wood market.
  - To study the perspective for the future wood market. Could the demand or the price to decrease in the future?
  - To compare poplar with high wood quality trees (walnut, cherry and red oak (Quercus rubra)).
  - To study what is better, to self-carry on the project or to contract a forestry company.
  - Could the administration guarantee a minimum price for wood?.
• A 150-ha farm with rotation of maize and irrigated prairie (for cattle).
  ⇢ Which tree density would allow to minimize the lost of rent?
  ⇢ To compare both less surface with higher tree density or the contrary, more surface with lower tree density.
  ⇢ To know the possible extra rent from tree plantations.

2. Scenarios at farm level

• In farms above 100 ha, with irrigation, it is planned to initiate an AF project in 10% of the farm, combining the present crop (maize, vegetable or alfalfa) with tree lines. There are a 14 m-width sprayer machine, and a 6 m-width harvester. There three types of irrigation: pivot, sprinkler and gravity.
  ⇢ What effect would have in the economy of the whole farm?
  ⇢ They are still paying the infrastructure, thus, they need to minimise the lost of the present rent.
  ⇢ What is more interesting, less surface with higher tree density or more surface with lower tree density.
  ⇢ Which combinations are more interesting?
  ⇢ Which irrigation system is more interesting?

• In a farm above 500 ha, with 75% of dehesa and 25% of cereal crop (without trees). The most important rent in the farm comes from the hunting.
  ⇢ He finds that with the cost of implementing a 10 ha AF project, he could buy 1 ha to crop cereal. To compare both alternatives.

3. Scenario at regional level

• Some municipalities have lands rent to different families, which are cropping tobacco.
  ⇢ To find any type of co-financiation, co-propierty and co-responsibility for AF plantations between municipalities and farmers.
  ⇢ Which effects could have the implementation of the AF projects for the municipality economy.
• A land perceiving subsidies from the afforestation of cropland program is qualify as forestry land and it can not be cultivated in the future, thus, only very marginal lands are been used to this program.

⇒ To compare the profitability of the afforestation of set-aside croplands with both monocrops and agroforestry projects (including also subsidies).
ANNEXE 6. Policy on silvoarable agroforestry in Spain

Contactor 6 (UEX)

A exhaustive revision of the first draft on Eligibility of Silvoarable Systems for Government Financial Support (Task 9.2) is presented here. We present a commented list of the different Rural Development and Forestry Programmes at both national and regional level, arising from the changes in the Rural Development Regulation (1257/99). We have focussed on:

a) tree-planting grants available at wide spacing
b) crop (and livestock) grants available within agroforests
c) agro-environmental grants potentially available for agroforestry

To achieve that, we have checked around 200 regulations (resolution, decree, order, law, Plan, ...) in order to identify practical and juridical obstacles for the implementation of Agroforestry projects in Spain (useful for preparing the Policy Guideline document, Task 9.3). Additionally, we have studied the theoretical\(^1\) possibility of financing of any agroforestry systems in different regions through consultation to different regional administrations, who were asked about the financing of the three different specific AF projects (implementation of alley crop and hedgerows, and maintenance of silvopastoral systems). Nevertheless, the respond was very poor (just 3 regions among 17).

As a next step (next 3 months) we will analyze the Future Policies in relation to agroforestry in Spain:

a) Common Rules for Direct Support Schemes Regulation (1783/03)
b) implications for agroforestry of proposed Single Farm Payment (Guidance Note AGRI/2254/03) (including discussion of definitions of ‘woodland’ used in a number of international conventions)
c) implications for intercropping in orchards of Regulation 2237/03.

Additionally, a first draft of a publication describing the traditional silvoarable systems in Spain and the new silvoarable systems in Europe, their potential

\(^1\) In Spain modern silvoarable technology is unused and in the context of the SAFE project no silvoarable plots as a social experiment has been set up.
ecological and financial benefits, and their political constraints in the context of the CAP, national and regional programmes has been recently prepared and it is expected to be published in next months (Annex 3.9). Also, in November, we are participating in a national congress New CAP (Cáceres, 10-12 November 2004), where we expose the present and future situation of the Agroforestry in CAP.
ANNEXE 7. Spanish Regulations of interest for silvo-arable agroforestry

INTRODUCTION

There are 4 types of Rural Development Programme in the Spanish Community Support Framework (2000-2006):

- Horizontal Programme 1 (Accompanying Programme). This includes all measures that are, irrespective of Objective, funded by the Guarantee section of EAGGF. These include: a) Agro-Environmental Payments; b) Early Retirement; c) less favoured areas compensatory allowances and d) afforestation.
- Horizontal Programme 2 (Improvement of Production Structures). This includes: a) investment in agricultural holdings; b) setting up of young farmers; c) water resources management.
- Regional Programmes – each of the 17 regions in Spain has measures, again funded by the Guarantee section of EAGGF which complement the horizontal measures above. Navarre and the Basque Country are special cases since their share of horizontal funding is administered directly by the Autonomous Regions.

The Leader+ Initiative is complementary to the above Programmes. This Programme will not be discussed hereafter owing to it is focused to fund the Local Action Groups (Grupos de Acción Local), who are responsive for the promotion of the Local Development through original strategies for the sustainable and integrative development accomplishing:

- valorisation of the natural and cultural patrimonies,
- improvement of the economic situation to contribute to the creation of employ.
- Improve the organization capacity of the territory.

HORIZONTAL PROGRAMME 1 (ACCOMPANYING PROGRAMME)

This programme is designed to promote sustainable development in the Spanish countryside by improving both the conditions of production and agricultural infrastructure and providing for environmental protection. Total public funding for the programme will amount to 3 132.081 million euro, with 2 222.856 million euro


3 Footnote to explain Guidance
provided by the European Community through the Guarantee Section of the EAGGF (European Agricultural Guidance and Guarantee Fund). It will cover all rural areas in Spain apart from Navarre and the Basque Country, which will part-finance the measures with their own resources. This programme completes the package of rural development measures programmed at regional level, which also includes horizontal programme 2 (limited to certain regions only). There are four priorities:

**Measure 1: Agri-environmental measures** are intended to: encourage less intensive cereal production and the use of traditional fallow periods and crop rotation (cereals/sunflower); reduce the use of chemical fertilisers and plant-health products and provide assistance for organic farming; combat erosion, prevent fires and maintain wasteland; encourage cultural practices that protect flora and fauna in humid areas; encourage better husbandry of irrigation water; promote the integrated management of holdings to help preserve agro-sylvo-pastoral systems, preserve endangered indigenous species and promote ecological livestock farming. The target is providing agri-environmental premiums for 179,000 producers occupying a total of 2.9 million ha. All member states and regions must include agri-environmental measures in their RDPs.

In national regulation (R.D. 172/2004) there are not any direct reference to the silvoarable systems or tree plantation for soil protection in arable lands. Nevertheless, some measures could indirectly affect the conservation of some traditional agroforestry systems:

* Measure 4.1. for woody crops in terraces or slope: maintenance of the natural vegetation in the border of the plots: 132.22 € / ha.

* Measure 8.1.1. for protection and maintenance of non-productive trees into the farms (at least 5 trees per ha): 18.03 € per ha.

* Measure 9.1.2. for maintenance of dehesas: Clearance of understory woody vegetation (48.08 € per ha) and tree regeneration (gen *Quercus* and *Olea*) (48.08 € per ha).

However, most of the regions have not applied these three measures in their regional regulations, and thus, they are not effective in most part of Spain (Table 1). On the other hand, the measure 6\textsuperscript{th} refers to systems with special environmental interest, but no agroforestry systems are included, and maybe in the future they should be. Up to now, only some general grants for holm-oak regeneration and for conservation of hedgerows are common in Spain; more rare it is to find grants for the conservation of non-productive trees on the farms. Only Pais Vasco seems to have an interesting plan for the maintenance the trees on the farms (Table 1), although nothing about of modern agroforestry systems (as alley crops). Anyways, grants are usually to low to make very interesting them,
mainly when the measure involves an important investment in the farm (as it is the case of tree plantation).

It is very difficult to know the amount of money spent in these measures because they are grouped with many others under the epigraph Landscape/Environment (EU term), where 16 millions of Euros were spent (for 144500 ha), from a total of 62 millions Euros for 660000 ha for the whole measure 1 in 2001.
Table 1. Agri-environmental measures affecting Agroforestry system in Spain.
<table>
<thead>
<tr>
<th>Region</th>
<th>Localization of normative measures</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Order 5/5/2003 (BOJA 90, 14/5/2003)</td>
<td>Tree regeneration in dehesas</td>
</tr>
<tr>
<td>Aragón</td>
<td>Resolution 30/01/2004 (BOA 19, 13/02/04), modified in BOA 24, 25/2/04</td>
<td>General help for olive trees in terraces</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintenance of non-productive trees</td>
</tr>
<tr>
<td>Asturias</td>
<td>Resolution 19/01/2004 (BOPA 06/02/04)</td>
<td>Trees in the borders and Hedgerows</td>
</tr>
<tr>
<td>Baleares</td>
<td>Order 15 January 2004</td>
<td>Improvement and introduction of alternatives to crops.</td>
</tr>
<tr>
<td></td>
<td>(BOIB 13, 27/01/2004)</td>
<td>To promote environmental-friendly systems</td>
</tr>
<tr>
<td>Canarias</td>
<td>Order 1/4/2003,</td>
<td>General help for orchard-trees in terraces</td>
</tr>
<tr>
<td></td>
<td>(BOC 70, 10/4/03)</td>
<td>Maintenance and conservation of traditional hedgerows</td>
</tr>
<tr>
<td>Cantabria</td>
<td>Order 12/01/01 (BOC 13, 18/01/01)</td>
<td>Nothing</td>
</tr>
<tr>
<td>Castilla-León</td>
<td>Order AYG/1727/03 (BOCL 31/12/03)</td>
<td>Nothing</td>
</tr>
<tr>
<td></td>
<td>Order AYG/922/04 (BOCL 116, 18/06/04)</td>
<td>Nothing</td>
</tr>
<tr>
<td>Cast-Mancha</td>
<td>Order 30/04/04 (BOCM 17/05/04)</td>
<td>Nothing</td>
</tr>
<tr>
<td>Cataluña</td>
<td>Order 1/3/2001 (DOGC 3345, 12/03/2001)</td>
<td>Maintenance of trees around the plots</td>
</tr>
<tr>
<td></td>
<td>Order ARP/26/2002 (DOGC 3568)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Order ARP/28/2003 (DOGC 3809)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Order ARP/28/04 (DOGC 4079)</td>
<td></td>
</tr>
<tr>
<td>Extremadura</td>
<td>Order 7/02/04 (DOE 16, 16/2/04)</td>
<td>Nothing</td>
</tr>
<tr>
<td>Madrid</td>
<td>Order 3838/2001 (BOCM 303)</td>
<td>General help for olive trees in terraces</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintenance of non-productive trees</td>
</tr>
<tr>
<td>Murcia</td>
<td>Order 17/1/2002 (BORM 17, 21/1/2002)</td>
<td>Nothing</td>
</tr>
<tr>
<td>Navarra</td>
<td>Order 1526/2003 (BON 149, 24/11/03)</td>
<td>Nothing</td>
</tr>
<tr>
<td></td>
<td>Order 19/2004 (BON 23, 23/04)</td>
<td></td>
</tr>
<tr>
<td>Region</td>
<td>Document Details</td>
<td>Measures Taken</td>
</tr>
<tr>
<td>---------</td>
<td>------------------</td>
<td>----------------</td>
</tr>
</tbody>
</table>
| Pais Vasco | Decree 89/2004 (BOPV 11/6/04) | Protection of rural landscape:  
Windbreak and Hedgerows: 48 Euros / ha  
Soil protection of farms against erosion through the maintenance of structural elements as line of trees, scattered trees (fruit orchards or wood). 60 Euros/ha/y  
Biodiversity conservation:  
Small forests, hedgerows, tree lines in river and streams. 120 Euros/ha/y. |
Non-productive trees: 18.03 €/ha.  
Hedgerows, ... 84.14 €/ha |
| Valencia | Order 7/3/2001 (DOGV 3957, 12.03.02) Order 19/6/02 (DOGV 4282, 01.07.02) Order 2004/X634 (DOGV 4677, 26/01/04) | General help for orchard-trees in terraces  
Organic farmer in open woodland |

- # It is included in selvicultural measures; table 3.

**Measure 2: Afforestation of Agricultural land** will help combat soil erosion and desertification and is particularly important in Spain and will help holdings diversity without producing products that are in surplus. There are direct references to the role of the trees in farmlands, to the needed to achieve a rational use of the natural resources, increasing farm productivity, and also refer to the rural landscape diversification, including the promotion of woods as a benefits for croplands (R.D. 6/2001).

With this program, 451.120 ha of agricultural land have been afforested in Spain in the period 1994-2000, and it is planned to plant 200000 ha in the period 2000-2006 (Plan Forestal de España). Indeed, this is the most important measures in Spain in term of money expenditure (Table 2).

The program offers support for establishment and maintenance of plantations (usually the whole cost) and also income support for agricultural income foregone (Appendix 1). The target is reforestation of 150 000 ha of agricultural land (involving 14 000 beneficiaries). The afforested land must be registered as forestal land and cannot be cultivated for at least twenty years (probably never more, because to reverse the situation from forestland to cropland is usually very difficult).

By contract, grazing could be anticipate (before year 20) if trees are not endangered by animals (evidently with the lost of the compensatory payment). This involves an opportunity for silvopastoral projects implementation.

The national regulation (RD 6/2001) has not any exigency respect to the scheme of tree plantation (continuous surface, density, lines of trees, ...), thus under this scheme it could be possible, but rare, for farmers to plant trees in part of the farm (e.g. field boundaries or in lines every 50 m) and ask for the help for reforestation of
the arable land. A commitment must be given that a percentage of the fields affected will not be cultivated, and this is the area subject to afforestation planting and income support grants.

However, both high minimum tree density (Appendix 1), the minimum plot size (Table 3) required for the afforestation, and mainly the qualification the plots as forestry, make difficult to find any agroforestry plantations with this measure. Indeed, only one region, Andalucía, has a direct reference to lineal plantations of trees in arable lands (Table 2), which are mainly addressed to landscape diversification. Only in one region (Murcia) it specified the exigency of continuity in the afforestation.

Finally, to point out that no information is yet available on how many farmers have applied for this type of agroforestry grant in Andalucia and other regions, but we have failed to found any new agroforestry plantation in Spain, in spite of the very high grants (Appendix 1).

Probably the un-knowledge of the modern silvoarable systems in Spain and the general belief that this program can not be used for this type of project⁴ have contributed to the absence of silvoarable projects in Spain.

⁴ This is the first reaction of most of the technical staff in the administration.
Table 2. Regional Rural Development Programmes for Spain (period 1996-2000).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Millions Euros</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation, Modernisation, etc</td>
<td>356,87</td>
</tr>
<tr>
<td>- Improvement of irrigation systems</td>
<td>181,73</td>
</tr>
<tr>
<td>- Other agricultural infrastructures</td>
<td>91,56</td>
</tr>
<tr>
<td>- Help for catastrophic events</td>
<td>83,58</td>
</tr>
<tr>
<td>Improvements in farms</td>
<td>932,96</td>
</tr>
<tr>
<td>- Setting up of young farmer</td>
<td>570,33</td>
</tr>
<tr>
<td>- Improvement in agricultural holdings</td>
<td>362,63</td>
</tr>
<tr>
<td>Training and human resources</td>
<td>26,86</td>
</tr>
<tr>
<td>Compensatory allowances in Less Favoured Areas</td>
<td>325,89</td>
</tr>
<tr>
<td>To promote of farmer associations</td>
<td>15,79</td>
</tr>
<tr>
<td>Accompanying Programme</td>
<td>1584,84</td>
</tr>
<tr>
<td>- Early retirement</td>
<td>144,98</td>
</tr>
<tr>
<td>- Agri-environmental measures</td>
<td>521,27</td>
</tr>
<tr>
<td>- Afforestation of agricultural lands</td>
<td>918,59</td>
</tr>
<tr>
<td>Measures for Local Development</td>
<td>465,5</td>
</tr>
<tr>
<td>- Leader II (Fund by U.E.)</td>
<td>298,6</td>
</tr>
<tr>
<td>- Proder (Fund by U.E.)</td>
<td>114,0</td>
</tr>
<tr>
<td>- I.C. Leader II and Proder (fund by MAPA)</td>
<td>52,9</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3708,69</td>
</tr>
</tbody>
</table>
Table 3. Afforestation of agricultural land program in Spain, with specific reference to the options for agroforestry plantations. Most outstanding limitations for agroforestry are underlined.

<table>
<thead>
<tr>
<th>Region</th>
<th>Regulation</th>
<th>Opportunities for AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andalucía</td>
<td>Decree 127/1998, BOJA 20-06-1998. Order 5/8/98, BOJA 95, 25-08-1998.</td>
<td>Two measures:&lt;br&gt;1. Landscape diversification&lt;br&gt;&lt;br&gt;Lineal plantation: max. 3000 trees with separation of 2-3 m and surrounded of arable strip of at least m width. Minimum length of tree line of 100 m.&lt;br&gt;&lt;br&gt;Hedgerows: maximum three lines with 2000 trees, and a separation between trees of 1-2 m.&lt;br&gt;&lt;br&gt;A pro-rata is applied to estimate the payments&lt;br&gt;2. Improvement of the woodland and silvopasto.&lt;br&gt;&lt;br&gt;2.1 Cork oak woodland (usually dehesas). 1500 E/ha.&lt;br&gt;&lt;br&gt;2.2 Other woodlands: 360 E/ha</td>
</tr>
<tr>
<td>Aragón</td>
<td>Order 28/10/03 (BOA 133, 5/11/03) Order 27/01/04 (BOA 51, 4/2/04)</td>
<td>Anticipate grazing could be possible (silvopastoral)</td>
</tr>
<tr>
<td>Asturias</td>
<td>Resolution 20/4/04 (BOPA 4/5/04) Resolution 4/4/04 (BOPA 6/6/04)</td>
<td>Minimum area is 0.5 ha&lt;br&gt;Anticipate grazing could be possible.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Afforestation of hedges and riverside could be eligible.</td>
</tr>
<tr>
<td>Balear</td>
<td>BOIB 46 13/04/99</td>
<td>NOT AVAILABLE</td>
</tr>
<tr>
<td>Canarias</td>
<td>Forestry Plan for Canary Islands (25/5/1999) Order 11/7/03 (BOC 152, 7/8/03)</td>
<td>Nothing is specified&lt;br&gt;Preferably afforestation higher 10 ha</td>
</tr>
<tr>
<td>Cantabria</td>
<td>Order 23/3/2001; BOC 62 29/03/01; Program cancelled by Order 8/11/2002 (BOC 225; 21/11/2002)</td>
<td>Preferably &gt; 5 ha&lt;br&gt;Anticipate grazed could be possible</td>
</tr>
<tr>
<td>Castilla-León</td>
<td>Order MAM/1591/2003 (BOCL 240 11/12/03)</td>
<td>Minimum area is 3 ha</td>
</tr>
<tr>
<td>Castilla-LaMancha</td>
<td>Order 31/1/2001 (DOCM 19, 16/2/01)</td>
<td>Minimum 1 ha</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td></td>
<td>Order 31-1-03 (DOCM 23/3/03)</td>
<td></td>
</tr>
</tbody>
</table>

| Cataluña          | Order 15/3/1999 ( DOGC 2855, de 25/3/99) |
|                   | without program in this moment.          |
|                   | In Rural Development for the period 2000-2006 Nothing is specified, in spite of an important percentage (12%) of the afforestation used commercial trees (walnut, cherry and cork oak). |

| Extremadura       | Decree 36/2002, DOE 46 of 23/4/02, |
|                   | In previous years minimum area 10 ha, now nothing is specified |
|                   | Exceptionally, grazed could be allowed if cattle do not endanger trees, with the loss of the compensatory payment (useful for silvopastoral systems). |

| Galicia           | Order 28/5/2001 (DOG 113 12/06/01) | Minimum 3 ha |

| Madrid            | Order 2803/2001 (BOCM 153, 29/06/01) |
|                   | Order 12338/2002 (BOM 130, 31/12/02) |
|                   | Favoured higher 10 ha. |
|                   | Anticipate grazing could be possible. |
|                   | Lineal plantations and plantations in the borders could be admitted under certain conditions (pers.comm). |

| Murcia            | Order 27/7/98 (BORM 180 6/8/1998) | Minimum 5 ha of continuous afforestation |

| Navarra           | Order 151/04 (BON 13/2/04)       | Minimum surface 1 Ha |

| Pais Vasco        | Decree 166/2000; BOPV 154 of 11/08/2000 | Only it is subsidized 85% cost of plantation; 80% cost of maintenance |
|                   | Afforestation of silvopastoral systems with low tree density |

| Rioja             | Order 13/2003 (BOR 85, 1/07/2003) | Minimum 1 ha for general cases. There are not exigencies in |
|                   |                                   | Afforestation of riverside |
|                   | b) Afforestation with Prunus and/or Juglans |
|                   | Many small area to sum the minimum area is allowed. |

|                   |                                                   | Nothing specified |

- **Measure 3: Compensatory allowances in Less Favoured Areas** compensates farmers in areas where geography, climate or environmental conditions limit production. Different allowances are available depending on the specific situation in three types of area: mountain areas, areas neglected due to low productivity and/or very low populations, and areas with a highly vulnerable environment or with a high ecological value. The target is compensatory allowances for 150 000
farmers occupying 12 million ha together with a 10% increase in the reference income. No specific helps for agroforestry are found in this measures, but a less favourable payment is given for plots with non-productive trees, that is, protective trees (common in many silvopastoral systems), respect to no-irrigated and irrigated crops, with coefficients of 0.3, 0.5 and 1 applied for the calculation of subsidies (RD. 3482/2000).

Measure 4: Early Retirement gives support to farmers between 55 and 65 to make the farm available for younger owners. The target is early retirement for 12 000 farmers, and transfer to new owners of 180 000 ha of land.

Table 4 Measures financed under the Accompanying Programme for Rural Development (2000-2006 – million Euro)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Total expenditure</th>
<th>EU contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Agri-environment</td>
<td>1207</td>
<td>827</td>
</tr>
<tr>
<td>2. Afforestation of agricultural land</td>
<td>880</td>
<td>641</td>
</tr>
<tr>
<td>3. Compensatory allowances</td>
<td>586</td>
<td>422</td>
</tr>
<tr>
<td>4. Early retirement</td>
<td>454</td>
<td>331</td>
</tr>
<tr>
<td>Total</td>
<td>3132</td>
<td>2223</td>
</tr>
</tbody>
</table>

HORIZONTAL PROGRAMME 2 (IMPROVEMENT OF PRODUCTION STRUCTURES)

The full title is ‘Improving Agricultural Structures and Production Systems’ (PRODER programme). There are two separate programmes: one for Objective 1 regions (Guidance section) and one for non-Objective 1 areas (Guarantee section). The measures in each programme are very similar:

Measure 1: Investment in agricultural holdings – which aims to produce more productive and environmentally friendly farming systems. Support for diversification and improved irrigation systems is also provided. The grant has been used for tree-planting. Usually between 40 and 50% of the investment.

The possible payments are listed in table 5 (Royal Decree 613/2001, 8th June), and they can amount till5:

- A maximum direct payment of 20000 Euros, and

5 www.mapya.es/es/desarrollo/pags/agrarias/ayudas.htm
• A maximum amount of 20000 Euros as discount of interest.

Table 5. Payments for investment in agricultural holdings in Spain (Royal Decree 613/2001, 8th June)

<table>
<thead>
<tr>
<th></th>
<th>Normal areas</th>
<th>Less Favoured Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum direct payment</strong>¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General cases</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>Young farmers (&lt; 40 y old)²</td>
<td>An additional 5%</td>
<td>An additional 5%</td>
</tr>
<tr>
<td>Canary Islands (R.D. 499/2003)</td>
<td>75%</td>
<td>75%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Normal areas</th>
<th>Less Favoured Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum capital financed ¹</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General cases</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Organic agriculture</td>
<td>An additional 5%</td>
<td>An additional 5%</td>
</tr>
<tr>
<td>Canary Islands (R.D. 499/2003)</td>
<td>40%</td>
<td>40%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Maximum direct payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per UTA (Unit of farm labour)</td>
<td>90.151,82 Euros</td>
</tr>
<tr>
<td>Per single-owner farm</td>
<td>180.303,63 Euros</td>
</tr>
<tr>
<td>Per several-owner farm</td>
<td>180.303,63 Euros x 4(maximum 4 members)</td>
</tr>
<tr>
<td>Per farmer</td>
<td>601,012,10 Euros</td>
</tr>
</tbody>
</table>

¹ Percentage applied either to the actual investment or the maximum direct payment.

² Plan of improvement in the first holding.

**Measure 2: Setting up of young farmers** – the aim is to support young people (up to age of 40) take on new farms, and support infrastructures and housing (Royal Decree 613/2001, 8th June).

The payments are⁶:

• Direct payment till **15.025** per farm.

• Discount of 100% of the interest till a maximum of **15025** Euros.

• An additional 10% is possible in three situations: women, less favoured areas, creation of employ.

The last two measures could support tree plantations⁷, and thus, they can support any agroforestry plantation with an important amount of the total initial expenditure. There


⁷ [www.mapya.es/es/desarrollo/pags/agrarias/ayudas.htm](http://www.mapya.es/es/desarrollo/pags/agrarias/ayudas.htm)
are not available information about how many farmer (if any) have used these measures to the implementation of an AF project, but observing table 6, where main funded aspect are summarize, we could conclude that these measures have not contribute to promote modern agroforestry in Spain. In fact, no commercial project of modern agroforestry have been detected in Spain.

**Measure 3: Management of water resources** – Support is given mainly to improving existing irrigation systems and networks. This measure combined with agri-environmental payments aims to improve the existing irrigation network for an area covering 830,000 ha.

Table 6. Summary of the money spent in the programs Investment in agricultural holdings and setting up of young farmers, for the period 2000-2003 in Spain (millions Euros).

<table>
<thead>
<tr>
<th>Sector</th>
<th>Nº of beneficiary</th>
<th>TOTAL INVESTMENT</th>
<th>TOTAL PAYMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN CROPS</td>
<td>5366</td>
<td>226,7</td>
<td>108,6</td>
</tr>
<tr>
<td>HORTICULTURE</td>
<td>4646</td>
<td>307,1</td>
<td>151,6</td>
</tr>
<tr>
<td>VITICULTURE</td>
<td>1112</td>
<td>38,1</td>
<td>17,4</td>
</tr>
<tr>
<td>FRUIT ORCHARD</td>
<td>1990</td>
<td>61,2</td>
<td>28,6</td>
</tr>
<tr>
<td>OLIVE PLANTATIONS</td>
<td>334</td>
<td>13,7</td>
<td>5,4</td>
</tr>
<tr>
<td>OTHER CROPS</td>
<td>9095</td>
<td>373,2</td>
<td>178,4</td>
</tr>
<tr>
<td>MILK CAWS</td>
<td>6225</td>
<td>292,9</td>
<td>126,4</td>
</tr>
<tr>
<td>MEAT CAWS</td>
<td>2429</td>
<td>75,8</td>
<td>33,7</td>
</tr>
<tr>
<td>PORK</td>
<td>362</td>
<td>21</td>
<td>9,7</td>
</tr>
<tr>
<td>Chicken</td>
<td>253</td>
<td>16,2</td>
<td>7,7</td>
</tr>
<tr>
<td>Other livestock</td>
<td>3760</td>
<td>156,3</td>
<td>74,5</td>
</tr>
<tr>
<td>OTHERS</td>
<td>666</td>
<td>28,8</td>
<td>14,1</td>
</tr>
<tr>
<td>TOTAL OBJ.1</td>
<td>36241</td>
<td>1610,7</td>
<td>756,1</td>
</tr>
</tbody>
</table>

**RURAL DEVELOPMENT AT A REGIONAL LEVEL**

Spain has 17 Regional Governments and each has its own forestry and agricultural regulations, based on those of both the National Government and the European Commission. The National Government has adapted its forestry and
agricultural regulations to match European Council Regulations 1257/1999 and 2316/1999. During the course of 2001 regulations emerged for all 17 individual Regional Governments. These broadly follow the national regulations. Funding comes from the EAGGF Guidance section for Objective 1 Regions\(^8\) and Guarantee for non-Objective 1 Regions\(^9\).

Whilst afforestation of agricultural land (1257/99 Article 31) is covered by the Horizontal Programme 1, most measures concerned with the restoration and extension of existing forests are contained in Regional Development Programmes. These include: afforestation of non-farm land, investments to restore the economic, ecological and social value of forests, improvements to harvesting, utilization and marketing, establishment of forest holder associations, and restoration of forests destroyed by natural disasters. Regions differ considerably on the importance given to forestry plans (Table 7). A more detailed description of Rural Development plans of the 14 Autonomous Spanish regions is given in Appendix II.

Detailed information on total expenditure was given in table 2, with a high expenditure in afforestation of agricultural lands in the period 1996-2000. More recent figures\(^10\) suggests that the total public spending in Spain on Rural Development and concludes that forest planning and management, agri-environment schemes and farmland afforestation receive respectively 9.8%, 9.7% and 7.2% of the total spend. A very small proportion of this expenditure will relate to agroforestry, but no information is yet available.

In fact, this program refer always to already existing forest (selvicultural measurements), which involve that only no arable lands are eligible. On the other hand, they are very few measures for introduction of trees in farms (Table 7). Thus, probably, nothing of this expenditure will relate to silvoarable agroforestry, but no information is available. Anyway, no modern agroforestry projects are known in Spain.

By contrast, this programmes are been very useful for the maintenance of the silvopastoral systems in Spain, namely the maintenance of dehesas (Table 7). In fact, many regions have a specific measures for the improvement of cork oak forests, which has support the regeneration of 92,564 ha of cork oak dehesas in period 1994-1999\(^11\).

Table 7. Regional selvicultural programs in Spain.

\[\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Andalusia, Asturias, Canary Islands, Cantabria Castile-la Mancea, Castile-Leon, Extremadura, Galicia, Murcia and Valencia.} \\
\text{Aragon, Balearic Islands, Catalonia, Madrid, La Rioja, Navarre & the Basque Country} \\
\text{Dyer, J et al ‘Europe’s Rural Features – the Nature of Rural Development II Rural Development in an Enlarging European Union. Land Use Policy Group and the WWF.} \\
\text{Plan Forestal Español.} \\
\end{array}\]
<table>
<thead>
<tr>
<th>Region</th>
<th>Localization</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andalucía</td>
<td>Plan Forestal de Andalucía</td>
<td>Diversification of the rural landscape through the conservation and introduction of forested areas in croplands. Dehesa conservation</td>
</tr>
<tr>
<td>Aragón</td>
<td>Order 13/10/98, BOA 121 16.10.98.</td>
<td>In Plan of Rural Development nothing is mentioned</td>
</tr>
<tr>
<td>Asturias</td>
<td>Resolution 7/04/03 (BOPA 6/6/03)</td>
<td>Nothing</td>
</tr>
<tr>
<td>Baleares</td>
<td>Order 15/1/2004 (BOIB 13, 27/01/2004) Resolution 27 may 2004 (BOIB 78, 3/6/04)</td>
<td>General helps, but nothing specific, just aids for hedges maintenance</td>
</tr>
<tr>
<td>Canarias</td>
<td>Order 1/8/2001, (B.O.C. 104, de 10.8.01)</td>
<td>Nothing is mentioned</td>
</tr>
<tr>
<td>Castilla-León</td>
<td>Order MAM/1593/2003; B.O.C.L. 240; 11712/2003</td>
<td>Improvement of silvopastoral systems</td>
</tr>
<tr>
<td>Castilla-LaMancha</td>
<td>Order 31/10/01 (DOCM 30/10/01 and DOCM 18/01/02)</td>
<td>Nothing specified</td>
</tr>
<tr>
<td>Extremadura</td>
<td>Decree 83/2004 (DOE 65, 08/06/04)</td>
<td>Agriculture lands are not eligible. Maintenance of woodland (as dehesa). Useful for silvopastoral systems For afforestation (to avoid risk of erosion) Maximum 30000 Euros and 50 ha and 70 % of total cost (85% in natural parks Tree density between 400-500 trees/ha. For poplar the density could lower.</td>
</tr>
</tbody>
</table>

12 www.juntadeandalucia.es/medioambiente/revistama/revista_ma33/plan_forestal.html
Galicia: Order 2004 24/03/04 (DOG 64, 01/04/04)
Only woodland are eligible; no options to maintain any agricultural activity. Useful to the maintenance of the silvopastoral systems. Till 1320 Euros per ha for clearance of hardwood forests.

Madrid: Plan Forestal de Madrid
Dehesa maintenance
Maintenance of woodlands and open woodlands.
Plan of afforestation

Murcia: Forestal Strategy for Murcia
Nothing is mentioned

Biodiversity: Setting up hedges
Landscape and recreational aspects: Linear tree plantations

Landscape and ecological function of forest: maintenance of small forest in agricultural lands and sustainable management of forests (100% of total cost).
Selviculture: Any afforestation without limitations (45% for fast growing species- 100% for slow growing species)

Rioja: Decree 114/2003, 30/10/03, BOR 136, 4/11/2003
Nothing is mentioned
All the afforested lands must be registered as forestal (even for temporary plantations)

Valencia: OK
Decree 106/2004, 25/6/04, DOGV 4785, 29.06.2004
Plan General de Ordenación Forestal de la Comunidad Valenciana
Only silvopastoral systems are considered

DISCUSSION & CONCLUSION

Agroforestry systems are not mentioned in the different Forestry & Agri-environmental measures (the latter is controlled by Real Decree 4/2001\(^\text{14}\)) supported within the Rural Development Plans (Appendix II) or specific regulations (Table 7) prepared by regional governments. However, these plans indicate that there could be scope for agroforestry grant support within the context of ‘cork-oak production; or ‘traditional silvopastoral systems’ or ‘fire prevention’ or ‘action against erosion and degradation’ or ‘renovation of terrace systems’ or ‘maintenance of biodiversity’ or ‘income diversification’ or ‘avoidance of depopulation’ or ‘watershed management’ or ‘recreational use. That is, opportunities do exist within the agri-

\(^{13}\text{Medioambiente.madrid.org/areastematicas/biodiversidad/planfo.html}\)

\(^{14}\text{http://noticias.juridicas.com/base_datos/Anterior/r0-rd4-2001.html}\)
environmental components of the Rural Development Plans to integrate trees with other land uses. Yet we are aware of no instances where silvoarable agroforestry schemes have been assisted by these forestry or agri-environmental measures, whereas silvopastoral systems, namely dehesas, are greatly favoured. Agroforestry is not mentioned in any of the recently approved National and Regional Forestry Strategies neither.

