Quality of Life and Management of Living Resources

Silvoarable Agroforestry For Europe (SAFE)

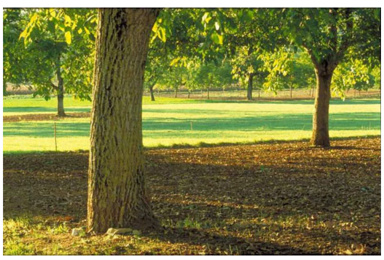
European Research contract QLK5-CT-2001-00560

SAFE FINAL REPORT

Synthesis of the SAFE project (August 2001-January 2005)

May 2005

Dupraz C., Burgess P., Gavaland A., Graves A., Herzog F., Incoll L.D., Jackson N., Keesman K., Lawson G., Lecomte I., Liagre F., Mantzanas K., Mayus M., Moreno G., Palma J., Papanastasis V., Paris P., Pilbeam D.J., Reisner Y., Van Noordwijk M., Vincent G., Werf Van der W.



The SAFE European Project

SILVOARABLE AGROFORESTRY FOR EUROPE

This final report is dedicated to Jacques Maffert. Jacques was one of the most enthusiastic farmer and partner.

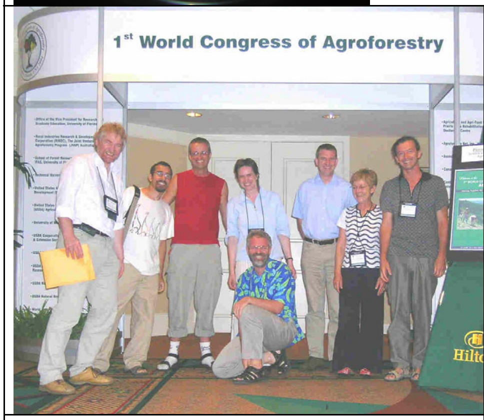
This tree (top, left) was his tree at the Pys farm near Lezat/Leze in Haute-Garonne (France). He planted some superb new agroforestry plots on his farm in 2000 (top, right).

He died in a car crash in July 2001. He would have been a key SAFE partner. Those who met Jacques will never forget him.

The SAFE European Project

SILVOARABLE AGROFORESTRY FOR EUROPE







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Content

Summary

The SAFE research project was sponsored by the European Union, and was coordinated by INRA (France). More than 70 scientists from eight European countries participated in the project from August 2001 to January 2005.

The SAFE project explored how trees could be maintained or re-introduced in agricultural systems of Europe. In agroforestry systems, trees and crops (or pastures) are mixed purposefully. The most prominent results are detailed below.

1. Many traditional European agroforestry systems disappeared during the 20th century. Intensification, mechanisation and land consolidation were the most important incentives for tree removal from cultivated areas. Isolated trees, trees in hedges, and low-density tree stands (such as traditional high-stem low density orchards) were massively removed.

2. The Common Agriculture Policy (CAP) was another reason for the removal of trees from agricultural systems in Europe during the last 30 years. Trees are not considered part of the cropping systems, and CAP payments for crops or pastures are often reduced for parcels with scattered trees (including boundary trees). This negative impact was not an objective of the CAP, but was the consequence of regulations that do not take into account the positive impact of rural trees. In the new member states, CAP regulations may induce the destruction of millions of trees in the coming decade.

3. The loss of many traditional agroforestry systems in Europe has had unfortunate consequences: loss of know-how by farmers, simplification and standardization of landscapes, increased environmental problems such as soil erosion and water pollution, significant carbon release, reduction of biodiversity, loss of habitat for natural enemies of crop pests, and the loss of a source of alternative income for farmers.

4. For the past four years, accurate monitoring of trees and crops in various silvoarable systems has been performed in experimental plots in France, England, Spain and Italy. The impact of tree density, tree size and tree pruning schemes on crops productivity was analysed, quantified and modelled.

5. The SAFE project has demonstrated that modern agroforestry systems are compatible with present-day agricultural techniques. Specific tree management schemes are necessary (such as tree alignment and stem formative pruning). In modern agroforestry systems, low final tree densities (30-100 trees/ha) allow crop production to be maintained until tree harvest. The SAFE project similarly has demonstrated that the average productivity of silvoarable systems is higher than the combined productivity of separate tree and crop systems. Productivity increases of up to 30% in biomass, and 60% in final products have been observed.

6. Biophysical models have been constructed to simulate the dynamics of tree-crop systems in various soil and climatic conditions. These models allow predictions of competition for light, water and nitrogen between trees and crops. They also predict how many years the crops will be profitable, and how fast the trees will grow. Finally model outcomes exemplify some very favourable environmental impacts of tree-crop systems, such as a reduction in nitrogen leaching or an increase in carbon sequestration. Management practices for silvoarable systems can thus be evaluated through 'virtual experiments' on computers using these models.

7. A key result of the SAFE project is that tree-crop systems are able to capture more resources from the environment than pure crop or pure tree systems: competition induces adaptation, and adaptation results in facilitation, a process that explains why mixed plots are significantly more productive than pure plots.

8. Using the SAFE models, optimum management schemes can be derived for tree stand densities, tree spacing, tree row orientation, tree species choice, intercrop rotation choice, and specific tree and crop management techniques, such as tree root pruning.

9. Economic calculations show that agroforestry plots are often as profitable as agricultural plots in no-grant scenarios, and that they are often more profitable when including high value timber trees (such as walnut or Sorbus trees). Annual crops maintain the annual income for the farmer, while managed low density tree stands provide capital for the future.

10. However current policies totally prevent European farmers from adopting silvoarable agroforestry: in most cases, farmers will loose the crop payments and are not eligible for any subsidy to plant the trees. This is why at the moment agroforestry is artificially unattractive for European farmers (with the exception of France who recently has adapted its regulations).

11. Most European farmers could develop an agroforestry activity on part of their cropland, without a significant reduction in crop annual income. A farm that would turn about 20% of its cropped land into agroforestry could increase significantly in value. With high-value timber, the timber income might double the farm profit in the long term (60 years).

12. Agroforestry adoption requires that tax rules and cadastral issues be implemented fairly for agroforestry plots. These regulations should be addressed by national regulations in each European country.

13. A survey of more than 260 European farmers in seven European countries has shown that European farmers are surprisingly perceptive with respect to agroforestry issues. More than 40% would be willing to adopt agroforestry techniques on their farm. In France, 12% of the surveyed farmers were already engaged in agroforestry activities, 2 years only after having been interviewed. They devoted about 15% of the cropped land of the farm to this activity.

14. At European scale, 90 million hectare are potentially suitable for silvoarable agroforestry and 65 million would benefit from silvoarable plantations to contribute to mitigation of some key environmental problems such as soil erosion or nitrate leaching. If 20% of the European farmers of these areas would adopt agroforestry on 20% of their farm, it would result in 2.6 million hectares of silvoarable agroforestry in Europe. The quality timber that would be available from this activity would help reduce the need for importing high quality tropical timber.

15. Current CAP regulations are not logical with respect to trees on cultivated land. On the one hand, CAP first pillar payments (Single Payment Scheme) provide incentives to farmers to destroy rural trees to get more payments. On the other hand, CAP second pillar arrangements (Rural Development Regulation) encourage farmers to protect or introduce trees. The SAFE project has produced guidelines for policy options in Europe that would permit European farmers to take advantage of agroforestry.

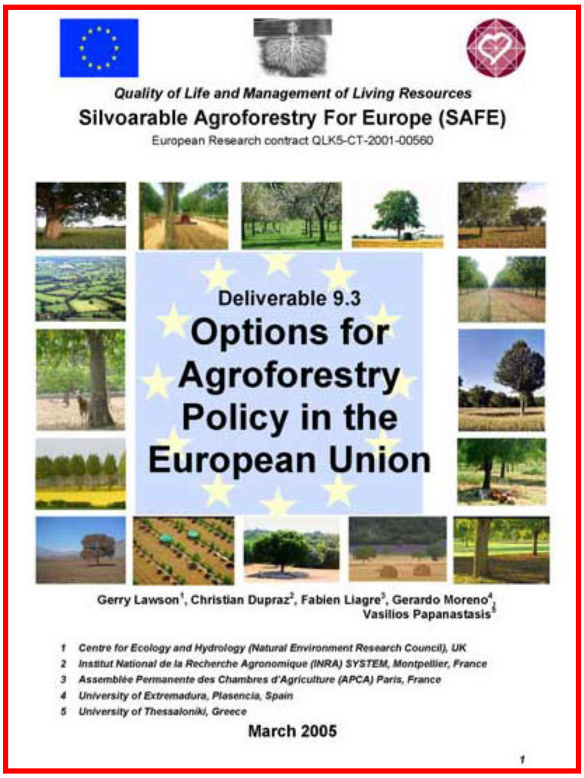
The four major SAFE policy proposals are detailed on the following pages.



The four SAFE policy proposals for allowing European farmers to adopt agroforestry

These proposals are detailed in Deliverable 9.3 of the SAFE project: Options for Agroforestry Policy in the European Union. The 34 pages deliverable is available on line on the SAFE web site (**http://www.montpellier.inra.fr/safe/**).

The central idea is to adopt a positive approach to rural trees in European regulations. The SAFE project results allow us to postulate that rural trees are part of productive agricultural systems and contribute significantly to environmental services. Contradictions within the CAP first and second pillars payments need to be removed. Rural trees play a positive role in both agriculture and the environment – and the regulations should reflect this.



SAFE Policy Proposal 1. A definition of agroforestry should be included in European regulations.

We suggest the following definition that would include isolated trees, tree-hedges and low-density tree stands.

Agroforestry systems refer to an agriculture land use system in which high-stem trees are grown in combination with agricultural commodities on the same plot. The tree component of agroforestry systems can be isolated trees, tree-hedges, and low-density tree stands. An agroforestry plot is defined by two characteristics:

- *at least 50% of the area of the plot is in crop or pasture production,*
- *tree density is less than 200/ha (of stems greater than 15 cm in diameter at 1.3 meter height), including boundary trees.*

This definition is simple, and clearly distinguishes between agroforestry and forestry. Member states could define specific thresholds for some traditional systems if required.

SAFE Policy Proposal 2. The total area of an agroforestry parcel should be eligible for the Single Payment Scheme.

This proposal

- is compatible with existing Regulations
- removes the contradiction between the two pillars of the CAP on rural trees (farmers will no longer be stimulated to remove trees to get CAP payments)
- simplifies controls, and therefore saves a lot of European money

SAFE Policy Proposal 3. Agroforestry systems should be backed by the Rural Development Regulation (RDR, CAP second pillar)

The current draft RDR for 2008-2013 includes a welcome and innovative Article 41 that introduces support for the establishment of new agroforestry systems. It could be supplemented

- ***To include maintenance costs for agroforestry planting in the same way as in Article 40 for forest plantations*.**

- ***To support the eligibility of existing agroforestry systems for improvement and environmental payments***

This is justified, because of additional management costs of improving the environmental and recreation value of agroforestry stands. Several proposed agri-environmental payments would be relevant, and the French agroforestry environmental measure that was approved by the STAR committee in 2001 could serve as a model.

SAFE Policy Proposal 4. The EU Action Plan for Sustainable Forest Management should emphasise the need to maintain or increase the presence of scattered trees in farmed landscapes (agroforestry)

The 1998 European Union Forest Strategy refers to agroforestry in several places, but agroforestry was not considered in the recent 85-page commission paper on implementation of the Forestry Strategy during the past five years. The EU Commission is preparing an Action Plan for Sustainable Forest Management (expected in 2006). This action plan should recognise the role of rural trees in a sustainable farming landscape.

Modern silvoarable systems allow trees to be introduced back in cultivated or grazed plots either as aligned (left) or scattered (right) widely spaced trees. In both cases, crop production is maintained, and environmental benefits from the trees are significant.

More details on the SAFE project web site: http://www.montpellier.inra.fr/safe/

Introduction

Silvoarable agroforestry is a land management technology where widely spaced trees are intercropped with arable crops. Many traditional silvoarable systems existed in the past in Europe. However, most European research institutes for agriculture or forestry ignored silvoarable technology during the 20^{th} Century. The SAFE project aimed at filling this gap by exploring new avenues for silvoarable agroforestry in the context of the present day agriculture of Europe.

The SAFE project intended to i) assess the production and value of silvoarable systems, ii) forecast the potential of silvoarable agroforestry to be adopted as a new farming system, and iii) suggest guidelines for a coherent package of forestry and agri-environmental incentives which will not disfavour agroforestry when compared with conventional forestry or agriculture. The work-plan consisted of 10 work packages (WP), each with deliverables and milestones.

The SAFE project was structured in 10 work packages (Figure 1). WP1 provided a common platform for the biophysical modelling of silvoarable systems. Quantitative information on existing traditional silvoarable systems were collected (WP2) and ongoing experimentation were surveyed and monitored for three growing seasons (WP3), allowing parameterisation and testing of above-ground (WP4) and below-ground (WP5) detailed biophysical sub-models. WP6 linked the detailed above and below-ground sub-models in one integrated and detailed silvoarable plot model (Hi-sAFe), but also produced a simple model called Yield-sAFe that can be used for long term simulations. WP7 developed an economic model to evaluate scenarios including year-to-year variability at the plot-scale (Plot-SaFe) and at the farm scale (Farm-sAFe). WP8 extrapolated growth and economic predictions to regional scales, allowing evaluation of policies and incentive strategies by WP9. WP9 finally elaborated guidelines for policy implementation of agroforestry in Europe. WP10 monitored the project, and managed the dissemination and exploitation activities.

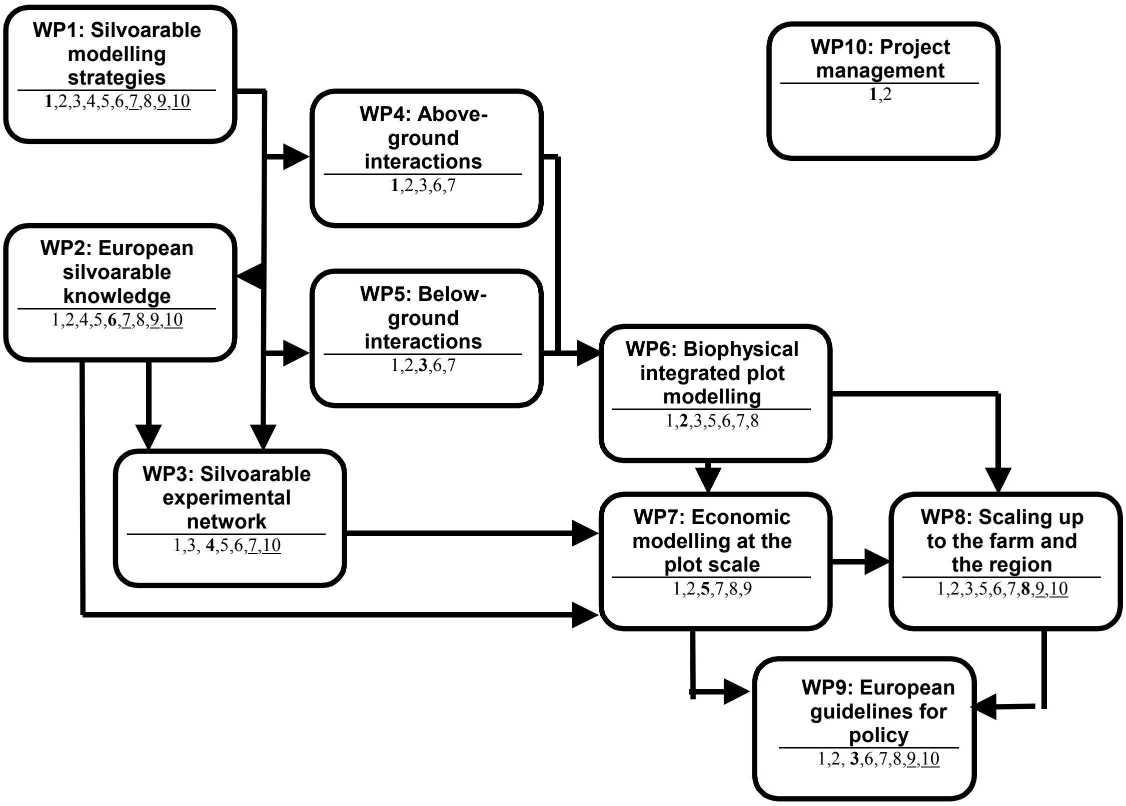


Figure 1: SAFE Project structure: project's components and participating partners

Material and methods

WP1: The SAFE modelling platform

WP1 aimed at identifying modelling strategies and building a common modelling platform for the project. The extensive experience of modelling of tropical silvoarable systems was included in the review. Five different modelling approaches to tree-crops interactions were identified in the world literature. Four had been developed by participants in the project. These approaches were compared and confronted with end-users' requirements (farmers, foresters and policy-makers) to identify the common modelling platform. The final platform for a detailed biophysical model was finally agreed at the Clermont-Ferrand workshop in December 2002. The tasks of WP1 included the collection of modelling strategies and the identification of appropriate models and sub-models; the development of a modular modelling framework and the choice of programming languages and data formatting instructions for WP4 and WP5 to ensure compatibility; the definition of time and space resolution of the models to achieve the integration of all relevant biophysical aspects and the expected long-term simulation target.

WP2: European silvoarable knowledge

WP2 aimed at collect and analyse available information on European silvoarable agroforestry, in order to identify and document the most prominent European silvoarable systems, including intercropped poplars in valleys, oak parks and intercropped fruit and nut tree orchards (walnut, chestnut, apple, pear and peach). Plots of innovative pioneer farmers or foresters were actively looked for across Europe.

During the course of the project, WP2 aims were extended to the assessment of the attitude of European farmers towards the silvoarable technology. This was considered as a key issue, and a survey of commercial farmers was done in 7 European countries for this purpose. This was not included in the Technical Annex, but produced one of the surprising results of the project.

WP3: European silvoarable experimental network

The SAFE contractors managed almost all the European silvoarable experiments, and decided to coordinate the monitoring of these plots during the SAFE project. The objective was to supply consistent data from field experiments to modellers. These data were data from previous years of established silvoarable agroforestry experiments of SAFE participants and current data collected during the duration of the project. About 200 hectares of silvoarable experiments were provided by the consortium in 5 different European countries, and in 12 different locations. Specific objectives were to provide field experimenters with a forum to exchange know-how and expertise; to manage field experiments in a sound and concerted way; to provide a unified protocol for basic field measurements accessible to the consortium so that comparable analyses can be done; to provide accurate and quality controlled data from field experiments for model parameterising and testing. Three tasks were defined: Collect data from existing experiments as required by the modelling activity. The data will be obtained from Mediterranean and temperate regions and will consist of three types: a) biophysical data to simulate above and belowground tree-crop interactions; b) data on the productivity of trees and crops and c) management data for economic modelling. Look-up tables of parameters and time series of data will be provided to modellers through the WEB-site. At the SAFE experimental sites specific information needed to parameterise the biophysical model will be collected. Special attention is given to seven additional aspects: impact on solar radiation and wind velocity; determination of water sources using stable isotopes of H and O; determination of tree transpiration using sap flow in tree roots and trunks; evaluation of tree leaf area for transpiration and shade; description of root architecture by root excavation or root coring; assessment of nutrient extraction with isotopic tracers; impact of management practices on competition such as sound crop timing or crop choice.