Royal Decree 6/2001\(^{15}\) sets the rules and maximum payments for afforestation of agricultural land in Spain. The EU reimburses 75% of costs in Objective 1 areas and 50% in non Objective 1 areas, and the Ministry of Agriculture Fisheries and Food undertakes to meet half of the balance with. The remaining funds will be provided by the Autonomous regions. Detailed regulations for species allowed, planting densities, minimum plantation areas etc. are determined independently by each of the Regions, although a general approximation is given at a national level (Appendix I).

As a consequence of the implementation of EU Regulations 2316/99 for Arable Aid, the presence of the trees amongst crops is allowed by the national regulation (Real Decree 1026/2002; article 2), but in some Spanish regions, the area used to calculate the arable payment is decreased in function of the abundance of the trees in different ways, but in many regions in a higher proportion of the area actually occupied by trees (Table 8). In the last years, the payment for arable lands is linked to the existence of good agricultural practice' required for 1783/03 and R.D 1322/2002, but among the different requirements, agroforestry or maintenance of trees in farms are not included.

We conclude therefore that, in spite of the many different incentives spent in improvement of farms and forests, very few seem to favour the implantation of silvopastoral systems, and fewer to favour silvoarable systems.

Nevertheless, the different programmes for afforestation now being implemented in the 17 Spanish regions could offer the opportunity for agri-environmental payments to allow the introduction of a larger number of trees on croplands. More interaction and lobbying is required with the national and regional authorities. Preferably in collaboration with farming organisations.

Table 8. Reduction of payment for crop surface caused by the presence of trees into the plot.

<table>
<thead>
<tr>
<th>Region</th>
<th>Localization</th>
<th>Comments</th>
</tr>
</thead>
</table>
| • Andalucía     | Order 2/2/2004 (BOJA 30, 13/2/2004) | No eligible plots with more than 40 trees/ha  
Alley crops (between olives, almond, fruit orchards) are not eligible, except if it is traditional in the area |
| • Aragón        | Order 27/1/2004 (BOA 51) | No mentioned                                                                                                                                 |
| • Asturias      | Resol. 19/01/2004 (BOPA 06/02/04) | It is allow to have trees without discount                                                                                               |
| • Baleares      | Order 11/12/2002, BOIB 152 19-12-2002 | The surface occupied by trees is considered as:  
Almond-trees 8 m²; Fig-trees 12 m², Carob-trees 15 m²                                                                                   |
| • Canatabria    | Order 12/1/2001, BOC 13, 18/1/2001 | Small forest in silvopastoral systems are discounted                                                                                        |
| • Castilla-León | Order AYG/1727/2003 (BOCL 31/12/03): | Olive-tree: 100 m²  
Small forest in silvopastoral systems are discounted                                                                                   |
| • Castilla-LaMancha | Order 30-12-2002, BOCM 5, 15/1/03 | The size of the highest tree is used as reference for the calculation of the reduction                                                     |
| • Cataluña      | Order ARP/41/2004, DOGC 4085, de 5.3.2004 | No mentioned                                                                                                                                  |
| • Extremadura   | Order 7th February 2004, DOE 16, 10th February 2004 | The eligible surface in is reduce by twice the crown area of the trees.  
For each olive tree an area of 100 m² is discounted  
(3 times the actual size, on average)  
Durum wheat crops with more than 20 trees/ha are not eligible  
In the case of silvopastoral systems, the reduction of area payment is not applied, but with oak-trees no payments are made if the tree cover is greater than 50% |
| • Galicia       | Order 23/12/2003, DOG 254 | Small forest in silvopastoral systems are discounted                                                                                         |
| • Madrid        | Order 945/2004 (BOCM 35, 11/2/2004) | For each olive tree an area of 100 m² is discounted, following the Resolution (CE) 2366/98                                                  |
The eligible surface is reduced by twice the crown area of the trees.

- Murcia Order 27/1/2004 (BORM 30) The surface discounted is:
  - 20 m² per tree in non-irrigated land and 35 m² in irrigated crops.
  - For olive-trees, oak-trees and similar: 100 m² per tree.

- Navarra Order 19/2004 (BON 23, 23/04) With the presence of scattered trees, only 25 of the pasture land is eligible.

- Pais Vasco Decree 11/2000 BOPV 26/1/00 Excluded small forest in pastureland

<table>
<thead>
<tr>
<th>Coniferous Tree/ha</th>
<th>Hardwood Tree/ha</th>
<th>% of eligible surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 100</td>
<td>&lt; 50</td>
<td>50</td>
</tr>
<tr>
<td>100-200</td>
<td>50-100</td>
<td>25</td>
</tr>
<tr>
<td>&gt;200</td>
<td>&gt; 100</td>
<td>10</td>
</tr>
</tbody>
</table>

- Rioja Order 8/2004; BOR 21, 12/02/2004 Nothing is mentioned

- Valencia Order 5/2/2004 (DOGV 4691) Nothing is mentioned
APPENDIX I: Payments for afforestation of agricultural lands
RD 6/2001 (BOE 12, 13/01/2001).

<table>
<thead>
<tr>
<th>GROUP of PLANTS</th>
<th>Tree density (tree/ha)</th>
<th>Maximum payment (euros/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.A</td>
<td>800</td>
<td>2.314</td>
</tr>
<tr>
<td>FRONDOSAS DE CRECIMIENTO LENTO Y MASA PURA</td>
<td>800</td>
<td>2.560</td>
</tr>
<tr>
<td>I.B</td>
<td>800</td>
<td>2.560</td>
</tr>
<tr>
<td>FRONDOSAS DE CRECIMIENTO LENTO Y MASA MEZCLADA</td>
<td>400</td>
<td>1.190</td>
</tr>
<tr>
<td>I.C.1</td>
<td>800</td>
<td>1.322</td>
</tr>
<tr>
<td>FRONDOSAS DE CRECIMIENTO DE RÁPIDO Y RAÍZ PROFUNDA</td>
<td>278</td>
<td>1.839</td>
</tr>
<tr>
<td>I.C.2</td>
<td>800</td>
<td>1.352</td>
</tr>
<tr>
<td>FRONDOSAS DE CRECIMIENTO DE RÁPIDO Y RAÍZ SUPERFICIAL</td>
<td>278</td>
<td>1.352</td>
</tr>
<tr>
<td>II.A</td>
<td>1.000</td>
<td>1.262</td>
</tr>
<tr>
<td>RESINOSAS DE CRECIMIENTO LENTO Y MASA PURA</td>
<td>600</td>
<td>685</td>
</tr>
<tr>
<td>II.B</td>
<td>1.000</td>
<td>1.382</td>
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<td>RESINOSAS DE CRECIMIENTO LENTO Y MASA MEZCLADA</td>
<td>600</td>
<td>757</td>
</tr>
<tr>
<td>II.C</td>
<td>1.000</td>
<td>1.226</td>
</tr>
<tr>
<td>RESINOSAS DE CRECIMIENTO RÁPIDO</td>
<td>600</td>
<td>667</td>
</tr>
<tr>
<td>III.A</td>
<td>1.000</td>
<td>1.779</td>
</tr>
<tr>
<td>FRONDOSAS X RESINOSAS (CRECIMIENTO LENTO)</td>
<td>600</td>
<td>950</td>
</tr>
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<td>III.B</td>
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<td>1.424</td>
</tr>
<tr>
<td>FRONDOSAS X RESINOSAS (CRECIMIENTO RÁPIDO)</td>
<td>600</td>
<td>799</td>
</tr>
<tr>
<td>IV.A</td>
<td>500</td>
<td>2.855</td>
</tr>
<tr>
<td>OTRAS ARBÓREAS (CRECIMIENTO LENTO)</td>
<td>300</td>
<td>1.803</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>V.A</strong></td>
<td><strong>1.600</strong></td>
<td><strong>1.557</strong></td>
</tr>
<tr>
<td>ARBUSTIVAS</td>
<td><strong>1000</strong></td>
<td><strong>1.166</strong></td>
</tr>
<tr>
<td>VI.A Cerramientos (Km.)</td>
<td></td>
<td><strong>6.172</strong></td>
</tr>
<tr>
<td>VI.B Cortafuegos (ha)</td>
<td></td>
<td><strong>150</strong></td>
</tr>
<tr>
<td>VI.C Puntos o Balsas de agua (ud.)</td>
<td></td>
<td><strong>2.110</strong></td>
</tr>
<tr>
<td>VI.D Vías de acceso para prevención incendios (Km.)</td>
<td></td>
<td><strong>6.647</strong></td>
</tr>
</tbody>
</table>
## Maximum payments for tree plantations

<table>
<thead>
<tr>
<th>GROUP of PLANTS</th>
<th>Tree density (tree/ha)</th>
<th>Maximum payment (euros/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I.A</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRONDOSAS DE CRECIMIENTO LENTO Y MASA PURA</td>
<td>400</td>
<td>150</td>
</tr>
<tr>
<td><strong>I.B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRONDOSAS DE CRECIMIENTO LENTO Y MASA MEZCLADA</td>
<td>400</td>
<td>150</td>
</tr>
<tr>
<td><strong>I.C.1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRONDOSAS CRECIMIENTO DE RÁPIDO Y RAÍZ PROFUNDA</td>
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<td></td>
</tr>
<tr>
<td><strong>I.C.2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>II.A</strong></td>
<td>1.000</td>
<td>180</td>
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<tr>
<td>RESINOSAS DE CRECIMIENTO LENTO Y MASA PURA</td>
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<td>90</td>
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<tr>
<td><strong>II.B</strong></td>
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<td>180</td>
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<tr>
<td>RESINOSAS DE CRECIMIENTO LENTO Y MASA MEZCLADA</td>
<td>600</td>
<td>90</td>
</tr>
<tr>
<td><strong>II.C</strong></td>
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<tr>
<td>RESINOSAS DE CRECIMIENTO RÁPIDO</td>
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<td>90</td>
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<td><strong>III.B</strong></td>
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</tr>
<tr>
<td>FRONDOSAS X RESINOSAS (CRECIMIENTO RÁPIDO)</td>
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</tr>
<tr>
<td><strong>IV.A</strong></td>
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<td>288</td>
</tr>
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</tr>
<tr>
<td><strong>V.A</strong></td>
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<td>90</td>
</tr>
<tr>
<td>ARBUSTIVAS</td>
<td>1.000</td>
<td>66</td>
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</tbody>
</table>
### Importes máximos para las ayudas por PRIMA COMPENSATORIA

<table>
<thead>
<tr>
<th></th>
<th>Para agricultores o asociaciones de agricultores</th>
<th>Para cualquier otra persona de derecho privado</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>masa pura (euros/ha)</td>
<td>masa mezclada (euros/ha)</td>
</tr>
<tr>
<td><strong>FRONDOSAS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tierras ocupadas por cultivos leñosos y/o herbáceos y huertos familiares</td>
<td>325</td>
<td>337</td>
</tr>
<tr>
<td>Prados</td>
<td>228</td>
<td>240</td>
</tr>
<tr>
<td>Pastizal</td>
<td>168</td>
<td>174</td>
</tr>
<tr>
<td>Barbechos y otras tierras no ocupadas</td>
<td>108</td>
<td>114</td>
</tr>
<tr>
<td>Erial a pastos</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td><strong>CONIFERAS</strong></td>
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</tr>
<tr>
<td>Tierras ocupadas por cultivos leñosos y/o herbáceos y huertos familiares</td>
<td>313</td>
<td>325</td>
</tr>
<tr>
<td>Prados</td>
<td>222</td>
<td>228</td>
</tr>
<tr>
<td>Pastizal</td>
<td>168</td>
<td>174</td>
</tr>
<tr>
<td>Barbechos y otras tierras no ocupadas</td>
<td>108</td>
<td>114</td>
</tr>
<tr>
<td>Erial a pastos</td>
<td>54</td>
<td>60</td>
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<tr>
<td><strong>OTRAS ARBOREAS</strong></td>
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<td></td>
</tr>
<tr>
<td>especial interés ambiental, laurisilva, insularidad</td>
<td>337</td>
<td></td>
</tr>
<tr>
<td>Tierras ocupadas por cultivos leñosos y/o herbáceos y huertos familiares</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>Prados</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pastizal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barbechos y otras tierras no ocupadas</td>
<td></td>
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</tr>
<tr>
<td>Erial a pastos</td>
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<tr>
<td><strong>Arbutivas</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tierras ocupadas por cultivos leñosos y/o herbáceos y huertos familiares</td>
<td>355</td>
<td></td>
</tr>
<tr>
<td>Prados</td>
<td>252</td>
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</tr>
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<td>Pastizal</td>
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<tr>
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</tr>
<tr>
<td>Barbechos y otras tierras no ocupadas</td>
<td></td>
<td>108</td>
</tr>
<tr>
<td>Erial a pastos</td>
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</tbody>
</table>
### APPENDIX II. Forestry and Environmental Measures supported within Regional Rural Development Plans of the 15 Spanish Autonomous Regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Forestry Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asturias</td>
<td>Forestry &amp; Environment</td>
<td>In the forestry sector, support is given to improve and increase the existing woodland, to protect the soil and maintain the hydrological cycle. Works will be carried out to prevent forest fires and reduce the damage caused by these. The program also finances activities to improve the areas included in Natura 2000 and to work towards a sustainable use of the existing biodiversity, by projects to improve public access and restore rivers and riverbanks, to name a few examples.</td>
</tr>
<tr>
<td>Balearics</td>
<td>Development and conservation of natural resources</td>
<td>Within forestry, support is for example given to projects that aim to prevent forest fires, protect the soil against erosion or degradation, or to preserve the biodiversity and the landscape, shaped by agriculture and forestry. Support may also be given to farm holders who wish to renovate terrace systems and partitions between properties.</td>
</tr>
<tr>
<td>Basque Country</td>
<td>Forestry</td>
<td>The forestry sector receives investment support to increase the added value of wood (in particular in small enterprises involved in the first transformation), to improve processing and marketing of forest products, etc. Reafforestation, resturation of deteriorated forest areas and creation of fire-breaks are other examples of improvements to maintain the ecological value of the forest areas.</td>
</tr>
<tr>
<td>Canary Islands</td>
<td>Forestry &amp; Environment</td>
<td>The programme intends to strengthen the threefold function of the forest sector: ecological, economical and social. This means to restore and protect forest areas and to arrange the infrastructure in such a way that it can be used for production (fire wood, timber etc), while still conserving the natural values and balances. Maintenance of forest areas and their use for recreation and production offer job opportunities, which contributes to stabilise the situation for the population and improve the conditions for a sustainable development. Works will also be carried out to prevent forest fires, improve forest roads and improve the silvicultural system.</td>
</tr>
<tr>
<td>Cantabria</td>
<td>Forestry &amp; Environment</td>
<td>Works will be carried out in forest areas, such as prevention of forest fires, reforestation and cultivation of quality plants. The programme also plans to set up groups of forest owners to coordinate preventive work. Support is given to improve and increase natural areas, maintain the biodiversity, protect endangered species, improve river flows, disseminate the code of good agricultural practice, etc.</td>
</tr>
<tr>
<td>Castile Mancha</td>
<td>Forestry &amp; Environment</td>
<td>The programme supports projects that aim to protect and re-establish the balance between water, soil and vegetation and restore the hydrological cycle in forest areas. Works on the infrastructure and preventive treatments are expected to reduce the number of forest fires. Other activities aim to control forest pests and diseases and to improve the cover vegetation. The forestry sector has potential to contribute to a diversification of the local economy and serve as a complementary income source. The wild flora and fauna is conserved by a series of environmental measures, and the programme also supports the creation of a regional network of protected areas.</td>
</tr>
<tr>
<td>Castile Leon</td>
<td>Forestry &amp; Environment</td>
<td>Active prevention of forest fires and improvement of forest areas are some of the planned activities. To increase not only the ecological but also the economic and social value of the forest, support is given for investments that aim to increase the outcome of forest products, by improving harvest and processing methods, and marketing of the final products. The environmental measures focus on restoration and preservation of habitats of interest and aim to strengthen the network of protected natural spaces (Red de Espacios Naturales Protegidos). The programme will also work on protection of the existing population of animals.</td>
</tr>
<tr>
<td>Catalonia</td>
<td>Forest Resources</td>
<td>A series of measures will support a sustainable development of forest areas. Some examples are to protect and improve forest areas, prevent forest fires, support forest owner associations and preserve fauna of high interest in the Pyrenees and pre-Pyrenees. Support is also given to increase the output, processing and marketing of forestry products.</td>
</tr>
<tr>
<td>Extremadura</td>
<td>Forestry &amp; Environment</td>
<td>In addition to its environmental values, the forest sector has an important socio-economic role to play in rural areas. A continued income in forestry may prevent people from moving to urban areas. To maintain forest areas in good condition, works will be carried out to prevent erosion, desertification and forest fires, to conserve areas of ecological value, for example sites included in the Natura 2000 network. Support is also given to ensure balance in the wildlife population.</td>
</tr>
<tr>
<td>Province</td>
<td>Action Area</td>
<td>Details</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Galicia (Obj 1)</td>
<td>Forestry &amp; Environment</td>
<td>Financial aid is given for works to protect, improve and increase forest areas, private as well as public. Private forest owners may receive support to organise themselves in associations. The programme will enable the public forest sector to improve the infrastructure, elaborate genetic improvement programmes within forestry and set up nursery gardens. Training, awareness rising activities and creation of more fire-breaks are expected to reduce the forest fires. In mountain forests, works are planned to plant cover vegetation and carry out hydrotechnical works to reduce the risk of flooding.</td>
</tr>
<tr>
<td>La Rioja</td>
<td>Environment &amp; Natural Resources</td>
<td>Support is given for management of forestry resources, for instance to prevent forest fires, and to protect natural spaces. Afforestation will continue, not only in view of increasing the forest area, but also to create a diversified forest environment that takes into account the multifunctional nature of the forest and its social importance. Education activities and other necessary support will be offered to the population living in or near protected natural areas.</td>
</tr>
<tr>
<td>Madrid</td>
<td>Forestry, Environment &amp; Natural Resources</td>
<td>The programme will contribute to improvements in management of resources, natural sites and waste. Further, support is given for improvement of soil, afforestation and protection against forest fires. Training on environmental issues will be organized.</td>
</tr>
<tr>
<td>Murcia (Obj 1)</td>
<td>Forestry &amp; Environment</td>
<td>Some measures aim to maintain the biodiversity and protect endangered species. Activities and programmes will be designed to combine the public use of natural areas for recreation and education on the one hand, and their conservation and protection on the other hand. Within forestry, priority is given to the areas most affected by (or at risk for) erosion and areas with woodlands in need of better maintenance and conservation. The works will consist of reforestation, hydrological improvements and other forestry measures.</td>
</tr>
<tr>
<td>Navarre</td>
<td>Forestry, Natural Environment &amp; Landscape</td>
<td>There are also measures to preserve and improve the forests and forest resources. Plans will be elaborated to carry out improvements on some 100 000 ha of forests, and the management of forests will be improved, with focus on reafforestation, infrastructure and preventive actions. The programme also contributes to the conservation of environmental values of interest and gives support for works to be carried out in some 20 protected natural areas.</td>
</tr>
<tr>
<td>Valencia (Obj 1)</td>
<td>Forestry &amp; Environment</td>
<td>In order to stop the deteriorating process caused by climate, fires and human activities, support is given to projects to protect the soil, improve the cover vegetation and control pasture and shrub to prevent forest fires. The programme also co-finances initiatives that aim to co-ordinate the different uses of the forest resources (wood production, pasture for animals, hunting, bee-keeping, etc) and will also encourage the use of forest areas for recreation, sports and increased winter tourism. Support is given to restore old cattle roads, which are part of the historical rural heritage and constitute a network of ecological corridors in the landscape. Other areas covered by the programme are protection of biodiversity, conservation of wild flora and fauna, sustainable management of hunting resources and actions to encourage long term use of cork trees, by restoring deteriorated forests.</td>
</tr>
</tbody>
</table>
ANNEXE 8. Effect of land use on the soil water dynamic in dehesas of Central-Western Spain

Contractor 7: UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

Cubera E*, Montero MJ, Moreno G

I.T. Forestal, Centro Universitario, Universidad Extremadura, Plasencia 10600, Spain.

* Corresponding author: ecubera@unex.es

Abstract

Dehesa ecosystems are open woodlands with scattered oak trees as their main component, located in the southwestern Iberian Peninsula. Different structures of vegetation are found as a consequence of a combination of land use: (1) oak tree intercropped with cereal, (2) oak tree with native grass vegetation and (3) oak tree with abundant understorey. We investigated whether land use affects the water dynamics of this ecosystem. Soil moisture was studied in the upper 200 cm of the soil, every 20 cm, and at different distances from the tree trunk (maximum 30 m), at four holm-oak dehesas in Central-Western Spain. Soil moisture was measured by Time Domain Reflectometry technique (TDR), between May 2002 and September 2003, two contrasting years in terms of rainfall, with 406 and 596 mm, respectively.

Soil moisture in the shrubby dehesa was lower than in cropped and grazed ones, indicating possible competition between trees and shrubs for soil water. Soil moisture was slightly higher beyond the tree canopy projection than beneath the tree, but only in the cropped plots. In other plots (with native grasses or shrubs) no significant differences in soil moisture with regards to distance were found. These results indicate a positive effect of ploughing, favouring water infiltration and soil re-watering.

Results have shown a high dependence of holm-oak on deep water reserves throughout late spring and summer, which contributes to avoiding competition for water between trees and herbaceous vegetation. Moreover, soil water depletion beyond the tree canopy projection continued even in summer, when herbaceous plants dried up and soil evaporation was negligible, indicating that trees could use water from beyond.
the canopy, implying clear benefits from tree spacing on soil water consumption.

**Keywords**

Soil moisture, TDR, dehesa land use, tree-understorey interaction, scattered trees.
INTRODUCTION

A dehesa can be defined as a multi-purpose agroforestry system with scattered oak trees (Joffre et al., 1988). This peculiar system dominates the landscape of the southwestern Iberian Peninsula (Gómez-Gutierrez and Pérez-Fernández, 1996), with more than 3,100,000 ha in the west and south-west of the Iberian Peninsula (Díaz et al., 1997).

A dehesa is characterised by the presence of a savannah-like open tree layer, mainly dominated by the evergreen holm-oak (Quercus ilex) and cork oak (Q. suber), and to a lesser extent by the deciduous Q. pyrenaica and Q. faginea. These oak species have a density of about 40 trees/ha. The herbaceous layer is comprised of either cultivated cereals (oats, barley, wheat,...) or, more commonly, native vegetation dominated by annual species, which are used as grazing resources (Joffre et al., 1999). When grazing pressure is removed, dehesas are invaded by Mediterranean matorral species (Lacaze and Joffre, 1987) such us Cistus ladaniferus, C. salviaefolius and C. monspeliensis. Thus, different structures of vegetation found in dehesas are dependent on land use (Joffre et al., 1999).

Tree density is also partly controlled by edaphic and climatic resources. Numerous studies carried out on silvopastoral systems have emphasised the importance of available water in determining the structure of the herbaceous and open-tree strata (Joffre and Rambal, 1993). Eagleson (1982) hypothesised that water limits natural vegetation systems, providing a canopy density that produces both minimum water stress and maximum biomass. Several studies focusing on water dynamics in different agroforestry systems have showed different spatial partitioning of water resources between tree and understorey (Eastham et al., 1988; Sala et al., 1989; Scholes and Archer, 1997; Gyenge et al., 2002).

The environmental modifications caused by tree cover in dehesas have been widely investigated (Montoya, 1982; Escudero, 1985; Joffre and Rambal, 1988). Soils developing under a tree canopy are richer in nutrients and organic matter (Escudero, 1985) and have greater water-holding capacity and a macroporosity
favourable to infiltration and redistribution of soil water (Joffre and Rambal, 1988). Joffre and Rambal (1993) comparing the water balance between two components of the dehesa (only grass beyond the tree versus tree-grass beneath the tree), reported a clear influence of the tree on the water dynamic, and Joffre et al. (1999) also reported a certain dependence of the trees on the water located beyond the tree cover.

This only study on soil water dynamic in dehesa was conducted in a subhumid ambient (= 700 mm of annual rainfall on average) in a grazed dehesa. Therefore, some of the statements derived from the aforementioned works could be different either in drier sites or under other dehesa land use. On the other hand, there are no studies that comprise either different vegetation structures in dehesas (tree with native grasses, crop or shrub), nor the interaction related to the water consumption by different vegetation strata.

In the present study, the effects of three different land uses (cropped, grazed and shrubby dehesas) on the soil water dynamic are analysed in holm-oak (Quercus ilex) dehesas of Central-Western Spain. The possible relations of facilitation and competition between vegetation types are also described, by analysing the seasonal evolution of soil water content at different distances from the trees.

**MATERIAL AND METHODS**

*Study area*

The work was carried out in four Q. ilex dehesas located in Cuatro Lugares county, Central-Western Spain (39° 41’ N, 6°13’ W). The climate is typically Mediterranean, with 597 mm annual rainfall, (90% occurring from October to May). Mean minimum temperature during January, the coldest month, is 3.4 °C, and mean maximum temperature during July is 35.5 °C. Soils are mainly chromic Luvisols and chromic Acrisols (FAO, 1998) developed over tertiary sediments with abundant quartzite. In some areas where sediments were eroded, eutric Leptosols are developed on schists, which outcrops locally. The soils of the former generally show a seasonal hydromorphism, with abundant concretions of iron and pseudo-gleyic characteristics.
Experimental layout

The study was conducted in four experimental sites: Cerro Lobato (CL), Sotillo (ST) Dehesa Boyal (DB) and Baldio (BA). Each farm included plots with intercropped (cereal) holm-oak trees (C, cropped plots), and plots with native grasses (G, grazed plots). One site (El Baldío) also included trees within a shrubby area (M, matorral plot). In the latter site, the effect of fertilisation (N+P+K) was also studied (F, Fertilised plots; nF, no fertilised plots). Soils varied among farms, but did not among plots of each farm. The major characteristics of the soils are summarised in Table 1.

Data collection

Time Domain Reflectometry (TDR) technique (Tektronic model 1502 C) was used to measure soil moisture (θ) at different distances from the tree trunk (from 2 to 30 m), from the soil surface until a maximum depth of 2 m, in intervals of 20 cm. In some cases maximum depth was 1 m because of the presence of abundant stone. A total of 843 TDR-probes were installed. Measurements from 0 to 1 m are available from May 2002 onwards and those from 1 to 2 from May 2003 onwards. Data were obtained monthly until September 2003 (details of measurements are given in Table 2).

TDR-probes were constructed by ourselves following the indications of Vicente et al. (2003): each probe comprised two parallel rods made of stainless steel, 200 mm in length and sharpened at one end to facilitate their introduction into the soil. Rod diameter was 6 mm and the separation between their axes was 30 mm. One rod was connected to a conductor of a low ohm-resistance coaxial cable and the other was connected to the mesh of the cable. All connections were coated with an epoxy resin (Stuers kit EPOFIX®) which acted as an electrical insulator, and held the rods firmly in a parallel position. TDR-probes were placed vertically in the soil. During installation, efforts were made to ensure maximum contact between the rods and the soil.

The calibration curve of the TDR-probes was done in the laboratory in eight 12-L pots, which were filled with soil collected from the entire profiles of the experimental sites. A permanent TDR-probe was installed in each pot. Soils
were wet above saturation point, and then TDR measurements were taken periodically, and soil moisture was monitored by weighing pots. Data were collected over a sufficiently long time period to cover a wide range of water moisture (beyond wilting point).

**Data Analysis**

Due to the differences in experimental layout among the first three dehesas (CL, ST and DB) and the last one (BA), we present results of $\theta$ from this last farm separately from the others. Linear regression was applied to calibrate the TDR equipment from TDR data and soil moisture of the soil pots. Different two-ways ANOVA were applied in order to detect differences among mean values of $\theta$ with different land uses (C, G and M), fertilisation treatments (F and nF), and sites (CL, ST, DB and BA); all of them as independent variables and $\theta$ as a dependent variable. Values of different dates were included as repeated measures. Results of ANOVA were expressed as F value (with degree of freedom) and level of significance (p value).

**RESULTS AND DISCUSSION**

*Calibration*

Data of TDR-probes measured in the pots were regressed with soil moisture values in order to calibrate the TDR equipment. The relationships between both data set follows a positive linear tendency (Figure 1), and the equation derived from the regression was highly significant:  

$$n_{TDR} = 0.0545 \times \theta \text{ %weight} - 0.0432; \quad R^2 = 0.82; \quad p < 0.0000$$

The TDR refractive index, $n_{TDR}$, was calculated from the travel time in the soil ($\Delta t_s$) and the length of the probe (L) according to:  

$$n_{TDR} = \frac{(c \Delta t_s)}{(2L)}$$

where $c$ is the electromagnetic wave velocity in air ($3 \cdot 10^8$ m s$^{-1}$) and $\Delta t_s$ was obtained with the travel time analysis presented in Heimovaara and Bouten (1990).

An important data dispersion is observed due to the fact that all the soil horizons are analysed together. Several authors have emphasised the importance of soil type (Jacobsen et al., 1995; Noborio, 2001), soil bulk density (Roth et al., 1992; Vicente et al., 2003), and temperature (Weast, 1987) on TDR measurements.
Nevertheless, the present equations is considered valid enough because the main aim of this study is to analyse the soil water dynamic instead of the soil water balance. When absolute values of soil water content are not so important and only the relative temporal change in soil moisture is needed, the dependence of a non-biased calibration is not as important (Daudet and Vachaud, 1977). Therefore, for future works of dehesa water balance, a specific equation for each soil horizon and different soil textures is advisable.

Consequences of soil management on soil moisture

Considering that only a few TDR-probes could be installed deeper than 1 m (Table 2), and that most of the results of soil management is expected to occur in the first layers of the soil, only data of the first 100 cm of the soil are analysed in this section.

On most dates, average values of $\theta$ on matorral plots (BA site) were found to be lower than average values in cropped and grazed sites ($F_{2, 267} = 12.28; p < 0.0000$; Figure 2). On the other hand, $\theta$ decreased slowly throughout the summer only in $M$ plots, while in other plots ($C$ and $G$) soil moisture remained quite constant. Cropped plots showed similar average values of soil moisture to grazed plots. On the other three sites ($CL$, $ST$ and $DB$; data not shown) no significant differences between cropped and grazed plots were found during the dry season ($F_{1, 129} = 0.12; p = 0.72$), but in wet season higher values of soil moisture were found in the cropped plots ($F_{1, 194} = 10.89; p = 0.0011$).

The difference between BA and the other three sites in soil re-watering of cropped plots could be explained by the difference in soil slope. In sloping farms ($CL$, $ST$ and $DB$), soil ploughing could favour water infiltration and soil re-watering in comparison to unploughed plots. On the contrary, where slope is not significant (BA site), water infiltration did not show any dependence of the soil ploughing. Thus, ploughing dehesas can facilitate soil re-watering in some situations and it seems that cereal crop does not introduce an additional competition for soil water with trees in comparison to grasses.

Seasonal trends of soil moisture were similar in fertilised and control plots (Figure 3) and no significant differences were observed ($F_{1, 268} = 0.34; p = 0.56$),
except in early spring when the water demand by vegetation was higher, differences in $\theta$ were significant (significant interaction: $F_{8, 2144} = 6,84; p < 0,0000$). However, throughout the summer, differences in $\theta$ between fertilised and control plots decreased. As a result, it can be concluded that fertilisation increases plant growth and water consumption by plants in spring when herbaceous vegetation is still active, implying an additional factor of water competition for trees. On the other hand, to crop dehesa could favour the water dynamic and soil re-watering and this would compensate the negative effect of crop fertilisation in the soil water reserve.

The different behaviour of the C and G plots with respect to the M one throughout the summer (in the latter soil becomes much drier; Figure 2) indicates that holm-oak trees could not absorb all the available water. This could be explained by the low root density shown by holm-oaks in these sites (Obrador et al., 2003). Passioura (1982) stresses the need for a dense root system in order to adequately exploit water in unsaturated soils, since the difficulty of water movement in the soil is greater than the force with which it is retained. Furthermore, the decrease in water content entails a pronounced decrease in hydraulic conductivity (Hillel, 1980). Nevertheless, other authors have emphasised the presence rather than the number of roots as influencing water uptake from a given soil volume (e.g. Stone and Kalisz, 1991). Anyway, the increased soil water depletion in M plot (Figure 2) indicates that shrubs could compete strongly with trees for water.

Spatial variability of soil moisture

Average soil moisture at cropped plots was higher beyond than beneath the tree, although no significant differences were found between distances (Table 3). This behaviour was also observed in cropped plots of the other three sites (data not shown). The opposite trend was found in M plots, although differences between distances were not significant again ($F_{4, 155} = 1,31; p = 0,27$). By contrast, no clear tendencies appeared at grazed plots (Table 3).

Results in grazed plots differ from those reported by Joffre and Rambal (1988) who found that soil moisture was significantly higher beneath than beyond the tree, justified by the positive effect of the trees, increasing the soil water holding
capacity beneath them. In our study, this positive effect of the tree has not been detected. Apart of a possible positive effect of ploughing in soil re-watering, as aforementioned, a decrease in water transpiration could occur as a consequence of the destruction of the fine roots at the upper layers of the cropped plots. In fact, Obrador et al. (2003) have reported a higher value of tree root density in grazed plots than in cropped ones in the first 20 cm of the soil. Both, a lower water transpiration and a higher soil re-watering out of the tree (cropped) respect to beneath tree (uncropped) could explain the increment of soil moisture with the distance to the tree in cropped plots (Table 3). Moreover, a lower rainfall beneath the tree is expected as a consequence of the rainfall interception; Mateos, 2001).

The fact that soil moisture in M plots increases in the vicinity of the trees could be explained as a positive effect of trees, which increase the soil water-holding capacity, as Joffre and Rambal (1988) suggested. However, this result could be a consequence of the competition for soil water between shrubs and trees. Shrub density is higher beyond rather than beneath the tree, and shrubs usually contribute to higher volumes of rainfall interception (Belmonte et al., 1996) and water transpiration (Domingo et al., 1999).

Soil moisture profile

Soil water content did not vary in the first metre of soil from June onwards (all distances of C and G plots; Figure 2). Thus, trees must have an additional water source in deeper layers of the soil, where only tree roots reach (Obrador et al., 2003) and thus avoiding competition with herbaceous plants for water. To clarify this, soil moisture profile must be analysed.

In analysing soil moisture profiles from January to July 2003 at BA site (Figure 4), it was observed that soil water depleted gradually from March to June. From as early as April, soil water consumption was decreasing (distances between two consecutive lines become narrower). Between June and July the difference was very slight, indicating that the soil was near wilting point as early as July in the first 100 cm. Afterwards, soil moisture profiles remained constant (lines overlapped, and thus, soil moisture profiles of August and September are not shown in figure 4). This trend was common in all analysed distances from the
tree trunk (only two distances are shown in Figure 4). The same temporal course of the soil moisture has been observed for the rest of the sites.

Results of TDR-probes installed at deeper layers (they had been installed in May 2003, and some of them reached 200 cm) are shown in Figure 5. Results for 100-200 cm depth were different to those of 0-100 cm depth, although in both layers most of the water was depleted between May and June, and then from June onwards soil moisture varied very little. Moreover, in some cases (deeper layers) soil moisture remained constant. We observed similar profiles at all distances from the tree trunk (Figure 5 shows 5 and 17 m of distance as examples). These results would indicate that the deeper part of the soil (near 200 cm) would not take part in the annual soil water dynamic; that is, soil rewatering does not reach below 200 cm and trees do not take water from there. In fact, we found abundant carbonates between 150 and 200 cm depth, while soils in the first 100 cm were acid (pH around 5; Obrador et al., 2004).

Results indicate that trees take very little water from the first 200 cm of soil depth in summer. However, in these same sites trees show a good water status, that is high leaf water potential, throughout two consecutive summer droughts (Montero et al., 2004), indicating that trees were taking water from elsewhere.

We could also consider a possible capillar rise of water from the lower to the upper horizons, which would allow trees to consume water from the soil, keeping the soil moisture constant. This would also justify the presence of carbonates at these depths (upward movement of bases). Daudet and Vachaud (1977) and Hillel (1980) point out that although no variation in soil water storage is detected, this does not mean that there is no water consumption, since it could be frequent in areas with summer drought but with enough winter rain to permit winter recharge at depth.

A possible use of deeper water by a deep rooting system could be also considered, given that Quercus ilex roots have been found near 500 cm of depth in these sites (Obrador et al., 2003). Abrams (1990), Rambal (1993) and Canadell et al. (1996) stressed the importance of the deep root system in oaks, considering it an efficient way to face the summer drought. Rambal (1984) detected water consumption up to a depth of 5 m by Quercus coccifera in
Southern France. In fact, deep roots (taproots) could be hundreds of times more efficient in absorbing water than roots in drier soil (Reicosky et al., 1964; quoted in Canadell et al., 1996). We have observed in different in-farm wells located in the study area that groundwater was at about 5-10 m depth throughout the summer. By contrast, Joffre and Rambal (1988) reported that holm-oak took water mostly from the first 150 cm of soil depth, in dehesas of Southern Spain.

The dependence of trees on a deep water reserve contributes to preventing competition for water between trees and herbaceous plants (crop or native grass), which showed a maximum rooting depth of 500 and 100 cm, respectively (Obrador et al., 2003). Eastham et al. (1990) point out that, in silvopastoral systems, competition between trees and grasses was reduced by the greater depth of tree roots when soil water reserves were partially depleted.

CONCLUSIONS

Soil water dynamics is dependent of dehesa land use. To crop dehesas could induce short-term changes in soil properties and favour water infiltration and soil re-watering. On the other hand, no additional competition for soil water with trees was detected in cropped plots with respect to the grazed ones. By contrast, dehesa encroachment results in drier soils, increasing the competition for soil water between tree and understorey.

In cropped and grazed plots, soil water was not exhaustively depleted throughout the summer drought, probably due to the low root length density shown by holm-oak in the sites studied (Obrador et al., 2003). On the contrary, we have found some evidence that holm-oak could be taking water from deeper layers (below 200 cm depth) during the summer. This water is not available to herbaceous plants; thus competition for soil water between trees and herbaceous plants is therefore avoided.

Moreover, soil water depletion beyond the tree canopy projection continued even when herbaceous plants dried up, indicating that trees could use water from beyond the canopy, implying a clear benefit of tree spacing on soil water consumption.

Acknowledgement

This study was supported by The European Union (SAFE project, contact QLX-2001-0560), Spanish Ministerio de Ciencia y Tecnología (MICASA project, contract AGL-2001-0850) and Consejería de Educación de la Junta de Extremadura (CASA project, contract 2PR02C012).
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References


Table 1. Main physical characteristic of the soils in the experimental farms.

<table>
<thead>
<tr>
<th>Experimental site</th>
<th>Soil type</th>
<th>Thickness of the layer cm</th>
<th>Sand %</th>
<th>Silt %</th>
<th>Clay %</th>
<th>Bulk density g cm$^{-3}$</th>
<th>Water (mm) at Field capacity</th>
<th>Wilting point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sotillo (ST)</td>
<td>chromic Acrisol</td>
<td>20</td>
<td>51,8</td>
<td>30,3</td>
<td>17,9</td>
<td>1,49</td>
<td>15,0</td>
<td>7,2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>39,7</td>
<td>23,1</td>
<td>37,2</td>
<td>1,85</td>
<td>21,7</td>
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</tr>
<tr>
<td></td>
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<td>38,8</td>
<td>23</td>
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<td>20</td>
<td>44,6</td>
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<tr>
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<td>chromic Luvisol</td>
<td>20</td>
<td>55,9</td>
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<td>1,49</td>
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<tr>
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<td></td>
<td>20</td>
<td>37,2</td>
<td>26,1</td>
<td>36,7</td>
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<td>20,9</td>
<td>11,7</td>
</tr>
<tr>
<td></td>
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<td>20</td>
<td>33,2</td>
<td>27,9</td>
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<td>1,43</td>
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<td>19,3</td>
<td>36,1</td>
<td>1,46</td>
<td>22,1</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>46,6</td>
<td>16,5</td>
<td>37</td>
<td>1,53</td>
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</tr>
<tr>
<td>Dehesa (DB)</td>
<td>eutric Leptosol</td>
<td>23</td>
<td>34,4</td>
<td>46,4</td>
<td>19,2</td>
<td>1,45</td>
<td>12,2</td>
<td>7,6</td>
</tr>
<tr>
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<td></td>
<td>35</td>
<td>29,6</td>
<td>49,5</td>
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<td>12,4</td>
<td>1,60</td>
<td>8,6</td>
<td>6,1</td>
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<tr>
<td>El Baldio (BA)</td>
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<td>39,7</td>
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<td>18,5</td>
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<td>1,45</td>
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<td>13,1</td>
</tr>
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<td></td>
<td></td>
<td>40</td>
<td>48,3</td>
<td>14,5</td>
<td>37,2</td>
<td>1,50</td>
<td>23,3</td>
<td>11,7</td>
</tr>
</tbody>
</table>
Table 2. Details of the number and localisation (distance and depth) of the TDR-probes and measurement periods.

<table>
<thead>
<tr>
<th>Experimental site</th>
<th>Slope %</th>
<th>Land use</th>
<th>N° trees</th>
<th>Distance (m)</th>
<th>Maximum depth (cm)</th>
<th>TDR-probes (Number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sotillo (ST)¹</td>
<td>2</td>
<td>Cropped</td>
<td>3</td>
<td>2, 5, 8, 12, 17</td>
<td>130³</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grazed</td>
<td>3</td>
<td>2, 5, 8, 12</td>
<td>130³</td>
<td>50</td>
</tr>
<tr>
<td>Cerro Lobato (CL)¹</td>
<td>4</td>
<td>Cropped</td>
<td>6</td>
<td>2, 5, 8, 12, 17</td>
<td>200³</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grazed</td>
<td>3</td>
<td>2, 5, 8, 12</td>
<td>200³</td>
<td>90</td>
</tr>
<tr>
<td>Dehesa Boyal (DB)²</td>
<td>2</td>
<td>Cropped</td>
<td>3</td>
<td>2, 5, 8, 12, 17</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grazed</td>
<td>3</td>
<td>2, 5, 8, 12</td>
<td>80</td>
<td>48</td>
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<td></td>
<td></td>
<td>Cropped-F</td>
<td>4</td>
<td>2, 5, 10, 20, 30</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cropped-nF</td>
<td>4</td>
<td>2, 5, 10, 20, 30</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grazed-F</td>
<td>4</td>
<td>2, 5, 10, 20, 30</td>
<td>100</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grazed-nF</td>
<td>4</td>
<td>2, 5, 10, 20, 30</td>
<td>100</td>
<td>80</td>
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<td></td>
<td>Matorral</td>
<td>4</td>
<td>2, 5, 10, 20, 30</td>
<td>100</td>
<td>80</td>
</tr>
</tbody>
</table>

¹ Measurements from May 2002 till September 2003.

² Measurements from May 2003 till September 2003.

³ TDR-probes from 1 to 2 m from May 2003 onwards.

⁴ Maximum depth was limited by the presence of bedrock (in DB) or by the abundance of coarse gravel (ST and BA).

⁵ F and nF mean fertilised and unfertilised plots, respectively.
Table 3. Average soil moisture at different distances from the tree trunk at dehesa Baldio (BA), under three land uses (cropped, grazed and matorral plots), from January 2003 to September 2003.

<table>
<thead>
<tr>
<th>Systems</th>
<th>Distance (m)</th>
<th>Average</th>
<th>Max (March)</th>
<th>Min (July)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropped</td>
<td>2</td>
<td>11.3 a</td>
<td>17.7 b</td>
<td>7.1 b</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>11.6 a</td>
<td>17.9 b</td>
<td>7.4 b</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>12.4 b</td>
<td>18.8 ac</td>
<td>7.8 b</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>13.4 c</td>
<td>20.1 a</td>
<td>8.5 a</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>12.5 b</td>
<td>20.3 ac</td>
<td>7.6 b</td>
</tr>
<tr>
<td>Grazed</td>
<td>2</td>
<td>16.3 d</td>
<td>23.2 a</td>
<td>10.8 a</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>15.9 cd</td>
<td>24.8 a</td>
<td>9.9 a</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>15.6 bc</td>
<td>24.0 a</td>
<td>9.5 ab</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>14.8 a</td>
<td>22.7 a</td>
<td>9.1 b</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>15.2 ab</td>
<td>24.3 a</td>
<td>9.1 b</td>
</tr>
<tr>
<td>Matorral</td>
<td>2</td>
<td>11.9 c</td>
<td>17.7 b</td>
<td>7.6 a</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>12.4 c</td>
<td>17.9 b</td>
<td>7.7 a</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>13.7 d</td>
<td>19.5 ab</td>
<td>8.6 a</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>9.6 a</td>
<td>15.2 b</td>
<td>4.8 b</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>10.2 b</td>
<td>16.9 b</td>
<td>5.0 b</td>
</tr>
</tbody>
</table>

† Values followed by a different letter differed significantly (p ≤ 0.05, LSD).
FIGURE CAPTION

**Figure 1** - Relationship between soil moisture (% weight) and TDR data measured in eight pots filled with soils from the studied sites.

**Figure 2** - Seasonal evolution of average soil moisture at dehesa *Baldio (BA)*, under three management types (cropped, grazed and *matorral* plots), from January 2003 to September 2003. Vertical bars represent standard errors.

**Figure 3** - Seasonal evolution of average soil moisture at dehesa *Baldio (BA)*, considering fertilised versus non-fertilised (control) plots, from January 2003 to September 2003. Vertical bars represent standard errors.

**Figure 4** – Temporal evolution of soil moisture profiles at dehesa *Baldio (BA)*, at two different distances from the tree trunk (2 and 30 m), from January 2003 to July 2003.

NOTES: Data refer to average values of soil moisture of C, G and M plots. Soil moisture profiles in August and September overlapped that in July, and thus they are not drawn. Soil moisture profiles at the other distances (5, 10 and 20 m) were similar.

**Figure 5** – Temporal evolution of the soil moisture profiles at two different distance to the tree trunk (5 and 17 m to the tree trunk), from February 2003 to August 2003.

NOTE: Data were average from C and G plots of *CL* farm. Soil moisture profiles in September overlapped that in August, and thus it is not drawn. Values at the other distances (2, 8 and 12 m) were similar.
FIGURE 1

\[ y = 0.0545x - 0.0432 \]

\[ R^2 = 0.8171 \]

FIGURE 2

soil moisture, % weight

soil moisture (g/g)

Refraction index (nTDR)
FIGURE 3

Soil moisture, % weight

---

- **FERTILIZED**
- **CONTROL**

Timeline:
- Jan
- Feb
- Mar
- Apr
- May
- Jun
- Jul
- Aug
- Sep
ANNEXE 9. Consequences of Dehesa land use on nutritional status of vegetation in Central Western Spain

Contractor 7 : UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

Obrador Olán JJ, García López E, Moreno G*
I.T. Forestal, Centro Universitario, Universidad de Extremadura, Plasencia 10600 Spain
* Corresponding author: gmoreno@unex.es

ABSTRACT

A dehesa is a silvoarable system, which results in structure and species simplification of Mediterranean forests. Activities like livestock, forestry, agriculture and, recently, hunting are carried out in these places, in which three main structures are found: trees with native grasses (G), trees with crops (C) and trees with woody understorey (M). In order to find out the effect of dehesa land use on nutritional status, we have measured the nutrient content (N and P) of the vegetation (holm-oak and crop) in three farms located in Central Western Spain, considering in each one the three aforementioned dehesa types. Additionally, the effect of the tree on soil fertility was studied in order to map soil resources around the oak-trees, which will be useful to model the tree-understorey interactions and dehesa functioning.

Soil samples (first 20-cm depth) were taken at different distances from the tree (from 2 up to 20 m) in three trees per plot (9 plots: 3 farms x 3 land uses). In all samples, pH, soil organic matter (SOM), cationic exchange capacity (CEC), total N and available P were determined. Foliar nutrient content of holm-oak (N and P) was measured in mature leaves of nine trees per plot. Crop samples were collected at four distances (2, 5, 10 and 15 m) of the trunk of 9 mature trees per plot (only cropped plots).

Trees in C plots presented the highest values of leaf-N, which is related to fertiliser application and to organic material incorporation/mineralization. Trees in M plots showed the lowest values of leaf-N, indicating a competitive effect of the matorral. By contrast, highest values of P were found in M plots, indicating a positive
interaction between trees and shrubs in P uptake. Differences between C and G plots were not significant.

In soils, values of all measured parameters, except pH, diminished according to the distance from the holm-oak, which indicates a marked and positive effect of trees on soil fertility. Regarding the land use, both N and P presented significant differences, being M and C, respectively, which had the highest contents, which does not coincide with the results from leaf nutrient contents. By contrast, N and P values in cereal had a similar behaviour to those of soil, indicating the high dependence of the crop on the nutrients of the first cm of the soil.

Keywords: soil fertility, leaf nutrients, dehesa management intercropped systems, tree-understorey interactions.

INTRODUCTION

Dehesas are the result of a simplification, in structure and species, of Mediterranean forest, where tree density is lowered, matorral cover is eliminated, and grass layer is favoured with crop culture in large periods of rotation. They are silvoarable systems of extensive utilisation, where autochthonous pastures and trees have a preponderant place (Montero et al., 1998).

Dehesas of holm-oak (Quercus ilex) and cork-tree (Quercus suber) occupy 28% of the total Spanish woody Quercus area, which reach 250 0000 ha (Campos et al., 2003). Land uses in dehesas are, in order of importance, livestock, forestry, agriculture and hunting, though in certain circumstances and regions the order of importance of each production can be altered.

These land uses result in three main types of vegetation structure in dehesas: holm-oak tree (Quercus ilex subsp. ballota) relations with pasture, crop and matorral, hereafter defined and named as cropped plots (C, trees with cereal), grazed plots (G, trees with native grasses) and encroached plots (M, trees with matorral, that is, woody understorey). In the last decades, a dramatic loss of cultivation has been taking place. On the other hand, an increase in the dehesa encroachment has been recommended in order to increase the natural regeneration of holm-oak in dehesas (Pulido et al., 2001). Moreover, in some areas this is also envisaged as a way to increase the hunting opportunities. However, these recent changes could have some effects on the soil chemical fertility and on the nutritional status of the holm-oak trees, and thereafter on the trees and dehesa productivity.
Several authors have already studied different aspects of the nutritional status of dehesas, namely, the effect of the tree on the soil fertility by comparing soil nutrient content beneath and beyond the tree canopy projection (e.g. Escudero, 1985; Gallardo et al., 2000; Joffre, 1987), the nutritional status of the pasture (e.g. Esselink et al., 1991; Joffre, 1987; Calabuig and Gómez, 1992; Vázquez-Aldana et al., 1995; Pérez-Corona et al., 1995) and trees (Mediavilla and Escudero, 2003; Escudero et al., 1992). These works have shown the general low soil fertility of the dehesa soils and a major role of the holm-oak trees in the soil fertility, which is observed also in other agroforestry systems (Menenzes et al., 2002; Sierra et al., 2002; Halvorson et al., 1995; Knops and Koening, 1997; Dahlgren et al., 1997).

Nowadays, comprehensive models of dehesa functioning are needed in order to improve its management and profitability and in order to detect both possible short and long-term consequences of the recent changes in dehesa land use. Nevertheless, some specific lack of information has been detected on the nutritional status of dehesas. For instance, no work has focused on the comprehensive study of the soil, tree and understorey nutritional status. On the other hand, previous studies have compared the soil fertility between beneath and beyond the trees, but none has quantified the vertical (depth) or horizontal (distance to tree) extension of tree influence. No study has been carried out to differentiate the specific sources of soil nutrient for tree and understorey, that is, we do not know if there is some type of temporal and spatial soil nutrient partitioning between vegetation strata. Finally, all the aforementioned studies have been carried out in grazed dehesas, while the possible consequence of the soil management on soil fertility and nutritional status of vegetation has not been studied yet.

*In order to find out the consequences of dehesa land use on the nutritional status of soil and vegetation, the aims of this study were:*

1. To estimate the nutritional status (N and P) of holm-oak trees under different land uses (cropped, grazed and encroached dehesa plots), in three farms of Central Western Spain.

2. To characterise the soil nutrient distribution around scattered holm-oak trees by studying soil nutrient content at five distances to the holm-oak trunk and three land uses.

3. To find out the nutritional status (N and P) of the crop at four distances to the holm-oak trunk in four farms, and with different fertiliser applications.
Results of this study will be used to build a biophysical model of dehesa functioning, with especial emphasis in tree-crop interactions, both negative (competition) and positive (facilitation). In this context other studies, regarding microclimate, rooting system, water dynamic, physiological tree status and production (cereal and tree) are being carried out.

METHODOLOGY

Study Area

Study area is located in Cuatro Lugares County (Central-Western Spain; 34°4'N, 6°13'W), which has a land area of 441 km², with around 50% of the surface occupied by dehesas (Plieninger and Wilbrand, 2001). The climate is Mediterranean (579 mm y⁻¹ of rainfall, and 16°C of annual mean temperature) with dry and hot summers and cool, rainy winters.

Soils, following FAO (1998) were chromic Luvisols (CL farm) and chromic Acrisols (ST farm), developed over tertiary sediments. Both types of soils had a light-brown and silty-sand surface horizon, one or several very red argic horizons, and a very sandy deep horizon (below 100 cm). The soils also showed bad internal drainage, which produces variegated colours and/or pseudo-gleyic properties, abundant gravel of quartzite (frequently between 10-40 cm depth), low soil chemical fertility, and CaCO₃ accumulation between 150 and 200 cm depth. Where the sediments have been eroded emerge the slates on which eutric Leptosols have been developed (DB farm). Soil slope varies between 2 and 4%.

The more common activities in the study area are cattle raising with native pasture and cereal intercrops. More marginal activities are firewood production and hunting. Tree density is from 5 to 50 tree per ha, depending of its main use (lower densities in intercropped areas and higher densities in areas reserved for hunting). Common native grasses are *Trifolium campestre, Medicago polymorpha, Anthemis arvensis, Geranium molle, Erodium cicutarium, Taraxacum obovatum, Lolium rigidum* and *Silene psamitis*, and more common shrub species are *Genista hirsuta, Cistus ladanifer, Retama sphaerocarpa* and *Lavandula stoechas*. 
In this county, three farms were selected: Cerro Lobato (CL); Sotillo (ST), and Dehesa Boyal de Talaván (DB), each one with three different land uses: cropped plots (C, holm-oak tree with cereal, wheat and oats), grazed plots (G, trees with native grasses) and encroached plots (M, trees with matorral, that is, woody understorey); as overall 9 plots were studied.

In order to find out the effect of dehesa land use on the nutritional status of trees, in each farm we randomly selected 9 trees in C and G, and 6 in M. Foliar samples composed of 4 subsamples (one per orientation) of mature leaves were collected in August 2002.

To study the effect of land uses in dehesas and the tree effect on soil fertility, three holm-oaks were randomly selected in each plot. Soil samples were taken out at 5 distances from the trunk: 2 m (under the tree), 5 m (tree periphery), 10, 15 and 20 m (beyond the tree canopy projection). With the help of a stainless steel drill, five subsamples of composed samples were taken in a depth of 0-20 cm, in March-April 2002.

To study the nutritional status of crops, we randomly selected 9 trees per farm in CL, DB and ST, where the fertiliser applications (formula 7-12-7) were 200, 160 and 0 kg, respectively. For sampling, two orientations and four distances (2, 5, 10 and 15 m from the tree trunk) were considered. Each 6 plants were oven-dried at 75°C until constant weight, ground finely in a stainless steel sail grinder and sieved to be analysed.

Table 1 summarises the chemical analysis carried out on both soil and plants samples.

Statistical analysis

Non-linear regressions have been applied to obtain the relationship between soil nutrient contents and distance to the tree trunk. The applied model was the logistic decrease:

$$y = A - \frac{B}{1 + C \times \exp(-D \times \text{DISTANCE})}$$

Results are expressed in term of percentage of variability explained ($R^2$).

Differences between land uses (C, G and M plots) and distance to the tree trunk (as independent variables) were assessed by two-way ANOVAs for each chemical parameter (pH, SOM, CEC, available-P and total-N) as dependent variables. Results are expressed as F values (and degree of freedom) and significance level (p value).

Statistical analysis was carried out in SPSS for Windows (SPSS Inc, 2001).
RESULTS

Soil nutritional status

Soil pH did not show differences due to holm-oak influence (Figure 1), which was backed up by the statistical analyses ($F_{4,103}=0.28$, $p=0.89$). This result contrasts with that obtained by Escudero (1985) in more northern dehesas. Differences among land uses (Figure 2) were not significant ($F_{2,78}=1.47$, $p=0.24$). The studied soils are defined as acid (mean value of 5.35; range of pH is 6.49-4.35), which could affect the availability of some nutrients or the decomposition velocity of the organic matter (Ulrich and Summer, 1991).

SOM clearly diminished with distance to the tree trunk (Figure 1), indicating a marked effect of tree organic contribution on the soil system (through litterfall and root decay). Statistical analysis ($F_{4,103}=24.3$, $p<<0.01$) showed highly significant differences between values of beyond and beneath the trees. The decrease of SOM with distance followed a logistic curve (Figure 3), which shows that the influence of the tree disappears from only a few meters beyond the canopy projection. SOM was higher in $M$ than in $C$ and $G$ plots (Figure 2), but differences among plots (land uses) were not significant ($F_{2,78}=0.80$, $p=0.45$).

In general, SOM contents were low, according to the range of values reported by Montoya and López (1998) for Spanish forests. On average, SOM contents were in the 30 percentile considering the values reported by Vanmechelem et al. (1997) for the whole of European soils. The SOM plays an important role in the physical, chemical and biological properties of the soil; for instance, the amount of nutrient in the soils of dehesa (total N) depends on organic matter quality and quantity (Gallardo et al., 2000). The low values of SOM of the studied dehesas are partly explained by the semiarid conditions, but it could also reflect a certain level of soil degradation.

N soil concentrations also diminished with the distance from the holm-oak trunk (Figure 1). Statistical analysis ($F_{4,103}=10.1$, $p<<0.01$) showed significant differences between the two first distances (2 and 5 m; beneath the tree) and the other ones (beyond the tree). Total N followed a similar tendency to SOM, although with a less sharp decline (Figure 3). A similar spatial heterogeneity of soil nitrogen in dehesas has been found by Escudero (1985), Puerto et al. (1987) and Gallardo and Merino.
The amounts of total-N were moderate under the tree and low beyond the tree canopy, according to the ranges reported by Montoya and López (1998). Considering the whole of European soils (Vanmechelen et al., 1997), our soils fall around the 30 percentile, that is, the total N content in these soils can be qualified as moderately low.

There were significant differences as regarding land use (Figure 2; $F_{2,78}=3.70$, $p=0.03$), with higher concentrations in $M$ plots (mean value of 1.4 mg g$^{-1}$) than in $C$ and $G$ plots. This result agrees with the result for SOM; both N and SOM tendencies show a positive effect of the shrubs on the soil fertility (Fisher and Binkley, 2000).

Soil available P (P-Olsen) values at different distances of the holm-oak trunk (Figure 1) also showed a positive effect of tree on soil fertility. In fact, available P concentrations beneath trees were significantly higher than those out of tree canopy ($F_{4,103}=3.59$, $p=0.01$). The decrease at the limit of the canopy projection was sharper than for other analysed soil chemical parameters (Figure 3). These results coincide with those obtained in more northern dehesas by Escudero (1985).

There were significant differences among land uses in available soil-P ($F_{2.78}=5.90$, $p<0.01$); the highest concentrations were found in $C$ plots (Figure 2); which could be related to P fertiliser applications. In fact, grazed plots, which are also periodically cultivated (and then fertilised) had higher values of available soil-P than $M$ plots (which were not fertilised at least in the last two decades). Thus, soil P levels could be determined by biological (tree effect) and antropic causes. Both could explain the slightly high levels of available P (based on values reported by Domínguez Vivancos, 1997), in spite of the soil acidity, which contributes to lessen the availability of soil P (Fisher and Binkley, 2000).

Overall, the studied soils showed moderately low concentrations of N and moderately high levels of available-P, which is characteristic of young soils. Soils developed on old and nutrient-poor substrates are usually P deficient, whereas N may be deficient even in young soils (Vitousek and Farrington, 1997).

The CEC values found in the present study were between the 30 and 50 percentiles considering the values reported by Vanmechelem et al. (1997) for the whole of European soils. Values of CEC are basically related to organic matter and clay
quality (mainly kaolinite) and quantity (below 20% in the first 20 cm of the studied soils; unpublished data). The moderately low values of CEC in the studied soils must be explained by the low soil organic contents. CEC values diminished with the distance from the trunk (Figure 1). Statistical analysis showed significant differences between distances ($F_{4,103}=7.67, p<<0.01$), with higher values beneath than beyond the trees, as a consequence of the levels of organic matter. However, CEC diminished much less than SOM with distance, because the clay content did not vary with the distance to the tree (data not shown). Similarly to SOM, there were no significant differences between soils of the three land uses (Figure 2; $F_{2,70}=0.15, p=0.86$).

The positive role of the holm-oak trees on soil fertility is explained by the annual input of organic matter to the soil through the litterfall (Gallardo and Merino, 1998; Escudero et al., 1992) and root decay (Jackson et al., 1996). Moreover, forests are particularly effective at scavenging and retaining atmospheric solutes due to their high surface area and aerodynamic resistance; this mechanism allows trees to thrive on poor soils and enabling soil improvement (Moreno et al., 2003).

**Crop nutritional status**

Mean concentrations of N in cereal plants diminished according to the increase in tree distance (Figure 4), indicating a positive effect of the tree canopy that is related to the holm-oak organic materials contribution and their incorporation into the soil due to agriculture machinery (Essenlik et al., 1991). Statistical analysis showed highly significant differences between the two first distances (2 and 5 m) and the rest ($F_{3,60}=22.07, p<<0.01$). The highest values of these concentrations imply that the materials that grow under the tree canopy have higher protein values, which rebound in a high quality of the pasture (Pérez-Corona et al., 1995). Nevertheless, on average the studied plants showed low levels of N in comparison with ranges reported by IFA (1992)

Figure 4 shows mean values and standard deviations of P concentrations in crop plants. Similarly to N, P concentrations diminished significantly as the distance to the oak trunk increases ($F_{3,60}=13.41, p<<0.01$). P levels ranged from normal (0.21) to very low (0.04) according to IFA (1992).
The concentration of N and P in crop plants changed in concordance with the aforementioned soil nutrient contents; both nutrients showed higher contents in the vicinity of the trees. This similarity between soil and herbaceous plants tendencies has been also shown by Puerto et al. (1987) and Escudero (1992). Our results indicate the high dependence of the crop on the nutrients of the first 20 cm of soil depth. This dependence coincides with the rooting system of these crops, which have most of the roots near the soil surface: 78% of the roots were located in the first 30 cm of soil (Obrador et al., 2003).

**Holm-oak nutritional status**

Figure 5 shows mean and standard deviation of N foliar concentrations in holm-oaks under three types of land use. Mean values of these concentrations (between 11.6 and 10.3 mg N g⁻¹) are in the range of those obtained in other studies for *Quercus ilex* in more northern dehesas (Escudero et al 1992; Mediavilla and Escudero, 2003) and for evergreen *Quercus* in California (Knops and Koening, 1997). Nevertheless, these values are in the low extreme of the range reported by Stephan et al. (1997) for oaks all over Europe (9.94 – 32.62 mg N g⁻¹).

Statistical analysis showed high significant differences (F₂,₆₃=9.06, p<<0.01) among the three different land uses, with highest values for trees of C plots, followed by G. These results show a clear positive effect of the dehesa management practices (mainly cropping, C), due to nitrogen fertiliser application and mineralisation of the incorporated organic materials (Esselink et al., 1991; Mansson and Falkengreen-Grerup, 2003; Frank and Roeth, 1996; Gallardo et al., 2000). The effect of the organic matter mineralisation is also revealed by the fact that the lowest concentrations of soil-N were found in *M* plots and the highest in *C* plots, while the opposite was found in the N contents in tree leaves.

Apart from comparing soil and tree N contents we can establish the following statements: shrubs compete strongly with trees for soil N and crop has no short-term negative effect on tree nutritional status. On the contrary, cropping activity leads to a higher leaf-N content in holm-oaks. These differences were found regardless of the fertilisation treatment, that is, trees in cropped plots of ST (unfertilised crops) also showed a higher leaf-N content than trees of *G* and *M* plots. This result indicates a positive effect of ploughing, probably an increase of the mineralisation rate. In order
to find out the N contribution that the two principal N inputs (SOM and mineral N fertiliser) have in the dehesa system, a specifically designed experiment would be advisable.

Regarding P, trees in M plots showed the highest values (0.65 mg P g\(^{-1}\)), continued by trees of G plots (Figure 5). Statistical analyses showed significant differences between M plots and other two plots (C and G) \((F_{2,63}=7.90, p<<0.01)\). Observed values in C and G plots (0.48 and 0.54 mg P g\(^{-1}\)) were below those obtained in other studies carried out with the same species in more northern dehesas (Escudero et al., 1992). Moreover, these values are even below the range reported by Stephan et al. (1997) for oaks all over Europe (0.56 – 2.22 mg P g\(^{-1}\)). P is considered in this county the most deficient nutrient; therefore, farmers apply higher quantities of this element in fertilisation doses.

The higher concentrations of P observed in leaves of M trees, must be explained in terms of a positive interaction between trees and shrubs. Most of the P could be in non-available forms (mineral and organic) and roots could have some direct role in the mobilisation of this P. More root density and diversity, and more mycorrhizae are expected in M plots than in C and G plots, so that the biological P mobilisation should be higher in M plots than in the others (Jackson et al., 1999).

Moreover, tree roots in studied dehesas are located rather in deep layers, with a low root density in the first 20 cm of the soil (Obrador et al., 2003), and thus, most nutrients could be taken up from these deep layers and not as many from the first 20 cm of the soil. In fact, P has a very low dynamic in the soil, so that it could depend just as much on the root density than on the P soil content. This would also explain why trees in M plots have the highest leaf-P contents while soils in M plots have the lowest available P in the first 20 cm of soil.

**CONCLUSIONS**

A positive effect of the tree in the soil fertility has been shown through four parameters (organic carbon, total N, CEC and available P). Nevertheless, the level of these four parameters decreased sharply in the limit of the canopy projection, that is, the effect of the trees was almost limited to the tree cover. The effect was null
(asymptotic values) beyond three meters to the canopy limit, although tree roots can spread horizontally to more than 25 m (Obrador et al., 2003).

The cultivation of dehesas increased the N concentration of holm-oak leaves as a direct consequence of organic matter mineralisation apart from the effect of mineral fertilisation.

A positive effect of dehesa encroachment was also found, with increased SOM and total soil N contents. On the other hand, shrubs could positively affect the P content of holm-oak leaves, probably by helping the soil P mobilisation.

Results of N and P contents in crop plants revealed the high dependence of these plants on the nutrients of the first 20 cm of the soil, according to the superficial rooting system of the crop plants (Obrador et al., 2003). By contrast, P and N contents of tree leaves do not coincide with soil nutrient contents (first 20 cm of soil depth), indicating a certain dependence of the deep soil nutrient. Thus, crop plants and trees could acquire most nutrients from different parts of the soil, which would imply a nice example of niche complementarity in an agroforestry system.

**Acknowledgement**

This study was supported by European Union (SAFE project, contract QLX-2001-0560), Spanish Ministerio de Ciencia y Tecnología (MICASA project, contract AGL-2001-0850) and Consejería de Educación de la Junta de Extremadura (CASA project, contract 2PR02C012). Jesús Obrador and Eustolia García were awarded grants by ANUIES and Colegio de Posgraduados (México).