WP4: Modelling above-ground tree-crop interactions

WP4 intended to design and validate sub-modules for aboveground tree-crop interactions that are relevant to both crop and tree growth. Emphasis was given to light and transpiration partitioning between trees and crops. The light model should take into account the main determinants of the aboveground interactions, i.e. spatial distribution of foliage, leaf and soil properties, and microclimate variables above the canopy. For the inclusion in the module in the integrated biophysical model, the final aboveground model should be compatible with the belowground model and be as simple as possible.
WP4 tasks included the characterisation of the aboveground space occupied by trees and crops, in some experimental sites, with measurements of the dynamics of foliage distribution: crown volume and leaf area density for trees and leaf area index for crops. Estimates will be based on fisheye photographs taken at a number of dates in year 1 and 2; the selection of an appropriate model for describing, analysing and predicting partitioning of light and transpiration between trees and crop; the design of a model for the effect of the tree-crop canopy on local microclimate, i.e. the 'forest ambience' (air temperature, humidity, wind speed); the design a model for tree development, in particular for occupation of space by the tree canopy. The model should compute canopy development from resource acquisition. Given the state of the art, the model was supposed to be based on empirical relationships established from field measurements to derive potential growth curves that will be affected by the resource acquisition as predicted by the model.

WP5: Modelling below-ground tree-crop interactions

WP5 intended to design and validate sub-modules for belowground tree-crop interactions that are relevant to both crop and tree growth. Trees and crops in mixed plots compete for soil resources (water, nutrients), but also explore resources that would be unavailable in monocultures. The spatial and temporal distribution of tree and crop root systems and their uptake of water and nutrient resources form the key to understanding inter-specific relationships in mixed cropping systems. This knowledge can explain why sustained yields of intercrops were observed in our experimental plots, making silvoarable systems with widely spaced trees a sustainable arable system, and not a stepping-stone to afforestation.

The tasks included in the Technical annex focussed on the writing of a simplified model for water extraction and sharing between a tree and a crop, taking into account water interception by the canopies, water redistribution by stem-flow and through-fall, transpiration, and water redistribution in the soil profile by water migration and water transportation by the rooting systems. This model should be able to take into account the dynamic colonisation of the soil by the crop roots, which is specific to silvoarable systems with annual crops. The model will allow assessment of the possibility of silvoarable systems in reducing nitrate leaching to water tables. However, during the course of the project, the dynamics of tree roots appeared to be of high importance, and a large emphasis was given to the design of a dynamic root model for trees that could fairly represent the behaviour of tree roots in our experiments. This was achieved with the design of a voxel automaton that models trees fine roots dynamics as a diffusion process.

Specific experimental protocols were designed and set up to validate and parameterise these modules.

WP6: Production of an integrated model of tree-crop interactions

The linkage of belowground and aboveground sub-models into one **integrated biophysical modular silvoarable model** was a scientific challenge. It included interactions and feedbacks between the two sub-models. A further challenge was the year-to-year memory effect on tree growth as a result of the competitive and facilitative (favourable) effects of the crop component during previous years. The silvoarable model was integrated within the modelling framework assigned in WP1. Functional relations for important interactions and feed-back among model components, such as microclimate, transpiration and water uptake by roots, were identified and elaborated in co-operation with WP4 and WP5. Wherever possible, physically and physiologically realistic approaches were used, but simplified relations were incorporated to a) facilitate realistic parameterisations where warranted by the availability of data (e.g. size allometries of wide-spaced trees) and or sensitivity analysis and b) to allow the final linkage to an economic model (WP6) and apply the model for analysis of the effect of different management scenarios on long-term yield stability and indicators of soil fertility.

WP6 was eventually split in two separate WPs: WP6a integrated the detailed biophysical model Hi-sAFe, while WP6b produce the simple model Yield-sAFe

WP7: Economic modelling at the plot scale

The financial benefit to farmers of silvoarable agroforestry, relative to arable cropping and conventional woodland planting, is a key factor determining the uptake of agroforestry systems. The overall objective of this work package was to develop an economic model that can be linked to the biophysical model (Yield-sAFe, elaborated by WP6b) to investigate the long-term financial benefits and costs of different agroforestry systems at a plot level. The resulting **bio-economic plot scale model** forms an essential precursor to examining the biophysical and economic feasibility of agroforestry at farm and regional scales (WP8). Silvoarable plots combine short-term revenues from the crops and long-term revenues from the tree. Both are physically linked by the tree-crop relationships that will be described in the biophysical model. The linkage of the biophysical model and of the economic model should therefore allow optimisations studies of silvoarable technologies. WP7 intended to review existing financial models of agroforestry, cropping and farm woodland systems; select and develop an economic model and templates which can be linked with the biophysical model described in WP6; To use templates to identify and quantify inputs, outputs, costs and revenues for the silvoarable network systems, and existing arable and forestry enterprises for different parts of Europe; use the model to identify the most profitable agroforestry systems (e.g.: tree species; tree spacing) for the network sites, and their sensitivity to changes in prices and grants; determine the optimum silvoarable system for other selected high-potential locations by using the model to assess the impact of changes in biophysical parameters (e.g.: site quality as reflected in tree and crop growth) on profitability.

WP8: Up-scaling to the farm and region scale

The objective was to assess the potential spatial extension of (silvoarable) agroforestry systems in Europe in terms of biophysical and economic feasibility. To achieve this, biophysical and economic models were linked using a geographic information system (GIS). The spatial up scaling was made at two scales. At the farm scale, yield predictions and economic assessments were investigated for characteristic experimental sites (prototype farms representative for the region under investigation) of three European countries and different management scenarios. The economic analyses were done from the farmers' perspective. At the region (European) scale, a ‘coarse-grained’ assessment of the potential extension of agroforestry across Europe was made, based on spatial analysis of constraints and potential benefits. The tasks were: to establish a European spatial database with respect to land use, climate and topography in a geographic information system (GIS Arc/Info) for the farm scale (aerial photographs, topographic maps, digital data, soil maps and climatic data) and the regional (European) scales. For the farm scale most data must still be made available in digital form. At the regional European scale, most of the data is already digitally available; to extrapolate plot-scale predictions to farm and regional scales using existing national farm survey information and physical spatial databases of soils, topography and climate.

WP9: Developing European guidelines for policy implementation

WP9 was expected to produce a synthesis report on Silvoarable Agroforestry in the context of economic and social changes to agricultural and forestry policies being implemented in Agenda 2000 (e.g. 1257/99), and provide guidelines to Member States and Autonomous Regions on the potential uptake of agroforestry systems. National forestry and agricultural policies were scrutinised in order to describe and classify the existing diversity in direct and indirect (dis)incentives to agroforestry across the EU; analyse reasons for current agroforestry policy (e.g. 2080/92) and prospects for change; collate, at a national or regional scale, benefits to farmers and policymakers of possible changes in the interpretation of rules for the implementation of EU forestry and agri-environment Regulations; document problems encountered by farmers in setting up new silvoarable plots in 5 different European countries. This was achieved by USERS partners that monitored social experiments consisting in creating silvoarable plots within the framework of the present day agricultural and forestry policies in **The Netherlands, Germany and Greece**.

The final aim of WP9 was to design a policy framework for the implementation of a European agroforestry scheme based on the data from the models. Fortunately, a key European regulation was drafted during the SAFE project (New Rural Development plan for 2007-2013) and included some of the SAFE project recommendations.

Results

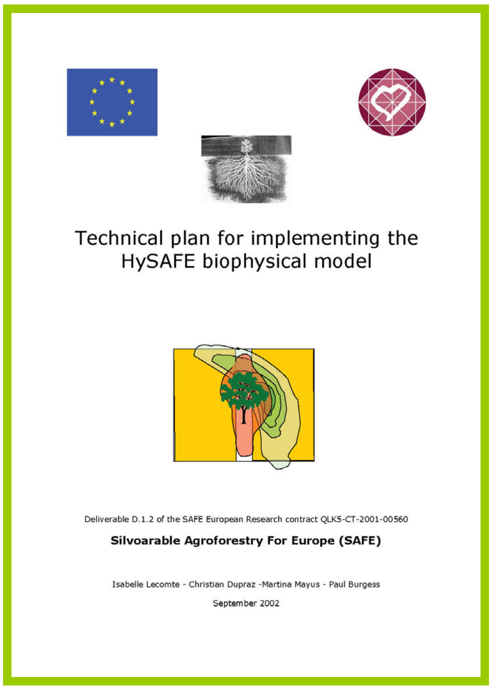
Most results are detailed in specific deliverables of the project that will be cited throughout the text. Scientific papers are listed in the last section, and will provide peer-reviewed results in the future. The results will be examined for each work-package successively. As most of the results are not yet published in refereed journals, citing or quoting this final report is not possible. Please contact the project coordinator (Dupraz@ensam.inra.fr) that will indicate relevant published papers for any particular result of interest if available.

WP1: A platform for modelling silvoarable systems

WP1 opened a WEB site for the project to share data, modules and the model platform. It included also a public section that was intensively browsed by the general public during the project. The site will still be maintained after the project by INRA (check http://www.montpellier.inra.fr/safe/)

WP1 collated modelling strategies and identified appropriate models and sub-models. The state of the art of tree-crop interaction s modelling was detailed in Deliverable 1.1. This report is based on the expertise of the SAFE participants, as shared in a common modelling workshop held at the University of Wageningen, in the Netherlands, from 7-13 January 2002.

The suggestions for implementing the modelling platform were included in Deliverable 1.2: **Common modelling framework platform including technical report**



Technical plan for implementing the
HySAFE biophysical model

Deliverable D.1.2 of the SAFE European Research contract QLK5-CT-2001-00560

Silvoarable Agroforestry For Europe (SAFE)

Isabelle Lecomte - Christian Dupraz -Martina Mayus - Paul Burgess

September 2002

After having carefully examined all aspects related to the implementation of the Hi-sAFe model, the SAFE consortium adopted the following technical plan at the Clermont-Ferrand workshop (4-6 December 2002):

1. Implementation of the Hi-sAFe biophysical model under the **CAPSIS** modelling platform
2. Writing of a new tree module in **JAVA**: translating part of the **HyPAR** code, and developing new modules when necessary
3. Adoption of the **STICS** crop model (C version) linked to the tree module
4. Implementation of a decision-making module (DMM) in JAVA under the CAPSIS environment.
5. Feeding of an external economic module with annual result of Hi-sAFe simulation, exported in CVS ASCII files. This economic model will be based on a spreadsheet approach, building on the best components of **ARBUSTRA** and **POPMOD**.

During the course of the SAFE project, some decisions were modified to take into account specific difficulties that could not be imagined at this stage of the project.

The most important one was the decision to build a second and simpler model of tree-crop interactions. It was soon apparent that the Hi-sAFe model was far too complicated to be able to run for the entire lifetime of trees. It was then decided to prepare a simpler model, finally named Yield-sAFe. This model would be able to predict tree-crop interaction during the whole lifetime of the tree (some decades, up to 100 years), while the Hi-sAFe model would be a tool to explore tree-crop interactions for a growing season. WP6 was finally split in two: WP6a was integrating the detailed Hi-sAFe model, while WP6b was preparing the simple Yield-sAFe model

WP2: Extant silvoarable systems in Europe

WP2 prepared a database of agroforestry publications, created a database of extant silvoarable systems in Europe, and examine the attitude of European farmers to the silvoarable technology.

The agroforestry publication database

References have been selected to be strictly relevant to the SAFE project and its objectives, and therefore do not include all publications on agroforestry in general, silvopastoral systems or studies from non-European sites. Although these may be of some relevance to specific aspects of the research conducted by SAFE, it would neither be practical nor useful to include all such references, and thus a conservative approach has been taken.

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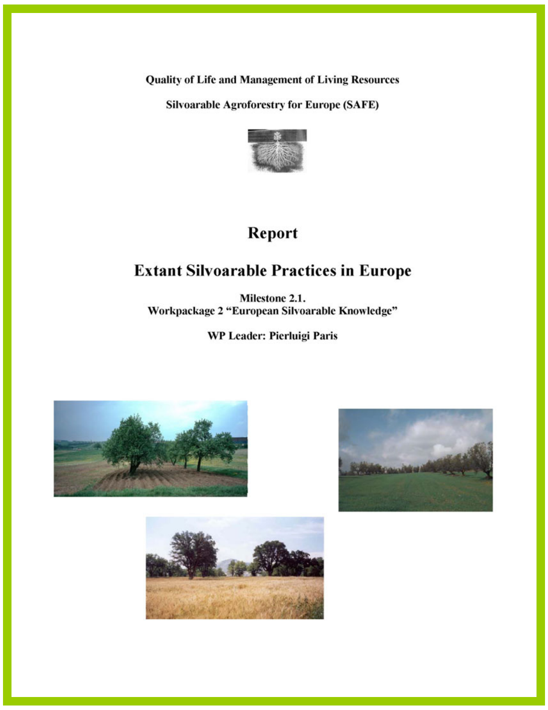
The extant silvoarable systems in Europe database

This database is available on the web site in different formats (deliverable 2.1). It was improved continuously until the end of the project. It will be a historical reference on the fate of silvoarable technology in Europe for the future.


Quality of Life and Management of Living Resources

Silvoarable Agroforestry for Europe (SAFE)

Report

Extant Silvoarable Practices in Europe

Milestone 2.1.
Workpackage 2 "European Silvoarable Knowledge"

WP Leader: Pierluigi Paris

The aim of this database was to document the most common systems present in Europe, both traditional and innovative. The database comprises the data obtained through an inventory of silvoarable systems conducted in France, Germany, Greece, Italy, Netherlands, Spain, United Kingdom and British Islands (to be soon included). The inventory was carried out using a common sheet agreed by the project partners.

The database includes sixty-three different systems that have been defined and grouped according to the main tree species and the associated crop categories (cereals, industrial crops, legumes both for fodder and food, vegetables, natural grass including grazing practice, fruit trees and shrubs). Each system has been described in reason of its general aspects (location, ownerships, purposes), physical characteristics (covered area, altitude, slope, rainfall, bedrock and soil type), tree components (main and other species, space arrangement and tree density, average height and diameter, age, origin, main and secondary products), crop components (main and other species, cultivation duration, water availability and annual yield) and management practices adopted by the farmers (tillage, fertilisation, pruning, weed control, grazing and fallow period).

The database contains a total of 111 inventoried plots. For the majority of the sites, the database inserts one photo of the system and maps to locate easily the site and the system distribution in Europe. A first map locates traditional systems and a second map locates innovative systems, at the State or the Province scale. Some more precise maps help to locate exactly the site (map at a scale of 1/50000).

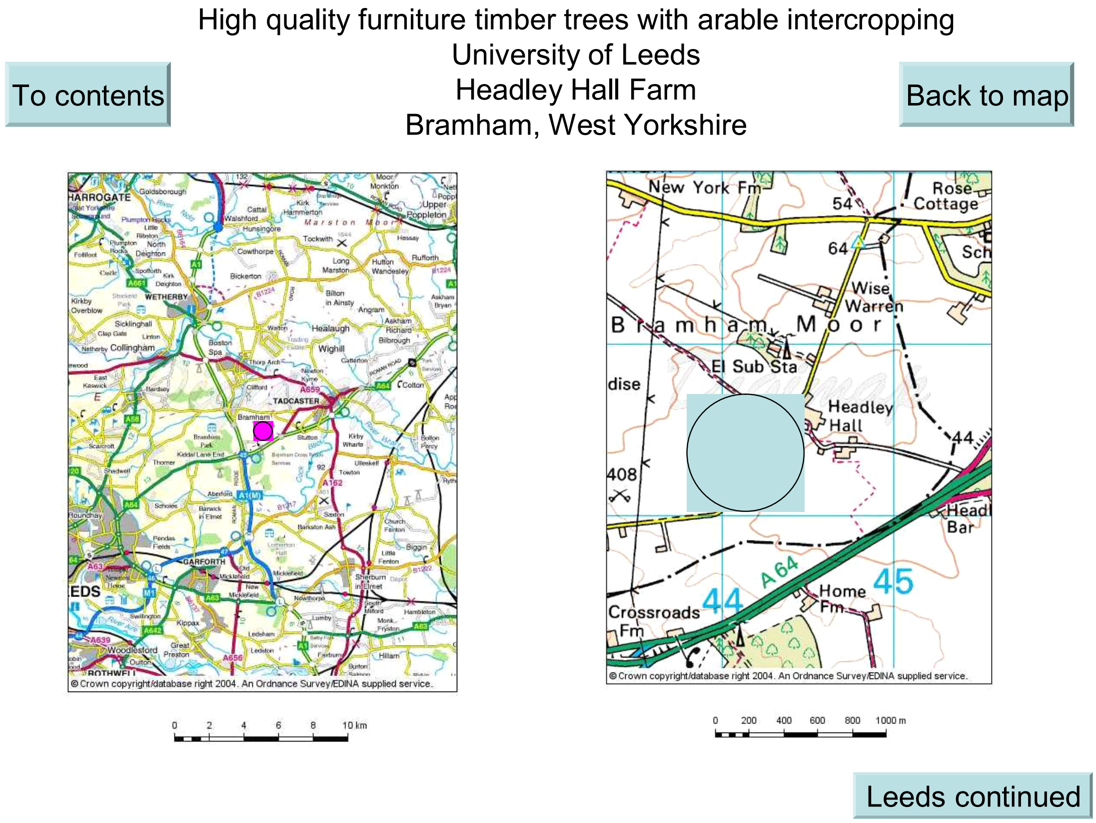


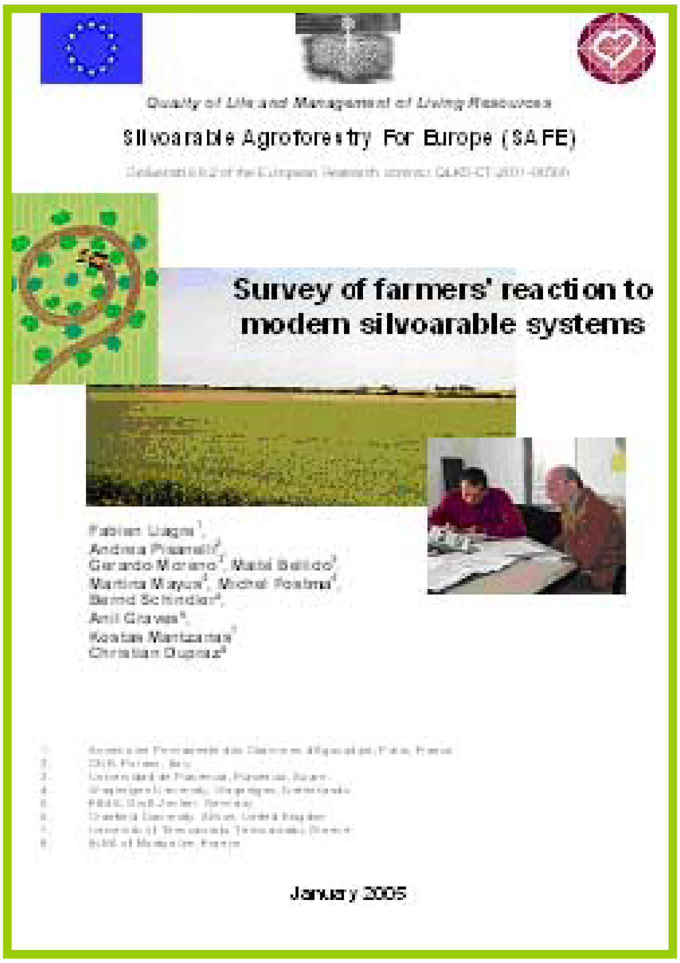
Figure 2: Maps included in the agroforestry database help to locate a silvoarable site in England

Markus Eichhorn with the contribution of Piero Paris carried out a synthesis of the extant silvoarable systems in Europe. From this work, the SAFE consortium produced a review paper that has been submitted to the journal “Agroforestry Systems”.

☞ ***Eichhorn E.P., Paris P., Herzog F., Incoll L.D., Liagre F., Mantzanas K., Mayus M., Moreno Marcos C., Dupraz C., Pilbeam DJ., 2005. Silvoarable agriculture in Europe – past, present and future. Agroforestry Systems, in press***

Survey of farmers' reaction to modern silvoarable systems

Introducing silvoarable plots in a farm results in a key change in the farming system or in the farmer activity. Although agroforestry played an important role in the history of European agriculture, introducing trees back in the middle of cropped fields is a radical innovation in the modern context. The new silvoarable systems proposed by the SAFE consortium depart from the ancient systems with little mechanization.



Initially, the come back of silvoarable agroforestry in Europe was a researcher vision. A vision that is provocative for intensive farmers such as those from the Beauce French Province or the Bedford English region. Will the Spanish farmers from Castilla or the Dutch farmers show some interest or some suspicion for this new system? Which technical method European farmers will adopt when setting up some silvoarable plot in their farm? Are they ready to intercrop the silvoarable plot of a neighbour landowner? What kind of questions do they raise and what advice do they expect from extension services in the future?

The goal of this deliverable was therefore to evaluate the acceptability of this major innovation by farmers. This was the main priority of the interviews.

The different objectives of the survey were:

- To record initial feelings about agroforestry from unaware farmers
- To identify the major constraints for silvoarable agroforestry adoption from the point of view of farmers.
- To define if setting up an agroforestry plot on their farm in the near future was a sound prospect.
- To analyse how local regulations impact on farmers reaction
- To classify farmers' according to their response to agroforestry.
- To define scenarios for WP7 farm-scale simulations

To achieve these goals, a questionnaire was prepared with the contribution of all the partners involved in this task.

Seven countries finally participated in the survey. **This is a significant effort compared to the 3 countries that should have done this according to the Technical Annex of the project.** This was considered as very important tasks by all SAFE participants and this explain that we concentrated more efforts to this task. The total number of interviews is very satisfactory. A total 264 interviews are available for the analysis.

Are farmers interested to carry out a silvoarable project?

At the end of the interview, we asked the farmers if they could be interested to set up some silvoarable plot in their own farm. The results were quite surprising: **48 % of the farmers are disposed to invest in agroforestry.** This result has to be considered by the regions due to a strong heterogeneity in the answers. Without any surprise regarding the preliminary results of the study, the Mediterranean farmers think more about the setting up of some plots, above all in Italy and Greece. In the northern countries such as France, England or The Netherlands, farmers are more reluctant. But, even in these countries, where man supposed that farmers try to put off the trees from their cropping area, 20 to 40% of the farmers consider this option. The idea of planting trees in a well-managed system attracted many farmers.

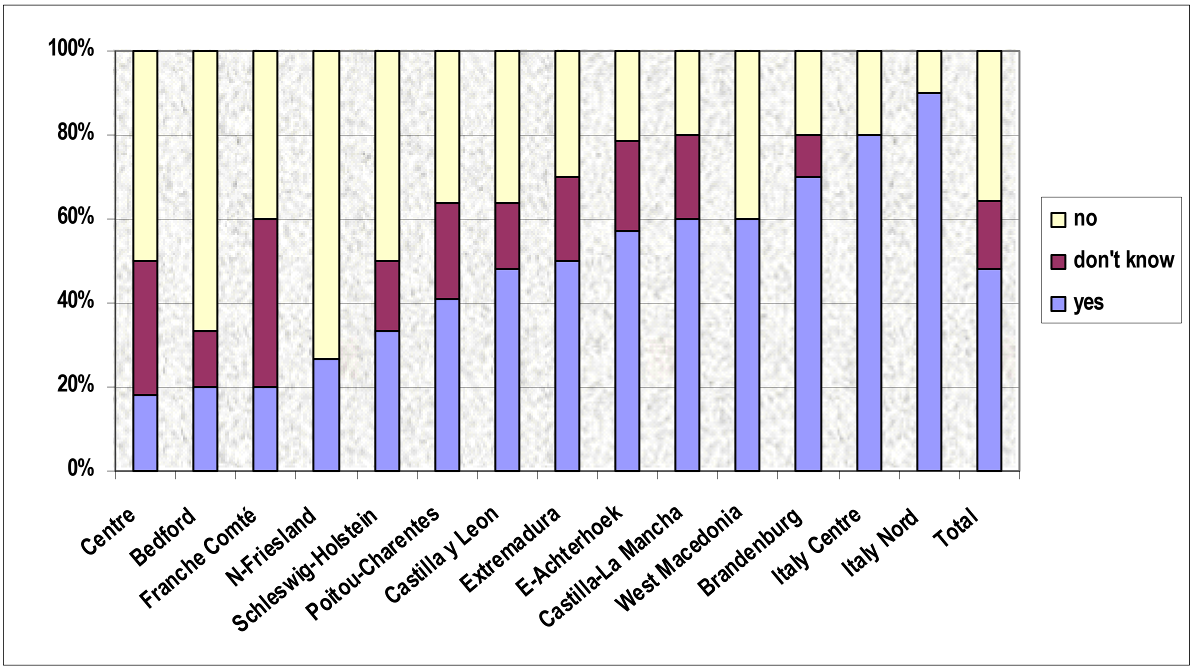


Figure 3: Percentage of farmers attracted by a silvoarable project according the regions.

This result shows clearly the interest of many farmers for agroforestry in all European countries. After only one hour of interview and a slide show of 10 pictures, the number of farmers ready to invest in a project in a near future is impressive. This result is much higher than our expectations before the interviews.

Who are the farmers interested to carry out a project?

A multi-dimensional analysis allowed discerning typical behaviours of farmers regarding agroforestry. The objective of this section is therefore to identify the determinants of the decision to carry out a project on one hand and on the other hand the factors that influence the importance of the planted area.

This statistical analysis pointed out 2 types of motivated farmers:

1. Older farmers constitute the most important group. They are between 45-55 years old in general. They would initiate a project more for environmental reasons. The presence of a successor in the farm is not really a motivation for them to plant, with the eventual objective to let a timber capital for inheritance. The silvoarable project would cover rather a small area (less than 10 %).

2. Young farmers constitute the second group. They are about 35-45 years old. Younger is the farmer, the most he tries to perform the economical profitability of his project. He would initiate a project for economical reason, and if the project seems profitable, he would plant a larger surface (from 20 to 100% of the cropping area…).

The statistical analysis allowed describing the main features of the motivated farmers:

1. They have smaller farms. The cropping area / worker is about 40 ha against 70 ha for the farmers not interested in a project. Farmers with few surfaces to manage have more time to invest in agroforestry. They want also to diversify the farm incomes without penalizing the existing productions.

2. The farmers better informed are more disposed to initiate a project than the others. And the surface of the project would be bigger. Some farmers showed some old articles they had conserved about agroforestry.

3. 25 % of the motivated farmers would plant more than 25 % of their cropping area. Many farmers consider agroforestry as a real diversification of their cropping area. Some very motivated farmers are ready to invest up to their total farming area… The motivated farmers use more workers than the average. The tree maintenance is a possibility to optimise better the worker activity. Agroforestry can convert the part time job of a worker to a full time. The motivated farmers would also ask to some companies to work in their project.

4. The motivated farmer comes from the Mediterranean than the temperate region. There is a strong disparity in the results according to the climatic zone. Spain and Italy are the countries of agroforestry. It's in France, England and the Netherlands that we the most statistical probability to find a farmer against any project. The farmers from the temperate zone demand more guaranties on the feasibility than the Mediterranean farmers.

5. 50% of the motivated farmers would also consider more the possibility to intercrop in some new parcels or, why not, in a parcel they rent to a land owner (40%).

Main technical option for their project

What would distinguish the motivated farmers from the others considering their technical options in the virtual project?

1. They would plant more surface

2. They would plant rather in several plots

3. They would choose good agricultural fields rather than bad fields (above all in the Mediterranean zone).

4. They would try to intercrop up to the end of the tree rotation.

5. The relative crop area would be more intensive in the Mediterranean zone than in the temperate zone. Mediterranean farmers would intercrop more near the tree lines. On the opposite, northern farmers would let a bigger distance between the tree line and the crop limit.

In France, the choice of the distance between the tree lines depends on the width of boom sprayers. The distance between the tree lines represents between 1.1 up to 1.4 the width of the boom. The motivated farmers would plant more area, which represent between 8 to 13 % of the total farming area. In Spain, we notice that the distance between the tree and the crop line in less than one meter. One of the reasons is the small size of the machines. A small machine is easy to drive and allow to crop near the trees. The use of a large boom demands a safe distance, to avoid any damage with the trees.

Two years after the first survey, farmers were interviewed again by phone. Most confirmed their interest for a silvoarable project, and were expecting to get more information from extension services.

WP3: European silvoarable experimental network

During the SAFE project participants in WP3:

- Provided field experimenters with a forum for exchanging know-how and expertise.
- Managed field experiments in a sound and concerted way with unified protocols for field measurements, for constructing models, for parameterising them and for verification.
- Collected data from the experimental sites.

It was realised at the start of the project that when dealing with scientific measurements being made at several sites across Europe it is crucial that measurements are made in the same way, and with similar levels of accuracy. One of the first tasks within the project was to establish a mechanism of rapid communication to facilitate discussion of the techniques used, which was facilitated through a closed email list. The use of study visits of members of the consortium to each other, and the linking of the regular Consortium Management Committee meetings to the Experimental Sites were also valuable tools for ensuring that communications within the work package were good.

Early in the project the methods used for measurement of trees and crops at the Experimental Sites, and any techniques already in use for parameterisation experiments, were checked to ensure consistency between the different research groups, and to ensure comparable levels of accuracy. Where techniques had to be designed specifically for the project protocols were written by consortium members.

The database was designed for accuracy and ease of operation. It was a relational database that could be run with the different software and different operating systems available to the consortium members. It was important that all site managers understood how their data were to be stored in it, so to this end standard input forms were designed. The data are now available to the modellers through simple query forms, and they should remain available after the end of the SAFE project. The design and construction of the database would be suitable for other projects on agroforestry in the future.

Data from the Experimental Sites were used for the models, and as such they feed into the conclusions on above-ground and below ground interactions between trees and crops that were investigated in the biophysical models and are reported in detail elsewhere. However, it is apparent from the data provided by the site managers that the silvoarable agroforestry systems investigated are productive.

Although the presence of the crops may depress tree growth, and the presence of trees may depress crop growth, the productivity of the two components of the system together may give higher total productivity than either alone, at least in the early years of establishment. This is obvious, for example, in the early years of the Partner 4 and Partner 5 poplar/cereal system, where in the early years there may have even on occasions been higher crop yields in the alleys between the trees than in the cereals as a sole crop.

It is also not the case that the presence of an intercrop necessarily decreases tree growth. In the walnut experiment at the Grazac site of Partner 1 the presence of the intercrop actually improved tree growth. This was shown to be possibly due to the intercrop making more nitrogen, and possibly sulphur, available to the trees.

The presence of the trees undoubtedly decreases crop growth, although in those systems where the crop development is well advanced before leaf emergence of the trees, such as the poplar/winter cereal combinations of Partners 4 and 5 in the UK, or the hybrid walnut/ clover combination of Partner 6 in Italy, yield reductions under the trees are not high. Pruning of the tree roots in the poplar/cereal system of Partner 1 at Vézénobres in France did not have a large effect on crop yields, indicating that belowground competition may not be a significant factor for crop growth under certain circumstances. However, results of canopy pruning experiments and hemispherical photography of canopies showed that interception of light by the tree canopies has a big effect on crops still at relatively early developmental stages under the trees.

Providing field experimenters with a forum for exchanging know-how and expertise.

Throughout the course of the SAFE project the managers of the Experimental Sites were in regular contact with each other, and in particular the coordinator of WP3, to ensure consistency of practice in their experiments. Contact was maintained by meeting at the six-monthly Consortium Management Committee Meetings. These were held at Montpellier, Wageningen, Silsoe, Plasencia, Orvieto, Toulouse and Zurich, thus giving the participants the chance to visit the Experimental Sites of Partners 1, 5, 6 and 7. The coordinator of WP3 (Partner 4, University of Leeds) ensured that staff from Leeds visited the Site Managers of these sites at least once during the project.

Very early in the work of the work package the SAFE-Agroforestry closed email list was implemented on the National Academic Mailing List Service (JISCmail) of the UK's Joint Information Systems Committee. This closed email list has been used for all aspects of coordinating the work of the SAFE participants, and has been used within Work package 3 to exchange information on the organisation, design and data collection methods at the experimental sites to be used to supply data to the modellers (Objectives 3.2 and 3.3, Task 3.1). The exchange of the actual data from the Experimental Sites to the modellers was carried out on the SAFE website, established as Task T1.4 of Work package 1 (and mentioned in T3.1).

By making the data from the field experiments available to all consortium members on the SAFE website, the arrangements for data flow in Figure 1 of the Technical Annex were changed. Data were made available from WP3 directly to WP4 (Above-ground modelling) and WP5 (Below-ground modelling), although WP3 remained the coordinator for all data collection and display.

Managing field experiments in a sound and concerted way

To satisfy the requirements of Objective 3.2 to manage field experiments in a sound and concerted way, and of Objective 3.3 to provide a unified protocol for basic field measurements, the managers of the Experimental Sites ran field experiments and carried out measurements on them.

At the start of the project it had to be agreed what tree species and what tree/crop combinations would form the basis of the experimental work in SAFE. To this end an inventory of experiments carried out by the consortium members was drawn up, as it would be from within this set of experiments that the data to be used for the main aspects of the project (analysis of growth of trees and crops for above-ground physiological modelling, below-ground physiological modelling, economic modelling and analysis of areas in Europe suitable for the introduction of silvoarable agroforestry) would be generated.

From this inventory it was decided that the best-represented systems for study involved poplar, wild cherry, walnut and oak. Other species that consortium members were growing, or had access to, including *Sorbus domestica* and *Alnus cordata*, were regarded as being insufficiently important as commercial tree species in Europe, so they were not included. It was agreed that the tree/crop combinations used should concentrate on annual crops, especially cereals, so combinations of trees and grape vines were excluded.

The experimental systems that were chosen to have their data included in the database were as shown in Table 1.

Partner Number	Tree-Crop System	Tree age in 2002 (years)	Area (ha)	Data received at end of year	Location
1	Walnut-Winter cereals			No	Restinclières
1	Walnut-Perennial fodder			No	Castries
1	Wild Cherry-Perennial fodder			No	Notre-Dame de L
1	Poplar-Winter cereals			No	Vézénobres
1	Wild Cherry and Walnut-Cereals	5	9	Yes	Grazac
1	Wild Cherry-Maize	17	5	Yes	Pamiers
4	Poplar-Winter Annual Rotation*	10	8	Yes	Bramham
5	Poplar-Winter Annual Rotation*	10	8	Yes	Silsoe
6	Walnut-Alfalfa	10	1.2	No	Biagio 1
6	Walnut-Clover	8	1.07	No	Biagio 2
7	Oak-Winter cereals	Est.	4.5	Yes	Sotillo
7	Oak-Winter cereals	Est.	4.5	Yes	Cerra Lobato
7	Oak-Winter cereals	Est.	4.5	Yes	Dehesa Boyal
10	Oak-Wheat	c.150	1.0	Yes	Ksinithra
10	Walnut-Barley	26	1.0	Yes	Gournes-potami
10	Poplar-Barley	4 (42)	0.27	Yes	Viliani

Note: Sites marked * have identical experimental design. Est.= experiment on previously established trees

Table 1. Experimental Sites and Tree-Crop Systems selected for use in the SAFE Experiments (as at January 2002).

With agreement to use data from these sites for the models it was clear that data would be available for poplar at two sites in the UK (northern Europe), one site in France (southern Europe) and one site in Greece (southern Europe), data for wild cherry at three sites in France, data for walnut at three sites in France, two sites in Italy and one site in Greece, and data for oak from three sites in Spain and one in Greece. Data from these sites were to be used for establishing the biophysical models in SAFE, with sites of Partner 10 in Greece being used for verification of the models, together with data from further experiments at the other sites. This gave 16 sites from which data would be available, as opposed to the 12 mentioned in the Technical Annex. Subsequently another site was added by Partner 1, and an additional site by Partner 7. Partner 10 established three new agroforestry plots during the course of the SAFE project, but measurement at one of their sites was discontinued in early 2003 as it was thought to be unrepresentative.

Agreement was reached at the Workshops in Wageningen in January 2002 and at Silsoe in September 2002 on the data that would be required for the modelling activity, and it was important to ensure that the data required would be consistent between the experimental sites. Methods in use for routine measurements at the different sites (e.g. measurement of tree height by rods or by clinometer, measurement of diameter at breast height by callipers or diameter tape) were checked to ensure that the different sites were able to produce data with similar levels of accuracy. The data that were required are shown in Appendix 1.

Providing data from field experiments in a standardised format for model parameterisation and testing.

It was clear at the beginning of the project that agreement had to be reached amongst the participants in Work package 3 as to how the data from the silvoarable agroforestry experiments of the SAFE participants would be arranged and made available to the consortium members. Initial work in WP3 was directed to both designing the structure of the database and setting up mechanisms for data input.

A protocol for data transmission was agreed, in which managers of Experimental Sites were sent an EXCEL file with a worksheet listing measures required, describing the units and linking the measurements with the experimental factors (site, soil, plot, crop, tree, management) for them to complete (Appendix 2 shows the instructions for completing these forms). The organisers of the Experimental Sites (Partners P1, P4, P5, P6, P7 and P10) agreed a timescale in which they would return their data, after which time the data files would be made available to the SAFE consortium members on a password-protected section of the SAFE website. This database of the experimental data (Deliverable 3.2) was first available on line in month 27 as a preliminary version, and it was posted in its completed format in month 28. Subsequently an introduction to it was written, and this comprised the Handbook to the European Experimental Resource (Deliverable 3.1).

In designing the database it was important that it should be suitable for easy retrieval of data by a person who did not set it up initially, and with a minimum number of operations. It had to be a 'relational' database, which links data grouped in different objects (tables) and so allows faster management and retrieval.

From this structure an Entities Relation Model was constructed. The layout of this for the SAFE project was initially as shown in Figure 4.