**REFERENCES**


Table 1. Methods of chemical analysis carried out with samples of holm-oak leaves, crop (total plant) and soil.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Parameter</th>
<th>Method</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant (oak</td>
<td>N total</td>
<td>Semi-micro Kjeldahl (modified to include</td>
<td>Bremner, 1965</td>
</tr>
<tr>
<td>and crop)</td>
<td>P total</td>
<td>Incineration and colorimetric</td>
<td>Bigham and Bartels, 1996</td>
</tr>
<tr>
<td>Soil</td>
<td>CIC</td>
<td>Ammonium acetic extraction</td>
<td>Bigham and Bartels, 1996</td>
</tr>
<tr>
<td></td>
<td>SOM</td>
<td>Walkley and Black wet combustion, modified</td>
<td>Dewis and Freitas, 1984</td>
</tr>
<tr>
<td></td>
<td>Total N</td>
<td>Semi-micro Kjeldahl (modified to include</td>
<td>Bremner, 1965</td>
</tr>
<tr>
<td></td>
<td>Available P</td>
<td>CaCl₂ (1:2)</td>
<td>Olsen and Dean, 1965</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td></td>
<td>Bigham and Bartels, 1996</td>
</tr>
</tbody>
</table>
FIGURE CAPTION

Figure 1 - Mean values and standard deviations of soil pH, organic matter (SOM), total-N, Cation exchange capacity (CEC) and available-P at different distances to the holm-oak trunk.

Data are average values of C (cropped), G (grazed) and M (matorral) plots. Different letters indicate significant differences.

Figure 2 - Mean values and standard deviations of soil pH, organic matter (SOM), total-N, cation exchange capacity (CEC) and available-P in dehesas soils with three different land uses: C (cropped), G (grazed) and M (matorral) plots. Different letters indicate significant differences.

Figure 3 - Relationships between the distance to the holm-oak and four chemical parameters of the dehesa soils in Central-Western Spain.

NOTE: The logistic decrease curves \( y = A - \frac{B}{1 + C \times \exp(-D \times \text{DISTANCE})} \) have been normalised, and the corresponding parameters are:

<table>
<thead>
<tr>
<th>Chemical parameter</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOM</td>
<td>39,9</td>
<td>19,6</td>
<td>26,9</td>
<td>0,744</td>
<td>99,57</td>
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<tr>
<td>Total N</td>
<td>1,31</td>
<td>0,42</td>
<td>71,7</td>
<td>0,898</td>
<td>99,30</td>
</tr>
<tr>
<td>CEC</td>
<td>10,1</td>
<td>2,54</td>
<td>7994</td>
<td>1,668</td>
<td>98,81</td>
</tr>
<tr>
<td>Available P</td>
<td>14,0</td>
<td>5,06</td>
<td>2252</td>
<td>1,699</td>
<td>99,01</td>
</tr>
</tbody>
</table>

Figure 4 - Mean concentrations and standard deviations of N and P in cereal plants at different distances to the holm-oak trunk. Different letters indicate significant differences.

Figure 5 - Mean concentrations and standard deviations of N and P in leaves of holm-oak in dehesas with three different land uses: C (cropped), G (grazed) and M (matorral) plots. Different letters indicate significant differences.
FIGURE 5

Land use

N (%)  
C  G  M

P (mg g⁻¹)  
C  G  M
ANNEXE 10. The Role of Dehesa land use on Tree Water Status in Central-Western Spain

Contractor 7 : UNEX

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Montero MJ, Obrador JJ, Cubera E, Moreno G


1 Corresponding author: gmoreno@unex.es

Abstract

Dehesas are recognised as the main type of agroforestry system in Europe. However, studies focusing on the interaction between different types of vegetation are still needed to understand how oak activity and productivity can be affected by land use and vegetation structure.

To achieve that, leaf water potential and CO₂ assimilation rate were studied in holm-oaks in dehesas with different types of land use: cropped (cereal), grazed (native grasses) and matorral (abundant shrubs as understorey) plots, in different farms of central-western Spain. The measurements were performed in two vegetative periods.

Significant differences were found among the three land uses, with higher maximum leaf water potential during the summer in trees of cropped plots (less stressed), followed by those of grazed and matorral plots. Nevertheless, both maximum leaf water potential (predawn) and minimum potential (midday) remained high throughout the dry period despite the land use. The lowest predawn water potential data were between -0.71 MPa and -1.30 MPa, values clearly higher than those reported in the literature for holm-oaks growing in higher stem density (usually lower than -2 MPa).

Results of photosynthesis coincided with water potential ones: trees maintained a high CO₂ assimilation rate throughout the summer; this rate was significantly higher in those plots where fertilisation treatment was carried out. The daily courses of photosynthesis had the characteristic shape of non-stressed or only slightly stressed plants.

In conclusion, the low tree density in dehesas contributes to the maintenance of a good oak water status throughout the summer, improving their productivity. Moreover, cropping dehesas leads to less water stress and additional benefit from fertiliser improves photosynthesis activity.

Keywords: water potential, photosynthesis, Quercus ilex, dehesa land use, tree density.
1. INTRODUCTION

Mediterranean environments are mainly characterised by summer drought and winter cold. The first one is traditionally recognised as the most important climate constraint of Mediterranean-type ecosystems (Savé et al., 1999). Among the numerous mechanisms for drought resistance, Mediterranean plants show a high capacity to adjust stomatal conductance, deep rooting systems and low leaf area index (LAI), which contribute to maintain high leaf water potentials, and thus, the turgence of leaves (Rambal, 1993).

Therefore Quercus, the most important representative genus of the Mediterranean basis, has been widely researched to determine physiological behaviour in drought terms. Studies that compare deciduous oak with evergreen oak, (Larcher, 1960, quoted in Mediavilla and Escudero, 2003) show a conservative strategy in holm-oak with lower rates of gas exchange than deciduous oaks. Recently, Mediavilla and Escudero (2003) also concluded that evergreen species (Q. suber and Q. ilex) show the most conservative water-use characteristics, having lower maximum stomatal conductance than the deciduous species (Q. pyrenaica, Q. faginea), and higher stomatal sensitivity to drought. Nevertheless, under moderate water stress, holm-oak (Quercus ilex) maintains higher stomatal conductance for longer periods than deciduous oaks (Acherar and Rambal, 1992). There are also studies which analyse how specific microclimate differences in habitat affect the intra-specific variability of stomatal responses and water relations of Q. ilex (Sala and Tenhunen, 1994).

However, all the aforementioned studies and others (Sala, 1999, Savé et al., 1999, Moreno, 2001) were carried out in natural forests or high tree density conditions, without or with scarce anthropic activities. To understand the response of Mediterranean vegetation and particularly the response of Quercus sp it is necessary not only to consider abiotic or biotic factors, but also human activities. Thus, a combination of gradient of natural resources and different anthropic management practices leads to a great diversity of adaptation strategies and functional attributes in the Mediterranean ecosystems (Joffre et al., 1999).

In this way, oak-savannah (Dehesa) is the most important consequence of human activity in Mediterranean systems, especially in the South West of Spain. This type of complex system has been described as being very efficient in terms of resource use, and therefore, environmentally friendly and economically profitable (Gómez Gutiérrez, 1992; Pulido et al., 2003). However, studies focusing on the interactions between different types of vegetation are still needed in order to understand how oak activity and productivity can be affected by land use and vegetation structure.

There are recent studies on physiological response of Quercus ilex to drought carried out in Dehesas (Mediavilla and Escudero, 2003; Infante et al., 1999), but without focusing on the effects of land use.

The first objective of the present study is to assess how tree clearance, as a traditional practice to create dehesas, affects holm-oak functioning by studying the physiological tree status. The second objective is to find out how land use influences holm-oak activity by studying trees with different vegetation structures. To achieve this, we have studied leaf water potential and CO₂ assimilation rate of Quercus ilex in dehesas with three types of land use: intercropped plots (C), grazed plots (G) and
encroached plots, that is, dehesas with abundant woody understorey (matorral, $M$), all of them situated in the North of Extremadura (Spain).

2. MATERIAL AND METHODS

2.1. Study area

The study was performed in three experimental farms situated in “Cuatro Lugares” county, province of Cáceres, Central-Western Spain (39° 41’ N- 6° 13’ W; elevation 380 m; slope 2%). Climate is classified as subtropical Mediterranean, following the Papadakis classification, with a mean annual temperature of 16.2 °C, mean annual rainfall of 506 mm, and a wide dry period covering three months, from June to August. The mean minimum temperatures during January (the coldest month) is 3.4 °C, and the mean maximum temperatures during July (the hottest month) is 35.6 °C. Soils types are mainly chromic Luvisols and chromic Acrisols (FAO 1998) developed over tertiary sediments with abundant quartzite and more than 100 cm depth.

2.2. Experimental layout

Three different types of dehesa structures, as a consequence of the land use, were chosen: intercropped plots ($C$; holm-oak with oats or wheat), grazed plots ($G$; holm-oak with native grasses), and encroached plots ($M$; holm-oak with abundant woody understorey, named Matorral). Additionally, some measurements were taken in a neighbouring holm-oak forest.

The study was carried out from June 2002 to October 2003. In the first year (2002) two farms (“Cerro Lobato” ($CL$) and “Sotillo” ($ST$)) were selected, where two types of land use were considered, intercropped and grazed plots. In the $CL$ farm, the crop was fertilised (N+P+K), whereas the crop in $ST$ was not fertilised. Grazed plots were not fertilised in either of the two farms. Three trees were studied per farm and land use (12 trees in total).

In the second year (2003) a third experimental farm (“El Baldío” ($BA$)) was studied in a manipulative experiment carried out in a 10 ha site. This site included four 1-ha intercropped plots ($C$), four 1-ha grazed plots ($G$), and one 2-ha encroached plot ($M$). The effects of the fertilisation were also studied in both intercropped and grazed plots. Thus, the treatments considered in this second year were the following: fertilised crop ($C_F$), unfertilised crop ($C_NF$), fertilised native grass ($G_F$), unfertilised native grass ($G_NF$), and unfertilised Matorral ($M$). Four trees per treatment were selected to make both measurements: photosynthesis rate and leaf water potential.

Mean tree density was between 11 and 39 tree ha$^{-1}$, slightly lower than in most dehesas (ranging between 10-80 trees ha$^{-1}$; Campos et al., 2003). The main characteristics of the oaks of the different studied farms are shown in table 1.

The study was performed along two contrasted years, 2002 with 406 mm of rainfall, and 2003, with 596 mm of rainfall. These annual rainfall amounts are clearly lower and higher, respectively, than the mean annual precipitation (506 mm).
summers were very dry, with 8.2 and 1.3 mm in the period June-August for 2002 and 2003, respectively.

2.3. Leaf water potential and leaf gas exchange.

In 2002, each selected tree was measured in CO₂ assimilation rate and leaf water potential bi-weekly from 28 June to 15 August. CO₂ assimilation rate was measured in four leaves (exposed to sun) at five different hours of the day (60 measurements per plot and day) from sunrise to sunset. In the case of the leaf water potential 3 twigs per tree were measured at 2 points of the day, predawn water potential (Ψpd) before sunrise as daily maximum water potential, and midday potential (Ψmd) as daily minimum water potential (18 measurements per plot and day). In the second year (2003), measurements were taken monthly, from March to October, following the aforementioned protocol for every selected tree.

Net CO₂ leaf assimilation (A) and leaf transpiration (E) were measured with a portable differential infra red gas exchange analyser equipment (IRGA, model LCI, ADC). A Scholander chamber (model Sky) was used to collect leaf water potential values. The units of parameters surveyed in these studies were: A (assimilation rate of CO₂), µmol CO₂ m⁻² s⁻¹; E (transpiration), mmol CO₂ m⁻² s⁻¹; LWP (Leaf water potential), MPa.

Effects of land use and treatments on both A and LWP were inferred from mean values by comparison with the Analysis of Variance (ANOVA). Two-way ANOVA were performed with land use (Cropped, Grazed, and Matorral plots) and treatment (Fertilised and No Fertilised) as independent variables, date as repeated measures, and photosynthesis and leaf water potential as dependent variables. When treatments (F and NF) were compared, data from Matorral plot were not included because this plot did not include fertilised oaks. Similarly, when land uses were compared (C, G and M), data from fertilised plots were not included, for the same reason.

3. RESULTS AND DISCUSSION

3.1 Effect of land use on plant water status

Results of maximum (predawn) and minimum (midday) leaf water potentials are shown in table 2. The most outstanding result was that both maximum and minimum leaf water potentials varied only slightly throughout the summer drought during the two years.

In 2002, the differences between land uses (C and G) were significant for both maximum and minimum daily leaf water potential: Ψpd (F₁,₇₀ = 35.7; p = 8.7 · 10⁻⁸) and Ψmd (F₁,₇₀ = 19.8; p = 3.2 · 10⁻⁵). Both, Ψpd and Ψmd were higher in cropped plots than in grazed ones throughout the summer (Table 2). In one farm (CL), the cropped plot was fertilised while the grazed one was not. However, neither cropped plot nor grazed one was fertilised in the other farm (ST). In fact, the aforementioned significant differences between cropped and grazed plots were significant only in the CL farm. The effect of fertilisation will be commented on later.
In 2003, significant differences among land uses ($\Psi_{pd}$: $F_{2,152} = 30.5$, $p = 7.5 \cdot 10^{-12}$; $\Psi_{md}$: $F_{2,152} = 9.0$, $p = 0.0002$) and dates ($\Psi_{pd}$: $F_{7,152} = 66.7$, $p = 0$; $\Psi_{md}$: $F_{7,152} = 20.0$, $p = 7.1 \cdot 10^{-19}$) were also detected. Thus, late in summer, values of $\Psi_{pd}$ were significantly lower (more stress) in oaks combined with shrubs (Matorral plot), followed by grazed and cropped plots; these two latter land uses (C and G) showed signs of significant differences between them, cropped plots being less stressed ($p = 0.06$) (Table 2).

Conversely, no clear trends were observed in midday leaf potential, except in summer, when significant differences were found among grazed plots and the other two land uses (Table 2). Midday potential showed high variability even in a single plant (data not shown) due to the fact that this parameter does not only depend on soil water potential and atmospheric conditions, but also on the shoot position in the canopy (which determines the cumulative amount of incident radiation, and thus the photosynthesis and transpiration rates). Moreover, dehesa trees show substantial genetic differences (Vazquez, 1998) among individuals. These limitations could be affecting our results, and we did not find any explanation for the grazed $\Psi_{md}$ behaviour.

Regarding fertilisation treatment there were differences between fertilised and non-fertilised plots for $\Psi_{pd}$, being less stressed the fertilised cases in summer ($F_{7,156} = 16.2$; $p = 8.9 \cdot 10^{-5}$). $\Psi_{md}$ showed a similar behaviour although not significantly, close enough to be considered relevant ($F_{7,156} = 3.3$; $p = 0.073$) (Table 2).

Sala (1999) described different levels of water availability during summer as a function of leaf $\Psi_{pd}$, indicating that when leaf $\Psi_{pd}$ values are above -1 MPa there are no water limitations for plants, and daily courses of photosynthesis have a no water stress shape. In the present study, daily maximum leaf water potentials remained rather high even in the dry period, with minimum values above or only slightly below -1 MPa, in 2003 and 2002, respectively. Differences between years, although not significant, reflected the difference in rainfall (406 versus 596 mm in 2002 and 2003, respectively). On the other hand, daily minimum values of leaf water potential ($\Psi_{md}$) were also high during the study period, and the threshold of stomata closure (-4 MPa; Sala, 1999) was never reached. As a result, during the two experimental years holm-oaks did not experience any significant water stress.

Nevertheless, a decrease of $\Delta \Psi$ ($|\Psi_{md}\Psi_{pd}|$) throughout the summer drought was detected in the trees studied (Figure 1a). This decrease responds to the gradual depletion of soil water availability (related to leaf $\Psi_{pd}$), in spite of leaf $\Psi_{pd}$ does not reach very negative values (Figure 1b). This early response of holm-oak is interpreted in terms of the conservative strategy of water use (Sala, 1999). Studies carried out with holm-oak in Seville (Joffre et al., 1999) and with deciduous oaks ($Quercus pubescens$) in France (Damesin and Rambal, 1995) reported similar behaviour.

In conclusion, in analysing predawn potential that is directly related to soil water availability, oaks growing with understorey showed more stress than oaks in cropped and grazed plots during a period of constraint (summer). Moreover, trees in cropped plots had slightly increased potentials (less negative leaf $\Psi_{pd}$) than trees in grazed ones. On the other hand, fertilisation led to better water status of trees in the dry period.
Finally, regardless of the dehesa land use or treatment all trees showed a good water status throughout the dry periods, quite far from reaching the threshold values of stomatal closure. This can be explained by the benefits of tree scattering in dehesas, which allows trees to take water beyond their canopy projection (Joffre and Rambal, 1993).

3.2. Effect of water status on photosynthesis rate

A progressive stomatal closure with decreasing predawn water potential indicates a conservative water use that leads to a simultaneous decrease in photosynthesis (Hinckley et al., 1983; Joffre et al., 1999). In addition, *Quercus ilex* usually shows higher leaf $\Psi_{pd}$ values and lower CO$_2$ assimilation rates than other species of genus *Quercus* in summer drought, exhibiting the most conservative water-use of them (Mediavilla and Escudero, 2003).

In the present study the results coincide with these statements. Thus, a slight drop in leaf $\Psi_{pd}$ throughout the summer caused a conservative response in oaks, decreasing significantly the photosynthetic rate. A gentle decrease in leaf $\Psi_{pd}$ led to a significant stomatal closure and lessened water consumption, but producing a decrease in the photosynthesis rate at the same time (Figure 2). This fact led to high $\Psi_{md}$ values (Table 2) and a decrease of $\Delta\Psi$ (Figure 1) during these months. Moreover, this conservative strategy allows the attainment of non-critical leaf $\Psi_{pd}$ values, still remaining high despite the summer drought. This fact indicates that oaks could recover from the stress during the night satisfactorily; probably due to the low tree density. So, in spite of oaks reducing their water consumption and photosynthesis, the latter was still high in both summer droughts studied.

3.3. Effect of tree density on photosynthesis rate

Some previous works have already studied the influence of tree density in physiology of plants (e.g. Abrams 1986), but there is no research focussing either on *Quercus ilex* or on Mediterranean ecosystems. By reviewing other studies performed with oak growing in high density and less dry climates (Savé et al., 1999 and Moreno, 2001), a clear effect of tree density in leaf water potential and photosynthesis can be observed (Figure 2). In the present study, holm-oak trees had rather high rates of CO$_2$ assimilation throughout the year, with only a slight decrease in the summer respect to the spring period (Figure 2). The same seasonal pattern, although much more marked, has also been reported by Infante et al. (1999) in a high tree-density dehesa (40-50 trees ha$^{-1}$) in Southern Spain. The highest differences between our research and the aforementioned studies were found during the summer drought, when maximum absolute rates of $A$ were between 19-20 $\mu$mol CO$_2$ m$^{-2}$ s$^{-1}$ in the present study. Daily courses of $A$ and $E$ from the present study showed a non-stressed or slightly stressed shape curve (Hinckley at al., 1983) even in the dry period, while Sala (1999) and Infante et al. (1999) have reported typical daily courses of water stress conditions (Figure 3). Thus, dehesas show a better response in spite of the summer drought. So, it can therefore be concluded that a low number of trees per hectare leads to significantly less water stress and much higher CO$_2$ assimilation rate than high tree densities.

3.4. Effect of dehesa land use on CO$_2$ assimilation rate of holm-oak
Regarding the influence of land use, significant differences were found in 2002 (F.<sub>2, 479</sub> = 91.6; p = 0.000; Table 2), with higher values of A in cropped plots than in grazed ones. Once more these differences were more evident in CL plots than in ST, probably due to the fertilisation treatment in the crop of the CL farm. The differences among land uses (including matorral) were not confirmed in 2003 (F.<sub>2, 672</sub> = 1.69; p = 0.18; Table 2), with similar values for trees of the cropped, grazed and matorral plots.

With respect to the fertilisation effect, A values were significantly higher in fertilised plots than in unfertilised ones, although differences were only significant in the summer months (F.<sub>5, 663</sub> = 6.2; p = 0.01; Table 2).

As a result, the increase of nitrogen in fertilised plots improved photosynthetic rates of holm-oak during the driest months. However, any further negative or positive effect of dehesa cropping on photosynthetic tree activity is inconclusive.

3.5. Effect of dehesa encroachment on oak activity

To quantify the effect of dehesa encroachment (increase of woody understorey) as a consequence of dehesa abandonment or soil degradation, we compare the physiological status of trees in three neighbouring holm-oak plots, differing in the level of encroachment, that is, in the abundance of shrubs: trees cropped and grazed plots without woody understorey (C_P), trees in a plot with slight encroachment, with low density of low-size shrubs (named M “matorral”) and trees in a plot with strong encroachment, with high density of shrub, included young holm-oaks (named F “forest”). Despite carrying out measurements only in September and October, it can be observed in figure 4 that photosynthesis had a clear tendency related to the level of encroachment. In such a way, oaks from cropped and grazed plots showed non-stressed daily courses for CO₂ assimilation rate, while the daily courses for trees with slight encroachment showed a clear midday depression, and trees with high encroachment showed a daily course characteristic of water-stressed plants. The mean daily values for A, and leaf water potential collected during those two consecutive months (Table 3) confirmed that the physiological status of trees worsen with the level of encroachment. This fact indicates that the traditional clearance practice in dehesas improves holm-oak physiological status and thus its productivity.

In recent years, an increasing need of dehesa encroachment has been emphasized in order to improve the perspective of tree regeneration and to increase the hunting opportunities. Further studies will be needed to assess the long term response of trees to dehesa encroachment.

4. CONCLUSIONS

In the present study, holm-oak trees have shown better leaf water status and CO₂ assimilation rates than those previously reported in the literature for close forests or dehesas with high tree density. These differences have been confirmed by our results from three different levels of dehesa encroachment.

The benefits of dehesa systems for tree activity must be explained in terms of soil availability for each single tree owing to the holm-oak root spreading system which
occupies all of the open space between trees (Obrador et al. 2003). This allows trees to take water from a huge volume of soil.

In spite of the general good physiological status of holm-oak in dehesas, some evidence of its conservative strategy on soil water consumption have been detected; namely an early stomatal closure with significant decrease in the photosynthetic activity even with predawn leaf water potential close to -1 Mpa. These results coincide with those already described by other authors (e.g. Sala, 1999).

Finally, a slight positive effect of fertilisation and cropping on tree physiological status has been shown, whereas, even a slight dehesa encroachment leads to increase the water stress experienced by trees.

Acknowledgement

This study was supported by The European Union (SAFE project, contract QLX-2001-0560), Spanish Ministerio de Ciencia y Tecnología (MICASA project, contract AGL-2001-0850) and Consejería de Educación de la Junta de Extremadura (CASA project, contract 2PR02C012). Elena Cubera has been granted by the Consejería de Educación, Ciencia y Tecnología de la Junta de Extremadura and Fondo Social Europeo. Jesús Obrador has been granted by ANUIES (México).

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<table>
<thead>
<tr>
<th>Farm</th>
<th>Management Practice</th>
<th>Trunk diameter (cm)</th>
<th>Canopy diameter (m)</th>
<th>Tree height (m)</th>
<th>Tree density (Nº ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sotillo (ST)</td>
<td>Crop</td>
<td>49,6</td>
<td>10,7</td>
<td>8,2</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Uncrop-pasture</td>
<td>47,3</td>
<td>11,1</td>
<td>7,5</td>
<td>11</td>
</tr>
<tr>
<td>Cerro Lobato (CL)</td>
<td>Crop</td>
<td>45,9</td>
<td>9,8</td>
<td>8,3</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Uncrop-pasture</td>
<td>37,0</td>
<td>10,1</td>
<td>7,2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Crop- fertilised</td>
<td>32,9</td>
<td>7,6</td>
<td>5,2</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Crop-unfertilised</td>
<td>19,7</td>
<td>5,3</td>
<td>4,5</td>
<td>19</td>
</tr>
<tr>
<td>El Baldío (BA)</td>
<td>Pasture-fertilised</td>
<td>22,4</td>
<td>5,7</td>
<td>4,5</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Pasture-unfertilised</td>
<td>23</td>
<td>6,0</td>
<td>4,7</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Uncrop-Shrub-unfertilised</td>
<td>19,6</td>
<td>4,6</td>
<td>4,5</td>
<td>39</td>
</tr>
</tbody>
</table>

Table 1: List of the main holm-oak (*Quercus ilex*) tree dimensions at different experimental sites in dehesas of *Cuatro Lugares* County (province of Caceres).
<table>
<thead>
<tr>
<th>Year</th>
<th>Farm</th>
<th>Period</th>
<th>Land use/ treatment</th>
<th>A  ( (\mu \text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}) )</th>
<th>Predawn ( \psi ) (-MPa)</th>
<th>Midday ( \psi ) (-MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>Sotillo</td>
<td>June-August</td>
<td>Cropped-nF</td>
<td>13,95 a</td>
<td>-0,80 a</td>
<td>-2,01 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grazed-nF</td>
<td>13,00 a</td>
<td>-1,10 a</td>
<td>-2,14 a</td>
</tr>
<tr>
<td>2002</td>
<td>Cerro Lobato</td>
<td>June-August</td>
<td>Cropped-F</td>
<td>11,05 a</td>
<td>-0,49 a</td>
<td>-1,64 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grazed-nF</td>
<td>7,20 b</td>
<td>-1,01 b</td>
<td>-2,24 b</td>
</tr>
<tr>
<td>2003</td>
<td>El Baldío</td>
<td>March-May</td>
<td>Cropped-nF</td>
<td>12,43 a</td>
<td>-0,26 a</td>
<td>-2,17 a</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Grazed-nF</td>
<td>12,70 a</td>
<td>-0,22 a</td>
<td>-1,90 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Matorral-nF</td>
<td>13,20 a</td>
<td>-0,24 a</td>
<td>-2,01 a</td>
</tr>
<tr>
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<td>El Baldío</td>
<td>June-August</td>
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<td></td>
<td></td>
<td></td>
<td>Grazed-nF</td>
<td>11,54 a</td>
<td>-0,43 a</td>
<td>-1,79 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Matorral-nF</td>
<td>11,27 a</td>
<td>-0,55 b</td>
<td>-2,25 a</td>
</tr>
<tr>
<td>2003</td>
<td>El Baldío</td>
<td>March-May</td>
<td>Fertilized</td>
<td>12,70 a</td>
<td>-0,22 a</td>
<td>-2,20 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unfertilized</td>
<td>13,30 a</td>
<td>-0,24 a</td>
<td>-2,10 a</td>
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<td></td>
<td></td>
<td>Fertilized</td>
<td>12,62 a</td>
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<td>-1,80 a</td>
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<tr>
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<td></td>
<td>Unfertilized</td>
<td>8,60 b</td>
<td>-0,41 b</td>
<td>-2,01 a</td>
</tr>
</tbody>
</table>

Table 2. Monthly CO\(_2\) assimilation rate (A) and leaf water potential (\(\psi\)) related to land use and fertilization treatment during 2002 and 2003 in Cerro Lobato (CL), Sotillo (ST) and Baldío (BA) farms. \(^1\) Values followed by a different letter differed significantly (\(p<0.05\), LSD). F: plots fertilized, nF: plots unfertilized.
# Table 3

<table>
<thead>
<tr>
<th>Encroachment</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>Predawn $\Psi$</td>
</tr>
<tr>
<td></td>
<td>$\mu$mol CO$_2$ m$^{-2}$ s$^{-1}$</td>
<td>MPa</td>
</tr>
<tr>
<td>C_P</td>
<td>9.75</td>
<td>-0.44</td>
</tr>
<tr>
<td>M</td>
<td>8.63</td>
<td>-0.79</td>
</tr>
<tr>
<td>F</td>
<td>2.41</td>
<td>-1.34</td>
</tr>
</tbody>
</table>

Table 3: Mean values for A and $\Psi$ related to the degree of encroachment performed in Baldio farm in September and October. (C_P): oaks in cropped and grazed plots (Dehesa); (G): Oaks growing with “Matorral” of low density; (F): oaks growing with “Matorral” of high density.
FIGURE CAPTIONS

Figure 1: a) Evolution of $\Delta \Psi$ (predawn minus minimum leaf water potential) from March to October; b) Relation of $\Delta \Psi$ to predawn leaf water potential; the line represented the boundary line analysis selecting the maximum $\Delta \Psi$ at different predawn leaf water potentials.

Figure 2: Comparative study for net CO$_2$ leaf assimilation (A) and leaf water potential (LWP) among the present research (BA: Baldío farm) and others carried out in higher holm-oak density (Savé, 1999 and Moreno, 2001).

Figure 3: Comparison of daily net CO$_2$ leaf assimilation (A) and leaf transpiration (E) courses among the present study and others: (Sala, 1999 and Infante et al., 1999).

Figure 4: Daily courses for A related to degree of encroachment during one day in September. ($C_P$): trees in cropped and grazed plots without woody understorey (Dehesa design); (MLD): trees in a plot with slight encroachment; ($M$): oaks growing with strong encroachment ($F$).
Figure 1

![Graph showing predawn leaf water potential](image1)

\[ y = -0.003x + 113.81 \quad R^2 = 0.6894 \]

Figure 2

![Graph showing photosynthetic activity](image2)
Figure 3

Figure 4
ANNEXE 11. Effects of management on acorn production and viability in holm oak dehesas

Contractor 7 : UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

Pulido, F.J.¹, García, E.¹, Obrador, J.J.¹, Montero, M.J.¹

¹Department of Plant Biology and Plant Production, School of Forestry, University of Extremadura. Avenida Virgen del Puerto 2, E-10600 Plasencia, Cáceres, Spain.

e-mail: nando@unex.es

SUMMARY

In this work we analyze the effect of different management combinations of dehesas, namely rotational cereal cultivation (C), continuos grazing (G) and reduced grazing with invasion by matorral (M), on acorn crop and percentage of seeds lost to abortion or infestation by weevil (Curculio) and moth (Cydia) larvae. Management had a significant effect on acorn production. Viable fruit production was higher in C plots and lower in M. Acorn viability was similarly affected by management, the percentage of non-viable acorns being higher in M and lower in C. Early abortion of fruits was the main cause of fruit loss and the relative incidence of different causes did not depend on management. Overall, these results confirm that dehesa cultivation favours acorn production and viability and that reduced grazing causes the opposite effect.

KEY WORDS: acorn production, acorn viability, dehesa, management.
INTRODUCTION

Dehesa is a kind of agrosilvopastoral system that covers 3.1 million hectares in western Spain and Portugal. Acorn production is the primary winter source of food for livestock and wildlife, yet little is known about factors explaining spatial and temporal variation in mast production (reviews in Vázquez 1998, Pulido & Díaz 2003). For a given year and locality, management of the understorey and the mature oak trees is supposed to influence the number, size and viability of acorns produced, but no study has addressed these effects explicitly (see Martín-Vicente 2000 for an partial study). In this work we analyze the effect of different management combinations on acorn crop and percentage of seeds lost to abortion or infestation by weevil (Curculio) and moth (Cydia) larvae.

METHODS

The study area is located in Cuatro Lugares county (Cáceres, central Spain). Climate is of a Mediterranean type with annual temperature averaging 16ºC and precipitation around 600 mm. In this area dehesas are private farms ranging in size from 300 to 600 hectares and with a mosaic composed by cereal cultivation (C), permanently grazed pastures (G) and areas with reduced grazing that are colonized by shrubs (matorral, M). We selected three representative farms and in each of them we selected one plot for each use (3 C, 3 G and 3 M plots). In each plot we randomly selected seven holm oak trees. Acorn production was estimated by means of four seed traps (0.12 m² in area) per tree, installed in May of 2002 and monitored until January 2003. We inspected seed traps biweekly and acorns found were classified as non fertilized, aborted, drippy, Cydia-infested, Curculio-infested, and full-sized viable.

RESULTS AND DISCUSSION

Phenology of acorn fall is characterized by two peaks, the first one in July reflecting early abortion of fruits and the second one in November reflecting acorn maturation and dispersal (Figure 1). Another peak is appreciated in the case of M plots, in which acorn fall occurs earlier as a consequence of high predispersal losses. Management had no significant effect on total production of propagules per square meter of canopy area (flowers plus fruits: F=4.58, P=0.011; two-way ANOVA for the effects of land use and plot). Considering just full grown viable acorns, there was a significant effect of use (F=5.016, P=0.007), with acorn production per square meter being higher in C (49.39), intermediate in P (32.33) and lower in M (13.39). Acorn viability was similarly affected by management, the percentage of viable acorns being higher in P and lower in M (F=5.067, P=0.0096; Figure 2). Early abortion of fruits was the main cause of fruit loss followed by fruit infestation by weevils. Management had no significant effect on the incidence of different factors with the exception of drippy fruits, that were much more frequent in shrubby plots (F=14.280, P<0.001).
Overall, these results show that dehesa cultivation favours acorn production and that reduced grazing causes the opposite effect. These effects have been assumed by many authors but our data are the first supporting evidence. The effect of cultivation may be explained by increased water infiltration since water stress have been shown to favour acorn abortion in holm oaks (Siscart y Diego 1999). This explanation would be also valid for the negative effect of shrub competition in M plots. The detrimental effect of shrub encroachment was also found for acorn viability as a consequence of increased abortion and infestation rates (see Pulido 1999 for a similar result). Finally, the effect of cultivation on acorn viability remains unclear, as grazed plot showed significantly higher values of viability.

![Figure 1. Seasonal changes in the intensity of seed rain (mean value of total number of flowers/fruit for three plots) in each management type.](image-url)

Figure 1. Seasonal changes in the intensity of seed rain (mean value of total number of flowers/fruits for three plots) in each management type.
Figure 2. Viability of acorn production according to management types. Bars show the mean percentage of acorns in each viability class for cultivated (C), grazed (G) and shrubby (M) dehesa plots.

REFERENCES


ANNEXE 12. Light availability for understorey pasture in Holm-oak dehesas

Contractor 7 : UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

Montero, M.J.¹, Moreno, G.²

¹ Centro Universitario, Universidad de Extremadura, Plasencia 10600, Cáceres, Spain
email: cmontero@unex.es

² Centro Universitario, Universidad de Extremadura, Plasencia 10600, Cáceres, Spain
email: gmoreno@unex.es

SUMMARY

In the present study we have modelled the percentage of radiation transmitted through the tree layer to the underneath pasture in dehesas of West-Central Spain. To achieve that, we have established different allometric relationships between tree ages and stem diameter (DBH), and between stem diameter and canopy size (tree height, canopy height and canopy width). Furthermore, the amount of the radiation available for grasses underneath was estimated by means of the fish-eye photographs (FEP). Results indicated a rapid increase in the light availability with the distance from the tree, except in the proximity of the tree stem, where the increment was not so sharp; beyond 20 m from the tree, the radiation was constant. Applying a multivariable regression, distance, DBH and canopy width explained 94.9% of the light variability. From the equations obtained we have generated different radiation map in dehesas differing in tree density and tree age (size).