In order to overcome the barriers between different database software packages and operating systems it was decided to convert it into Structured Query Language (SQL) to allow it to be run by Access running under MS Windows on a PC or by MySQL running under Linux on a mainframe server. This format also allows for the storage of both data and metadata (i.e. text and image files, for example maps of the layout of the Experimental Sites) in the same environment. Normally these different file types would run with different software. SQL also allows for the writing of 'Query Reports', reports that export selected data in other desired formats.

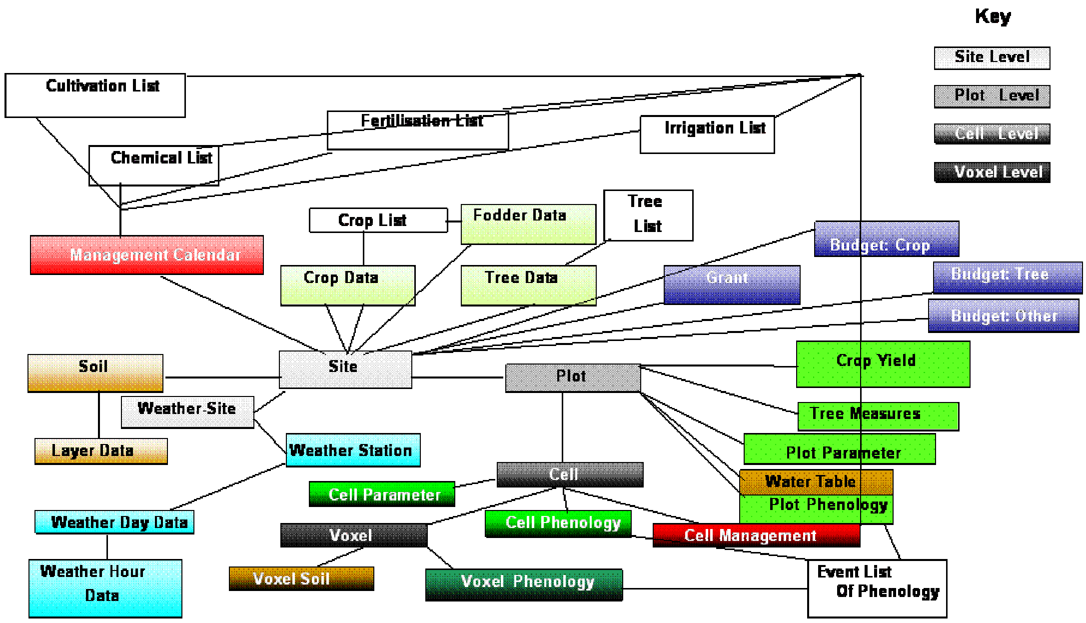


Figure 4: The original form of the Entities Relation Model on which the SAFE database was based.

The returned EXCEL files were put in ACCESS format on the Disk Space of the SAFE website, and they were edited by staff in WP3 with SQL so that they could be further edited in MySQL to be made available to the SAFE consortium members in this format on a password-protected section of the SAFE website linked to MySQL at INRA (Figure 3). Excel versions of the files were also posted on the website. The procedure of conversion from SQL to MySQL was tested during the visit of staff from the co-ordinating partner (P4) to Montpellier in September 2003, and the procedure was found to work satisfactorily.

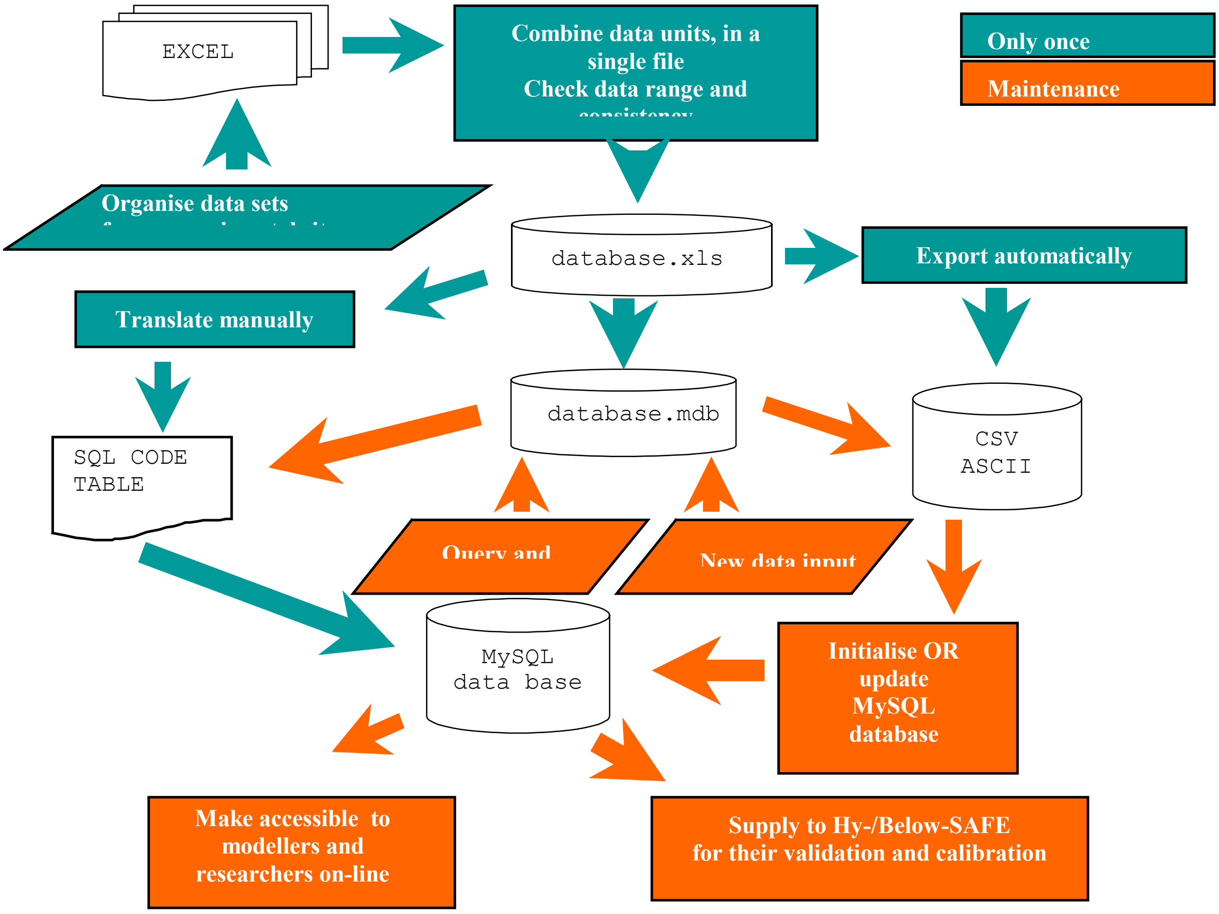


Figure 5: Setting up the SAFE experiments database.

The final version of the database was modified slightly from prototype versions. Originally data required for the economic model were incorporated in the database (Figure 4), but it was later decided to restrict the database to biophysical data. Its final structure is shown in Figure 6.

The database was set up in Excel, Access and MySQL, and all forms were accessible on the SAFE website. For each of the experimental sites characteristics of the site (soil and weather data, metadata and details of the trees and crops grown in the experiment) are listed, with crop yields and tree measures for each plot, and measures of crop yield and tree growth at the level of the cell and voxel where appropriate. The Access version has stored images and maps, allowing for descriptions of the experimental sites, plots and even individual subplots. The Access files are present both as Access 97 and Access XP to give compatibility with the software of all consortium members.

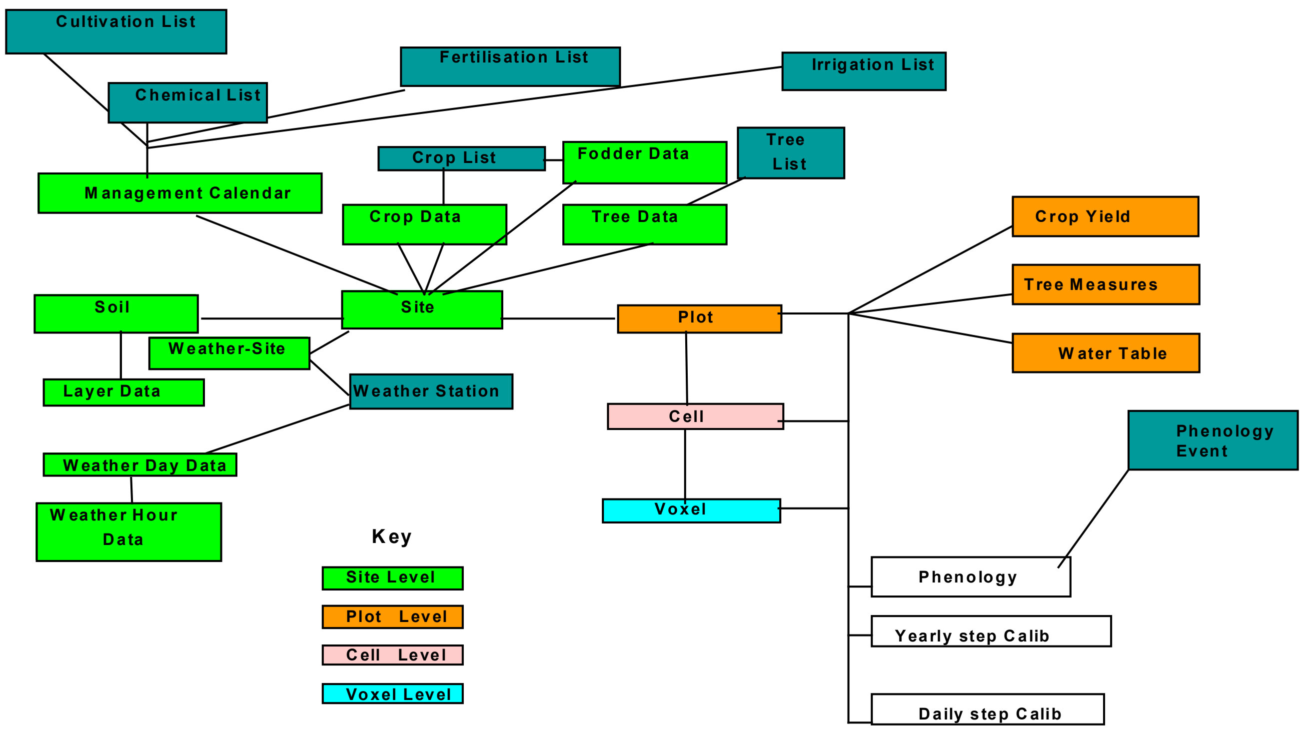


Figure 6: Final structure of the database of the SAFE experimental results

At an early stage it was decided that the data files would be formatted according to the conventions of the International Consortium for Agricultural Systems Applications (ICASA). These conventions are a revision of the standards drawn up by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), as used in the DSSAT software package. They have three levels of hierarchy, with the use of character strings to link information both in other parts of a file or in other files, and they create a partially relational database that is in an easily editable, transferable and readable ASCII file format (Hunt *et al.*, 2001).

The ICASA format gives an international standard for reporting results of agronomic experiments, but has previously only been used for agricultural crops. The WP3 team spent some time on codifying tree growth parameters, and these codes were suggested to the ICASA members. However, there was an apparent conflict between keeping the ICASA codes as simple as possible and the number of measurements required to adequately represent experiments in silvoarable agroforestry. This conflict could not be resolved during the course of the SAFE project, although it may still be possible to develop ICASA codes for agroforestry at some time in the future.

Collecting data from the Experimental Sites

Collection of data from existing experiments as required by the modelling activity

Partner 1 (INRA, France) managed four experimental sites (INRA-SYSTEM) near Montpellier (Restinclières, Castries, Notre-Dame de Londres and Vézénobres) and (initially) two experimental sites (UMR-DYNAFOR) near Toulouse (Grazac and Pamiers). In any silvoarable agroforestry system the impact of the trees on the intercrop depends on tree density, tree height and canopy size, tree leaf area density and on the overlapping growth period of trees and crops, so work on these sites investigated these characteristics of the components of the system and their interactions.

The site at Restinclières had hybrid walnut (*Juglans nigra* x *Juglans regia*) trees which were intercropped with durum wheat, the Castries site had hybrid walnut intercropped with lucerne and fescue grasses in two different treatments, the Notre-Dame de Londres site had wild cherry (*Prunus avium*) intercropped with sainfoin and tall fescue in two different treatments and the Vézénobres site had poplar clones intercropped with cereals and asparagus. At the first of these sites both tree and crop growth were measured during 2002, and in the summers of 2003 and 2004 crop yields were taken at different distances from the trees (2 and 6 metres) and in alleys between tree lines of different orientations. A detailed study of the cereal yields at Restinclières was written up by Rivest (2002). At Castries and Notre-Dame de Londres tree growth was measured during year 1, but as the intercrops were fodder crops it was decided that these were in effect silvopastoral sites, and they were not used in subsequent years.

The agroforestry system in Vézénobres consisted of two silvoarable poplar stands, set up in 1996 and 1997, with tree rows in the North-South and East-West direction respectively. These plots are the most mature silvoarable sites in France, possibly even in Europe. The poplar plantations showed a fast growth in height and diameter, and it is expected that their life cycle will be not more than 10 - 12 years. Phenology, height, diameter, leaf area, sap flow, and root length densities at different depths and distances were recorded.

One objective of the crop measurements was to measure state variables of the wheat crop to calibrate the STICS crop model used in Hi-sAFe. The model is an important tool to fully integrate our knowledge and understanding of silvoarable systems and thus add to the insights obtained from experiments (see Report of WP6). Secondly, the field observations aimed to assess the influence of the trees on the growth and yield of the crop species. In 2004, for example, this was durum wheat at Vézénobres, following on from a previous durum wheat crop in 2003 and a fallow year in 2002, and its growth was monitored by measuring its development and grain yields along transects of the tree-crop interzone and in the crop control, i.e. outside the influence of trees. Measures in 2003 were done at 1.5, 2.5 and 8 metres from the tree line. In 2004 the experimental unit was a subplot (micro-plot) of 1 m^2, consisting of 7 to 8 one metre-long crop rows parallel to the tree line. In the 2002/3 season there was a root-pruning treatment, but as this showed no effect on grain yield during the 2003/4 season a tree canopy pruning treatment was introduced. The overall treatments in 2004 were:

*2 tree row orientations * 2 plot orientation * 2 pruned/ unpruned * 2 distances*

Every two weeks measurements were made of crop height, the phenological stage (Zadoks scale) and the number of organs (brown and green leaves, tillers). Determination of the time of flowering (onset, 50% and 100%) was made, and around the time of flowering leaf area and specific leaf mass of the upper two leaves was calculated.

At both Restinclières and Vézénobres, INRA-SYSTEM meteorological stations recorded hourly data of air temperature, air humidity, photosynthetically active radiation and rainfall. Both stations were set up at a minimum distance of 30 m from the trees in the experimental agroforestry plots, in order to record the boundary climate outside the influence of the trees.

The sites run by UMR-DYNAFOR included an experiment on wild cherry (four INRA clones, Ameline, Coulonge, Gardeline and Monteil) and hybrid walnut (NG23xRA) grown with an annual intercrop (sunflower in 2002 after durum wheat, barley in 2003 and oilseed rape in 2004), with alleys weeded with herbicides and with fallow alleys (Grazac). Within the experiment there were also treatments with *Alnus incana* as a companion tree, *Betula verrucosa* as a companion tree, and alleys sowed with clover. Tree growth was compared within the treatments, but unfortunately crop growth of the sunflower was not measured, as it was too heterogeneous. Similarly, the barley yields were so heterogeneous that it was not even harvested. Despite the extent of pod shatter in oilseed rape a harvest was taken of this crop (into polyethylene bags before threshing, to minimise loss of seeds), so crop measurements were obtained in 2004.

Figure 7: Harvest of oilseed rape at Grazac in 2004.

The yields of samples taken from 1 m^2 squares with their centres 1.5, 2.75 and 4 metres both to the east and to the west of trees were compared with samples taken as far as possible from any trees. Data on tree growth (height and diameter at breast height) were provided for the 5 years before the SAFE project commenced and data on the yields of the intercrops over that time period were also supplied. In year 2 of the SAFE project tree diameters were measured weekly throughout the summer to enable growth curves to be drawn up for both wild cherry and walnut.

The second experiment (Pamiers) was on wild cherry (nine clones at three spacings) intercropped with maize in which the growth of trees was compared with trees grown in stands without crops present. This had previously been allowed to become naturally vegetated, but the arable crop was reintroduced during 2002 as it gave the capability to study intercropping in stands of trees that were already 17 years old. Some trees were left without intercropping, as 'forestry' controls. Data for tree height and diameter at breast height were provided for each year of the project, but crop yields were not measured in 2002, as they were too heterogeneous. Yield components were measured for the maize in 2002 and 2004, with yields being measured for 12 'average' samples in the middle of alleys, at the crossing of diagonals between four trees, and for 6 'gradient' samples, located on a line between two trees and perpendicular to the tree line. Samples were taken every 2 metres on these 'gradients', from one tree line to the next.

After the SAFE project had started UMR-DYNAFOR were able to introduce results from a third site, Les Eduts. Here wheat was intercropped with black walnut (*Juglans nigra*), common walnut and wild cherry in 2003. No crop yields were determined, but diameter at breast height was measured in black walnuts grown in a stand of trees alone and in all three tree species grown with the intercrop.

Partner 4 (University of Leeds, UK) ran one experimental site, with poplar trees that were intercropped with winter barley in 2001/2 (following winter wheat), oilseed rape in 2002/3 and winter wheat in 2003/4. There were four cultivars of poplar (Trichobel, an intraspecific hybrid of *Populus trichocarpa,* Gibecq, a hybrid of *Populus deltoides* x *P. nigra*, Beaupré, a *P. deltoides* x *P. trichocarpa* hybrid and Robusta, another *P. deltoides* x *P.nigra* hybrid) grown both intercropped and with fallow alleys, and the tree row understorey was vegetated with a grass/legume mixture or was kept weed-free in different treatments. Comparison of tree growth was made between the cultivars, between cropped and fallow alleys and between understorey treatments. Crop yields were compared between the alleys and a control area away from the trees. During the SAFE project tree growth (height and diameter at breast height) was measured in winter 2001/2, 2002/3 and 2003/4 and crop yields of the 2000/2001 winter wheat, the 2001/2 winter barley and the 2003/4 winter wheat were measured. The oilseed rape in 2002/3 was harvested, but yields were not recorded as pod shatter made the data too unreliable for use. Management details for each of the cycles were recorded, and meteorological data were provided from a meteorological station on site. This site formed part of the UK Silvoarable Network, and growth measurements for trees and crops from the time of planting in 1997 until the SAFE project commenced were made available to the consortium.

Crop yields are now below 50% of the control values in the cropping alleys, a value that would be regarded as uneconomic in a commercial operation. At this point a commercial farmer would put the alleys into set-aside, so it is intended that this is what will happen to the Experimental Site in the future. Tree growth will continue to be measured annually until harvest of the trees in 10-15 years time. It is anticipated that, at least to start with, the cropping alleys kept fallow during the experiments will continue to be kept fallow so that the effect of the set-aside conditions on tree growth can be assessed.