KEY WORDS: allometric relationships, dehesa, light transmission, pasture, *Quercus ilex*. 
INTRODUCTION

Dehesa (oak-savannah) is the most important silvopastoral system in the Mediterranean basin, located mainly in the southwestern part of Iberian Peninsula. Dehesas are consequence of human activity, especially during the second half of the 19th century and the beginning of the 20th century (Pulido et al., 2001). Grazing is considered as an important element of productivity and stability control in these ecosystems; thus a good knowledge of the performance of herbaceous component, as well as of the tree-crop interactions could be useful for assessing the optimum productivity and sustainable management of dehesas. It has been described that, in general, where soil nutrients, water and temperature are not limiting, crop growth and yields are dependent on the total solar radiation intercepted during growing season (Monteith, 1978; quoted in Bellow and Nair, 2003). Although studies on radiation availability for understory species have been reported from other agroforestry systems (McMurtrie and Wolf, 1983; Sinoquet and Bonhomme, 1992; Sinoquet and Caldwell, 1995; Bellow and Nair, 2003), no such reports are available for dehesas of Holm-oak (Quercus ilex). Thus, the main objective of the present study is to model the percentage of radiation transmitted through the Holm-oak canopy to the pasture beneath in dehesas of West-Central Spain. The model will be part of a more general model of agroforestry system functioning (HySAFE), which is intended to be a tool of optimisation of the agroforestry system design, management and profitability.

MATERIAL AND METHODS

The study was conducted in an experimental farm, “El Baldío” situated in “Cuatro Lugares” county, West-Central Spain (39º 41´ N- 6º 13´ W; elevation 380 m), with a climate classified as subtropical Mediterranean. First, the relationship between tree age ($A$), (number of rings), and tree stem diameter ($DBH$) was established using data of 78 trees of $DBH > 10$ cm (Plieninger et al., 2002) in the same area, and 200 trees
with DBH < 10 cm measured the present research. A second allometric relationship was determinated by measuring stem diameter (DBH), tree height (Th), canopy height (tree height minus stem height; Ch), and canopy width (mean diameter of canopy; Cw) in 360 trees (covering all the size classes). By combination of both relationships, tree growth with age was modelled.

The percentage of transmitted radiation was studied by means of fish-eye photographs (FEP) (Sinoquet and Caldwell, 1995). We have taken FEP in 28 trees covering all the diameter classes found in the farm (2 to 73.2 cm of DBH), four orientations (N, S, E, W) and six distances from the tree trunk (0.5 to 30 m). Photos were taken in spring 2003 early in the morning (before sunrise) and in the evening (after sunset), at a height of 70 cm from the ground, giving a total of 577 photos, covering around four trees per day. In every FEP we analysed the percentage of total transmitted radiation using the software “Gap Light Analyzer” and considering from the 1November to 31 May as the integrating period (the growing season for grasses). Then, the relationship among intercepted radiation (I, %) and DBH (cm), canopy width (Cw, m) and distance from the trunk (D, m) was estimated by multiple regression.

RESULTS AND DISCUSSION

Both allometric equations had high R² values (> 90%) indicating high goodness of fit.

\[ DBH = 98.73 \times (1 - \exp(-0.00546 \times AGE)); \quad (R² = 91.47\%) \quad (1). \]

\[ Cw = 0.598 \times DBH^{0.736}, \quad (R² = 90.3 \%) \quad (2). \]

Transmitted radiation was very well related to canopy width, with slightly lower R² values for DBH and tree height. The sigmoid trend levelled off with the distance from the tree trunk;
the percentage of transmitted radiation was close to 100% at distances more than 20 m, irrespective of tree size. The increment of transmitted radiation with distance followed an exponential trend, regardless of the orientation and tree size, indicating a rapid increase in the light availability with the distance. Applying a multivariable non-linear regression including the four variables (DBH, Cw, Th, Ch) defining the tree size and the distance to tree trunk, only distance (D), DBH, and canopy width (Cw) explained significantly the light interception (I):

\[ I = \left( \frac{19.32}{1+64.4 \times e^{-0.62\times DBH}} \right) \times \left( \frac{17.96}{1+5.82 \times e^{-0.05\times Cw}} \right) \times 1.26^{-D}; \quad (R^2 = 94.4 \%) \]  \hspace{1cm} (3).

Applying equations 1, 2 and 3, the intercepted radiation by trees can be calculated and mapped using an interpolation software (SURFER), considering different scenarios based on tree density and age. In figure 1 an example of simulation (75 year-old trees, 25 trees per ha) is shown. In figure 2, the average percentages of radiation intercepted in 1 ha for every simulated scenario are summarized.

From these results the equation relating the average transmitted radiation (I) with tree age (A) and tree density (Dens) has been estimated by mean of a multiple regression:

\[ I = 0.297 \times Dens^{0.641} \times A^{0.521}; \quad (R^2 = 92.89\%; n=30) \]

This equation is useful, for instance, to determinate the optimum tree density at different ages of a tree-plantation in order to maintain a specific level of light availability for pasture.
CONCLUSIONS

The present model is a simple tool to determine the light availability for understory in dehesas of Holm-oak from very easy measurement (DBH). The amount of available light for understory is highly dependent on the tree age and density because light reduction is only significant in the close vicinity of the trees.

ACKNOWLEDGEMENT

This study was supported by E.U. (SAFE project, QLX-2001-0560), Spanish government (MICASA project, AGL-2001-0850) and Consejería de Educación de Extremadura (CASA project, contrast 2PR02C012).
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ANNEXE 13. Soil nutrient status and forage yield at varying distances from trees in four dehesas in Extremadura, Spain

Contractor 7: UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

Obrador, J.J.1, Moreno, G.2


2 Centro Universitario, Universidad de Extremadura, Plasencia 10600, Cáceres, Spain

email: obradoro@colpos.colpos.mx; gmoreno@unex.es

SUMMARY

The aim of this study was to understand the effect of holm-oak (*Quercus ilex*) on the soil-nutrient concentration and its consequence on the yield of understory forage (*Avena sativa*) in four dehesas of CW-Spain. The soils of the dehesas varied in soil fertility (chromic Luvisols and Achrisols, and eutric Leptosols). Forage dry-matter yields were determined from 1-m² sample plots at distances ranging from 2 to 20 m from the tree (9 trees per farm and year). Soil samples (0-30 cm depth) were also collected from the same sampling locations, and were analysed for pH, Electrical Conductivity, organic C, CEC, total-N, available N and base cations. Soil analysis results showed that the most of the values increased in the vicinity of the tree: organic C, total-N, CEC and exchangeable Ca²⁺ and K⁺. Differences in forage yield were mainly explained by fertilization dosage, light availability (estimated from Montero and Moreno, 2004) and soil CEC. In more fertile soils, forage production was negatively affected by the presence of the trees, as a consequence of light reduction (Competence), while in more oligotrophic soils, forage production was positively affected by trees (Facilitation).

KEY WORDS: Dehesa, Soil Nutrient Heterogeneity, Forage yield, Competence, Facilitation.
INTRODUCTION

Dehesas are silvopastoral systems of extensive utilization, where autochthonous pastures and periodical crops are combined with scattered trees. Dehesas are the result of simplification in structure and species of Mediterranean oak forests, where tree density is reduced and shrub cover is eliminated. Periodical crop (usually cereal) aims to control shrub encroachment and to obtain a fodder complement for cattle (very useful in both dry and cold seasons).

Research data on the effect of trees on understory forages in the dehesas are required for modeling agroforestry functioning based on tree-crop interactions (HySAFE; Dupraz, 2004), which is expected to be useful to improve the management of these agroforestry systems. This study was therefore undertaken to gather data on the effect of holm-oak (Quercus ilex) on the soil-nutrient status and its consequence on the forage yield in four dehesas of Extremadura, Spain.

MATERIAL AND METHODS

The study was carried out in four holm-oak dehesas of the Cuatro Lugares County, Cáceres (West-Central Spain: 34°4’N, 6°13’W). Climate is Mediterranean, with dry and hot summers and cool, rainy winters, mean annual rainfall of 579 mm, and mean annual temperature 16°C. Soils are mainly chromic Luvisols, in CL, and chromic Acrisols, in SO and BA developed over tertiary sediments (Miocene feldespatic sands) with abundant quartzite. Both types of soils show a low chemical fertility (Obrador et al., 2004). Eutric Leptosols (in T, more fertile soils) have developed on slates from where the sediments have been eroded. Common management practices in dehesa are cattle raising with native pasture and cereal intercrops. Tree density varies from 15 to 50 tree per ha, depending of its main use (lower densities in
intercropped areas and higher densities in areas reserved for hunting). Dehesas were dominated by mature trees, ranging from 80-120 years old, and 7-12 m of canopy width.

Forage dry matter yields were estimated from 1-m² samples taken at the physiological maturity stage of forage species in four intercropped dehesa farms, with different soil fertility (in decreasing order: T, CL, SO and BA; see CEC in Figure 1), and fertilization dosage (from 0 to 250 kg N+P+K ha⁻¹; noted as subscript after farm name). Samples were taken in 2002 and 2003, around nine trees per farm, in two orientations, and four distances (from 2 m, beneath the tree, to 20 m, out of the tree canopy area). Soil samples (composed by five subsamples; 0-30 cm depth) were taken from the same locations in the first days of March. Soil samples were analysed for pH (1:2.5 water), Electrical conductivity, organic C, Cation Exchange Capacity, total N, available P and exchangeable base cations (Ca²⁺, Mg²⁺, K⁺ and Na⁺), following Bigham and Bartels (1996).

RESULTS AND DISCUSSION

Soil analysis results showed that the values of most parameters (CEC, Exchangeable Ca⁺ and K⁺, Electrical conductivity, organic C and total-N) decreased with the distance away from the tree (see CEC in Figure 1 as example). Similar results have been previously showed in dehesas by Escudero (1985), Puerto et al. (1987), Joffre (1987) and Obrador et al. (2003). No definite pattern was observed for changes in pH, base saturation, available P and exchangeable Mg²⁺ and Na⁺ with distance from trees.
Forage productivity showed a very irregular tendency (Figure 1 shows some examples), increasing significantly with distance in T200-2002, BA250-2003 and SO0-2003. Only in one case, forage yield decreased significantly with distance (SO50-2002). Other cases (CL150-2002, CL150-2003, T200-2003, SO50-2003 and BA0-2003) did not show any significant tendency. Puerto et al (1987) also showed that the pattern of pasture yield around oaks varied with soil quality.

Figure 1 -Mean values of forage yield (including both oats (grain and straw) and weeds) at different distances from the tree stem in four intercropped dehesas, which vary in soil fertility (dashed lines show the mean values of CEC) and in doses of fertilization (50, 150, 200 and 250 Kg ha\(^{-1}\) of N+P+K in SO, CL, T and BA, respectively; solid lines show the variation of N+P+K doses with distance).

Multiple regressions have been applied in order to discriminate the role of the different parameters in the forage production (Table 1). The highest part of the variability was explained by the fertilisation (N+P+K) dosage, which increased with the distance to the tree stem (Figure 1). Light played a minor role (\(r^2\) around 7%). Among the soil parameters, CEC explained around the 16% of the oats yield variability (both straw and grain). Surprisingly, SOM and total-N did not contribute significantly to explain the forage variability.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total Biomass</th>
<th>Oats Biomass</th>
<th>Grain Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r²</td>
<td>(r)</td>
<td>r²</td>
</tr>
<tr>
<td>Distance to tree</td>
<td>(+)</td>
<td></td>
<td>(+)</td>
</tr>
<tr>
<td>Light #</td>
<td>0.066 (+)</td>
<td>0.079 (+)</td>
<td>0.072 (+)</td>
</tr>
<tr>
<td>Fertilization dose</td>
<td>0.358 (+)</td>
<td>0.346 (+)</td>
<td>0.231 (+)</td>
</tr>
<tr>
<td>pH-water</td>
<td>(-)</td>
<td>0.049 (-)</td>
<td></td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>0.030 (+)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td></td>
<td>(+)</td>
</tr>
<tr>
<td>Available P</td>
<td>0.032 (+)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEC</td>
<td>(+)</td>
<td>0.167 (+)</td>
<td></td>
</tr>
<tr>
<td>Exchangeable Ca²⁺</td>
<td></td>
<td></td>
<td>(+)</td>
</tr>
<tr>
<td>Exchangeable Mg²⁺</td>
<td>(+)</td>
<td>0.037 (+)</td>
<td></td>
</tr>
<tr>
<td>Exchangeable K⁺</td>
<td>0.030 (+)</td>
<td></td>
<td>(+)</td>
</tr>
<tr>
<td>Exchangeable Na⁺</td>
<td>0.167 (-)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base saturation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Explained Variability</td>
<td>0.74</td>
<td>0.77</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Table 1 – Percentage of forage yield variability explained by different parameters. Values have been estimated by multiple regression (r² values). In both cases, only significant variables are included. # Data from Montero and Moreno (2004).

**CONCLUSION**

Soil fertility was significantly improved by the presence of the trees only in the close vicinity of them. However, it seems that the increased fertility did not play any prevailing role on the determination of the forage productivity, except in unfertilized oligotrophic soils, where forage production was very low, being slightly higher beneath trees than out of the trees.

**ACKNOWLEDGEMENT**

This study was supported by E.U. (SAFE project, QLX-2001-0560) and Spanish government (MICASA project, AGL-2001-0850). Jesus Obrador was awarded grants by ANUIES and Colegio de Posgraduados (México).

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ANNEXE 14. Consequences of dehesa management on the tree-understorey interactions

Contractor 7 : UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

Moreno, G.¹, Obrador, J., García, E., Cubera, E., Montero, MJ., Pulido, F.

¹Centro Universitario, Universidad de Extremadura, Plasencia 10600, Cáceres, Spain ¹email: gmoreno@unex.es

SUMMARY

We have studied the distribution of resources (light, microclimate, soil moisture and soil nutrients) and fine roots (herbaceous plants and tree) around trees in four dehesas with three types of management: cropped (forage) grazed (native grasses) and encroached (matorral). Additionally, we have measured the forage yield and the physiological status, growth and acorn production of Holm-oaks. A low overlapping of the root systems of herbaceous plants and trees have been found, which could contributed to avoid competition. Soil water consumption by trees did not affect negatively to the forage productivity. Light interception by trees was limited to the close vicinity of the trees, with very low effect out of the canopy. On the other hand, both microclimate and soil fertility improved significantly in the vicinity of the trees, although only in less fertile soils contributed to increase forage yield. Dehesa management affected significantly to the physiological status, growth and productivity of trees.

KEY WORDS: Dehesa, aboveground resources, belowground interactions, root system.
INTRODUCTION

Dehesa generally consists on a mosaic of scattered trees combined with crops, pasture and shrubs, as a result of the different management practices, namely agriculture, livestock husbandry, forestry and hunting activities. Some pioneer works on dehesa functioning have shown the positive effects of the trees on soil nutrient contents (Escudero 1985), soil water storage capacity (Joffre and Rambal 1988) and pasture production (Puerto et al 1987). On the other hand, an improved physiological status and productivity of the tree in dehesas respect to the forest has been also shown by Infante et al (1999) and Pulido and Díaz (2003), respectively.

In this paper, we summarize the main results found in a comprehensive study where the distribution of the main above and belowground resources in dehesas with three main types of management are analysed in order to understand the functioning of the whole system. This information will be use, as a next step, to build a model (HySAFE) based on the intensity of the tree-understory interactions.

MATERIAL and METHODS

The study has been carried out in four dehesas located in “Curator Lugar’s” county, in CW Spain (39° 41’ N - 6° 13’ W; altitude: 380 m.a.s.l.). In the four farms (T, CL, ST and BA in decrease order of soil fertility), three main type of management were defined and studied: intercropped plots, with combination of cereal forage and Holm-oak (C), grazed plots, with combination of native grasses and Holm-oak (G), and encroached plots, with combination of shrubs (matorral) and Holm-oak (M). The distribution of several above and belowground parameters were studied around trees (from 1 to 30 m of distance from the tree trunk) in three type of plots (dehesa
managements): transmitted radiation by fish-eye photographs (28 trees, 4 orientations, from 0.5 till 30 m distance), air temperature and humidity by microdataloggers (2 trees, from 1 till 30 m distance), soil temperature by digital termistor (2 trees, beneath and out of the tree canopy), soil moisture by TDR technique (33 trees, from 0 till 200 cm depth, from 2.5 till 20 m distance), soil fertility (pH, organic carbon, ECC, total-N, P-Olsen, base cations (exchangeable Ca$^{2+}$, Mg$^{2+}$, K$^{+}$, Na$^{+}$) in samples taken from the first 20 cm of soil depth (47 trees, from 2 till 20 m distance), herbaceous plant and tree rooting system by soil cores (13 trees, from 0 till 20 m distance and till 200 cm depth) and studying 51 profiles located in 7 different road cuts). Additionally, tree nutritional (N and P) and physiological status (leaf water potential and CO2 assimilation rates) were measured in several trees (269 trees and 28 trees, respectively). Finally, tree growth was measured through current year shoots in 188 trees and acorn production was measured by hung traps in 84 trees.

RESULTS

![Figure 1](image)

Figure 1 - Mean values of forage yield at different distances to the tree stem in fertile (e.g. T-2002) and unfertile (e.g. SO 2002) intercropped dehesas.
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>EFFECT of DISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Availability</td>
<td>Sigmoid increase of light availability with distance ( Light, % = \frac{100}{1+4.18*\text{EXP}(-0.43*\text{DIST})} )</td>
</tr>
<tr>
<td>Soil Temperature (Maximum)</td>
<td>Maximum measured temperatures of 29.6 versus 46 °C under and out of the tree, respectively</td>
</tr>
<tr>
<td>DmxT: Daily maximum Air Temp</td>
<td>DmxT: 1m (27.8) &lt; 10m (28.8) ≈ 20m (29.0) ≈ 30m (29.5)</td>
</tr>
<tr>
<td>DmnT: Daily minimum Air Temp</td>
<td>DmnT: 1m (7.4) &gt; 10m (6.6) ≈ 20m (6.3) ≈ 30m (6.6)</td>
</tr>
<tr>
<td>Mdv: Mean daily Air Temp variation</td>
<td>Mdv: 1m (14.2) &lt; 10m (16.1) ≈ 20m (16.5) ≈ 30m (16.6)</td>
</tr>
<tr>
<td>DmxAR: Daily max. Air Humidity</td>
<td>DmxAR: 1m(91.2) &lt; 10m(95.1) ≈ 20m (94.7) ≈ 30m (95.6)</td>
</tr>
<tr>
<td>DmnAR: Daily min. Air Humidity</td>
<td>DmnAR: Not significant differences</td>
</tr>
<tr>
<td>Mdv: Mean daily Air Humidity variation</td>
<td>Mdv: 1m (42.9) &lt; 10m (46.9) ≈ 20m (47.3) ≈ 30m (46.8)</td>
</tr>
<tr>
<td>Soil water content</td>
<td>Overall: No significant differences between distances</td>
</tr>
<tr>
<td></td>
<td>Cropped: SWC slightly higher out of the tree</td>
</tr>
<tr>
<td></td>
<td>Grazed: SWC slightly higher beneath the tree</td>
</tr>
<tr>
<td></td>
<td>Matorral: SWC significantly higher beneath the tree</td>
</tr>
<tr>
<td>Soil fertility</td>
<td>CEC, Exch Ca(^{2+}) and K(^{+})</td>
</tr>
<tr>
<td></td>
<td>Negative exponential decrease</td>
</tr>
<tr>
<td></td>
<td>organic C and Total-N</td>
</tr>
<tr>
<td></td>
<td>Logarithmic decrease with</td>
</tr>
<tr>
<td></td>
<td>pH, P and Exch Mg(^{2+}) and Na(^{+})</td>
</tr>
<tr>
<td></td>
<td>No clear tendency with distance</td>
</tr>
<tr>
<td>Root system</td>
<td>Herbaceous -</td>
</tr>
<tr>
<td></td>
<td>Exponential decrease with depth. ( d_{50} = 10.7 ) ( d_{95} = 46.2 )</td>
</tr>
<tr>
<td></td>
<td>Root Length Density</td>
</tr>
<tr>
<td></td>
<td>Not significant differences between distances</td>
</tr>
<tr>
<td></td>
<td>Tree -</td>
</tr>
<tr>
<td></td>
<td>Linear and slow decrease with depth and distance</td>
</tr>
<tr>
<td></td>
<td>Root Length Density</td>
</tr>
<tr>
<td></td>
<td>( d_{50} = 96.4 ) ( d_{95} = 416.6 ) Maximum distance around 25 m</td>
</tr>
</tbody>
</table>

Table 1.- Spatial variation of the several resources around Holm-oaks in dehesa of CW Spain.
Figure 2. – Effect of the dehesa management on tree growth and productivity.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>EFFECT of MANAGEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil water content (% v/v)</td>
<td>C ≈ P &gt;&gt; M</td>
</tr>
<tr>
<td>Soil fertility</td>
<td>SOM (%)</td>
</tr>
<tr>
<td></td>
<td>M (2.52) &gt; C (2.17) ≈ G (2.12)</td>
</tr>
<tr>
<td></td>
<td>Total N (g kg⁻¹)</td>
</tr>
<tr>
<td></td>
<td>M (1.07) &gt; C (0.97) &gt; G (0.81)</td>
</tr>
<tr>
<td></td>
<td>Available P (ppm)</td>
</tr>
<tr>
<td></td>
<td>C (8.56) &gt; M (7.84) ≈ P (7.45)</td>
</tr>
<tr>
<td></td>
<td>Exchangeable cations,</td>
</tr>
<tr>
<td></td>
<td>M (6.1) &gt; C (4.0) &gt; G (3.0cmolc kg⁻¹)</td>
</tr>
<tr>
<td></td>
<td>ECC</td>
</tr>
<tr>
<td></td>
<td>Not significant differences (14.0 cmolc kg⁻¹)</td>
</tr>
<tr>
<td></td>
<td>pH</td>
</tr>
<tr>
<td></td>
<td>Not significant differences (5.45)</td>
</tr>
<tr>
<td>Tree status Nutritional</td>
<td>N (%)</td>
</tr>
<tr>
<td></td>
<td>C (1.13) &gt; G (1.07) &gt; M (0.96)</td>
</tr>
<tr>
<td>Tree physiological status</td>
<td>P (%)</td>
</tr>
<tr>
<td></td>
<td>M (0.065) &gt; G (0.054) &gt; C (0.048)</td>
</tr>
<tr>
<td></td>
<td>Leaf Water Potential¹</td>
</tr>
<tr>
<td></td>
<td>Predawn C (-0.43) ≈ P (-0.45) &gt; M (-0.79) &gt; F (-1.34) MPa</td>
</tr>
<tr>
<td></td>
<td>Midday C (-1.7) ≈ P (-2.05) &gt; M (-2.57) &gt; F (-3.57) MPa</td>
</tr>
<tr>
<td></td>
<td>Photosynthesis¹</td>
</tr>
<tr>
<td></td>
<td>G (10.0) ≈ C (9.2) ≈ M (8.6) &gt; F (2.41) μmol CO₂ m⁻² s⁻¹</td>
</tr>
</tbody>
</table>

Table 2.- Effect of dehesa management on resources availability and tree physiological status.¹


Leaf water status, photosynthetic rate, growth and acorn production were significantly higher in trees of C and G plots than in M and forest ones. This could be explained for the great amount of soil explored by tree roots (more than 20 m of distance and more than 4 meters of depth). This extensive root system involves an unusual low density in the first 80 cm of the soil, which determine a low intense-competence with herbaceous plants for resources. As result, forage production was rather...
independent of the distance, except in more fertile soils, where yield increased with
distance, indicating that light *consumption* by trees is only relevant in term of
competition in very fertile soils.

**CONCLUSION**

Dehesa management affected significantly to the physiological status, growth and
productivity of trees. Moreover, trees affected more positively than negatively on
forage yield in most of the cases studied.

**ACKNOWLEDGEMENT**

This study was supported by E.U. (SAFE project, QLX-2001-0560), Spanish
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project, contract 2PR02C012). Elena Cubera was awarded a grant by Junta de
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and Colegio de Posgraduados (México).

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ANNEXE 15. TDR-measurement for the study of the seasonal variations of soil moisture on Quercus ilex dehesas

Contractor 7 : UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

Elena CUBERA¹, Gerardo MORENO, Alejandro SOLLA

Departamento de Biología y Producción de los Vegetales. Universidad de Extremadura.

Ingeniería Técnica Forestal. Av. Virgen del Puerto 2, 10600-Plasencia, Spain

¹For correspondence: ecubera@unex.es

Keywords: Soil water content, scattered trees, root distribution, leaf water potential

ABSTRACT

Most evergreen oak forests growing in the flat areas of the southwestern Iberian Peninsula have been gradually transformed into a unique kind of pastoral woodland, the Spanish dehesas and Portuguese montados, by means of an agroforestry use. Eagleson and Segarra (1985) have emphasised that, where a marked seasonality in water availability occurs, a mixed formation of grasses and woody plants is the only stable state of equilibrium. A positive effect of trees on soil bulk density, water-holding capacity and water content has been shown by Joffre and Rambal (1988) in dehesas.

We have investigated how holm-oak trees use the soil water in four dehesas of CW Spain (39° 41’ N, 6°13’ W) by measuring the soil moisture at different distances from the tree trunk (maximum 30 m), from the soil surface until a maximum depth of 2 m, in intervals of 20 cm. Soil moisture was measured monthly by TDR technique, between May 2002 and October 2003. Additionally, tree and herbs root systems have been studied by mean of 2 m-depth soil cores (Obrador et al., 2003) and the water stress experienced by trees have been characterized by mean of leaf water potential (Montero et al., 2004).

We did not found any significant difference in soil moisture with regards to distance to the tree (Fig 1), which differ from those reported by Joffre and Rambal (1988). Soil
water depletion beyond the tree canopy projection continued even when herbaceous plants dried up (mid-may) (Fig 1), indicating that trees could use water from open areas, a clear benefits from tree spacing on soil water consumption. Results have also shown a high dependence of holm-oak on deep water reserves throughout late spring and summer, which contributes to avoiding competition for water between trees and herbaceous vegetation (Fig 2).

In conclusion, we have not found a positive redistribution of soil water near the trees, however we have found an very extended tree rooting system in dehesas (both in depth and distance; Fig. 3), which allows them to use efficiently the soil water of a huge volume of soils and to maintain a near-optimum water status along the summer (Fig 4).

References


Figure 1.- Seasonal variation of soil moisture (average form dat of 1 m depth) at different distance of holm-oaks in dehesas.
Figure 2.- Monthly variation in soil moisture profile from soil surface till 2 m.

Most of the water was depleted between May and June.

Figure 3.- Profiles of Root Lenght Density (RLD, Km m$^{-3}$) of herbs and trees in dehesas at different distances of the trees (holm-oak).

Figure 4.- Monthly variation in leaf water potential of holm-oaks in dehesas. Arrows indicate the thresholds of significant water deficit (Sala, 1999).

Acknowledgement

This study was supported by E.U. (SAFE project), Spanish goverment (MICASA project, MCyT) and Junta de Extremadura (CASA project and E. Cubera was awarded a grant).
ANNEXE 16. El árbol en el medio agrícola

Contractor 7 : UNEX

Gerardo Moreno Marcos

Ingeniería Técnica Forestal, Universidad de Extremadura

RESUMEN

Del análisis comparativo de los sucesivos Censos Agrarios se ha podido constatar que en las últimas décadas se ha producido una pérdida acusada y progresiva de arbolado en la mayoría de los ambientes agrícolas en Extremadura, hecho que es común al resto de Comunidades Autónomas del Estado, y a la práctica totalidad de países de Europa.

Todas las combinaciones de cultivo herbáceo con vegetación leñosa, denominados sistemas agroforestales, que se han analizado han experimentado una pérdida en superficie, llegando en la mayoría de los casos a cifras casi testimoniales, y despreciables en comparación con la superficie ocupada por los diferentes monocultivos. Sólo los cultivos herbáceos en montes abiertos de especies forestales mantienen niveles significativos, muy especialmente en el suroeste español.

En el presente trabajo se describen las diferentes ventajas ambientales y económicas que podría conllevar la utilización de diferentes tipos de sistemas agroforestales, tradicionales o novedosos, incluyendo aquellos con especies forestales de crecimiento rápido o de madera de alta calidad. La aplicación de estos sistemas combinados se sugiere como mecanismo para posibilitar la introducción de arbolado en los ambientes más productivos, en muchos casos completamente desforestados y sometidos a diferentes grados de degradación del suelo.

Por último se analizan las diferentes carencias detectadas en la normativa agrícola comunitaria que están dificultando la implementación de estos tipos de sistemas, sugiriéndose algunos cambios que deberían ser contemplados en la PAC referidos a los Sistemas Agroforestales, como sistemas diferenciados y ambientalmente deseables, que podrían jugar un papel importante en el desarrollo sostenible del medio rural.

16 Centro Universitario. Avd Virgen del Puerto. Plasencia 10600 CÁCERES.

E-mail: gmoreno@unex.es Tfn: 927 427000
INTRODUCCION

El hombre siempre ha perseguido la simplificación del medio natural con objeto de favorecer las especies de su interés en detrimento del resto, con una pérdida significativa de la diversidad, no sólo de especies, sino también de procesos e interacciones. La necesidad de distintos productos en una economía mayoritariamente de subsistencia favoreció, no obstante, el mantenimiento de cierta combinación de elementos, siendo muy comunes hasta hace pocas décadas los cultivos mixtos, en muchos casos combinando especies anuales con otras arbóreas, frutales o forestales. El tamaño de las parcelas, generalmente reducido, y la presencia de vegetación leñosa entre las mismas contribuía a la presencia del arbolado en el medio agrícola.

Los cambios producidos en modelo económico del medio rural, junto con la mayor capacidad de mecanización, han contribuido a una pérdida espectacular de arbolado en muchos ambientes agrarios, donde los monocultivos han ido cobrando protagonismo en detrimento de los sistemas mixtos o agroforestales, hecho que puede constatarse fácilmente a través de los valores recogidos en los diferentes Censos Agrarios de España, iniciados en 1962.

Sin embargo, los problemas asociados a los monocultivos son muchos y bien conocidos: el elevado empleo de fertilizantes y biocidas, la inseguridad económica, la pérdida de biodiversidad, ... . A estos problemas se suman otros propios de la agricultura europea: sobreproducción de productos mayoritariamente subsidiados. Y, a su vez, a éstos, se le unen otros problemas de carácter ambiental, como son la degradación de los suelos agrícolas (erosión, salinización, ...), eutrofización de acuíferos y aguas superficiales por lixiviación de fertilizantes, necesidad de sumideros de CO₂, pérdida de biodiversidad, ... Todo ello llevó al nacimiento del programa de reforestación de tierras de cultivo (Subprograma I: EC 2080/92, EC 1257/1999).

Sin embargo este programa no satisface todas las necesidades actuales de reforestación. Así por ejemplo, las áreas más productivas, generalmente las más desforestadas y sometidas a mayores problemas de degradación de suelo, no se están beneficiando del programa de reforestación. Por otro lado, la reforestación casi exclusivamente de áreas degradadas y marginales, no están permitiendo la producción de madera de calidad, producto que presenta una creciente demanda en...
el mercado. Se necesita por tanto otro tipo de programa, o modificaciones significativas en el actual, que hagan atractivo la introducción de arbolado, incluso en las tierras más productivas.

En la Universidad de Extremadura se ha iniciado un proyecto de investigación, junto con universidades de otros 7 países europeos, centrado en el estudio de los sistemas mixtos de árbol-cultivo (Sistemas Agroforestales; en adelante SAFs) como alternativa a los monocultivos. En el presente artículo se analiza la pérdida de superficie ocupada por los diferentes tipos de SAFs en las últimas décadas en España, y se ofrecen algunas reflexiones acerca de la necesidad y las dificultades para la reintroducción de arbolado en muchas áreas, especialmente en las más productivas.

**EVOLUCION DEL ARBOLADO EN EL MEDIO AGRARIO**

La evolución de los principales sistemas agroforestales en España puede deducirse a partir de los 5 censos agrarios llevados a cabo por el Ministerio de Agricultura y el Instituto Nacional de Estadística (INE 1963, 1975, 1985, 1991 y 2002).

Los datos de los diferentes censos no son totalmente comparables, por haber utilizado diferentes criterios para su recopilación y presentación. Por otro lado, los datos recogidos son muy generales, sin especificar en muchos casos las especies implicadas, así por ejemplo, se habla de cultivo en monte abierto, sin especificar si se trata de encina, alcornoque, roble, algarrobo, chopo, nogal, ... Finalmente, existen 2 tipos de sistemas agroforestales que no están reflejados en los diferentes censos, pero que sin embargo son de gran valor, tanto ambiental como paisajístico; estos son los setos arbustivos y arbolados (protectores o linderos), y los huertos familiares.

A pesar de estas limitaciones, se puede observar que la extensión de los principales tipos de SAFs en España ha disminuido muy significativamente en las últimas décadas (Tabla 1). Así, por ejemplo, sólo en 7 años (1982 a 1989), se produjo una reducción superior al 32% de la superficie ocupada por el conjunto de SAFs. Los SAFs más afectados fueron los cultivos anuales bajo frutales y bajo viñedo (reducidos al 34,9 y 37,7 %, respectivamente). La evolución de la combinación de diferentes cultivos leñosos sigue una pauta similar, reduciéndose entre 1972 y 1999 a un 36,7 %.

Por el contrario, el cultivo en monte abierto (Foto 1), que experimentó perdidas en superficie muy importantes hasta finales de los 80s (entre 1962 y 1989 se redujo al 52 %), ha visto incrementada su superficie en los años 90 (de 1989 a 1999 aumentó en un 58%). Este incremento quizás se deba a una mayor precisión en la recogida de datos, o la puesta en cultivo de zonas marginales, al abrigo de las ayudas comunitarias. En la información recogida en los Anuarios de Estadística Agroalimentaria (Figura 1; MAPA 1985 y 2000) se
observa una continua pérdida de superficie cultivada hasta 1998. En cualquiera de los casos, el cultivo bajo especies forestales se muestra, con diferencia, como el Sistema Agroforestal tradicional más relevante y documentado en España, y posiblemente el más importante en extensión a nivel Europeo (Paris et al 2002), siendo aún común en Grecia, Italia y Portugal. En todos los casos se combina algún tipo de cereal o legumbre (veza, garbanzo y altramuz) con especies de *Quercus* (en España fundamentalmente encina; 80% en 1982).

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</thead>
<tbody>
<tr>
<td>Combinación cultivo anual con arbolado</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultivo anual con frutales</td>
<td>402005</td>
<td>78999</td>
<td>27562</td>
<td>13484</td>
<td></td>
</tr>
<tr>
<td>Cultivo anual con Viñas</td>
<td></td>
<td>21677</td>
<td>8175</td>
<td>8359</td>
<td></td>
</tr>
<tr>
<td>Cultivo anual con Olivos</td>
<td>242628</td>
<td>39092</td>
<td>20219</td>
<td>15030</td>
<td></td>
</tr>
<tr>
<td>Cultivo anual en monte abierto</td>
<td>685893</td>
<td>478375</td>
<td>433000</td>
<td>357000</td>
<td>566865</td>
</tr>
<tr>
<td>Combination of woody crops</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olivo + Viña</td>
<td>181866</td>
<td>67875</td>
<td>78270</td>
<td>39203</td>
<td>48605</td>
</tr>
<tr>
<td>Frutal + Viña</td>
<td>57406</td>
<td>33058</td>
<td>14981</td>
<td>7389</td>
<td></td>
</tr>
<tr>
<td>Olivos con frutales</td>
<td>217816</td>
<td>195566</td>
<td>107485</td>
<td>74675</td>
<td></td>
</tr>
<tr>
<td>Combinación de frutales</td>
<td>60913</td>
<td>85563</td>
<td>47650</td>
<td>17859</td>
<td></td>
</tr>
</tbody>
</table>

Las causas probables de la reducción del arbolado en el medio agrícola han sido:

a) *Cambio en sistema de economía rural*, pudiéndose prescindir de los sistemas multifuncionales, y pasando a depender de un solo producto.

b) *La mecanización de la agricultura* ha determinado la eliminación del arbolado en muchos sistemas agroforestales, o la disminución de la densidad de arbolado en otros. En las dehesas esta reducción ha sido estimada en un 23% entre 1957 y 1981 (Miguel et al 2000).

c) *La concentración parcelaria*, facilitó la eliminación de miles de Km de setos y franjas de vegetación natural (generalmente leñosas). A modo de ejemplo, citar que en Cataluña la longitud total de setos fue reducida en un 46% entre 1957 y 1985 (Miguel et al 2000).

d) *Proyecto de regadíos*, con la transformación de dehesas en monocultivos. La inclusión en los censos y anuarios estadísticos de las dehesas junto con otros tipos de montes abiertos en incremento (e.g., monte bajo de montaña rebrotado tras el incendio de bosques) explican el aparente mantenimiento de la superficie total de monte abierto en España (Figura 1), a pesar de la disminución de la superficie ocupada por dehesas (Elena 1987, Fernández-Alés et al 1992).

e) *Abandono de pequeñas explotaciones*, fundamentalmente en áreas de montaña, debido a su escasa rentabilidad y la pérdida de población. Estas explotaciones generalmente eran combinaciones de cereales y hortalizas con
frutales y olivos. Su pérdida se pone de manifiesto al analizar la evolución del número de frutales dispersos en el medio rural (Figura 2).

**Figura 2.-** Cambios recientes en el nº de frutales combinados con otros cultivos, frente a la superficie ocupada por plantaciones monoespecíficas (MAPA 2000).

**SITUACION ACTUAL DE LOS SISTEMAS AGROFORESTALES**

La continua disminución de los sistemas mixtos de cultivos herbáceos con arbolado ha llevado a que la práctica totalidad de las tierras cultivadas sean monocultivos (Tabla 2).
Sólo alrededor del 5,2% de las tierras labradas presentan algún tipo de asociación de cultivo con arbolado, y sólo el 4,9% de los cultivos herbáceos se realizan en parcelas arboladas (frutales o forestales). Estos porcentajes son muy variables entre Comunidades Autónomas, con 11 CC.AA. en las que los SAFs sólo representan el 1,1% de las tierras labradas, por término medio, y los cultivos herbáceos bajo arbolado sólo representan el 0,3% con respecto a los monocultivos herbáceos (Tabla 2; ver Resto de CC.AA.). En el otro extremo se sitúa Extremadura, con porcentajes superiores al 30% en ambos casos.

Si analizamos los diferentes SAFs en Extremadura, observamos que el 88% corresponde a cultivos herbáceos con especies forestales (Tabla 3). No existe información acerca de las posibles combinaciones de especies herbáceas cultivadas con las especies forestales. Así aquí pueden estar englobadas combinaciones tan tradicionales como dehesas cultivadas de cereal, como otras mucho más novedosas de maíz con chopo o nogal. No obstante, hemos podido constatar a través de una búsqueda activa que la práctica totalidad se refieren a dehesas cultivadas, exceptuando algunas parcelas de hortalizas bajo chopo. Esta es muy probablemente la realidad del resto de CC.AA, aunque no existe información estadística al respecto.
Tabla 3.- Superficie ocupada en 1999 por los diferentes tipos de Sistemas Agroforestales en Extremadura (INE 2002).

<table>
<thead>
<tr>
<th>Tipo de Sistemas Agroforestales</th>
<th>Superficie, Ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Todas las asociaciones</td>
<td>342.853</td>
</tr>
<tr>
<td>Viñedo - Herbáceos</td>
<td>169</td>
</tr>
<tr>
<td>Viñedo - Olivar</td>
<td>16.112</td>
</tr>
<tr>
<td>Viñedo - Frutales</td>
<td>183</td>
</tr>
<tr>
<td>Olivar - Herbáceos</td>
<td>1.630</td>
</tr>
<tr>
<td>Olivar - Frutales</td>
<td>2.128</td>
</tr>
<tr>
<td>Frutales - Herbáceos</td>
<td>192</td>
</tr>
<tr>
<td>Frutales - Frutales</td>
<td>746</td>
</tr>
<tr>
<td>Cultivos agrícolas - Especies forestales</td>
<td>305.174</td>
</tr>
<tr>
<td>Otros cultivos asociados</td>
<td>14.151</td>
</tr>
</tbody>
</table>

**EL FUTURO DE LOS SISTEMAS AGROFORESTALES**

Existen muchas razones para apostar por políticas que favorezcan la reintroducción de arbolado en los ambientes agrícolas más deforestados. Razones ambientales de protección de suelo, reducción de consumo de agroquímicos, fijación de CO₂ y la mejora del paisaje. Otras razones son de carácter socio-económico, como son la reducción de la producción agrícola, la diversificación de la renta rural y la producción de madera de calidad, para la que hay que anticiparse varias décadas a las necesidades de mercado. No ha existido ningún tipo de política activa que haya propiciado la reforestación de zonas productivas, como por ejemplo en regadíos, o con especies de madera de calidad (e.g. cerezo, nogal, arces, ...). Hasta el año 2002, en Extremadura no se había realizado ni una sola plantación con especies con interés maderero en el marco del subprograma I (Tapias 2002).

Cierto es que no resulta nada fácil la transformación de explotaciones agrícolas y ganaderas en explotaciones forestales. Supone una pérdida de renta por un largo (a veces larguísimo) periodo, durante el cual, los gastos serán continuos. Un posible camino que posibilite la plantación de árboles en áreas productivas es la
introducción de sistemas agroforestales. En los sistemas agroforestales (SAFs) se plantan los árboles (frutal o forestal) en filas espaciadas entre sí, dejando amplias calles que continúan siendo sembradas (habitualmente marcos entre 4x10 y 5x12) (Foto 2). Inicialmente alrededor del 80% de la superficie es cultivada, manteniendo una renta anual a lo largo del ciclo de crecimiento del arbolado. La superficie cultivable podrá reducirse a medida que los árboles crecen.

En los últimos años se han acumulado numerosas evidencias de que los SAFs son ambientalmente eficientes (Dupraz et al 1999), además de incrementar significativamente el valor paisajístico de los espacios agrícolas (Herzog 1998). Su eficiencia se debe a su mayor capacidad para captar recursos, tanto aéreos como subterráneos (doble sistema radicular), por lo que son sistemas que en muchos casos, además de ser ambientalmente recomendables, son económicamente rentables (Gordon y Newman 1997). Los beneficios que podría reportar la introducción de arbolado en los cultivos podrían resumirse en (Vandermeer 1989):

a) La complementariedad de los estratos puede ser expresamente manejada para reducir los aportes químicos al sistema.

b) Se minoriza la erosión, garantiza el mantenimiento de la fertilidad del suelo y un óptimo aprovechamiento del agua.

c) Otros beneficios ambientales son la reducción de lixiviación de nitratos, sumidero de CO₂, ...

d) La mayor diversidad de ambientes que se producen en los SAFs contribuyen al mantenimiento de la biodiversidad, tanto vegetal como animal.

e) Los SAFs tienen un gran potencial en cuanto a la producción de maderas de calidad, mercado actualmente dependiente de la producción en países tropicales, con fuertes procesos de deforestación y generalmente, gestión no sostenible de sus bosques.

f) Los SAFs en el oeste español, dedicado fundamentalmente a la cría de ganado en libertad, es una fuente de producción de carnes de calidad.

g) Los SAFs contribuyen a la diversificación de la renta agraria y por ende al desarrollo sostenible del medio rural. Permite ingresos anuales y al mismo tiempo capitalizar en madera.

h) Los SAFs podrían contribuir a una mayor oportunidad de empleos.
i) Incrementan significativamente el valor paisajístico de los espacios agrícolas, y podrían representar una figura importante en los planes de ordenamiento rural.

j) Finalmente, los SAFs cubren el objetivo de la Unión Europea de retirada parcial de tierras de cultivos.

Paradójicamente, los SAFs son muy comunes en los países tropicales (Nair 1985), mientras que en Europa son poco relevantes, aunque en los últimos han surgido diversas experiencias y modelos (e.g. Lawson et al 1997) muy prometedores a lo largo de Europa. Algunas de las combinaciones más interesantes descritas en otros países europeos de la cuenca mediterránea (Grecia, Italia y Francia) se resumen en la (Tabla 4). En ella se incluyen sólo las combinaciones que tienen entre sus objetivos la producción de madera o leña, y que mantienen cultivos en bandas (se excluyen los sistemas silvopastorales, no cultivados).

<table>
<thead>
<tr>
<th>Árbol</th>
<th>Cultivo</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Populus sp</em></td>
<td>Maíz, Trigo, Guisantes, Soja, Altramuz, Espárrago, Patata, Verduras.</td>
</tr>
<tr>
<td><em>Juglans regia</em></td>
<td>Trigo, Cebada, Sorgo, Altramuz, Kiwi, Tabaco, Girasol, Lavanda, Colza, Viñedo</td>
</tr>
<tr>
<td><em>Castanea sativa</em></td>
<td>Trigo, Maíz, Sorgo,</td>
</tr>
<tr>
<td><em>Sorbus domestica</em></td>
<td>Soja, Trigo, Colza, Viñedo</td>
</tr>
<tr>
<td><em>Prunus persica, P. avium</em></td>
<td>Trigo, Colza, Viñedo</td>
</tr>
<tr>
<td><em>Alnus incana</em></td>
<td>Soja, Trigo</td>
</tr>
<tr>
<td><em>Pinus pinea</em></td>
<td>Viñedo</td>
</tr>
<tr>
<td><em>Olea europea</em></td>
<td>Trigo, Altramuz, Lavanda, Viñedo</td>
</tr>
<tr>
<td><em>Quercus sp</em></td>
<td>Trigo, Maíz, Altramuz, Tabaco, Verdura, Viñedo</td>
</tr>
</tbody>
</table>

**Tabla 4.- Ejemplos de Sistemas Agroforestales en países europeos de la cuenca mediterránea (sólo se incluyen combinaciones de cultivos con árboles productores de madera o leña).** Datos extraídos de Paris et al (2002).

Uno de los principales escollos con los que se encuentran los SAFs en Europa, es su no inclusión en los programas de la PAC como sistemas específicos, encontrándose incluso determinados criterios de aplicación de la PAC que podrían estar actuando como impedimento para el mantenimiento o ampliación del uso de los SAFs. Una de las dificultades estriba el régimen de subsidio que existe para
muchos cultivos herbáceos, pero no así para leñosos, y menos aún madereros. Por otro lado, la prima en los cultivos herbáceos en presencia de arbolado, decrece proporcional al doble de la superficie ocupada por el arbolado.

Tampoco los programas de reforestación de tierras agrarias posibilitan la implantación de SAFs, dado que su principal objetivo es la retirada de tierras de cultivo. Sin embargo la implantación de un SAF debe interpretarse también como un mecanismo de retirada de tierra de cultivo. Si se desea reforestar el 20% de la superficie de una explotación, manteniendo el 80% restante para cultivado, se puede realizar de 2 formas. Una manteniendo ambas áreas separadas, y la otra intercalando ambos elementos, cultivo y árbol. En ambos casos la superficie cultivable se reduciría en un 20%, pero en el último caso, la superficie retirada se distribuiría en líneas entre franjas de cultivo o en forma de bandas periféricas.

De este modo ha sido interpretado en Francia, donde son compatible las primas por reforestación de tierras agrarias, con las primas por cultivos herbáceos, cada una de ella en su parte proporcional, a lo que se suma una prima específica del programa de medidas agroambientales (Manchon 2001; Foto 3). Esto sin duda es un buen camino para potenciar este tipo de sistemas, permitiendo reducir algunos de los problemas asociados a los monocultivos, generar madera de calidad, introducir paisajes de calidad, al vez que se reduce la producción de productos excedentarios (objetivo principal del programa de reforestación de tierras agrarias).

Conclusiones

En las últimas décadas muchos de los Sistemas agroforestales (SAFs: cultivos con presencia de arbolado) se están abandonado en España, al igual que en el resto de Europa occidental (Paris et al 2002). Posiblemente el cultivo en dehesa sea el único SAF tradicional que permanece con cierta relevancia en Europa, aunque sometido a importantes problemas de conservación y cambio de usos, con una pérdida evidente de la diversidad de los mismos.

A pesar de los muchos beneficios ambientales y los paisajes de gran valor que aportan los sistemas agroforestales, tanto los tradicionales, como otros muchos novedosos, existe aún mucha incertidumbre en cuanto a su rentabilidad, por la mayor complejidad de los procesos y relaciones implicadas con respecto a los sistemas monoespecíficos, agrícolas o forestales.
Existe por tanto una necesidad de sintetizar y adquirir nueva información acerca del funcionamiento y rentabilidad de los sistemas agroforestales en sus diferentes combinaciones, con en fin de elaborar propuestas coherentes de política agraria que puedan contribuir a mejorar la situación de los SAFs a través de la aplicación de la PAC.

Bibliografía


Foto 1.- Dehesa cultivada de cereal con el sistema de cuartos de labor.

Alternativa a la foto 1
Foto 2.- Esquema de filas y calles característico de los Sistemas Agroforestales (photo from C. Dupraz)
Foto 3.- Esquema de ayudas para los sistemas agroforestales en Francia (Manchon 2001).
ANNEXE 17. Root distribution in dehesas of Central-Western Spain

Contractor 7: UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

G Moreno¹*, JJ Obrador¹, E Cubera¹, C Dupraz²

¹ I.T.Forestal, Centro Universitario, UEX. Plasencia 10600. Cáceres. Spain

* Corresponding author: gmoreno@unex.es

² INRA Montpellier. 2 Place Viala. 34060 MONTPELLIER Cedex.

Abstract

Dehesa is a structurally complex system, where at least two strata of vegetation, trees and herbaceous plants, coexist competing for the resources:. Dehesas are generally located in shallow and/or oligotrophic soils, where water and nutrients are hypothesized to be the most important factor limiting plant productivity. Given that both resources, nutrients and water are uptaken by roots, to a realistic map of both vertical and horizontal root distribution of the different co-occurring plants is very useful to understand and to model the functioning of the dehesa.

The aim of this work was to study the root distribution in intercropped and grazed dehesas of Central Western Spain. 72 soil cores of 10 cm diameter and 2 m depth were taken out around four trees, in two orientations (east and west), and at different distance to the tree (maximum 20 m). Length density herbaceous, tree-fine and tree-coarse roots was measured using the soil cores break method (van Noordwijk et al 2000). Additionally, we have mapped tree roots in 51 profiles of 7 recently opened road cuts.

Herbaceous plant fine roots are located mostly in the upper 30 cm, above a clayey, dense soil layer; then its density decreases exponentially with depth. By contrast, fine tree roots decrease smoothly with depth and distance to trees, reaching 5 m depth and 33 m of distance, resulting in a very huge volume of soil occupied by tree roots. Certains evidences of the complementarit y supporting the two-layer model of deep- and shallow-water partitioning between herbaceous plants and trees are dicussed

Keywords

Root length density, root distribution, dehesa, Quercus ilex, herbaceous plants.
INTRODUCTION

Dehesa is a multi-purpose system, where at least two strata of vegetation coexist competing for resources (light, water, nutrients, ...). Dehesas have been common in the Iberian Peninsula, and in a less extension in other Mediterranean Basin countries, at least since the middle ages (Montero et al 1998), when natural oak forests started to be cleared to increase the light availability for the herbaceous vegetation, cereal crops and natural grasses (Gómez Gutiérrez 1992).

Humans have maintained a certain number of oak trees in the crop fields or pastureland probably because they know by intuition a common profit (positive interaction) between trees and herbaceous strata. Nowadays, dehesa is probably the most extensive agroforestry system in Europa (Paris 2002). However, in the last decades, an excessive dehesa clearance, even a complete elimination of the trees, has been occurring as a consequence of the increase mechanisation of the crops. A better knowledge of the role of trees on dehesa functioning and sustainability could be contribute to future policy measures to its conservation.

Some pionner works on the effect of trees in dehesa functioning have shown the positive effects of the trees on soil nutrient contents (Alonso et al 1979, Escudero 1985, Puerto et al 1987), soil water storage capacity (Joffre and Rambal 1988), water stress for the underlying herbaceous stratum (Joffre and Rambal 1993), and pasture production (Puerto et al 1987).

On the other hand, the positive effect of the tree clearance on the physiological status of the trees has been shown by Infante et al (1999), Montero et al (2003), Mediavilla and Escudero (2003), who found very advantageous water potential and CO2 assimilation rates along the summer in holm-oak trees growing in dehesas of Western Spain, in comparison to holm-oak trees growing in closed forests (e.g. Sala and Tenhunen 1996, Save et al 1999, Damesin and Rambal 1995). The improved physiological status of the dehesa trees could be due to an increment in the available soil, and thus water and nutrients, for each individual tree. In fact, Joffre et al (1999) has shown the importance of the water availability (through the rainfall) in the tree density in Southern Spain.

However, the nature and intensity of the interactions between trees and understory in dehesas are still poorly/insufficiently known. In the last decades, more and more positive interactions or complementarity have been described for different types of agroforestry system all over the world (e.g. vandermeer 1989; Ong et al 1996; van Noordwijk et al 1996; Casper and Jackson 1997; Gordon and Newman 1997; Dupraz et al 1999; Schroth 1999). In fact, productive use of a higher proportion of resources available from belowground can be achieved if deep networks of tree roots take up water or nutrients draining or leaching through the rooting zone of the crops (van Noordwijk et al 1996). On the other hand, researchers find that belowground competition is a major problem in simultaneous agroforestry systems and it has been the focus of much research in recent years (van Noordwijk et al 1996).

Much of the competition among plants takes place underground (Casper and Jackson 1997), thus understanding and predicting ecosystem functioning (e.g. nutrient cycling, carbon and water fluxes) requires an accurate assessment of plant rooting distribution (Jackson et al 1996). Root growth and root distribution respond to the assimilate availability (Thaler and Pagès, 1998), and a realistic map of the root
length density both horizontal and vertically is needed to model the possible interactions (facilitation, competition and complementarity) between plants. This needed is still more stressful in agroforestry systems, owing to the root distribution determines the spatial pattern of the nutrients and water acquisition by trees and herbaceous plants.

However, most of the existing models of agroforestry functioning (e.g. HyPAR: Mobbs et al 1999, WaNuLCAS: Van Noordwijk and Lusiana 1999) often assume a simple shape of the tree rooting system: an exponential decrease with soil depth and distance from the tree trunk is often considered. This simplicity is explained by the difficulty and hardness of the root studies, which have determined a very important lack of quantitative information on root distribution in agroforestry systems (Smith et al 1999; Jose et al 2001).

After a whole century of research on root systems, the means of obtaining data on root distribution and structure has not changed substantially: manual digging of trenches and the use of various mechanical excavation devices (Canadell et al 1996). Nevertheless, in the last decades some new methods has been proposed to describe the root system: soil windows, minirizotrons, soil cores washing, ... (Smith et al 2000) However all them have any limitation in term of representativity, cost or time (Smith et al 2000). To solve the problem of representativity, some authors have follow a combination of methods, e.g. trenches plus soil cores (e.g. Jones et al 1998, Silva & Rego 2003), in order to characterise the horizontal and/or vertical root extension, and to determine the root density, respectively. Additionally, to solve the problem of the time, van Noorwicke (2000) proposed an indirect methods to estimate the root lengh density by counting roots emerging from the horizontal planes of broken soil cores. Compared with a method based on washed root samples which demand much time and energy, the core break method can be the alternative one. The core-break method is a rapid and simple method for observing and recording the presence of root as function of depth (Van Noordwijk et al 2000).

Following these methods, in the last years, some few studies have characterise the spatial distribution of the root systems of co-occurring plants in agroforestry systems (e.g. Smith et al 1999; Jones et al 1998, Vanlauwe et al 2002). Results of these works show that the space occupied for trees varies both horizontally and vertically, showing different ability to compete for soil resources with co-occurring vegetation.

To our knowledge, only two studies have been carried out to characterise the root system in dehesas (Joffre et al 1987, Barrera et al 1987), and both were limited to natural grasses roots, in the first 30 and 60 cm of soil, respectively. None of these two work dealt with the tree root distribution. As Joffre et al (1999) have already stressed, a better knowledge of the extension of the root system of holm-oak is needed to understand the implications of the soil water balance on the stability of the dehesa (tree-tree and tree-understory interactions), and therefore to predict the consequences of the long-term climatic and land uses changes (i.e. overuse of underground water).

The present study focus the root distribution (Root length density) of both tree (holm oak) and herbaceous vegetation (cereal crop or natural grasses) considering both vertical and horizontal root distribution. Additionally, we have consider the effect of soil tillage on root density of the tree. To achieve that, we have used two alternative methods, soil core-break and mapping roots in recently oponed road cuts.
MATERIAL and METHODS

Study Area

The study has been carried out in the Cuatro Lugares county, in Central-Western Spain (coordinates: 39° 41' N - 6° 13' W; altitude: 380 m.a.s.l.), in two dehesas with both, grazed and cropped plots, with a tree density of 15 holm-oak per hectare, on average. Main tree dimension parameters were: 44.3 cm of DBH, 10.6 m of canopy width, and 7.8 m of tree height, on average.

In the grazed plots the main pasture species were *Lolium rigidum*, *Plantago lanceolata*, *Erodium* sp, *Taraxacum obovatum*, *Echium plantagineum* and *Ditrichia viscosa*. In the intercropped plots the culture was oats, fertilized with 200 kg ha\(^{-1}\) of NPK in one farm (CL) and unfertilized in the other one (ST). Crop yield was very low in both cases, 1.1 and 2.1 Mg ha\(^{-1}\), respectively. In both cases, the culture had abundant weeds (herbicides are not applied in dehesas crops).

The climate is semi-arid mediterranean, with an annual rainfall of 579 mm, mean annual temperature of 16.2 °C, and mean annual PET of 864 mm (Thornwaite). Climate is classified as subtropical mediterranean, following the Papadakis classification, with dry, warm and cold (with frost) periods of 4, 3 and 5 months, respectively.

Soils were mainly chromic Luvisols, in CL, and chromic Luvisols, in ST (FAO 1998) developed over tertiary sediments with abundant quartzite. Both types of soils had one or several argic horizons, very red, with slight brown and silty-sand texture in the surface horizon and a very sandy layer in dept (below 100 cm). The soils also showed a bad internal drainage, which produces variegated colours and/or pseudo-gleic, abundant gravels and stone of quartzite (frequently between 10-40 cm), low soil chemical fertility, and CaCO\(_3\) accumulation between 150 and 200 cm depth.

Soil cores: Root Lenght Density

Soil sampling

Soil cores were taken with a stainless steel soil column cylinder with cutting shoe and removable cover (101.6 x 93.5 mm, length 1000 mm), putting down with a heavy electrical powered percussion hammer (Eijkelkamp). Between 23\(^{th}\) - 28\(^{th}\) april 2002 thirsty six soil cores of 1 m-depth were extracted at 2, 5, 8 and 12 m of distance from the tree trunk of 4 intercropped holm-oaks. Between 10\(^{th}\) - 20\(^{th}\) may 2003 thirsty six soil cores of 2 m-depth (at maximum) were taken at 2, 5, 10 and 20 m of distance from the tree trunk of 3 intercropped holm-oaks and 6 'intergrazed' holm-oaks.

Soil cores were covered by a gutter (a half of PVC tube) and transparent plastic to avoid damage during the transport to the laboratory, where they were put into 5-6°C refrigerator to maintain fresh the roots till the analysis.
Sample procedure

The method of soil core break allows to estimate the Root Lengt Density (RLD) from the number of roots sticking out of two soil surfaces of a horizontally broken soil core (Van Noordwijk et al 2000).

Cylindrical soil cores were divided into 10 cm-length samples by knife. Each sample then again was divided into 2 parts by hands, and the number of tree and herbaceous plant fine roots (we used 2 mm as a diameter limit of tree fine root) were recorded in both sides of the sample parts. Decayed tree roots was excluded. We considered only the roots having black color in exterior as holm-oak fine roots and the white as crop/grass roots. To differenciate crop and native grass roots was not posible. Some minor errors could happen because very young holm-oak roots are also white, although generally stronger than crop/grass roots.

A total of 65 radomly selected samples were washed in both years to obtain a direct calibration of root length versus counts (Van Noordwijk et al. 2000). The washing activity used different filters having between 2 an 0,125 mm mesh size. It was done to avoid loosing fine roots. All samples had tree fine roots, and only 46 had crop/grass fine roots.

The length of fine roots obtained from the washing activity were measured manually for each soil core. Roots were lied in a plastic paper and then photocopied. Dry weight was also measured, although in the present work data are only shown as root lenght because root lenght is a better stimator of root system function in terms of uptake of water and nutrientes tha root weight is (Jones et al 1998).

Road Cuts: Maximum tree rooting depth and horizontal spread

We have taken advantage of the current works in the road that crosses the study area, to check the maximum distance and depth of the holm oak roots. Road cuts had been recently (3-4 moths) opened. We counted the number of the emerging tree roots (fine and coarse). No attemps were made to separate dead from live roots given the difficulties to distinguish these two categories in the field (Silva and Rego 2003).

Roots were counted in 51 profiles located every 5 meters in 7 different road cuts. To facilitate the identification the roots, we use a small palette knife to move the soil. To identify the position of the root (depth and distance from the nearest tree), we used and metallic square of 50 cm of side, divided in small squares of 100 cm². Then data of the 5 square of the same row were summed. The maximum depth of the profiles varied between 250 and 550 cm. The slope of the road cuts were measured to calculate the real depth of toots. Only in four of the road cuts we were able to confirm (by means of recent aerial photographs) that no trees had been removed during the works. In these cases we measured the data of distances to the nearest trees. In other three cases we confirmed the previous existence of some trees where the road cuts had been created. In these latter cases, data were only used to describe the root distribution in depth. Thus we have data of 51 profiles for the description of the vertical root distribution, and only 34 for horizontal root distribution.
**Data Analysis**

Results of root density are expressed as Root Length Density (Km of root per m$^{-3}$ of soil) for data of the soil core break study and as Root Number for data of the road cuts study. Schenk and Jackson (2002a) have shown that results of rooting profile based on root length (soil cores) and root count (road cuts) do not differ. Thus, results of both studies could be compared.

Simple linear regression have been applied to get the relationships between RLD and number of counted roots in order to estimate the RLD of non-washed samples (van Noordwijk 2000). Root density has been regressed with depth (simple linear and non-linear regressions) or with both depth and distance (multiple regression) in order to describe rooting pattern of both trees and herbaceous plants.

Differences between treatments and position in RLD were assessed by analysis of variance. Two-way ANOVAs were applied to detect differences in mean values of RLD between distances and depths (as dependent variables) for both herbaceous plants and trees. Two-way ANOVAS were also applied to contrast the effect of soil management (cropped versus grazed) on RLD densities at different distances or depths. Results are expressed as F values (and degree of freedom) and significance level (p).

Depth of 50% and 95% cumulative root density ($d_{50}$ and $d_{95}$, respectively) were calculated according to the Gale and Grigal (1987) model. Following these authors, a non-linear regression was used to fit the function $f_c = 1 - \beta^d$ to the profile of cumulative root fraction ($f_c$), from the soil surface to depth $d$ (cm). $\beta$ is the fitted “extinction coefficient”. Values of $d_{50}$ and $d_{95}$ were then calculated from $d_{50} = \ln (0,5) / \ln (\beta)$ and from $d_{50} = \ln (0,05) / \ln (\beta)$, respectively.

**RESULTS**

**LINEAR RELATIONSHIPS FOR ROOT LENGTH DENSITY ESTIMATION**

As a first step, the relationships between Number of Counted Roots (Nh) versus Root Lenght Density (RLD) were determined for both, herbaceous plant and tree fine roots (Figure 1). For herbaceous plant fine roots, regressions with or without term of interception were very similar, with a term of interception close to zero. By contrast, a positive and significant term of interception was found for tree root relationships. The use of this latter regression could produce a slight overestimation of Root Length Density at low ranges of RLD; moreover, we would obtain presence of fine roots where they do not exist. Thus, for the estimation of RLD we will use the regressions without term of interception, in spite they are slightly worse than the biparametric ones. The performance of the relationships for herbaceous plant roots was clearly better than the performance of the tree one (Figure 1). This difference is explained because the range of Nh and RLD are much lower for tree (0-3800 Nº m$^{-2}$ and 0-8 km m$^{-3}$, respectively) than for herbaceous plants (0-28000 Nº m$^{-2}$ and 0-44 km m$^{-3}$).
Profiles of Root Length Density

The root length density of herbaceous plants was very high in the first centimetres of the soil, decreasing very sharply, exponentially: \( RLD = 122.1 – \text{Depth}^{0.999}, r = 0.75 \) (Figure 2). The depth of 50% cumulative root length \( (d_{50}) \) was found at 10.7 cm (Table 1). At 40 cm of depth RLD was ten times lower than in the first 10 cm. Below 90 cm herbaceous plant roots were only found very occasionally, reaching a maximum rooting depth of 100 cm.

By contrast, only a slight decrease in tree RLD was observed from 0 till 200 cm of soil. At 2 meter depth the holm-oak RLD was still about the half respect to the upper soil layer. From the regression between tree RLD and depth: \( RLD(\text{Km m}^{-3}) = 2.24 – 0.0056 \times \text{Depth(cm)}; r = 0.75 \), the expected maximum rooting depth for holm-oak in this area was estimated in 400 cm, and the \( d_{50} \) value in 96.4 cm (Table 1).

Results of a two-way ANOVA (depth and distance as independent variable, and RLD as dependent variable) show a significant diminution of RLD with depth for herbaceous but not for holm-oak (Table 2).

As it is observed in Figure 3, RLD varies with the distance to the tree trunk, for both trees and herbaceous plants. This is confirmed with the comparison of means conformed by the aforementioned ANOVA (Table 2). Herbaceous plants RLD is significantly higher at 10 and 20 m of distance than at 2.5 and 5 m of distance. By contrast, tree RLD decreases slightly and significantly with the distance to the tree.

In spite of the differences with distance, the RLD profile shape does not vary with distance, neither for herbaceous plants or for holm-oak (Figure 4). In fact, we did not found any significant interaction between both factors (Distance x Depth; Table 2) neither for herbaceous plants or for trees. Only a slight increase in \( d_{50} \) value with the distance for herbaceous plant roots has been estimated (9.6, 9.3, 10.6 and 14.4 at 2, 5 10 and 20 m of distance); the contrary was observed for tree roots (67, 69, 57 and 55 cm at 2, 5 10 and 20 m of distance, considering only the roots of the first 200 cm of soil).

Effect of Soil Management on Root Distribution

Two main differences have been observed in the root distribution when the two different soil management (cropped or grazed) are compared (Figure 5). Root length density of herbaceous plants was much lower in grazed plots (native grasses) than in intercropped plots (oats + native grasses) \((F_{1, 249} = 5.55; p = 0.004)\), at any distance (not-significant interaction: \( F_{6, 249} = 0.062; p = 0.991 \)). \( d_{50} \) value was also clearly deeper in intercropped plots (cm) than in grazed plots (13.9 and 7.4 cm, respectively; Table 1).

On the other hand, tree RLD was very similar in both type of management, cropped and grazed plots. Nevertheless, RLD decreased slightly in the first 20 cm of depth in intercropped plots respect to the grazed ones, although the differences were not statistically significant \((F_{1, 104} = 1.18; p = 0.31)\). \( d_{50} \) value was only slightly deeper in intercropped plots (cm) than in grazed plots (69.1 and 64.6 cm, respectively, considering only the two first meters of depth).
**Road cuts**

Results of this study show that the maximum number of holm-oak roots counted decrease linearly with depth, reaching a maximum depth of 450 cm (Figure 6), and $d_{50}$ value of 81,3 cm. Considering mean values, the profile of root distribution follows an exponential decrease with depth (Figure 6), mainly in the closeness of the tree (0-10 m and 10-15 m of distance), but not further (15-20 m and >20 m) (Figure 7).

A clear and significant ($\alpha$) decrease of the tree root density with the distance to the trees was found ($F_{3,27} = 96,81; \, p=3,0E-05; \, \text{Figure 7}$). Significant differences were found between 0-10 m and 10-15 m, between 10-15 m and 15-20 m, but not between 15-20 m and >20 m. The maximum measured distance was 26 m, where roots were found even at 3 m of depth.

Considering the relationship between the number of roots and both distance and depth, the following equations was found: $N_{\text{root}} = 76,2– 0,14 \cdot \text{Depth(cm)} – 2,23 \cdot \text{Distance(m)}$; with $r = 0,75$ and $F_{2, 155} = 36,24; \, p<0,0000$. From this equation, 33 m was estimated as the maximum distance, and 520 cm as the maximum depth.