Partner 5 (Cranfield University, UK) managed a silvoarable experiment with poplar hybrids, which formed another part of the UK Silvoarable Network, and had the same experimental design and the same four poplar hybrids as the Leeds site. This had a winter barley crop planted in November 2001 (after winter wheat the previous season), and field beans as a break crop in 2002/3. Unlike the Leeds site, yields were obtained for the break crop, but cropping finished after this due to the cessation of funding for the UK Silvoarable Network so no further data were obtained after measurement of tree growth in the 2003/4 winter. The site has been put into set-aside. At the Partner 4 and Partner 5 sites the growth of the poplar trees is expected to take 20-25 years, considerably longer than the life cycle of the poplars grown by Partner 1. This has given the SAFE scientists access to growth data on one species of tree in two widely different sets of growing conditions.

Partner 6 (CNR Istituto di Biologia Agro-ambientale e Forestale, Italy) ran two experimental sites, one on walnut (common walnut *Juglans regia* and a French hybrid walnut, NG23) intercropped with lucerne (after wheat) and the other on walnut (an Italian cultivar of common walnut, Feltre) intercropped with clover (initially *Trifolium subterraneum* but subsequently *Trifolium pratense* and then *Trifolium incarnatum* in 2003/4) or grassed down with natural vegetation. The treatments at the first site were either continuous cultivation of the alleys, with either bare understorey or understorey covered with plastic mulch, and agroforestry with alternate crops and the same two understorey treatments. The treatments at the second site were continuous cultivation of the alleys and bare understorey, grassed-down alleys and bare understorey, alleys planted with clover and bare understorey and alleys planted with clover and understorey covered with plastic mulch.

In the first site yields of lucerne were determined in spring and autumn 2002, and subsequently the lucerne was replaced with wheat in the 2002/3 season and clover (*Trifolium incarnatum*) in the 2003/4 season. Tree heights and diameters at breast height were measured. Work was carried out to test the hypothesis that bigger trees are less susceptible to competition from the lucerne due to a) shading of the lucerne by the trees (WP4) and b) a deeper tree root system giving the trees access to more water (WP5). Measurement of lucerne yield was made at three distances from the trees. At the second site measurements of the dry yields of the clover were made at two distances from the trees. Tree heights, bole heights, diameters at breast height and crown diameters were also measured. Data on tree and crop growth going back to the planting of the trees were provided for both sites, with soil and meteorological data (air temperature, rain, percent humidity, atmospheric pressure, solar radiation, photosynthetically active radiation, and wind speed and direction) from a local meteorological station.

Figure 8: 11 year old common walnut trees at the Biagio 2 site of Partner 6. Continuous cultivation with bare understorey (foreground), clover intercrops with understorey mulched with polyethylene (background).

Partner 7 (University of Extremadura, Spain) monitored 3 on-farm field experiments. Two of these comprised Holm oak (*Quercus ilex*) intercropped with oats in a traditional Dehesa, and the third one comprised oak intercropped with mixed oats and wheat. Each experimental site had three treatments: cropped, uncropped with pasture under the trees, uncropped with shrubs under the trees. Triplicate plots of (on average) 0.5 ha containing 10 randomly located trees were delimited within each treatment, and measurements of tree diameter, trunk height, tree height, canopy width, and tree density were made in March 2002. In the second year work was carried out on the same farms, but in different plots, because each plot is cultivated only every four years, in a traditional / rotational cycle: 1 year Crop – 2 years pasture – 1 year fallow.

In these three farms manipulative experiments were not being carried out, so work started on a fourth farm in year two, allowing introduction of control plots (Figure 7). The same experimental design was used as in the initial experiments. This farm belongs to FGN, which was an UEX subcontractor in the SAFE project. It was located in the same county as the other three farms, so the climate was similar. In this farm different plots (cropped and uncropped) were established. They were maintained for two consecutive years in order to analyse the mechanisms involved in the response of the trees and crop to management practices. For doing this, a two factor, nested design was implemented to analyse the effects of cultivation, resource addition (fertilisation) and location (nested factor) on variables related to resources used by two types of plants (tree and crop), crop yield and tree physiological condition and production. Experimental treatments started in October 2002.

In the new and the old plots crop yields, tree shoot elongation, seedling emergence, seedling survival and acorn production were measured.

Some new experiments on the establishment of Holm oak seedlings were initiated during year 3, and new farms were located for a study on the effect of Holm oak on soil fertility and crop yield in the 2004-growing season. Soils from 9 new farms were analysed, and crop samples were also taken in these farms. The data were used for calibration of the Hi-sAFe model, and have formed the basis of a paper being prepared on "The role of the oak-trees on soil fertility and crop yield in Dehesas of Central-Western Spain".

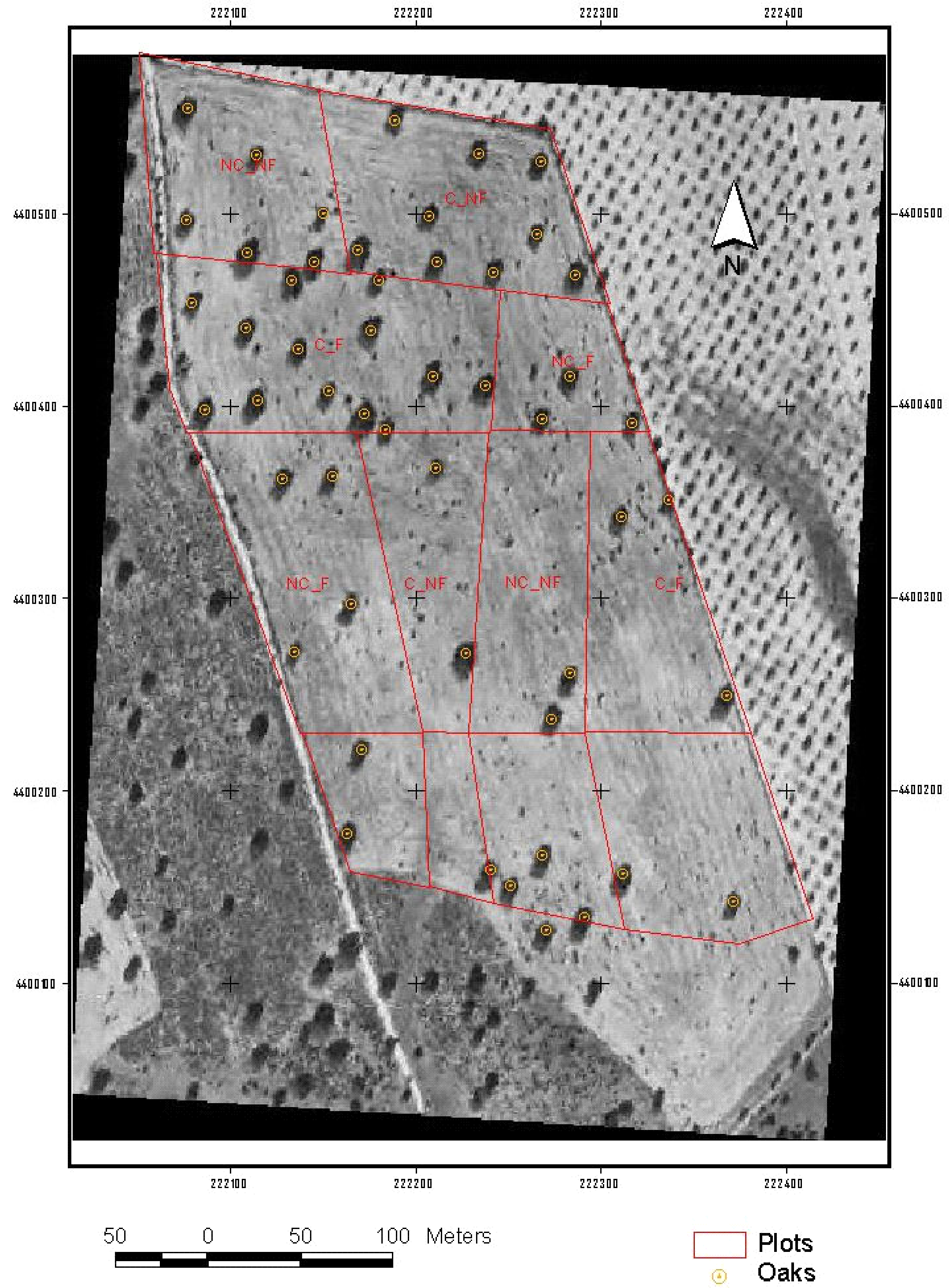


Figure 7. Aerial photograph of the experimental plots on the ‘El Baldio’ site, Spain. C = intercropped, NC = natural pasture, not cropped, F = fertilised, NF = not fertilised. At the bottom there was a ninth plot with abundant understorey that was not cropped.

Partner 10 (University of Thessaloniki, Greece) provided data that were intended for use for the validation of the models. They worked on three sites on commercial farms, one with 17 oak (*Quercus pubescens*) trees intercropped with durum wheat, one with 9 walnut (*Juglans regia*) trees intercropped with barley and one with 50 poplars (*Populus* x *Canadensis*) intercropped with barley.

Tree heights were measured, as was diameter at breast height. Work on the walnut-wheat system was discontinued in February 2003 following a visit by the project coordinator as it was decided that it was not representative of other walnut-wheat experiments. Measurements continued at the other sites, and included crop yields at 2, 5, 10 and 20 metres from the trees as well as tree height and diameter at breast height. At the oak/wheat site (Ksinithra) this was carried out on five transects to the west of trees and five transects to the east of trees, but at the poplar/barley site (Viliani) this was carried out on transects from five trees in one direction only. This direction was towards the crop, and the trees were on the boundary of the farm. At both sites data on budburst and start/end of flowering were also obtained, and meteorological data were recorded at a meteorological station close to the sites. Three new agroforestry sites were established during year 2. Hybrid walnut and wild cherry were planted (with *Celtis australis*, outside of the SAFE project) and they were intercropped with maize/wheat in one instance and winter barley/durum wheat in the other two cases.

Collection of specific information to parameterise the biophysical model at the SAFE experimental sites

It was realised at the beginning of the SAFE project that where common measurements were to be taken across a range of the Experimental Sites it was important that these measurements were taken in a standard way. The data required from the experimental sites for the parameterisation of the Hi-sAFe model were agreed in month 14, and after this protocols for budburst, leaf fall, hemispherical photography of tree canopies and for root coring to determine root length density were written. Some of these protocols were based on those already in use by consortium members. In other cases (e.g. budburst, leaf fall) they were written from new. Measurement of tree leaf photosynthesis, tree leaf N content, soil water content and tree sap flow was only carried out at a small number of sites, and the people responsible used accepted methods that they were already familiar with.

The protocol for hemispherical photography was based on the equation

$$D_p = 0.25\ d$$

where D_p is the distance between photographs (in metres) and d is the distance between trees (also in metres). Photographs taken were analysed with the Gap Light Analyser (GLA) software. The protocol for hemispherical photography is available in the SAFE project annual reports.

Data for budburst and leaf fall were collected at all of the Experimental Sites, commencing in year 2. Other data collected included canopy development (by hemispherical photography) for walnut and cherry at the Restinclières, Grazac, Pamiers and Les Eduts sites of P1, poplar at Vézénobres and the sites of P4 and P5, and oak at one site of P7, light availability in relation to canopy size under poplars and oaks at P10, tree leaf photosynthesis and tree leaf N content for oak at P7, tree leaf water potential in the oak trees at one site of P7, distribution of tree roots by soil coring for walnut at P1 and for oak at P7, amounts of leaf litter, nutrient concentrations and nutrient contents of walnut and wild cherry at the Grazac site of P1, daily change in soil water potential at Grazac, soil moisture content, soil fertility and soil physical parameters under the oaks of P7.

At the Restinclières and Vézénobres sites of Partner 1 the soil water content was measured with neutron probes, both during the growing season and at other times of the year, at two-weekly intervals over the previous two growing seasons. The water table level is needed to compute a correct water budget of the silvoarable system with the Hi-sAFe model, so INRA-SYSTEM therefore equipped the plots at Restinclières (in 2002) and Vézénobres (in 2003) with piezometers, and the data were analysed and used for the Hi-sAFe model.

Hemispherical photography was carried out in 2003 to estimate the reduction of available light at a given point in the intercrop, i.e. adjacent to the micro-plots at 2 and 6 m from the tree line at Vézénobres. In 2004 further photographs were taken in May and June. Photographs were also taken in the 2003/4 winter to give values for interception of irradiance by the trees after leaf fall. The results of 2003 indicated that the available daily light is homogeneous on the plot with a North-South orientated tree row and heterogeneous for the plot with a West- East tree row orientation. The data were used to validate the Hi-sAFe model, which requires information of the available radiation around an average tree surrounded by average trees (torus symmetry), as can be obtained by hemispherical photographs (see WP4 report for further details). Phenological measurements continued, with final leaf fall during the SAFE project being observed at the end of November 2004.

At the Grazac site tree growth (both height and diameter at breast height) was shown to be better with intercropping than with the weeded treatment, so foliar analysis (N, P, K, Ca, Mg and S) was carried out on leaves of both species in both treatments in year 1. Leaf nitrogen concentration had been shown to be higher in the intercropped trees than in the weeded trees, although whilst it was 'optimal' in the intercropped cherry trees and 'critical' (Bonneau, 1995) in the weeded cherry trees it was within the 'optimal' range for the walnut trees in both treatments. Measurements of sap flow in the wild cherries were made in year 3, and leaf litter was collected from the trees and prunings were weighed to fit an allometric model.

Hemispherical photography was carried out at the Grazac, Pamiers and Les Eduts sites both in the summer and after leaf fall. This photography covered wild cherry, hybrid walnut and black walnut.

Root coring was carried out on three wild cherry trees (ten cores per tree) at the Pamiers site and on three hybrid walnut trees at the Restinclières site (data required for WP5) in year 1. Partner 1 also carried out measurements of root growth in container-grown trees to provide parameters for the Hi-sAFe model.

At the Les Eduts site of Partner 1 work was carried out on characterising the root system of trees actually growing in silvoarable agroforestry. Four black walnut (*Juglans nigra* L.) trees were felled at the beginning of 2002, and the root systems of two of these (a tree from agroforestry and a tree from a forestry area) were described.

For the tree from agroforestry roots were divided into segments, and each segment was physically measured in respect of distance to centre of trunk at the beginning of the segment, depth to ground surface of each end of the segment, diameter of each end of the segment and azimuth of the segment. Not all the roots could be measured, but 163 root segments were and the total length was 70.7 metres. The root system occupied a total volume of 0.242 m^3. For the forestry tree the root system had its three dimensional characteristics recorded with a 3D digitiser. 1290 root segments, with an average length of 14 cm, were observed. The total root length was 177 metres, and the root system occupied a volume of 0.129 m^3.

At the Partner 4 site (Leeds) phenological measurements of budburst and leaf fall were made in 2003 and 2004. It is intended that measurements of leaf emergence and leaf fall will continue to be made during the remaining life of the trees partly as a record that could be used in the study of climate change but also to relate to the annual growth of the trees. Hemispherical photography of the plots was carried out in summer 2003, and was repeated after leaf fall that year to give an estimate of reduction of irradiance due to branches in winter.

Partner 5 took on an MSc student (P. Pasturel), who carried out measurements of tree phenology, light interception (by hemispherical photography), fine and coarse root distribution (by root coring and trenching respectively) and soil water content (by Diviner Capacitance down to 1.6 metres and by neutron probe analysis at lower depths). He was successfully examined on his thesis in April 2004, and the thesis is accessible on the members' section of the SAFE website.

At the Partner 6 sites (CNR, Italy) work was carried out in year 1 to digitise the tree foliage to work out Leaf Area Index and Leaf Area Density for WP4. This work was validated by a number of techniques, such as destructive sampling of similar trees for allometric scaling of leaf area, and litter sampling. Subsequently the foliage was studied by hemispherical photography. Root coring was carried out on 5 common walnut and 5 hybrid walnut trees at the Porano 1 site in year 1. Phenological measurements of bud burst and leaf fall of the walnut trees were made. The latter occurred between September and December.

Some of the work on model parameters by Partner 6 was carried out by a student, A Ecosse, whose thesis was defended in February 2005. The main objective of the thesis investigation was to study the interrelations between adult walnut trees and two intercrops, wheat and clover (*Trifolium incarnatum),* during two growing seasons (2003 and 2004) in the two experimental walnut plantations.

In year 1 leaf water potential, tree leaf photosynthesis and fine root length density (by root coring) were measured at two of the sites run by Partner 7, sap flow was measured at one of the sites and soil total N content was measured at all three sites.

At the fourth experimental site set up in Spain by Partner 7 an experiment was run to analyse the mechanisms involved in the response of trees and crops to management practices. In addition to monthly measurements of crop growth and annual measurements of tree growth there were measurements of tree leaf water potential, tree leaf photosynthesis, tree leaf N and P content, light interception by hemispherical photography, soil moisture analysis and fine root length density.

New TDR probes were installed in year 3 between 1 and 2 metres deep in the soil to improve results on soil water dynamics at the Partner 7 experimental sites. The study of tree and herbaceous plant root length density, comparing RLD between winter and spring, was continued. Two new experiments on the establishment of *Quercus ilex* seedlings were initiated, together with new measures of sap-flow, plant water potential and leaf photosynthesis in three plots.

Time of budburst and flowering of the oak trees and time of budburst of the oaks and poplars was recorded by Partner 10 in year 3 for their experimental sites.

Validation of models with the field data in a dynamic interaction with the modellers

It was anticipated that data from the Partner 10 sites would be used for verification of the models. It was found that these sites did not have historical data of tree growth, so this option was not feasible. Data from other experiments on the Experiments Sites were used for model verification (see reports on the modelling activities). The site managers were in regular contact with the modellers, and were able to supply information for both parameterisation and verification of models over and above what was posted in the consortium database.

Reporting the results of silvoarable experiments

Results from the Experimental Sites are extensive. Many of the results are particularly relevant to the aboveground interactions (WP4) and belowground interactions (WP5), and are dealt with elsewhere. A summary of some of the key findings that relate to the growth of the trees and crops is given here.

Clear and simple data illustrating the interactions between crops and trees can be seen from the poplar/cereal system of Partners 4 and 5.

At the Partner 4 sites yields of the crops were barely affected by the presence of the poplar trees for the first four years after planting (historical data, from before the SAFE project commenced). Indeed, for two of the first four years yields of crops were actually slightly higher under the trees than in the control areas. After this time there were significantly lower yields of crops under the trees (by ANOVA, P=0.05), except for in 1999 (when yields were not significantly less) (Table 2). By 2003 yields were probably much lower in the alleys, although the harvested crop was not weighed as pod shatter of oilseed rape makes it a very difficult crop to obtain meaningful results for. The 2004 harvest was inaccurate, due to the harvest difficulties referred to above, but appeared to show a reduction in crop yields under the trees to less than 50% what was obtained in the control areas. This is below the threshold at which a farmer would continue to grow crops in a commercial silvoarable agroforestry system.

The growth of the trees can be seen in Table 3a (for trees grown alongside alleys that were continuously cropped) and in Table 3b (for trees grown alongside alleys that were continuously fallow during the course of the experiment).