**DISCUSSION**

**Herbaceous plants root system**

Most of the herbaceous plants roots were located in the first centimeters of the soil, a common pattern for most of the herbaceous plants in the world (Jackson et al 1996). In fact, the 95% of the root length was located in the first 46 cm, slightly shallower to those reported by Jackson et al (1996) as mean value of many different species from all over the world (table 1).

Native grasses shown a very shallow root system, with $d_{50}$ at 7,4 cm, and with the 94% of the root length in the first 30 cm soil. The maximum rooting depth was established around 80 cm. Two previous studies on grass root systems in dehesas of Quercus ilex reported an even shallower root system to those found in the present study. Barrera et al (1987) measured a $d_{50}$ value at around 4 cm in more northern dehesas, and by Joffre et al (1987) found a $d_{50}$ value below 5 cm for annual grasses in a more southern dehesa. By contrast, the latter authors found for perennial grasses a $d_{50}$ value near 10 cm, deeper than our study.

Other authors have reported deeper root systems for temperate grassland, i.e. Jackson et al (1996) reported that the cumulative root biomass at 30 cm depth averaged from many different grass species was the 83%, and Canadell et al (1996) reported a mean value of 2,6 m for the maximum rooting of 82 species of temperate grassland (all of them going down more than 100 cm). Kutschera (1960; quoted in Canadell et al 1996) estimated an average maximum rooting of 1,1 m for 69 grassland species in Mid Europe.

In term of root length, our results are slight lower to those reported by Joffre et al (1987) for native grasses in a dehesa of Southern Spain. These authors found a value of 50 km m$^{-2}$ in the first 60 cm of soil for annual grasses, while in our plots the mean value for native grass was 39,6 km m$^{-2}$ (with 720 and 579 mm of mean annual rainfall, respectively).
Crop (oats) had a clearly deeper rooting pattern than native grasses, with ‘only’ the 78% of the root length in the first 30 cm, and with a maximum rooting depth of 100 cm. Jackson et al (1996) reported a mean value of 70% of root biomass in those 30 cm of soil, and Canadell et al (1996) reported a maximum rooting depth of 2.1 m, on average. In this last study, the maximum rooting depth for oats was 1.8 m. The apparent low capacity of oats to go deep in our study area could be explained by the presence of a width very clayey soil layer between 40-80 cm of depth.

A surprisingly result it is the significant increment of herbaceous RLD in cropped plots (dominated by Avena sativa) respect to the grazed (with native grasses) ones. This result does not agree with the reported values by Jackson et al (1996), who found that crops shown very low root density respect to the other biomes (even a tenth part respect to the temperate grassland, on average).

The higher and deeper root system in oats crop respect to native grasses involves a complementary competetion for soil resources (mainly water) with trees respect to the pasture.

Finally, to note that the observed increment of herbaceous RLD with the distance to the tree should be explained by a parelled increment in the aboveground biomass. In fact, in the same plots a significant increment of crop biomass with distance to the tree has been found (unpublished data). Other authors has shown a similar pattern for native grasses on average conditions (e.g. Puerto et al 1987).

**Holm-oak root profile**

We have found an unusual deep rooting system for holm-oak in dehesas here studied, with a d50 value between 96.4 cm (soil core method) and 81.3 cm (road cuts method), and with a very important percentage of roots located below 1 m deep. By contrast, Schenk and Jackson (2002a), after an exhaustive review of 475 root studies, concluded that most of the plants have at least 50% of the roots in the first 30 cm of the soil, even in the desert. They also concluded that by far the majority of ecosystem root biomass resides in the upper 2 m of soil (at least 95% root biomass).

For sclerophyllous mediterranean plants, these authors reported mean values of 19 and 171 cm for d50 and d95 (Table 2). Canadell and Roda (1991) studying a close forest of Quercus ilex in Northwestern Spain found that roots usually did not exceed a depth of 50-60 cm in xeric sites, and only under mesic conditions, some roots went down deeper than 1 m. From their data, we have estimated a d50 values for fine-root in close forest of holm-oak of 17 cm. In the same region, López et al (2001) found that most of the roots of Quercus ilex were located in the first 40 cm of the soil. Other sclerophyllous plant communities reported in Iberian Pensinsule has shown also d50 values rather shallow. A sand dune shrub community of southern Spain had a d50 at around 10 cm (calculated from data reported by Martinez et al 1988). Silva and Rego reported d50 values of 22 and 40 cm for Erica and Ulex species, respectively in CW Portugal. Cañellas and San Miguel (2000) also reported a very shallow root system for Quercus coccifera, with most of the roots in the first 35 cm of the soil.

Regardless of the equation type describing the root profile (linear versus exponential negative, in soil core break and road cuts studies, respectively), holm-oak growing at
the site studied showed a clearly deeper root system than those reported by aforementioned authors.

Nevertheless, an outstanding point is that most of the aforementioned studies report data on root biomass, which trends to give shallower $d_{50}$ than those using root length (Schenk and Jackson 2002a) or root count (Silva and Rego 2003). Thus, when we compare our data with those compiled data by Jackson et al. (1996) and Schenk and Jackson (2002a), a slight methodological difference (bias) must be taken into account. In fact, the latter authors pointed out that $d_{95}$ values $> 2$m are likely more common than suggested by data of their study.

The difference of results between both methods used in the present work could be due to some specific methodological limitations. The performance of the relationships between root number and RLD was rather poor ($r = 0.65$), but this could have contributed to increase the standard errors and to make difficult the detection of differences between mean values, but we have no reasons to think in some under or overestimation of RLD values. Moreover, any possible bias in the results should be similar to any soil layer, and thus it should not affect to $d_{50}$ and $d_{95}$ values.

On the other hand, in the road cuts, we included both fine and coarse roots, while in soil core study we included only fine roots. Moreover, in the first case, both dead and alive roots were included, while in the second case, only alive roots were included. Finally, in road cuts finer roots could have disappeared in the moment of the study, owing to the study was carried out in road cuts 3-4 months old. Generally, the ratio coarse/fine root decreases with depth (e.g. Canadell et al 1991; Silva and Rego 2003). All these aspects could have contributed to overestimate roots in upper layers respect to the deeper layers in the road cuts study and could have contributed to the exponential shape of root decrease with deep.

Although, the root profile usually follow a exponential negative trend (many examples in Jackson et al 1996), in this same paper some examples with rather linear trends are given (mainly in desert plants). Also, Kummerov and Mangan (1981) with Quercus dumosa, Schulze et al. (1996) with Nothofagus in Patagonia, Silva and Rego (2003) with Ulex jussiaei in Portugal, Vanlauwe et al (2002) with Senna siamea in Togo, reported root densities decreasing with deep following an almost linear tendency (not exponential negative).

Rooting patterns must been expalined in term of biotic and abiotic factors (Schenk and Jackson 2002). Some abiotic conditions could be determining the deep rooting pattern of Quercus ilex in the dehesas studied, i.e sandy soil, thin organic horizon, low rainfall/PET ratio and long warm and dry season. All these parameter are positively correlated with rooting depth (Canadell and Zedler 1994; Vanlauwe et al 2002; Schenk and Jackson 2002a). The former authors pointed out that many cases root depth was more determined by the soil characteristics than by genetic characteristics of the species. López et al (2001) explained the low root density of Quercus ilex in the first 10 cm of the soil as a consequence of the aridity of the site (537 mm of rainfall per year), seasonal high temperature and coarse texture of the soil in a forest of North-Eastern Spain.

However, Schenk and Jackson (2002a) pointed out, as a whole, the abiotic factor can only explain very partially the tree root pattern (no more than 40% of variability). Biotic factors, as plant competition probably play also a very important role in
determining root patterns. The deep root system of *Quercus ilex* at the dehesas studied could be be explained as a consequence of the coexistence of two vegetation strata. The presence of the abundant native grasses (and periodically cereal crops) could force trees to generate a deeper root system. Thus the tree RLD in the first layers is rather low, and anycase it is not much higher than in the underlying layers. This could be a good example of complementarity in an agroforestry system, which could imply a better use of soil resources respect to the a single-specie system (forest or monocrop). Probably, the maximum rooting depth does not change, but tree-roots would be located deeper, on average, in dehesa than in close forest. To our knowledge, this induced complementarity has not been experimentally shown before, and this oustanding aspect will need further research. Smith et al (1999) comparing rooting system of *Grevillea robusta* growing alone and in combination with crop, did not found significant differences neither in RLD nor in $d_{50}$, although a slight decrease in RLD and increase in $d_{50}$ (deeper roots) in tree growing with crop were described. Moreover, crop (maize) roots grew shallower and less dense when combined with trees.

In the present work, we had also found some insight on this aspect. Trees growing in-farm plots (soil cores study) showed a deeper root system than trees out of the farm (road cut study). This constiue only a weak proof of the consequence of dehesa structure and management on the holm-oak root deepening. Undoubtly, this hypothesis still need more specific studies in the future, because the consequence on holm-oak dehesa and forest functioning in term of resources use must be very important, mainly for water uptake of both co-ocurring vegetatio strata.

Thus the different rooting patterns of trees and herbaceous plants should reflect different ecological strategies, but also the result of competition between plants with different characteristic (Casper and Jackson 1997).

**Maximum rooting depth of Holm-oak**

We have found a maximum rooting depth for holm-oak around of 5 m, which agrees with the average maximum rooting depth reported by Canadell et al (1996) for sclerophyllous shrubland and forest (5,2 ± 0,8 m). This deep-root pattern is often found in water-limited situations.

Previous works have reported a maximum root depth for *Quercus ilex* of 1m and 3,7 m (Canadell and Rodâ 1991; Canadell et al 1996). The difference between these studies (1, 3.7 and 5 m) could be probably due to the limitation into the substrate, which has a determinant influence on maximum rooting depth (Canadell and Zedler). In our site studied, roots seem to grow freely without any substrate limitation.

Canadell et al (1996) have also reported maximum rooting depth of 3,5 m *Arbutus unedo*, 2 m for *Erica arborea*, 7,5 m *Pinus halepensis* and 5 m for *Pinus pinea*, all of them under mediterranean climate (NE Spain). In a sand dune shrub community of Southern Spain, we have estimate a maximum rooting depth at around 250 cm from data reported by Martinez et al (1998). Silva and Rego (2003) has reported values of 329 and 349 cm for *Erica* and *Ulex* species, respectively in CW Portugal. Nevertheless there many references reporting very much deeper maximum rooting all over the world, mainly in desert, savanna, tropical evergreen forest and sclerophyllous shrubland and forest (Stone and Kalisz 1991; Canadell et al 1996),
with many species going down deeper than 10 m (even some of them more than 50 m). Regarding to other evergreen *Quercus* species there are several references with maximum rooting depth between 5 and 10 m, with a only example reaching more than 20 m depth (*Quercus wislizenii*; Canadell et al 1996).

Comparing with these latter references, it can be pointed out that *Quercus ilex* is not a very deep-rooting tree. However, most of the aforementioned references refer to “record” values, which could be not realistic for many ecosystem and/or situations given that the maximum rooting depend on plant density and soil characteristic, while are fairly variable in space (Canadell and Zedler 1994; Canadell et al 1996). For instance, Silva and Rego (2003) reported a maximum rooting depth of 329 cm for *Erica* sp, while 82% of deep roots were not reach more than 175 cm. Thus, this type of information should only be considered in a orientative way, owing to it is probably very variable, and data from many different sites are still needed to describe a general pattern of maximum rooting depth in function of the abiotic (mainly soil) characteristic.

On the other hand, our methodological approaches are not suitable to determine the existence of the taproot, which would needs of the entire plant excavation. Canadell and Zedler (1994) reported the existence of the taproot for many mediterranean woody plants, probably as an adaption to summer drought. By contrast, Canadell and Zedler (1991) found that most the excavated holm-oak did not have a main taproot.

In our site studied, the water table is usually found in the first 10 m of soil along the summer (personnal observation in several in-farm wells). In fact, holm-oaks of this area had high water potential (non-stressed status) along two summer drought (Montero et al 2003), indicating that holm-oak roots are probably tapping water from the water table. In fact, a local proveb says “In sandy soils, an only vertical roots, in rocky soils, many shallowly spreads roots”. Although this tap root could be a very low percentage of total root system, its functional signifance may nevertheless be most important for ecosystem water and carbon fluxes, and nutrient cycling (Canadell et al 1996). In fact, taproots could be hundreds of times more efficient in absorbing water than roots in drier soil (Reicosky et al 1964; quoted in Canadell et al 1996).

**Lateral root distribution**

In semiarid conditions, the survival of the trees in the event of severe drought is only possible if the tree root system can extend beyond the influence of the tree canopy (Eastham et al 1988; Joffre and Rambal 1999). On the other hand, lateral root spread influences how many neighbours compete for resources available to plants in a ecosystem (Schenk and Jackson 2002b). These latter authors in an comprehensive study on lateral root study with references from all over the world, reported a mean value of 11,5 m for one-sided lateral root spread for trees. Canadell and Rodá point out that holm-oak growing in close forest did not usually extend more than 2.5 m from the trunk, and occasionally reached till 4,5 m.

In the present study, the maximum lateral rooting (estimated on 33 m) was slightly above the mean distance between trees (26 m on average), indicating that a certain level of tree-tree competence for water could occur. An outstanding consequence of this result it is that lateral roots can explore the whole inter-tree space, allowig an optimal use of the soil resources by trees in dehesas.
This pattern could be common in open woodland (scattered or arranged trees), as a consequence of the low tree density. The belowground area occupied by dominant shrubs in a California chaparral, for example, was over 10 times the area occupied by their canopy (Kummerow et al 1977, quoted in Casper and Jackson 1997). Other example was reported by Vogt et al (1995) who found that a forest gap (Pinus menziesii) of 50 m diameter was completely rooted only six month later. Schenk and Jackson (2002b) found that larger lateral root spreads were found in plants growing in dry environments, in a low density, where plants could explore the soil in interspaces between plants. These latter authors study reported in their comprehensive study, maximum distances around 50 m and several species with values around 20 m.

Our results indicate the dependence of the dehesa holm-tree on the resources located out of the canopy projection, and support the hypothesis that tree density in dehesas could be water-availability dependent (Joffre and Rambal 1999). According to the lateral root distribution, trees should use almost similarly the soil water located outside and beneath the tree. Our preliminary results on temporal dynamic of soil water content (unpublished data) show a very similar seasonal pattern of soil water content at 5 different distances to the tree (from 2 to 20 m). Joffre and Rambal (1993) also showed that soil water outside of the tree was depleted along the summer, while no grasses were actives, that is, water was being uptaken by trees. Moreover, comparing two approaches to estimate the holm-oak water transpiration in summer (based on estomata conductance and VPD versus soil water balance), they found an underestimation of the tree transpiration by the soil water balance approach, concluding that the holm-oak root system either exceeded 1,5 m of depth or extended beyond the influence of the tree canopy. Our results confirm both possibilities, deep and lateral root extension.

The lateral extension of the tree roots does not support the classical division of dehesas in two ecological components: an open herbaceous layer dominated by annual species, and an area affected by tree canopy which includes an herbaceous stratum (Joffre and Rambal 1993). Nevertheless, these authors, studying more humid dehesas (annual rainfall around 700 mm), found significant differences in the soil water balance between two components of the dehesa: tree-grass (beneath the tree) and only grass (outside of the tree). They found a much higher excess of water (runoff and deep drainage) out the tree and a higher transpiration beneath the tree rest still unexplained according to our results on lateral rooting pattern.. Thus lateral rooting spread found in the present study should be confirmed in other situations.

Available soil for a single holm-oak in dehesas

On the base of the assumption that roots grow only as deeply and further as needed to fulfil plant resource requeriment (Schenk and Jackson 2002b), it is clear that holm-oak need of a huge volume of soil to acquire its belowground resources in oligotrophic soils, under a semi-arid climate with a long summer drought. Considering 26 m as the mean distance among trees, 5m as the maximum rooting depth, and an elipsoid shape for the explored soil by roots, we have estimated than roots of a single tree can uptake resources from around 7000 m$^3$ of soil for a 350 m$^3$ canopy. (10,7 m of canopy diameter and 5,9 m of canopy height).
As Joffre et al (1999) have pointed out, dehesas have to cope with the high variability of the Mediterranean climate; an extent root system undoubtly it must contribute both to adapt to natural conditions and to overcome unpredictability. This extent root system could also confer to dehesa trees a certain stability respect to climatic variability. In fact, usually dehesa trees have a better water status than holm-oak growing in close forest (Infante et al 1999, Mediavilla and Escudero 2003, Montero et al 2003).

Nevertheless, an hypothetical decrease in rainfall amount and an increase in the probability of extreme events such as severe drought, as a consequence of the atmospheric CO$_2$ increment (Gregory and Mitchell 1995), together with an progressive overuse of the groundwater resources, could lead to a more water stressed tree in dehesas, which could be overcome by a reduction on the tree density (Joffre et al 1999).

**Combined root system: implication in competition for soil resources**

To reduce competition with crops/grasses for belowground resources, the ideal tree for agroforestry should have a deep root system and little root proliferation near the top of the profile, thereby enabling the herbaceous plants to utilise resources from near the soil surface, while the trees have sole access to deeper layers (Schroth 1995). We have shown a certain degree of spatial separation between herbaceous plants and tree root system, that is, trees have an uncommon deep root system, with a rather low RLD in the upper layers of the soil, and herbaceous vegetation can not reach deep layers, where tree roots are still abundant. This rooting pattern surely contribute to reduce belowground competition, thereby probably falling in the general category of ‘niche separation’ (Casper and Jackson 1997). Thus, although water limitation is an important feature in most dehesas (included our study area), this does not necessarily mean that competion for water is high, as Casper and Jackson (1997) has already pointed out.

Walter (1954; quoted in Casper and Jackson 1997) first proposed the two-layer model of deep- and shallow-water partitioning between grasses and shrubs/trees in subtropical savannas. This simple model could also describe the rooting pattern in dehesas. In fact, this two-layer model appearars to be most appropiate in drier regimes and in systems with substantial winter precipitation (Schenk and Jackson 2002b). Some authors have shown that woody plants took up water from deeper layers than herbaceous ones (e.g. Walker et al 1981; Sala et al 1989; Ehleringer et al 1991; Smith et al 1997).

**CONCLUSIONS**

In this work we have reported the vertical and horizontal root distribution on dehesas developed on deep soils, with a very low nutrient content and semirarid conditions. Holm-oak in this area has a more extensive than intensive root system. The maximum rooting depth for trees is around 5 m, and maximum horizontal distance is around 30 m. Moreover, tree RLD decreases with distance and with depth more smoothly than it commonly happens in other woody sytems. Considering both root depth and horizontal spread (schematised in Figure 8), we have estimated that the volume of explored soil by roots can be 20 time the volume
occupied by canopy. The low tree RLD in the first meter of soil and the much deeper root system of tree respect to the herbaceous plants support the two-layer model of deep- and shallow-water partitioning between grasses and shrubs/trees in the dehesas studied. In fact, this two-layer model appears to be most appropriate in drier regimes and in systems with substantial winter precipitation (Schenk and Jackson 2002b). The existence of this water partitioning should be addressed in future researches.

By contract, the very high RLD of herbaceous plants respect to the tree in the first cm of soil could imply a very strong competence for nutrients (mainly N), owing to the uptake of nutrients may be limited primarily to upper soil layers (Jackson et al 1996).

This rooting pattern should have important consequences in modelling the coexistence of tree and grass/crop, and support the idea that the model based on a horizontal partitioning of resources could be not satisfactory to explain the coexistence of trees and grasses as have been already emphasized by Joffre and Rambal (1993) analysis soil water dynamic in dehesas of southern Spain.

Our data will be use to model the dehesa functioning considering the tree-understory interactions. The model should be useful to address the effects of dehesa management, changes in land use or climate for the cycling of C, H₂O and nutrients. Nevertheless, more information is still required on temporal root dynamic of both holm-oak and herbaceous plants.

Acknowledgement

This study was supported by European Union (SAFE project, contact QLX-2001-0560), Spanish Ministerio de Ciencia y Tecnología (MICASA project, contract AGL-2001-0850) and Consejería de Educación de Extremadura (CASA project, contrast 2PR02C012). Elena Cubera has been granted by the Consejería de Educación de la Junta de Extremadura (Spain) and Jesús Obrador has been granted by ANUIES (México)
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<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>$\beta$</th>
<th>$R^2$</th>
<th>$d_{50}$</th>
<th>$d_{95}$</th>
<th>Maximum rooting depth</th>
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<tr>
<td>Herbaceous plants</td>
<td>0.937</td>
<td>96.0</td>
<td>10.7</td>
<td>46.2</td>
<td>100</td>
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<tr>
<td>Oats + weeds</td>
<td>0.951</td>
<td>97.4</td>
<td>13.9</td>
<td>60.2</td>
<td>100</td>
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<tr>
<td>Native grasses (mostly annual)</td>
<td>0.911</td>
<td>98.8</td>
<td>7.4</td>
<td>32.1</td>
<td>80</td>
</tr>
<tr>
<td>In-farm Holm-oak (soil cores)</td>
<td>0.993</td>
<td>98.9</td>
<td>96.4</td>
<td>416.6</td>
<td>400</td>
</tr>
<tr>
<td>Out-farm Holm-oak (road cuts)</td>
<td>0.992</td>
<td>99.5</td>
<td>81.2</td>
<td>350.9</td>
<td>450</td>
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<td>Mediterranean woody plants</td>
<td>19$^{(1)}$</td>
<td>171$^{(1)}$</td>
<td>520$^{(1)}$</td>
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<td></td>
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<tr>
<td>Temperate grassland</td>
<td>0.943$^{(2)}$</td>
<td>82.0</td>
<td>11.8$^{(2)}$</td>
<td>51.0$^{(2)}$</td>
<td>260$^{(3)}$</td>
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<tr>
<td>Crops</td>
<td>0.961$^{(2)}$</td>
<td>94.3</td>
<td>17$^{(2)}$</td>
<td>75$^{(2)}$</td>
<td>210$^{(3)}$</td>
</tr>
</tbody>
</table>

(1) Schenk and Jackson 2002a; (2) Jackson et al 1996; (3) Canadell et al (1996)

Table 1. Summary of values describing the root profile of holm-oak and herbaceous vegetation in dehesas of Central-Western Spain. Some mean values from the recent comprehensive studies are also shown.

NOTE: $d_{50}$ and $d_{95}$ indicate the depth corresponding to 50 and 95%, respectively, of the cumulative root fraction. Both values are estimated from the Gage and Grigal (1987) model: $Y = 1 - \beta^d$, where $Y$ is the cumulative root fraction from the surface to depth $d$ (cm), and $\beta$ is the fitted “extinction coefficient”.
Table 2. Summary of two two-way ANOVA, where DEPTH (From 0-20 to 180-200 cm) and DISTANCE (2, 5, 10 and 20 m to the tree trunk) are the independent variables, and RLD (Root Length Density) is the independent variable.

NOTES: D.F.: Degree of Freedom. Different letters mean significant differences. n.s. Differences not significant. Data of 10m of distance is 2002 were calculate by averaging data of 8 and 12 m.

<table>
<thead>
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<th></th>
<th>F value (D.F.)</th>
<th>p</th>
<th>Differences</th>
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<td><strong>HERBACEOUS PLANTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Depth</td>
<td>94,46 (9, 442)</td>
<td>0.000</td>
<td>0  20  40  60  80  100 120 140 160 180 200</td>
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<tr>
<td>2. Distance</td>
<td>10,26 (3, 442)</td>
<td>0.004</td>
<td>2.5  5  &lt;&lt;  10  20</td>
</tr>
<tr>
<td>1 x 2</td>
<td>1,16 (27, 442)</td>
<td>0.289</td>
<td>n.s.</td>
</tr>
<tr>
<td>1. Depth</td>
<td>0,36 (9, 442)</td>
<td>0.952</td>
<td>n.s.</td>
</tr>
<tr>
<td>2. Distance</td>
<td>7,64 (3, 442)</td>
<td>0.001</td>
<td>2.5  5  10  20</td>
</tr>
<tr>
<td>1 x 2</td>
<td>0,80 (27, 442)</td>
<td>0.702</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

| **TREE**       |                |        |                      |
| 1 x 2          | 0,80 (27, 442) | 0.702  | n.s.                 |
LEGEND of FIGURES

Figure 1. Linear regressions between (a) number of herbaceous plant roots crossing a horizontal plane (Nh) and root length density (RLD); (b) the same for tree roots; (c) dry weight of herbaceous plant roots (Dw) and root length density (RLD); and (d) the same for tree roots. NOTE: Data refer to fine-roots. Herbaceous plants refer to oats and native grasses.

Figure 2. Variation of the Tree and Herbaceous plants Root Length Densities with soil depth in dehesas developed over Chromic Luvisols and Acrisols of Central Western Spain. NOTE: Tree refers to holm oak and herbaceous plants includes oats and natural grasses.

Figure 3. Means values of Root Length Density of tree and herbaceous plants measured at different distances to the tree trunk in dehesas of holm oak.

Figure 4. Distribution of fine root length density plotted in function of the distance to the tree trunk and depth for both herbaceous plants and trees.

Figure 5. Distribution of the tree and herbaceous plants root length densities at differences distances and depth under two different types of dehesa management: cropped and grazed.

Figure 6. Exponential decrease of the holm oak roots with depth, measured in recently opened road banks in dehesas developed over Chromic Luvisols and Acrisols of Central Western Spain. NOTE: Data were grouped every 35 cm.

Figure 7. Profiles of the holm oak roots described in in recently opened road banks, at differences distances to the trees. The maximum depth is different to that shows in figure 6, because here some profiles are not included (see methods).

Figure 8. Schematic diagram of the tree and herbaceous plants roots distribution in dehesas developed over Chromic Luvisols and Acrisols of Central Western Spain.
FIGURE 1

Herbaceous Plants

\[ \text{RLD} = 0.0012 \times \text{Nh} - 0.289 \]
\[ r = 0.92 \]

Tree RLD (km m\(^{-3}\))

Holm-oak

\[ \text{RLD} = 0.0012 \times \text{Nh} + 0.6382 \]
\[ r = 0.68 \]

\[ \text{RLD} = 0.0015 \times \text{Nh} \]
\[ r = 0.65 \]
FIGURE 2

Root length density, Km m$^{-3}$

- **Herbaceous Plants**
- **Holm-oak**
FIGURE 3

To be selected on of them
FIGURE 4

The figure shows the distribution of herbaceous plants and holm-oak RLD (roots and rhizomes density) at different depths (cm) and distances (m). The x-axis represents distance, and the y-axis represents depth. The circles denote the density of herbaceous plants and holm-oak RLD, with shading to indicate varying densities.
FIGURE 6

Nº of Tree Roots (50x50 cm square)

Mean number of tree roots (50 x 50 cm square)

$y = 454.22e^{-0.0392x}$  $r = 0.99$
FIGURE 8
ANNEXE 18. Integrating Soil Erosion and Profitability in the Assessment of Silvoarable Agroforestry at the Landscape Scale

Contractor 7 : UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

Workshop 5

Combined micro-economic and ecological assessment tools for sustainable rural development

Palma, J.1; Graves, A.2; Bregt, A.4; Bunce, R.5; Burgess, P.2; Garcia, M.3; Herzog, F.1; Mohren, F.4; Moreno, G.3; Reisner, Y.1

1 – Swiss Federal Research Station for Agroecology and Agriculture, Reckenholzstrasse 191, 8046 Zurich, Switzerland
2 – Cranfield University, Silsoe Campus, Cranfield, Bedfordshire MK43 OAL, United Kingdom
3 – Universidad de Extremadura, Centro Universitario de Plasencia, Avda. Virgen del Puerto, 10600 Plasencia, Spain
4 – Wageningen University and Research Center, Costerweg 50, 6701 BH Wageningen, The Netherlands
5 – Alterra, Green World Research, Droevendaalsesteeg 3, 6708 PB Wageningen, The Netherlands

Abstract

Silvoarable AgroForestry (SAF), the deliberate combined use of trees and crops on the same area of land, could potentially Improve the environmental performance of agricultural systems in Europe. The present study assessed six different silvoarable systems, according to their impact on soil erosion and their net present value (NPV) near Torrijos in Castilla la Mancha in Spain in comparison with existing arable agriculture. The Universal Soil Loss Equation (USLE) was used to calculate soil erosion under the different silvoarable and arable systems and an economic model was used to determine their NPV. SAF combined with contouring decreased soil loss by 80%. Economic analysis showed that the NPV of densely planted, but widely
spaced silvoarable system could be similar to the one of existing arable systems. However, current grant schemes were higher for the arable system and made the silvoarable systems less attractive in terms of cash flow and NPV. It is concluded that where soil erosion is problematic, grant systems should not increase the attractiveness of arable systems at the expense of SAF.

**Keywords:** Silvoarable agroforestry, soil erosion, economic assessment, landscape modelling, scenario studies

**INTRODUCTION**

Silvoarable agroforestry (SAF) involves the deliberate combination of trees and agricultural crops on the same land management unit in some form of spatial arrangement or temporal sequence such that there are significant ecological and economic interactions between tree and agricultural components (Sinclair, 1999). Recent findings indicate that modern SAF production systems are efficient in terms of resource use; therefore they are proposed as innovative agricultural production system that will be both environmentally friendly and economically profitable. This would improve farming systems’ sustainability and diversify farmers’ income as well as provide new products to the wood industry, and create novel landscapes of high value. These possibilities are investigated in the EU-funded project “Silvoarable Agroforestry for Europe (SAFE)” (http://www.montpellier.inra.fr/safe/).

Economic and environmental assessments are usually undertaken separately (Adesina et al., 2000; Belaid and Karteris, 1995). The aim of this paper is to combine the economic and environmental assessments of SAF by modelling various scenarios and evaluating their effects on soil erosion and profitability. This approach is illustrated in a Landscape Test Site (LTS) of 16 km² in Spain (province of Castillia la Mancha), where the current land use is compared with different implementation designs of SAF.

**MATERIAL AND METHODS**

**Landscape Test Site (LTS)**

Based on an Environmental Classification of Europe which resulted from a statistical analysis of climatic and topographic data (Metzger et al., 2002), three landscape test sites of 4x4 km were selected in the three dominating environmental classes in Spain. The selection was random but was restricted to agricultural areas where indispensable data are available (soil, land use, farm statistics). Areas dominated by forest were excluded by masking them through an overlay of the Environmental classes with the PELCOM land cover classification. Aerial photographs and digital land use were made available through a collaboration with Prof. Ramon Elena Rosello (Universidad Politécnica de Madrid). During a field survey, land-use information was updated and soil maps were produced based on soil samples and topography. Digital elevation models were elaborated by digitising the contour lines of topographic maps. Monthly averages of rainfall and temperature from the nearest weather stations were compiled. All spatial information was stored and processed in the Geographic Information System (GIS) ArcInfo 8.3. The Torrijos LTS was chosen for this pilot study. The agricultural statistics of Castillia de la Mancha were used to compile the relevant agro-economic and forestry data for the Torrijos LTS.
**Soil Erosion**

USLE for silvoarable agroforestry

The USLE (Universal Soil Loss Equation) (Wishmeier and Smith, 1978) was used (Equation 1).

\[ E = R \times K \times LS \times C \times P \]  \hspace{1cm} (eq. 1)

- **E** = annual soil loss (tons ha\(^{-1}\) year\(^{-1}\))
- **R** = rainfall erositivity factor (MJ mm ha\(^{-1}\) h\(^{-1}\) year\(^{-1}\))
- **K** = soil erodibility factor (t ha h ha\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\))
- **LS** = slope length factor (unitless)
- **C** = cover Management factor (unitless)
- **P** = erosion control practice factor (unitless)

The R-factor was calculated according to Renard and Freimund (1994), based on the mean annual precipitation; the K-factor was based on the soil texture components according to Römkens et al. (1986) and Renard et al. (1997), respectively. The AML (Arc Macro Language to run with ArcInfo) developed by Van Remortel et al. (2001) was used to compute the LS-factor.

Because SAF systems have an arable and a forestry component, Equation 2 was derived to calculate the C-factor for a SAF plot.

\[ C = [Cov_a \times C_a] + [Cov_f \times C_f] \] \hspace{1cm} (eq. 2)

- **C** = C-factor of a SAF field
- **Cov\(_a\)** = land cover fraction of the arable component (crop) (%)
- **C\(_a\)** = C-factor for the arable component
- **Cov\(_f\)** = land cover fraction of the forestry component (grassland strips under the trees) (%)
- **C\(_f\)** = C-factor for the forestry component
Figure 0: Conceptual design of silvoarable agroforestry (SAF).

$C_{ov_a}$ and $C_{ov_f}$ depend on the distance between the tree rows and its strip width ($C_f$ was computed according to Dissmeyer and Foster (1980), based on the trees’ canopy diameter and centroid height which are species specific.

**Input parameter for the LTS**

The closest climatic station used for the study has a mean annual rainfall of 357 mm. The calculated R-factor is 621 MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$. The soil map of the LTS contains seven different soil types with $K$-values ranging from 0.03854 to 0.04389 t ha h ha$^{-1}$ MJ$^{-1}$ mm$^{-1}$. The LS-factor values vary from 0 to 11.19 (no unit). A prototype full-grown agroforestry poplar tree of 16 m high with 8 m of canopy diameter was assumed, with the strip being invaded by natural vegetation. The $C_a$-factor for the study area was assumed to be 0.05, based on a crop rotation with 75% cereals and 25% grassland.

To calculate the P-factor, SAF can be considered as strip cropping. The original contouring value was reduced by 50% according to Morgan (1995).

**Economic Modelling of hypothetical farms**

The economics of silvoarable agroforestry

A computer model (Graves et al. unpublished paper) was developed in order to compare the effects of silvoarable, forestry and arable enterprises on a farm business. The model assumes that the farm business comprises a series of “enterprises” which generate revenue ($R$) and costs expressed on a per unit area basis. These costs could be both variable costs ($V$), such as the costs of fertilizer, seed and sprays, and assignable fixed costs, such as labour and machinery ($A$).

Whereas an economic comparison of two arable crops can often be undertaken on an annual basis, the economics of a silvoarable system are typically considered over the rotation of the tree crop which lasts many years. As most people have a preference for immediate income, there is therefore a need to ‘discount’ the value of revenue obtained in the future (most commonly at the opportunity cost of capital), to give the investment a “present” value, termed the “net present value” (NPV) (Pearce, 1971). At a plot-scale, the NPV (€ ha$^{-1}$) of an arable, forestry or silvoarable enterprises can therefore be expressed as (Equation 3):
\[ NPV = \sum_{t=0}^{T} \frac{(R_t - V_t - A_t)}{(1+i)^t} \]  
(eq. 3)

\[ NPV \] = net present value of the arable, forestry or silvoarable enterprise within a unit (€ ha\(^{-1}\))

\[ R_t \] = revenue from the enterprise (including subsidies) in year \( t \) (€ ha\(^{-1}\))

\[ V_t \] = variable costs in year \( t \) (€ ha\(^{-1}\))

\[ A_t \] = assignable fixed costs in year \( t \) (€ ha\(^{-1}\))

\[ T \] = time horizon (years)

\[ I \] = discount rate

Implementation design

Three different silvoarable poplar tree densities were selected (25, 50 and 100 trees ha\(^{-1}\)). For each density, two different strategies in the layout of the trees in the field were considered.

The first strategy maximized the row distance and minimized the in-row tree distance (25 trees ha\(^{-1}\): 40 x 10 m; 50 trees ha\(^{-1}\): 40 x 5m; 100 trees ha\(^{-1}\): 20 x 5m). The second strategy minimized the row distance and maximized the in-row tree distance (25 trees ha\(^{-1}\): 20 x 20 m; 50 trees ha\(^{-1}\): 10 x 20m; 100 trees ha\(^{-1}\): 10 x 10m). These six silvoarable systems were compared with a hypothetical arable rotation.

Physical data for the LTS

The Farm Accountancy Data Network (FADN) (European Commission, 2003) for Castilla la Mancha in 2000 indicated that over 50% of the total utilised agricultural area was devoted to “specialist cereal, oilseed and protein crops” farms, the farm enterprises being dominated by cereal enterprises, comprising 62% of the average total utilised agricultural area of 66 hectares. It was therefore assumed that a hypothetical arable system would comprise a four-year rotation of wheat, oats, barley and a fallow break. The wheat yield for “specialist cereal, oilseed and protein crops” farms for 2000 was 2.6 t ha\(^{-1}\). Due to limited data, oat and barley yields were derived using the wheat value as a relative yield indicator. Oat yields on an experimental site in Extremadura were 1.6 times that of wheat grain yields for the same site (SAFE, 2003). Barley yields in a low yielding area in northern Spain were found to be approximately 1.3 times that of wheat yields for the same site (Austin et al., 1998). These relative values for oats and barley suggested that the yields in Castilla La Mancha would be approximately 4.1 t ha\(^{-1}\) and 3.2 t ha\(^{-1}\) for oats and barley respectively.

Production data for the tree component of the silvoarable systems were derived from yield tables of pure stands of poplars (Christie, 1994). In the absence of other information, a yield class of 10 (ie. the maximum mean annual increment of the stand is assumed to be 10 m\(^3\) ha\(^{-1}\) a\(^{-1}\)) was taken to be representative of the growth of poplar on the site. Tree mortality of 5% was assumed. Consequently, these trees were replanted in year 2. No thinning was assumed, but pruning of the poplar was assumed to occur in years 4 and 7. Clear felling occurred in year 15, as per the usual practice with poplar in the area. Production data for the crop and tree component of the
A significant difficulty lies in assigning a correct value to harvested timber. The value of timber is often dependent on the size of each individual piece of timber. For example, one cubic metre of wood as a single piece of timber is worth more than one cubic metre of wood comprised of many small pieces of timber. The changing volume to price relationship is represented by timber price-size curves. Here, price-size curves (€ m$^3$) were derived for Spain from Antonanzas et al. (1992) and Molowni (1998) (Figure 1).

![Figure 1: The value of poplar in Spain, developed from Antonanzas et al. (1992) and Molowni (1998).](image)

A further difficulty lies in modelling the area payments available on silvoarable systems. Although there are extensive grants systems available for the establishment of forestry enterprises in Spain, these are forfeited when crops are grown under the tree canopy, as in silvoarable systems. However, the area payment is still available on crops grown in alleys, but these are reduced by twice the canopy area of the trees and may theoretically be assessed every year. In order to model the predicted grant revenue it was therefore necessary to predict the canopy development of the silvoarable systems. Here, the shading model developed from POPMOD (Burgess et al., 2003) was used to predict canopy evolution over time.

**Scenarios**

Scenarios are farm management options, other than field implementation design (described in chapter 0) to change the actual land use to the new system. The approach to use scenarios is to come close to the farm management reality. For this study only one scenario was calculated due to ongoing improvements in the
assessments. This scenario models the complete (100%) conversion of the farm arable land area to SAF. In future, these scenarios can include decisions based on different farmer criteria (e.g. economic, biophysical, environmental).

RESULTS AND DISCUSSION

Soil erosion

The C-factor as an indicator of soil erosion

The C-factor being the USLE parameter which captures the impact of land use, the effect of SAF implementation designs on erosion can be explored by analysing the C-factor.

The C-factors of different SAF implementation designs are shown in Table 1.

A lower C-factor value corresponds to a lower soil loss. Increasing the tree density does not result in a linear decrease of soil erosion (Figure 2a). SAF systems with 25 trees ha\(^{-1}\) can have almost the same erosion as 100 trees ha\(^{-1}\) system if the distance between the rows is maximised. The distance between tree rows is more important than the distance of the trees in the row (Figure 2b).

Table 1: C-factors for six different implementation designs of SAF.

<table>
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<tr>
<th>Tree density (trees ha(^{-1}))</th>
<th>Distance between tree rows (m)</th>
<th>Distance between trees in the row (m)</th>
<th>Cov(_a)</th>
<th>Cov(_f)</th>
<th>C(_a)</th>
<th>C(_f)</th>
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<td>25</td>
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<td>20</td>
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<td>0.10</td>
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</table>
Soil loss in the LTS

69% of the LTS is arable land from which the average potential erosion is 37 tons ha\(^{-1}\) year\(^{-1}\). The actual soil erosion based on the C- and P-factors is on average 1.8 tons ha\(^{-1}\) year\(^{-1}\) for non contouring practices and 1.5 tons ha\(^{-1}\) year\(^{-1}\) if contouring practices are applied. By implementing SAF, the same area can have soil erosion rates varying from 0.4 to 1.8 tons ha\(^{-1}\) year\(^{-1}\) depending on the design (Table 1) and on the contouring practices (Figure 3).

Changing the arable system to SAF without contouring or introducing contouring practices without SAF lead only to minimum reduction of soil erosion. But when SAF is combined with contouring practices, erosion is reduced by approximately 80%.

Figure 3: Average soil loss in the LTS’ arable land as affected by land use and practices (C- and P-factors). Error bars indicate the range of soil erosion due to different implementation designs.
Economic results

The NPV of the arable system was higher than the silvoarable systems at all discount rates, except at 0% where the 20 m x 5 m system (€3675 ha\(^{-1}\)) gave a higher value than the arable system (€3535 ha\(^{-1}\)) (Table 2). However, in Europe, discount rates of between 2.5% and 5% are commonly used and the arable system was preferable to all the silvoarable systems at these discount rates.

Table 2: The predicted revenue, grants and costs associated with the arable and silvoarable systems and the net present value at each of five discount rates.

<table>
<thead>
<tr>
<th>Tree spacing</th>
<th>Arable system</th>
<th>Silvoarable</th>
<th>25 trees ha(^{-1})</th>
<th>25 trees ha(^{-1})</th>
<th>50 trees ha(^{-1})</th>
<th>50 trees ha(^{-1})</th>
<th>100 trees ha(^{-1})</th>
<th>100 trees ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(20 x 20 m)</td>
<td>(20 x 10 m)</td>
<td>(10 x 20 m)</td>
<td>(40 x 5 m)</td>
<td>(10 x 10 m)</td>
<td>(20 x 5 m)</td>
<td></td>
</tr>
<tr>
<td>Crop income (€ ha(^{-1}))</td>
<td>4622</td>
<td>3961</td>
<td>4181</td>
<td>3344</td>
<td>2991</td>
<td>3510</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop grants (€ ha(^{-1}))</td>
<td>1222</td>
<td>1088</td>
<td>1088</td>
<td>953</td>
<td>1002</td>
<td>710</td>
<td>781</td>
<td></td>
</tr>
<tr>
<td>Crop costs (€ ha(^{-1}))</td>
<td>5602</td>
<td>1687</td>
<td>1780</td>
<td>1499</td>
<td>1780</td>
<td>1499</td>
<td>1687</td>
<td></td>
</tr>
<tr>
<td>Tree income (€ ha(^{-1}))</td>
<td>571</td>
<td>571</td>
<td>1142</td>
<td>1142</td>
<td>2284</td>
<td>2284</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree grants (€ ha(^{-1}))</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Tree costs (€ ha(^{-1}))</td>
<td>418</td>
<td>418</td>
<td>552</td>
<td>552</td>
<td>822</td>
<td>822</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Net present value, including grants at discount rate of:

- **0.0%**: 3535 3124 3229 3040 3446 3317 3675
- **2.5%**: 2994 2591 2680 2469 2804 2602 2888
- **5.0%**: 2576 2188 2266 2046 2327 2087 2319
- **7.5%**: 2250 1879 1948 1728 1968 1710 1902
- **10.0%**: 1992 1640 1701 1486 1694 1430 1592

Net present value, excluding grants, at discount rate of:

- **0.0%**: 2313 2140 2140 2087 2444 2607 2894
- **2.5%**: 1959 1658 1748 1640 1939 1960 2194
- **5.0%**: 1686 1454 1454 1315 1570 1502 1696
- **7.5%**: 1473 1232 1232 1076 1296 1172 1336
- **10.0%**: 1304 1062 1062 897 1091 932 1073
The relatively high NPV of the arable system in comparison with the silvoarable systems was largely due to the higher availability of grants. The tree component of the silvoarable system received no grant revenue at all. The predicted area payments made on the silvoarable systems decreased over time and the area payments in the most densely planted systems were the most heavily reduced. In the 50 and the 100 trees ha\(^{-1}\) systems, the predicted area payments were lower where the trees were planted less densely along the rows (and therefore in more rows per hectare), due to greater predicted canopy coverage of the alley crops by the tree component. Thus, under the current grant system, a farmer might consider it worthwhile planting fewer rows with more trees in them to maximize the payments made on the alley crop.

Without grants, the more densely planted silvoarable systems have higher NPV than the arable system at 2.5% (10 m x 10 m and 20 m x 5 m systems) and 5% (20 m x 5 m system). In silvoarable systems planted at the same density, it is those systems with fewer tree rows (and more trees on each row) that have higher NPV, largely because the alley crop area is increased and shading of the crop reduced, so that income from the crop component is increased.

It is worth noting at this point that farmers may not choose to view the NPV of competing enterprises as the sole criterion of choice. The short term cash-flow of an enterprise is especially important if farmers require immediate returns to survive. The cumulative cash flows of the arable and silvoarable enterprises show that for most of the rotation the arable enterprise provides higher cash flows than the silvoarable enterprise (Figure 4).

![Figure 4: The predicted cumulative cash flow (€ ha\(^{-1}\)) for an arable system and each of six silvoarable systems (discount rate = 0%).](image)

Given the current grant scenario and commonly used discount rates, the 40 m x 5 m system and the 40 m x 10 m system are the main alternatives to the arable system, but would not be selected on the basis of NPV alone. However, if competing with the same grant payments as the arable system, silvoarable systems with wide alleys and closely planted tree rows could provide a viable alternative to arable systems at the discount rates commonly used in Europe, provided that farmers are willing to view the investment over a time horizon of 15 years.
Integrated assessment

Silvoarable systems can reduce erosion significantly, especially if combined with contouring practices and if distances between the tree rows are minimised. On the other hand, more crop intensive silvoarable systems which maximise the distance between rows are have higher NPV. This ‘conflict of interests’ between environmental and economic goals is illustrated in Figure 5.

Figure 5: Common assessment results of profitability (at 5% interest rate) and soil loss in the LTS.

It is also observed that for the same tree density, the NPV of silvoarable systems (without grants) increases with wider row spacing. This is because wider rows allow a greater proportion of the land to be put under the alley crop and more light reaches the crop as tree shading is reduced. Additionally as grants are related to canopy area, wider row spacing also increases area payments made on the alley crop. This could potentially reduce the effectiveness of silvoarable systems for erosion control, as farmers could be tempted to establish silvoarable systems with wider row spacings to maximise revenue.

Nevertheless, erosion is always better controlled under SAF, especially when contouring is used. Given an equal footing with regards to grant revenue, the use of SAF with widely spaced tree rows could provide equivalent NPV to arable systems at commonly used discount rates in Europe, with the added advantage of reduced soil erosion.

CONCLUSIONS AND OUTLOOK

The results of this study showed that under current circumstances farmers are unlikely to adopt silvoarable systems due to lower cash flows and NPV when compared with arable systems.

However, in the absence of grants, widely spaced and densely planted silvoarable systems have similar NPVs to the arable systems at discount rates of between 2.5% and 5%. The present grant system, however, distorts this balance in favour of arable

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crops. To date, no special grants for SAF exist and this may be a major reason for the low uptake of silвоarable systems. The results suggest that minor modifications of the grant system would make SAF a viable alternative for farmers. The modifications to the grant schemes could be justified by improved soil erosion control and other environmental benefits accruing as a result, under silvoarable systems, as demonstrated in this case study.

The results presented here are a pilot study for an integrated assessment which will be extended to other test regions in Spain, France and The Netherlands and in which other tree species will be taken into account. Furthermore, the environmental assessment will be extended to water recharge, nutrient leaching, landscape and biodiversity issues. In the economic assessment, the main criteria will be cash flow and the NPV. The integrated environmental and economic assessment will then be conducted using multicriteria analysis.

Acknowledgements: Part of this study was funded through the European Union 5th Framework through the contract QLK5-2001-00560 and the Swiss Federal Ministry of Science and Technology contract 00.0158.

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ANNEXE 19. Modelling the potential distribution of agroforestry systems in Europe using GIS

Contractor 7 : UNEX

Publications produced by UEX group and in collaboration with other SAFE groups in the period August 2003-July 2004.

R de Filippi\textsuperscript{17}, Y Reisner\textsuperscript{1}, F Herzog\textsuperscript{1}, C Dupraz\textsuperscript{2}, A Gavaland\textsuperscript{3}, G Moreno\textsuperscript{4}, DJ Pilbeam\textsuperscript{5}

Abstract

Silvoarable agroforestry (SAF) could mitigate negative environmental impacts of agricultural land use in Europe. A GIS (Geographic Information System) toll was developed to identify Agroforestry target regions where productive growth of trees in SAF systems can be expected and where, at the same time, SAF systems could potentially reduce risk of soil erosion, contribute to groundwater protection and increase landscape diversity. In these areas environmental benefits could justify the support by subsidies.

\textsuperscript{17} Agroscope FAL Reckenholz. Swiss Federal Research Station for Agroecology and Agriculture, Reckenholzstrasse 191, CH-8046 Zurich, Switzerland.

Email: riccardo.defilippi@fal.admin.ch

\textsuperscript{2} INRA-system. Institut National de la Recherche Agronomique - Unité SYSTEM 2 Place Viala 34060 Montpellier Cedex France

Email : monique.cortot@ensam.inra.fr

\textsuperscript{3} INRA-UAFP Institut National de la Recherche Agronomique Unité Agroforesterie et Forêt Paysanne BP 27 31326 Castanet Tolosan Cedex France

Email: vcalvo@toulouse.inra.fr

\textsuperscript{4} UEX Centro Universitario Plasencia Forestry School Avd. Virgen del Puerto 2 10600 Plasencia – Cáceres España

Email: gmoreno@UNEX.es

\textsuperscript{5} University of Leeds. European Office Woodhouse Lane Leeds LS2 9JT, United Kingdom

Email: m.hamilton@adm.leeds.ac.uk
INTRODUCTION

Silvoarable agroforestry (SAF) (the intercropping of trees and arable crops) provides an opportunity for achieving policy goals of diversifying farm incomes, increasing tree planting and make marginal areas more attractive. In silvoarable systems, the trees are usually planted in rows with an arable crop in the alleys between.

In Europe today, agroforestry is not supported by subsidies, whereas agriculture and forestry receive government support in all countries. Still, agroforestry in arable landscapes can mitigate negative environmental issues as soil erosion and nitrate leaching while enhancing landscape and biodiversity.

MATERIALS AND METHODS

In this study we build a GIS toll for the identification of target areas for SAF systems for five tree species: *Pinus pinea*, *Juglans ssp.*, *Populus spp.*, *Quercus ilex* and *Prunus avium*. Free data sources were chosen at the beginning of the study, to keep the data search as simple as possible and to test the availability of European environmental datasets and the quality of the final result at a continental scale. The investigation covers the entire European continent. GIS were used to standardise, integrate and query data on soil, climate, relief, biodiversity and land cover.

Target regions were defined as overlaying:

1. **Regions where productive tree growth in an agroforestry setting is possible**

Using the Forestry Compendium (CAB International 2003) criteria were defined to describe the optimal living condition for the five selected tree species; the information was completed by expert assessments. The climatic data were derived from Metzger et al. (2002) and Mücher et al. (2003), the soil data from the European Soil Bureau (ESB 2002). The analysis was restricted to arable landscapes as defined in the PELCOM land cover map (Mücher, 1998). Topographical were calculated from HYDRO1k, downloaded for free from the Internet.

2. **Regions where negative environmental issues exist (high risk of soil erosion, nitrate vulnerable areas and uniform arable landscape).**

The assessment of soil erosion was based on the maps produced by the PESERA project. From the ELPEN project the areas with high risk of nitrate leaching were taken. From the PELCOM land cover map, arable landscapes with low landscape diversity were selected using a moving windows analysis method (focal majority).

RESULT AND DISCUSSION

Around 53% of the arable land in Europe was found to be suitable for at least one of the five tree species under investigation. Of this area,

- 5% were classified as being in danger of erosion with an erosion rate of more than 5 tonnes of soil per hectare per year
- 30% of the arable land were categorised as a nitrate vulnerable zone and
- 68% have a uniform arable landscape
On 80% of arable land at least one environmental risk exist.

Target regions cover 38% of European arable land and are located on 75% of the areas where a high risk of erosion is present, on 58% of nitrate vulnerable zones and on 44% of those areas where a uniform arable landscapes exist.

As an example, the arable areas which would be suitable for the productive growth of the Cherry tree was calculated. The potential planting zone encompasses an area of around 278,000 km$^2$ which is equal to approximately 15% of the European arable land area. This area is mainly restricted to the temperate zones of Europe. Around 7% of the potential planting area have an elevated risk of soil erosion and approximately 30% were classified as nitrate vulnerable regions (see Reisner & Herzog 2004).

CONCLUSION AND OUTLOOK

The exercise has shown the need for common and standardised dataset at European scale for environmental studies, as much time was spend to make the data comparable and to retrieve the exact data source. Although limited by constrained data availability, the study shows that productive growth of the investigated tree species can be expected throughout all climatic zones except the boreal zone. The development and introduction of new agroforestry techniques could contribute to reduce environmental risks on a considerable share of the European arable area.

ACKNOWLEDGEMENTS

This research was carried out as part of the SAFE (Silvoarable Agroforestry for Europe) collaborative research project. SAFE is funded by the EU under its Quality of Life programme, contract number QLK5-CT-2001-00560, and the support is gratefully acknowledged.

The Swiss Federal Ministry of Science and Technology (contract 00.0158) funded part of this study.

Bibliography:


ANNEXE 20. “L’agroforesterie peut-elle intéresser les céréaliers des régions Poitou-Charentes et Centre ?”

Contractor 9 : APCA

Maria Teresa BELLIDO training report (July 2003)

Résumé

L’agroforesterie qui associe arbres et cultures sur une même parcelle est une voie de diversification qui semble prometteuse pour les exploitations agricoles européennes. Dans le cadre du programme européen SAFE, des bases de données et des modèles informatiques seront élaborés pour évaluer l'intérêt économique de l'agroforesterie. Les résultats des simulations permettront de suggérer des aménagements réglementaires ouvrant la voie au développement de l'agroforesterie à l'échelle européenne. Une part essentiel de ce travail consistait à recueillir les réactions des agriculteurs face à ce concept innovant et inconnu que représente pour eux l'agroforesterie.

Dans le cadre de l’Assemblée Permanente des Chambres d’Agriculture et de l’INRA de Montpellier, l’étude a été menée auprès d’un échantillon de 44 agriculteurs des régions Centre et Poitou-Charentes, régions céréalières où il existe très peu d’exemples d’agroforesterie. Après une présentation de systèmes agroforestiers modernes, il a été recueilli la réaction à chaud des agriculteurs. Dans un deuxième temps, un projet virtuel était envisagé sur l'exploitation. L'ensemble des contraintes ou avantages des systèmes agroforestiers ont été soigneusement relevés. Enfin, l'agriculteur indiquait en conclusion ce qu'il pensait du projet et s'il était prêt à se lancer dans une telle initiative.

Dans un contexte agricole où les agriculteurs se posent beaucoup de questions quant à l’avenir évolutif de la PAC et l’évolution des prix des principales cultures, les résultats des enquêtes ont révélé un intérêt certain voire surprenant vis à vis de l’agroforesterie. Considérée autant comme une voie de diversification que comme une mesure agroenvironnementale, l’agroforesterie a suscité une demande d’information complémentaire chez la plupart des agriculteurs. Et près d’un tiers serait disposé à se lancer dans un projet tandis qu’un autre tiers ne se prononce pas. Ces résultats remettent en cause l’image du céréalier de la Beauce refusant par principe la présence d’arbres au milieu des cultures. En construisant un projet réfléchi et rationnel, il est sensible aux avantages économiques et environnementaux que de tels systèmes peuvent présenter.

Les inconvénients et contraintes soulevés par les agriculteurs ont permis de dresser une liste de questions à résoudre pour favoriser le développement de l’agroforesterie. Certaines situations empêchant la mise en place de tels projets ont été clairement définies. Dans la majorité des cas, la notion de rentabilité du système, à court ou long terme, est une condition essentielle à l’adoption du projet.

La synthèse des enquêtes a permis d’établir une ébauche de typologie de comportement de l’agriculteur vis à vis de l’agroforesterie. Une liste de scénarios a été imaginée à partir des préoccupations et propositions des agriculteurs afin de
mener à bien des études de faisabilité technico-économiques via le modèle créé dans le cadre de SAFE.

Cette étude a été financée par l'Union Européenne dans le cadre du programme européen SAFE - QLK5-CT-2001-00560
**ANNEXE 21. The questionnaire for studying farmers’ reaction to silvoarable systems (WP2)**

**Questionnaire**

**GENERAL DATA**

<p>| 1 | Interviewer's name |
| 2 | Country |
| 3 | State |
| 4 | Province |
| 5 | Date |
| 6 | Respondent's name |
| 7 | Responsibility | 1 political representative, 2 agricultural representative, 3 cooperative representative, 4 agricultural society representative, 5 other |
| 8 | Age | years |
| 9 | Address |
| 10 | Phone no. |
| 11 | e-mail |
| 12 | Land Tenure | 1 owner farmer, 2 non-farmer owner, 3 farmer who is renting, 4 small farmer, 5 other |
| 13 | Farming system | 1 crops, 2 legumes, 3 crops and livestock, 4 other |
| 14 | Other farming system? |
| 15 | Respondent's farming status | 1 individual, 2 society, 3 other |
| 16 | Total number of workers |
| 17 | Total number of salaried workers |
| 18 | Total cropping area | ha |
| 19 | Area owned | ha |</p>
<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area rented</td>
<td>ha</td>
</tr>
<tr>
<td>Number of crops</td>
<td></td>
</tr>
<tr>
<td>Is there a successor for the farm?</td>
<td>1 yes, 2 no, 3 don't know</td>
</tr>
<tr>
<td>If &quot;yes&quot; what is the age of the successor?</td>
<td>years</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>Have you heard of the word &quot;agroforestry&quot;?</td>
<td>1 yes, 2 no</td>
</tr>
<tr>
<td>If &quot;yes&quot; how have you heard of it?</td>
<td>1 technical bulletin, 2 newspaper, 3 neighbour, 4 personal experience, 5 other</td>
</tr>
<tr>
<td>What's your definition of agroforestry?</td>
<td>1 an association of trees and crops, 2 an association of trees and livestock, 3 tree-planting on arable land, 4 silviculture, 5 don't know, 6 other</td>
</tr>
<tr>
<td>Have you ever seen any agroforestry systems?</td>
<td>1 yes, 2 no</td>
</tr>
<tr>
<td>Do you know anyone doing agroforestry?</td>
<td>1 yes, 2 no</td>
</tr>
<tr>
<td>Do you have hedges on your farm?</td>
<td>1 yes, 2 no</td>
</tr>
<tr>
<td>How long are the hedges?</td>
<td>m</td>
</tr>
<tr>
<td>Do you have trees in the cropped area of your farm?</td>
<td>1 none, 2: &lt;10 trees/ha, 3: 10-20 trees/ha, 4: 20-30 trees/ha, 5: &gt;30 trees/ha</td>
</tr>
<tr>
<td>Who planted them?</td>
<td>1 parents, 2 grandparents, 3 yourself, 4 don't know</td>
</tr>
<tr>
<td>Are these trees pruned, or maintained in any way?</td>
<td>1 yes, 2 no</td>
</tr>
<tr>
<td>Have some isolated trees been cut?</td>
<td>1 yes, 2 no</td>
</tr>
<tr>
<td>For which reason were the isolated trees cut?</td>
<td>1 for getting subsidies, 2 due to mechanical problem, 3 for increasing crop productivity, 4 to get some cleared areas, 5 other</td>
</tr>
<tr>
<td>If isolated trees have not been cut, for which reason were they kept?</td>
<td>1 production, 2 landscape value, 3 rules, 4 inheritance, 5 other</td>
</tr>
<tr>
<td>Other reason for maintaining isolated trees?</td>
<td></td>
</tr>
<tr>
<td>In general, do you like trees?</td>
<td>1 yes, 2 no, 3 uninterested</td>
</tr>
</tbody>
</table>
SLIDE SHOW QUESTIONS

39 Does the slide show correspond to your idea of agroforestry?

Classify the answers for each following question in the column A, B, C and D:

A - If the slideshow is different from your idea of agroforestry, what are the main differences?

41 B - According to you, what are the positive aspects of agroforestry?

42 C - According to you, what are the negative aspects in agroforestry?

D - If you planned to undertake an agroforestry project, what would be your main objectives?

Question:  A     B     C     D

PRODUCTION

<table>
<thead>
<tr>
<th>Timber productivity</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inheritance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project feasibility</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Market risk</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saving on the maintenance cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercrop productivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercrop quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hunting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possibility of pasture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diversification</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mechanisation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Complexity of work
- Subsidy
- Plot status
- Other 1
- Other 2

### ENVIRONNEMENT
- General Environment
- Water quality
- Soil conservation
- Biodiversity
- Climate
- Landscape
- Other

### SOCIETY
- Relationship between farmer/owner
- Relation between farmer/hunter
- Farmer image
- Farmer job
- Tourism
- Originality
- Other
### Virtual project...

**44 Kind of association**

<table>
<thead>
<tr>
<th>Tree</th>
<th>Reason</th>
<th>Intercrop</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **45** Do you envisage a secondary product?  
  - 1 yes, 2 no, 3 don't know

- **46** If "yes", which one?  
  - 1 fruits, 2 flower, 3 hunting, 4 mushrooms, 5 fire wood, 6 pharmacy, 7 other, 8 don't know

- **47** Planted area: ha

- **48** Planted area at the end of the interview: ha

- **49** On which kind of land unit?  
  - 1 good, 2 medium, 3 bad, 4 don't know

- **50** Number of plots planted

- **51** Density: trees/ha

- **52** Distance between the tree lines: 26 m

- **53** Why?  
  - 1 field surface 2 plot area, 3 machine, 4 tree priority, 5 crop priority, 6 rules, 7 association optimisation, 8 other, 9 don't know

- **54** If "other", what?  
  - 1 field surface 2 plot area, 3 machine, 4 tree priority, 5 crop priority, 6 rules, 7 association optimisation, 8 other, 9 don't know

- **55** Distance between the trees on the line: m

- **56** Why?  
  - 1 field surface 2 plot area, 3 machine, 4 tree priority, 5 crop priority, 6 rules, 7 association optimisation, 8 other, 9 don't know

- **57** Width of the intercropping strip in the establishment year: 24 m

- **58** Why?  
  - 1 field surface 2 plot area, 3 machine, 4 tree priority, 5 crop priority, 6 rules, 7 association optimisation, 8 other, 9 don't know
<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>59 If &quot;other&quot;, what?</td>
<td>optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>60 Width of the intercropping strip in the last year of intercropping:</td>
<td>m</td>
</tr>
<tr>
<td>61 Why?</td>
<td>1 field surface 2 plot area, 3 machine, 4 tree priority, 5 crop priority, 6 rules, 7 association optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>62 If &quot;other&quot;, what?</td>
<td>optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>63 Width of the crop border or headland:</td>
<td>m</td>
</tr>
<tr>
<td>64 Why?</td>
<td>1 field surface 2 plot area, 3 machine, 4 tree priority, 5 crop priority, 6 rules, 7 association optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>65 If &quot;other&quot;, what?</td>
<td>optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>66 Minimum width of the plot</td>
<td>m</td>
</tr>
<tr>
<td>67 Why?</td>
<td>1 field surface 2 plot area, 3 machine, 4 tree priority, 5 crop priority, 6 rules, 7 association optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>68 If &quot;other&quot;, what?</td>
<td>optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>69 Minimum length of the plot</td>
<td>m</td>
</tr>
<tr>
<td>70 Reason</td>
<td>1 field surface 2 plot area, 3 machine, 4 tree priority, 5 crop priority, 6 rules, 7 association optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>71 If &quot;other&quot;, what?</td>
<td>optimisation, 8 other, 9 don't know</td>
</tr>
<tr>
<td>72 Would you plant along the contour lines?</td>
<td>1 yes, 2 no, 3 don't know</td>
</tr>
<tr>
<td>73 Comments</td>
<td></td>
</tr>
<tr>
<td>74 Machinery</td>
<td>Width (m) Lenght (m)</td>
</tr>
<tr>
<td>Harrow</td>
<td></td>
</tr>
<tr>
<td>Combined machines</td>
<td></td>
</tr>
<tr>
<td>Tractor</td>
<td></td>
</tr>
<tr>
<td>Seed drill</td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Options</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Treatment line</td>
<td></td>
</tr>
<tr>
<td>Combine harvester</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td>1 pivoting ramp, 2 gun, 3 fixed sprinkler, 4 ramp + roller, 5 gravity, 6 other</td>
</tr>
<tr>
<td>75 State the kind of irrigation system</td>
<td></td>
</tr>
<tr>
<td>76 Comments</td>
<td></td>
</tr>
<tr>
<td>77 With time, would you decrease the intercropping width?</td>
<td>1 yes, 2 no, 3 don't know</td>
</tr>
<tr>
<td>78 Why?</td>
<td>1 subsidy, 2 machine, 3 crop return, 4 save part of the maintenance cost on the area covered by trees, 5 weeding control, 6 other, 7 don't know</td>
</tr>
<tr>
<td>79 Decreasing system</td>
<td>1 suppress seed drilling, 2 suppress seeded line, 3 mow the lateral strip before harvesting, 4 other, 5 don't know</td>
</tr>
<tr>
<td>80 Who would do the operations?</td>
<td>1 you, 2 enterprise, 3 another farmer, 4 temporary worker, 5 permanent worker, 6 farmer, 7 other</td>
</tr>
<tr>
<td>If tree maintenance requires 3 or 4 days/ha, who would do the maintenance?</td>
<td>1 you, 2 enterprise, 3 another farmer, 4 temporary worker, 5 permanent worker, 6 farmer, 7 other</td>
</tr>
<tr>
<td>81 What kind of soil maintenance would you do on the tree line?</td>
<td>1 natural, 2 seed, 3 bare soil, 4 plastic mulch, 5 other, 6 don't know</td>
</tr>
<tr>
<td>82 How would you maintain the system on the tree line?</td>
<td>1 mowing or cutting, 2 harrowing, 3 total chemical weeding, 4 selective chemical weeding, 5 combined control (mech.+chem.), 6 none, 7 other, 8 don't know</td>
</tr>
<tr>
<td>83 What would you do with the intercrop area after the last annual crop?</td>
<td>1 pasture, 2 perennial crop, 3 seed, 4 bare soil, 5 don't know, 6 keep intercropping</td>
</tr>
<tr>
<td>84 Would you choose a winter or a spring crop?</td>
<td>1 winter, 2 spring, 3 don't know, 4 both</td>
</tr>
</tbody>
</table>
Would you choose an annual crop or a perennial crop?

What do you think would be the best crop for intercropping?

What do you think would be the worst crop for intercropping?

Do you think it's possible to irrigate?

Is there some chemical product you would like to avoid?

Which partner would you like to have?

Who would take the planting decisions?

If a neighbour proposed an intercropping area for you to use, would you accept?

If your landlord proposed to make an agroforestry project on the land you rented from him/her, would you agree?

If the investment was between 1000 to 1600 euros/ha, what proportion would you be willing to pay?

Project development

Do you envisage a collective project?

Would you be ready to share machine costs?

Would you be ready to share worker cost?

Which partner would you like to have?

If "other" who?

Who would take the planting decisions?

If "other" who?

If a neighbour proposed an intercropping area for you to use, would you accept?

If your landlord proposed to make an agroforestry project on the land you rented from him/her, would you agree?

If the investment was between 1000 to 1600 euros/ha, what proportion would you be willing to pay?
107 What kind of subsidy would you need?
108 Would you need technical advice on the trees? 1 yes, 2 no, 3 don't know
109 On which aspects?
110 Would you need technical advice for the intercrops? 1 yes, 2 no, 3 don't know
111 On which aspects?

Conclusion

As a result of this interview, which problems do you think could discourage or altogether stop an agroforestry project?

What kind of solutions or research themes would you propose to solve these problems?

112

114 What is your opinion on agroforestry? Note from 0 to 10
115 Would you attempt an agroforestry project? 1 yes, 2 no, 3 don't know
116 If the farmer agreed, would you attempt an agroforestry project? 1 yes, 2 no, 3 don't know
117 For when? 1 near future, 2 far future, 3 when retired, 4 don't know, 5 other
118 Is your age a factor in deciding this? 1 yes, 2 no, 3 don't know
119 For what reasons?
120 Do you want to be contacted again? 1 yes, 2 no, 3 don't know

Post-interview comment

121

Scenario to be tested

122