It can be seen that by 2004 the growth of the trees was noticeably higher alongside the continuously fallow alleys, with timber volume at that time being 32% higher. The trees adjacent to fallow alleys were taller (significantly so from 1994, by ANOVA, P=0.05) and had greater diameter than trees adjacent to alleys that have been continuously cropped since planting (significant by ANOVA, p=0.05, from 1995). This was due to a much larger increment of growth in the trees next to the fallow alleys in summer 1995. For every season since that time the increase in timber volume relative to the volume at the start of the season has been slightly higher for the trees next to cropped alleys than for the trees next to the fallow alleys.

Year of harvest	Crop	Sole crop yield ($t\ ha^{-1}$)	Silvoarable yield ($t\ ha^{-1}$) cropped area	Ratio of silvoarable to control yield
1992	Spring barley	6.34	6.62	1.04
1993	Peas	5.46	4.83	0.88
1994	Winter wheat	8.67	9.24	1.07
1995	Winter wheat	8.17	7.81	0.96
1996	Winter barley	7.68	6.92	0.90
1997	Spring mustard	4.17	3.56	0.85
1998	Winter wheat	10.55	9.55	0.91
1999	Winter barley	5.63	5.50	0.98
2000	Winter wheat	6.55	6.04	0.92
2001	Winter wheat	6.38	4.70	0.74
2002	Winter barley	7.86	5.39	0.69
2003	Winter oilseed rape	*	*	*
2004	Winter wheat	7.37	3.10	0.42

* not harvested due to pod shatter

Table 2. Crop yields at the Leeds Experimental Site, Bramham, from 1992 to 2004.

The growth of the trees can be seen in Table 3 (for trees grown alongside alleys that were continuously cropped) and in Table 4 (for trees grown alongside alleys that were continuously fallow during the course of the experiment).

Day of year	Year of measurement	Height (m)	Diameter at breast height (cm)	Calculated cylindrical volume (m^3)	Estimated form factor	Estimated timber volume (m^3/tree)
87	1992	Estimate 1.20				
356	1992	1.59				
25	1994	2.52	2.36	0.001	0.42	0.000
25	1995	3.47	4.07	0.005	0.42	0.002
339	1995	4.46	6.15	0.013	0.42	0.006
3	1997	5.81	8.69	0.034	0.42	0.015
20	1998	7.50	12.00	0.085	0.42	0.036
40	1999	8.78	15.58	0.167	0.42	0.070
48	2000	10.11	16.63	0.220	0.42	0.091
79	2001	11.45	18.65	0.313	0.41	0.129
80	2002	12.81	20.40	0.419	0.41	0.172
72	2003	14.17	22.08	0.543	0.41	0.221
91	2004	15.21	23.97	0.690	0.40	0.280

Form Factor calculated from J M Christie, Yield Models for Forest Management, HMSO, London, 1981.

Table 3. Leeds tree data: height, diameter at breast height and estimated timber volume of four poplar hybrids in the continuously-cropped arable treatment at the Leeds experimental site at Bramham from planting on 27th March 1992 to 31st March 2004. (Values are means, n = 60)

Day of year	Year of measurement	Height (m)	Diameter at breast height (cm)	Calculated cylindrical volume (m^3)	Estimated form factor	Estimated timber volume (m^3/tree)
87	1992	Estimate 1.20				
356	1992	1.72				
25	1994	2.64	2.70	0.002	0.42	0.001
25	1995	3.79	4.96	0.007	0.42	0.003
339	1995	5.44	8.77	0.033	0.42	0.014
3	1997	6.80	12.03	0.077	0.42	0.033
20	1998	8.36	15.18	0.151	0.42	0.063
40	1999	9.70	19.05	0.277	0.41	0.115
48	2000	11.00	20.36	0.358	0.41	0.148
79	2001	12.20	22.19	0.472	0.41	0.193
80	2002	13.72	23.89	0.615	0.40	0.249
72	2003	15.15	25.68	0.785	0.40	0.314
91	2004	15.92	27.26	0.930	0.40	0.370

Table 4: Leeds tree data: height, diameter at breast height and estimated timber volume of four poplar hybrids in the continuously-fallow arable treatment at the Leeds experimental site at Bramham from planting on 27th March 1992 to 31st March 2004. (Values are means, n = 60).

It can be seen that by 2004 the growth of the trees was noticeably higher alongside the continuously fallow alleys, with timber volume at that time being 32% higher. The trees adjacent to fallow alleys were taller (significantly so from 1994, by ANOVA, P=0.05) and had greater diameter than trees adjacent to alleys that have been continuously cropped since planting (significant by ANOVA, p=0.05, from 1995). This was due to a much larger increment of growth in the trees next to the fallow alleys in summer 1995. For every season since that time the increase in timber volume relative to the volume at the start of the season has been slightly higher for the trees next to cropped alleys than for the trees next to the fallow alleys.

In order to assess the productivity of the silvoarable plots it is possible to calculate Land Equivalent Ratios. This is a common calculation in experiments on intercropping two annual crops, but within the SAFE consortium has been controversial, as it has not been used extensively before to compare yields of mixed annual and perennial crops. If LER is calculated as an annual value (LER = (crop yield per intercropped hectare/ yield of sole crop per hectare) + (timber increment per season of intercropped trees per hectare/ timber increment per season of trees by fallow alleys per hectare)) the results for the Leeds Experimental Site are as shown in Table 4.

It can be seen that LER values are higher than 1.0 throughout the time of cropping, reaching a maximum of 1.58 for the harvest in 2000. This indicates that the productivity of timber and annual crops together is higher than the production of either would be on their own.

Year	1995	1996	1997	1998	1999	2000	2001	2002
LER	1.13	1.19	1.38	1.38	1.42	1.58	1.36	1.30

Table 5: Annual values of LER (based on annual crop yield and annual increment in timber volume) for the Leeds Experimental Site.

The LER values indicate that this is an efficient production system, which would be of benefit both in terms of carbon sequestration per land area and in terms of maximising production per land area so allowing farmland to revert to natural ecosystems. However, it should be pointed out that the Leeds system is an experimental system set up for scientific measurements. It would never be established for commercial agriculture as the tree spacings have been set out to give a tree density similar to those found in farm woodland blocks of poplar, and would not be suitable for agronomic operations on a commercial farm.

Work on a poplar/wheat system by Partner 10 gives some indication as to why cereal yield is reduced under poplar trees (Table 5). It can be seen that at the Partner 10 site in Greece there was lower plant density, fewer ears per land area, fewer grains per hear and a lower thousand grain weight close to the trees.

No of transect	Tree distance	Density (plants/m^2)	Ears/m^2	Grains/ear	Weight of 1000 grains (g)
1	2	144	68	16	29.39
	5	148	240	22	43.03
	10	168	176	26	33.26
	20	264	388	28	40.56
2	2	-	-	-	
	5	140	156	25	38.00
	10	116	164	32	37.12
	20	144	100	32	35.18
3	2	72	172	24	32.29
	5	104	176	29	40.69
	10	124	204	19	32.28
	20	242	312	26	40.45
4	2	80	104	17	37.93
	5	144	228	21	33.54
	10	120	216	18	22.99
	20	116	192	25	40.40
5	2[1]	-	-	-	
	5	12	188	25	43.71
	10	124	260	24	32.28
	20	116	216	22	27.84
Means	2	98.67	114.67	18.89	33.20
	5	109.60	197.60	24.41	39.79
	10	130.40	204.00	23.88	31.59
	20	176.40	241.60	26.51	36.89

[1] This point was out of the cropped area.

Table 6: Crop yield measurements in the poplar/wheat experimental plot at the Municipality of Askio, Greece.

Effects on crop yields can be partly explained by competition for light. The poplars of Partners 4 and 5 were high-pruned, minimising their effect on crop growth. In the cool, relatively damp conditions of northern Europe, competition for light might be expected to be more important than competition for nutrients and water, and this is minimised by 1) planting winter crops, which complete much of their development before the tree leaves emerge and 2) pruning.

In 2004 an experimental treatment was introduced into the poplar/wheat system of Partner 1 at Vézénobres in which the trees were pruned. The grain yields of durum wheat in the poplar agroforestry stand were highly reduced compared with in the monocropping control plots (Table 6). Overall the reduction was about 50%, with large differences between the treatments. Two major tree management characteristics can be see to have effects on crop yield: pruning and orientation of the plots. The distance to trees appears to be less important (Figure 9).

Agroforestry treatment	Yield in agroforestry (AF) t/ha		Yield in crop control t/ha	Ratio Yield AF/ Yield control	
All agroforestry plots	1.94		4.11	0.47	
	unpruned	*pruned*		unpruned	pruned
Plot 96: Tree row N-S	2.08	2.38	5.16	0.40	0.46
Plot 97: Tree row W-E	0.97	2.35	3.06	0.31	0.77
Plot 97: Tree row W-E*	0.97	2.35	4.11*	0.24*	0.57*
Plot 97: Tree row W-E**	0.97	2.35	5.16**	0.19**	0.46**

* and **: Results using the mean of the two crop control plots and the value of Plot96, respectively.

Table 7: Durum wheat yields in an eight-year-old poplar stand at Vézénobres in 2004.

It is striking that the production on the control plot 97 was in all years much lower than on plot 96. One of the reasons may be the shade of poplars in the morning (the control is located west of the agroforestry plot). In dry regions morning hours are very important with respect to growth. The fact that the difference increased in 2004 (the ratio of yield of plot96/ yield of plot97 was 0.82 in 2003 and 0.61 in 2004) may also be due to the shade. When we correct the yield of the monoculture crop plot 97 for an eventual shade effect (e.g. using the yield of plot 97 or the mean yield of both control plots), the influence of poplars appears to be higher on a silvoarable field with West-East oriented tree rows.

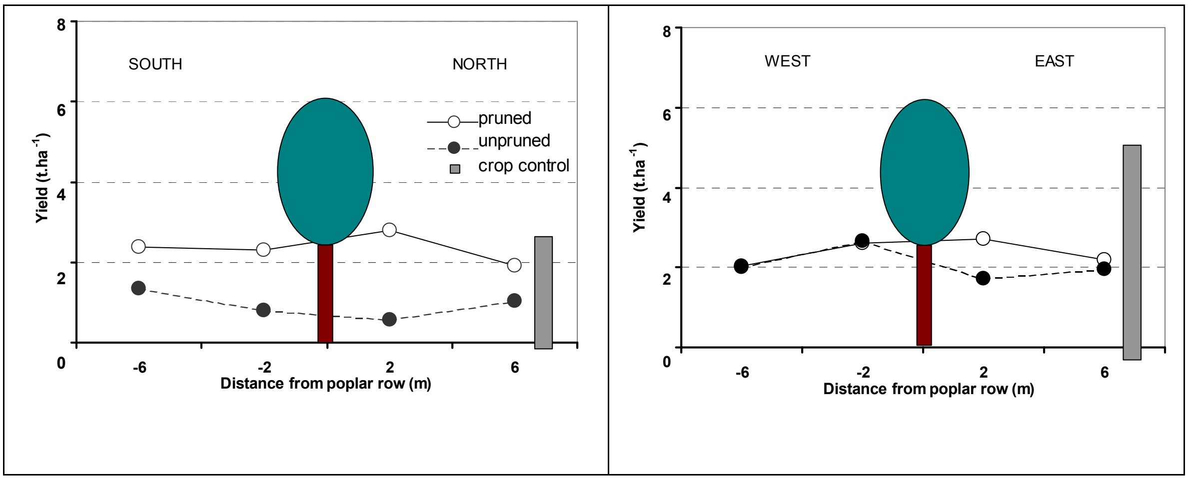


Figure 9. Yields of durum wheat at different distances and orientations from a pruned and unpruned poplar row in Vézénobres in 2004.

The impact of the pruning regimes on wheat yield was impressive in the 1997 plot, but was less pronounced in the 1996 plot (Figure 10). The lowest yield was found in alleys between low-pruned poplars, most striking in the south and north plots. Here the light condition is heterogeneous and pruning treatment had the largest effect in the north, where light reduction by low-pruned trees was highest. The standard errors (not presented) are large, due to a combination of few repetitions and large spatial variability. In the plot with East-West tree rows it can be seen that the best yields were observed NORTH of the poplars in 2004, which is the opposite of the result in 2003. This can be explained by the simultaneous effect of increase in tree height and high pruning. Tree height increase moved the sun shade further north, to the extent that it reached the next tree row, while high pruning allowed this light to reach the cropping zone situated North of the trees. This total change in only one year illustrates the fast dynamics of a silvoarable system.

This effect of pruning on availability of light to the north of trees can be seen clearly in Figure 10.

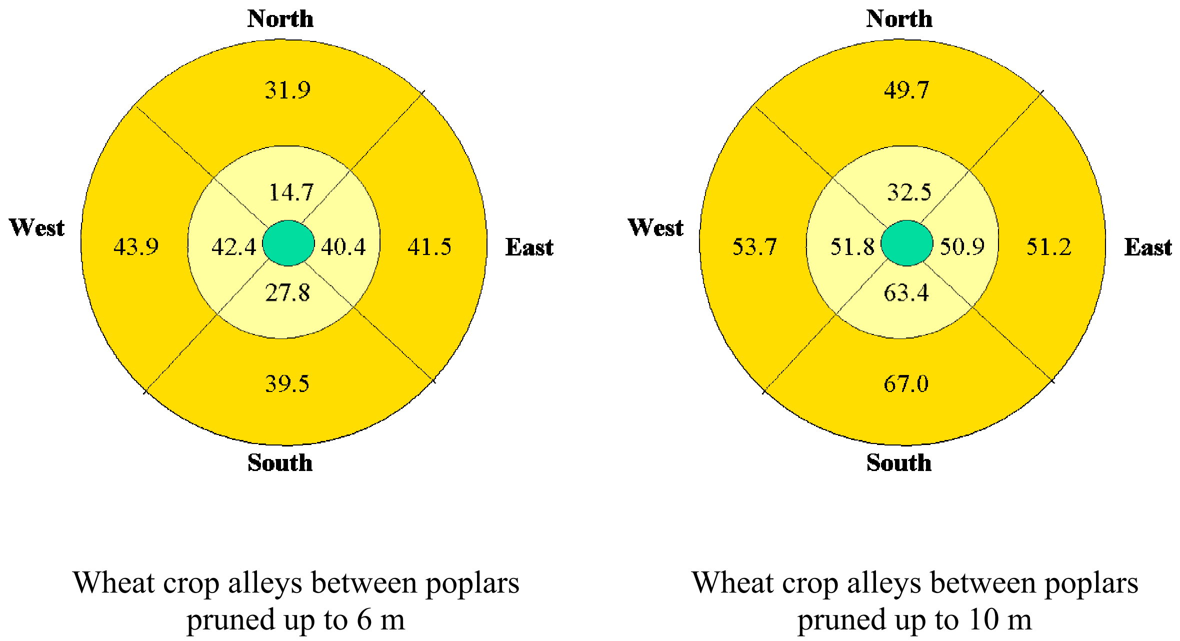


Figure 10. Light availability, as % of global radiation transmitted to the crop, at different orientation from the poplar row (green) at 2 m (yellow) and 6 m (orange) for both pruning treatments at Vézénobres in 2004.

With the exception of DOY 120 (before booting) and the ripening phase, the phenological development appeared to be similar everywhere on the silvoarable field as well as on the crop control plot. Thus the influence of light availability had no effect on the wheat development during most of its life cycle. In the more shady regions (micro-plots in the vicinity of the north side of trees) the physiological maturity was delayed for about 7 days and even at harvest, when wheat was mature everywhere in the agroforestry plots, grains were still more humid in the more shady micro-plots. Data are currently being analysed.

From these data, is it possible to conclude that shade is the limiting factor for wheat production in this mature silvoarable system. Water competition may also play a role, as pruning also reduces water use by the tree. However, unless we assume that the rooting pattern of the poplars is not symmetrical on both sides of the tree row, the water competition effect should be symmetrical. Furthermore, experiments on root pruning in 2003 had shown no significant effects on crop yield. What we observe is a non-symmetrical impact, well correlated with the light availability. This indicates that light is the limiting factor.

A similar effect on crop growth of uneven light distribution under trees is seen from the results of the experiments on maize yield at Pamiers. Hemispherical photography was carried out under three typical wild cherry trees in summer 2003, and the percentage transmittance was mapped with SURFER software (Figure 11).

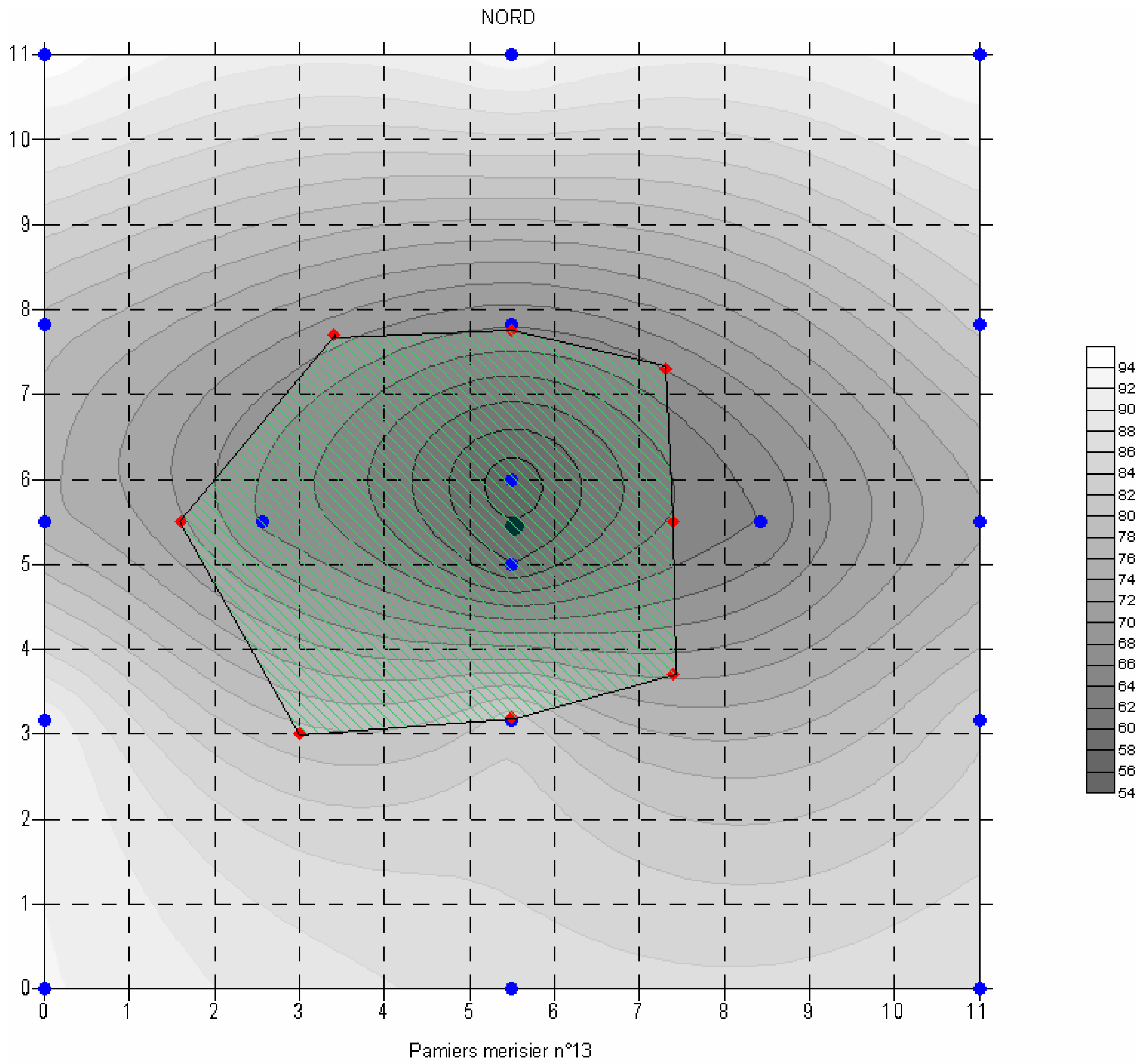


Figure 11. Irradiance (54% to 100% of background) under tree number 13 at Pamiers. The tree is in an East-West row, and at the time of photography had a height of 10.50 m, a bole height of 4.33 m and dbh of 21.8 cm.

When the irradiance around a typical tree is compared with the maize yields in the 2002 season it can be seen that there was a strong relationship between the amount of shade cast under the tree and loss of yield (Figure 12). The most obvious reduction in both light transmittance and yield was seen close to the tree, but it is also clear that there was a bigger reduction in light and yield to the north of the tree than to the south.

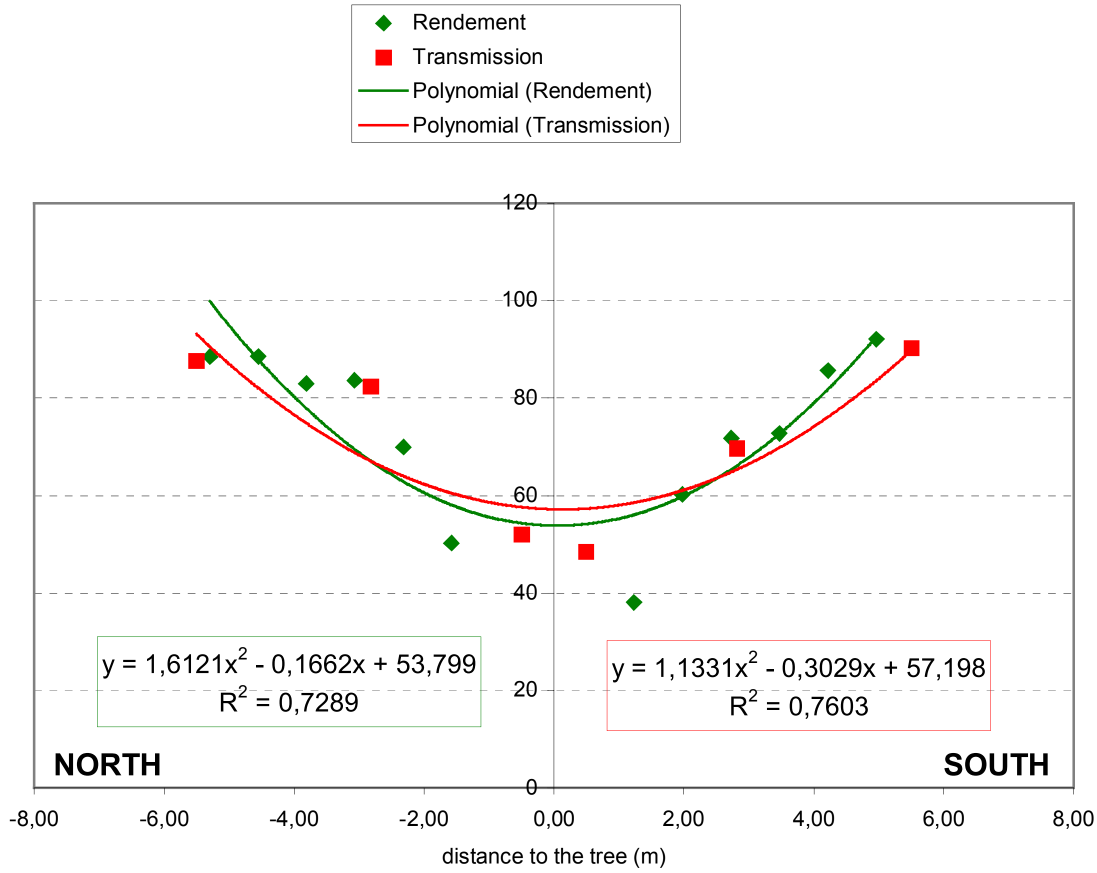
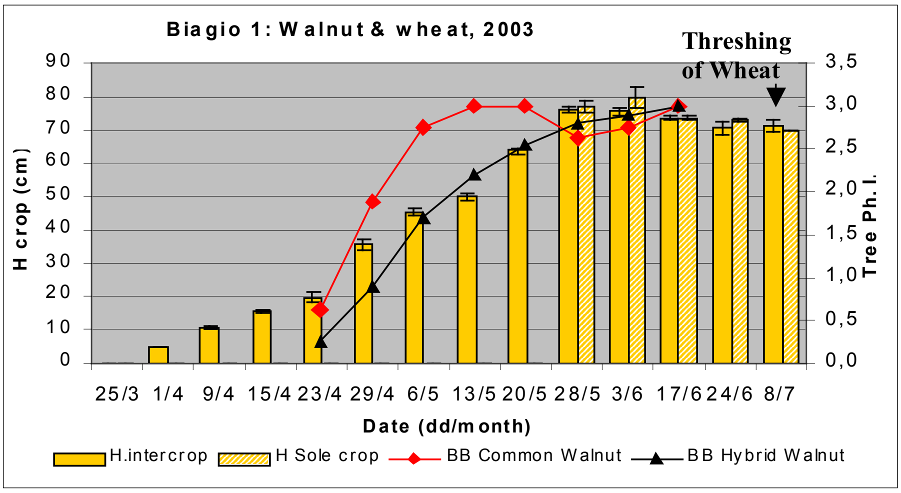


Figure 12: Reduction of maize yield as % of control (green line) and light transmittance as % of background (red line) to the north and south of a typical wild cherry tree at Pamiers.

It was suggested that the high crop yields in the Partner 4 poplar experiment, at least in the early years of tree growth, was possible because winter cereals grown in the UK have finished much of their development before the full emergence of the poplar leaves. A similar effect was definitely observed in the experiments of Partner 6 on walnut in Italy (Figure 13). The growth of clover occurs early in the season, before leaf emergence of the trees. This is particularly true for clover growing under the hybrid walnuts, in which leaf emergence occurs later than in the common walnut. By contrast, wheat grows later in the season than the clover.

The consequence of this earlier growth in clover is shown clearly in Figure 14. Yields of clover under walnut trees are only slightly depressed compared with clover grown away from the trees. In comparison, the wheat grown under the trees had much lower yield than wheat grown as a sole crop. For the clover, at least, the yields were slightly higher under hybrid walnut than under common walnut.

In this experiment the tree rows were mulched with polyethylene, to avoid competition for water and nutrients from plants growing immediately under the trees. Although the effects of shade from the trees on crop yield have been clearly demonstrated, and appear to be the major factor, competition for water and nutrients is also important. Although root pruning was found to have no effect on crop growth at the Vézénobres site of Partner 1 in 2003, the presence of an intercrop can still give rise to below-ground competition that might affect tree growth.



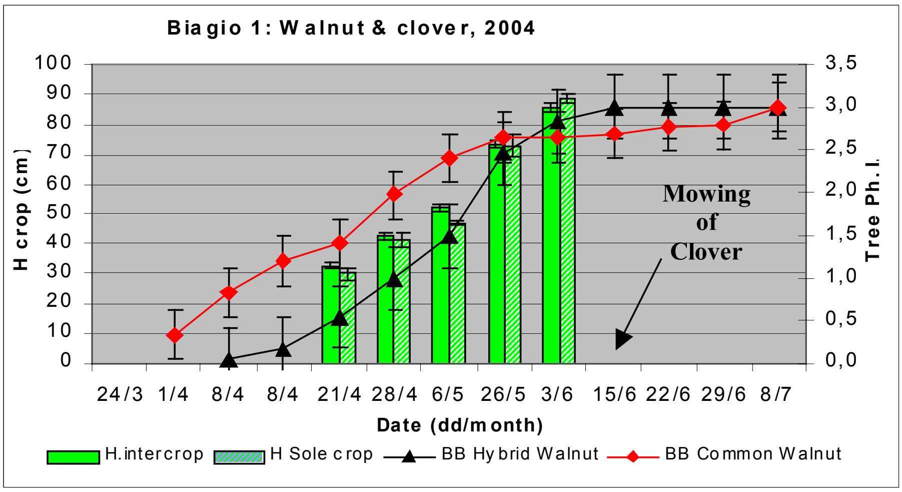
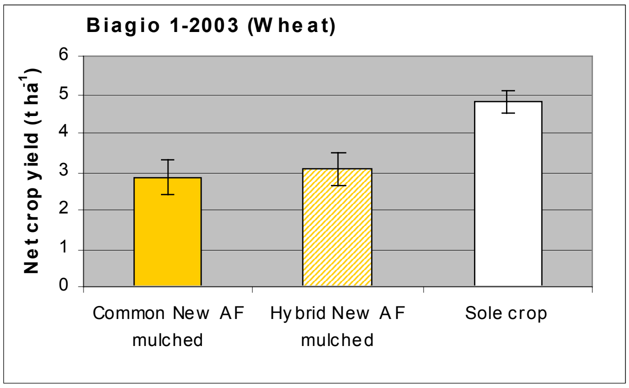


Figure 13. Growth of Walnut/wheat in 2003 (top) and walnut/clover in 2004 (lower) at the Biagio 1 site (Italy) of Partner 6. The phenological stages of common walnut (red line) and hybrid walnut (black line) are shown, together with the height of the crop (orange wheat, green clover, hatched sole crop, plain intercrop) during the spring and summer.



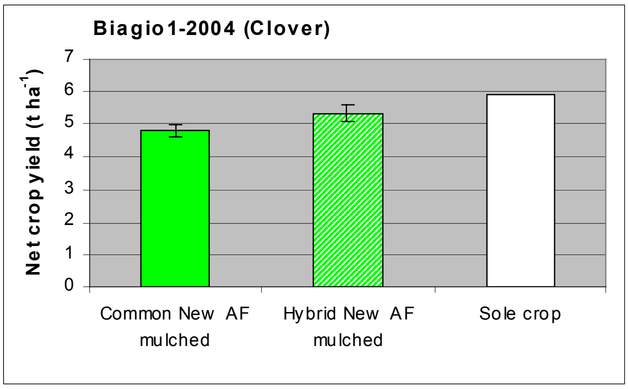


Figure 14. Yield of wheat (upper) and clover (lower) under common walnut, hybrid walnut and as a sole crop in the Biagio 1 site of Partner 6.

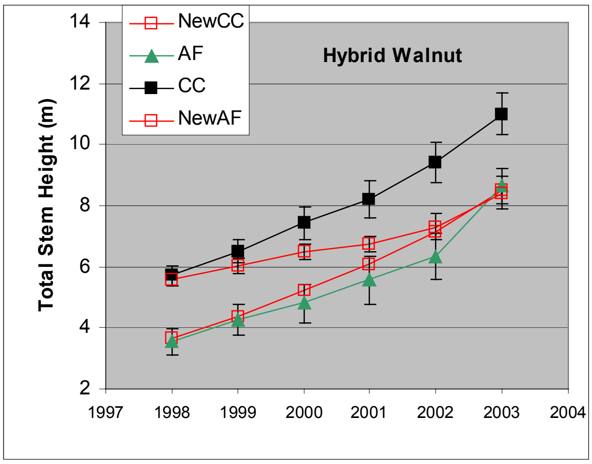


Figure 15. Tree heights of hybrid walnut in the Biagio site of Partner 6, trees in agroforestry continuously (AF), in continuous tillage of the land between them (CC), trees in which continuous tillage was imposed in 1998 on areas previously used for agroforestry (new AF) and trees in which crops were grown under them from 1998, having been previously subjected to continuous tillage (new CC).

The walnut trees at the Partner 6 sites grew better when the land underneath them was kept continuously tilled than when crops were grown in agroforestry. In 1998 half of the treatments were reversed, so that crops were introduced under trees previously kept free of plants and some of the agroforestry trees were switched to continuous tillage. It can be seen from Figure 15 that there was a dramatic change in growth of the trees, with those of the new agroforestry treatment slowing in growth and those kept free of plants for the first time increasing in growth rate.

This effect of competition from surrounding plants on tree growth was also apparent in the experiments of Partner 6 on mulching. Stem growth of walnut trees was higher with polyethylene mulching along the row than without (Figure 16).

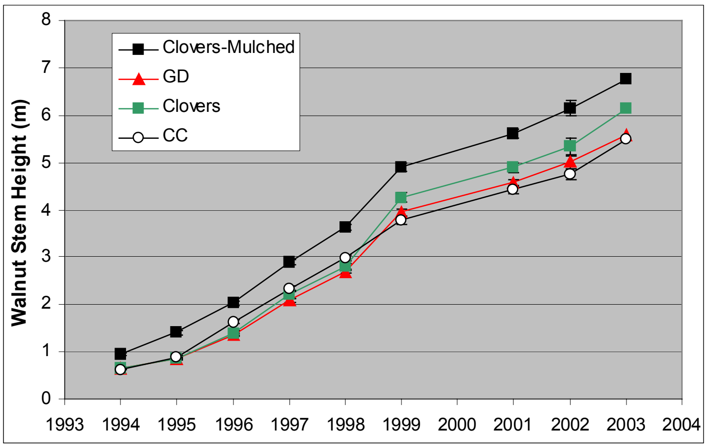


Figure 16: Growth of common walnut with continuous tillage between the trees and bare understorey (CC), grassing down between the trees and bare understorey (GD), clovers between the trees and bare understorey (clovers) and clovers between the trees and mulched understorey (clovers-mulched) at the Biagio 2 site, Italy, in 2003.

The agroforestry treatment of common walnut associated with clovers and with plastic mulching along the tree line gave the best stem growth rate. This was due to the associated action of plastic mulching and the intercropping with a cool season legume crop. Where the experiments with wheat had shown big effects on tree growth due to the competitive nature of the wheat, here tree growth without plastic mulching was still better than the control trees when clover was grown between the trees.

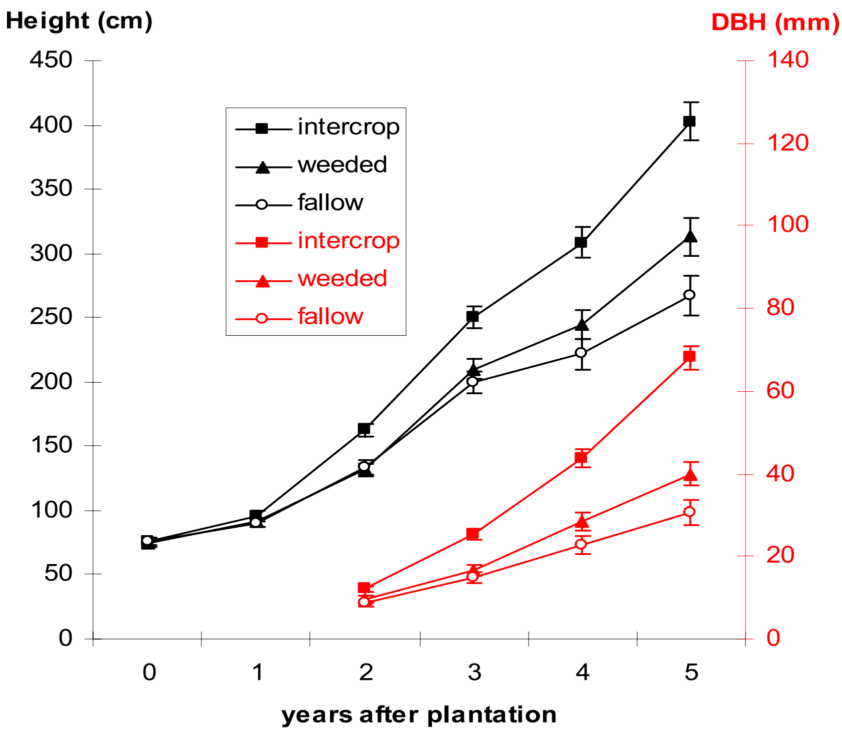


Figure 17: Growth (stem height and diameter at breast height) of hybrid walnuts at Grazac, France.

In some instances intercropping may actually promote tree growth, as can be seen for the growth of hybrid walnut at the Grazac site of Partner 1 (Figure 17). Here the presence of an intercrop not only gave better tree growth than where the alleys were left fallow (i.e. natural vegetation, including competitive weed species, was allowed to grow) but also than where the alleys were weeded with herbicides. A similar effect was seen for wild cherry, although in that case there was less difference between the fallow and weeded treatments.

This positive effect of the intercrop may possibly be explained in terms of nutrient availability. Rather than competing for nutrients could the intercrop make nutrients more available for the trees? When this was examined it was found that nitrogen was present in the leaflets of the trees with intercrops at higher concentrations than in the trees by the weeded alleys, and to a small extent sulphur also (Figure 18). However, for potassium there appeared to be a higher concentration in the trees by weeded alleys than in those grown with an intercrop.

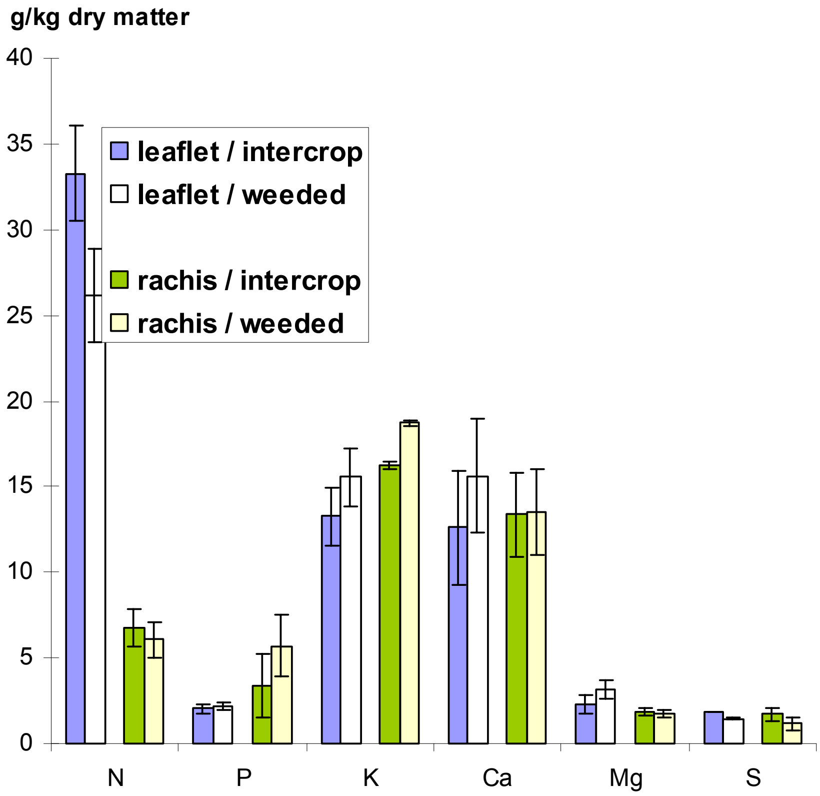


Figure 18: Concentrations of N, P, K, Ca, Mg and S in leaves of hybrid walnut trees at Grazac, France, in 2002. The intercrop was sunflower.

In the poplar/field bean treatment of Partner 5 at Silsoe in the UK in 2003 it was found that both fine roots and coarse roots extended out to the middle of the arable alleys, a distance of 5 metres from the trees. Bean yields in the alleys were only 208-475 g m^{-2}, compared with 501 g m^{-2} in the control plots, so here too competition for nutrients could have been affecting crop yields, as well as shade from the trees. There was a negative correlation between root density and both number of pods per plant and number of seeds per pod, indicating that there was poorer growth of the plants. Measurement of soil moisture content showed little difference between the cropped alleys and the control plots down to 1.6 metres depth, but water use was substantially greater between 1.6 -3.2 metres depth in the alleys than in the control areas. It is possible that competition for water affects crop growth as well as competition for nutrients and shading by the trees.

Partner 7 carried much of the work on oak out. Here the systems of isolated trees in Dehesa had been established for many years before the experiments started, so precluding the provision of data with control values of trees with the same management treatments except absence of crops. The initiation of experiments on the El Baldio farm gave the possibility of setting up particular treatments with relevant controls, and measurements were carried out here for parameterisation of the models. This work is described in more detail in the aboveground and belowground modelling sections of the report. Work of Partner 10 on an oak/durum wheat system in Greece showed the effects of the trees on crop growth. In measuring components of crop yield at 2, 5, 10 and 20 metres from the trees they found that in a westerly direction from the trees plant density increased up to 5 metres from the trees and density of ears, grains per ear and thousand grain weight increased up to 10 metres from the trees. A similar trend was seen in an easterly direction from the trees, except that plant density and ear density increased up to 10 metres, grains per ear increased up to 10 metres and thousand grain weight increased up to 20 metres from the trees.

WP4: Modelling above-ground tree-crop interactions

WP4 main results covered the following aspects:

- Field characterization of tree and crop competition for light
- Delivery of a 3D light competition module for the Hi-sAFe detailed process-based model
- Delivery of a tree growth module for the Hi-sAFe detailed process-based model

Characterisation of tree and crop competition for light

This was achieved mainly by detailed recording and modelling of the tree phenology and tree canopy volume, and by the characterisation of the light competition using hemispherical photographs. In this synthesis report, we will emphasise the light competition aspects. More data on tree phenology are available in the annual reports.

Measurement of light availability with hemispherical photographs

The common SAFE protocol for measuring light competition in silvoarable systems was designed during the second year of the project, and is described in the second year report. Hemispherical photography is a powerful tool for analysing radiation transmission by tree canopies. Photographs are taken below the canopy in the zenith direction, so that the sky vault is shown on the photograph. Light transmission is computed from counts of sky pixels in the image. This technique is used in the SAFE project to estimate the spatial distribution of light available to the understorey crop.

The common protocol for hemispherical photographs has been applied in the following experimental sites of the SAFE project during the 2003 and/or 2004 growing seasons: Restinclières (INRA-SYSTEM), Vézénobres (INRA-SYSTEM), Grazac (INRA-UAFP), Biaggio (CNR), Silsoe (CRAN) and El Baldio (UEX).

At INRA-SYSTEM

The results of the hemispherical pictures taken in 2003 were already available in the second year report. These results evidenced the striking difference between plots with a North-South tree row orientation (homogeneous light availability) and plots with an East-West tree row orientation (very heterogeneous light availability).

In 2004, more hemispherical pictures were taken at the Vézénobres experimental plot. A high pruning experiment was set up in April 2004 comparing the standard pruning regime (7 m) to an extreme high pruning regime (10m) (Figure 19). Hemispherical pictures were taken in May and June 2004, during the end of the growing season of the wheat intercrop.

Figure 19: The two different regimes of pruning height compared at the Vézénobres experimental plot (7 versus 10 m height)

The pruning regime had a strong impact on light availability on the cropped zone. The 10 m height pruning regime maintained a 50% light availability on the cropped zone. The 7 m height pruning regime resulted in only 30% light availability with East-West oriented trees, and 42% with North-South tree rows. The more vigorous trees in the East-West plot probably explain the difference.

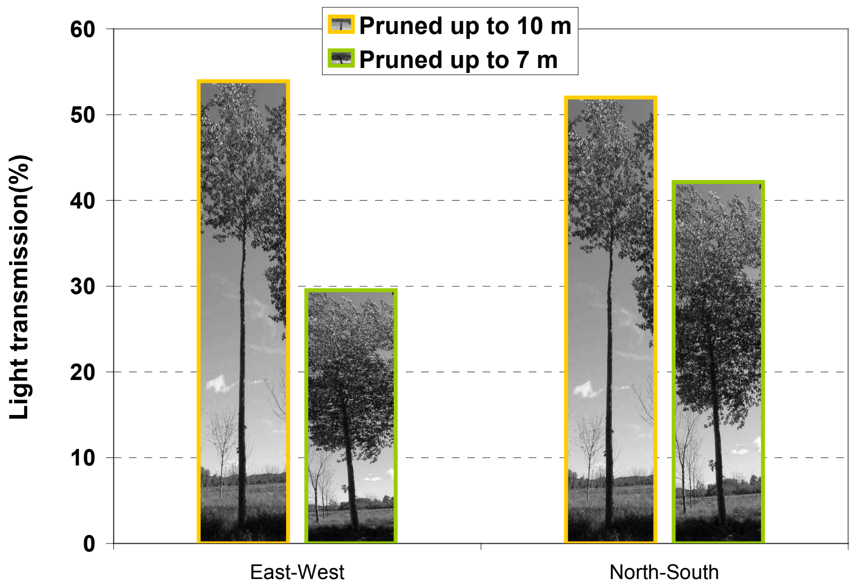


Figure 20: Impact of the pruning height on the average light transmission in June 2004 on the cropped zone in the Vézénobres experimental plot for two tree row orientations

With East-West oriented tree rows, a strong variability of the light availability is evidenced across a North-South transect. The pruning impact is more striking on the Southern side of the tree row.

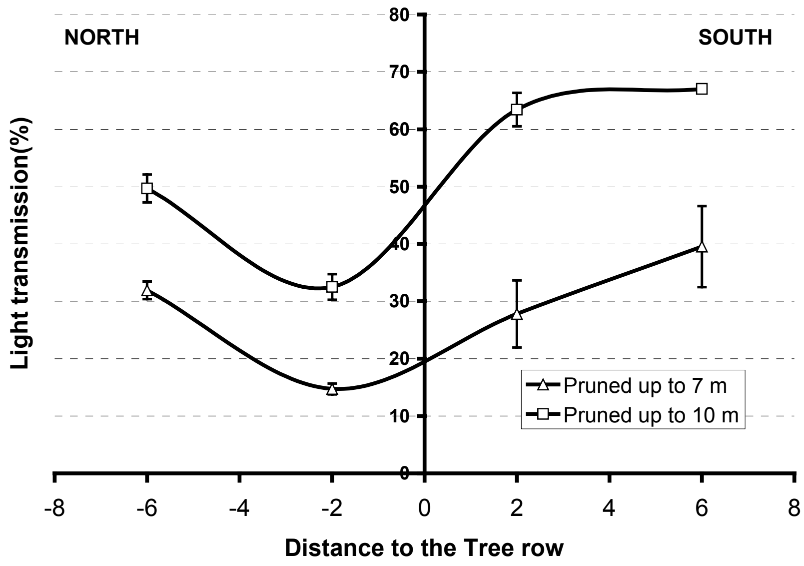


Figure 21: Light availability across a North-South transect in June 2004 (Vézénobres experimental plot)

With North-South tree rows, the light availability is very uniform across the plot, and the intensive pruning allows 10% more light to reach the cropping zone.

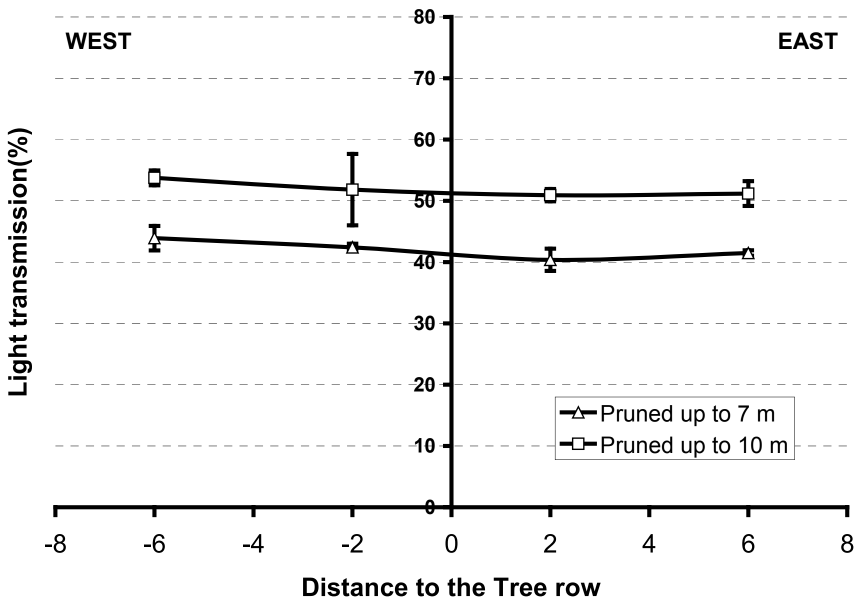


Figure 22: Light availability across an East-West transect in June 2004 (Vézénobres experimental plot)

In 2004, no hemispherical pictures were taken at the Restinclières plot. The walnut plots were thinned and pruned, and the light interception by the remaining 100 trees/ha was considered insufficient to warrant a measurement effort.

At INRA-UAFP

In addition to the hemispherical pictures taken in 2003 at three experimental sites (Grazac, Pamiers and Les Eduts) and 4 periods, INRA-UAFP also documented the light interception of the 4 walnut trees cut at Les Eduts in February 2004. Winter pictures were useful to measure the light interception of the woody parts of the trees in winter. The common SAFE protocol was applied (18 pictures per tree). A total 1476 pictures are available.

Site	Tree species	Year	Date of the photographs (Day Of Year)			
Grazac	Wild cherry	2003	156	210;214	251;252	351-353
	Hybrid Walnut		-----------	210;212	251;252	351-353
Pamiers	Wild Cherry		156	210	252;258	343
Les Eduts (n° 1 to 6)	Black Walnut		168	211;212	260;261	349;350
Les Eduts AF1, AF2 F1, F2		2004	47	-----------	-----------	-----------

Table 8: The hemispherical photographs calendar in 2003-2004 by INRA-UAFP

All the photographs have been processed with GLA and Surfer8 softwares. GLA outputs and the 82 Surfer pictures are available on the common SAFE disk in the Gavaland file.

Figure 23 displays the irradiation under a walnut tree at the Les Eduts farm. Asymmetries are the results of both the tree canopy dissymmetry and of the variability of the surrounding trees.

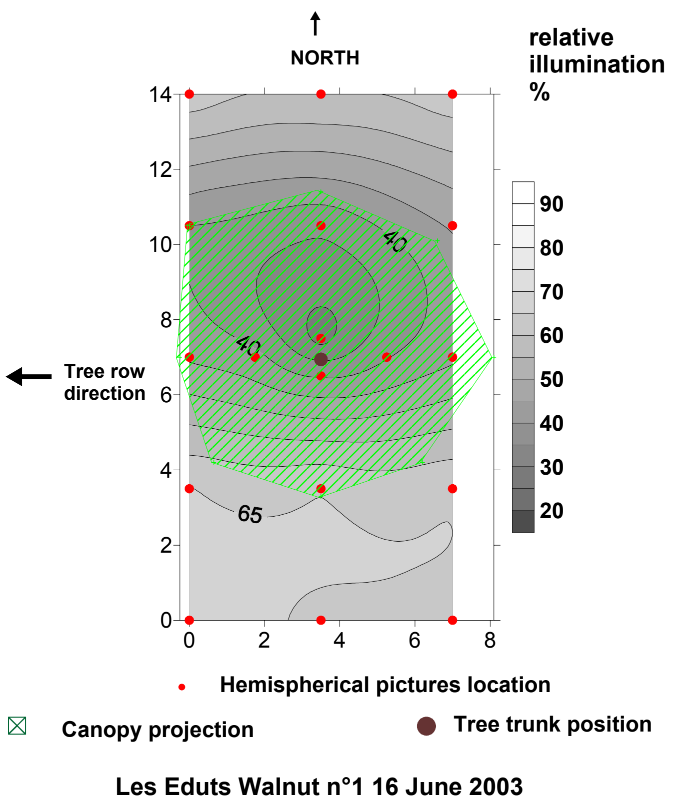


Figure 23: The map of the available illumination below a walnut tree at the Les Eduts farm in June 2003 (interpolated with the SURFER software from the 18 hemispherical pictures)

Figure 24 features the dynamics of light availability during the year. The shade of the woody parts of the tree in winter is not negligible (32 m² get less than 90% relative radiation, and 4 m² less than 80%). This may be significantly effecting the winter crops as the level of irradiation in winter is low. It was introduced in the Hi-sAFe model.

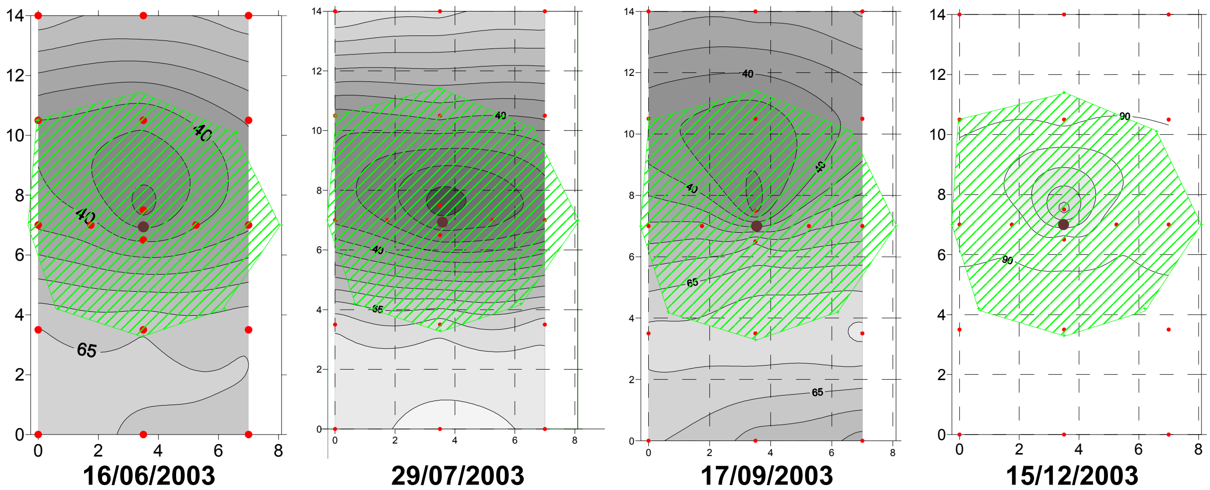


Figure 24: Dynamics of the irradiation in a walnut tree stand at the Les Eduts farm in 2003. The right image shows the winter shade of the woody parts of the tree

The detailed analysis of the radiation available under the trees show that in some circumstances, an increase in the relative light available may occur at the end of the summer. The explanation for this increase is not yet clear and is being investigated.

In the young silvoarable experiments (4 < tree height < 5 m), the average light transmission is around 80% during the summer. In the mature agroforestry systems (Les Eduts and Pamiers, tree height between 9 and 12 m), the average light transmission is between 60 and 70% during the summer. Wild cherry is intercepting less light than walnut, but a more precise comparison is required.

At UEX

UEX investigated the light availability in the Dehesa silvoarable system (scattered oak trees) by taking 577 hemispherical pictures at the El Baldio farm in Spring 2003. The study involved 28 trees covering all size classes, and 24 pictures per tree (6 in each cardinal direction at 0.5, 1, 2, 5, 10, 20, 30 m from the trunk). The light transmission was calculated for the growing season of the grasses (1 November to 31 May). We then tried to predict the intercepted radiation (*I*, %) with simple indicators such as *DBH* (cm), canopy width (*Cw*, m) and distance from the trunk (*D*, m) by multiple regressions. We also fitted allometric equations to predict DBH and Cw from tree age.

Transmitted radiation was best predicted by canopy width. The percentage of transmitted radiation was close to 100% at distances farther than 20 m, irrespective of tree size. The increase of transmitted radiation with distance was exponential, regardless of the orientation and tree size, indicating a rapid increase in the light availability with the distance. Local light interception was well predicted by distance to the tree trunk (*D*), *DBH*, and canopy width (*Cw*):

$$I = (19.32 / (1+64.4 * e^{-0.62*DBH})) * (17.96 / (1+5.82 * e^{-0.05*Cw})) * 1.26^{-D}; \ (R^2 = 94.4\ \%)$$

The intercepted radiation by trees was mapped using an interpolation software (SURFER), considering different scenarios based on tree density and age. Figure 25 displays an example of simulation (75 year-old trees, 25 trees per ha). Figure 26 summarises the averaged radiation interception for the different scenarii.

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

$$\boldsymbol{I = 0.297 * Dens^{0.641} * A^{0.521};} \qquad \mathbf{(R^2 = 92.89\%;\ n=30)}$$

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

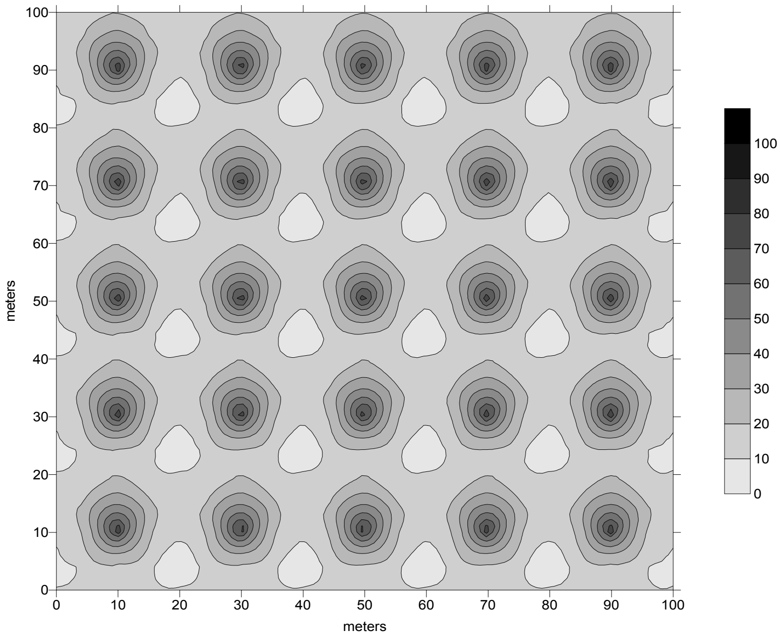


Figure 25: Map of intercepted radiation in a 25 trees/ha 1 ha square plantation of Holm-oak 75 year-old.

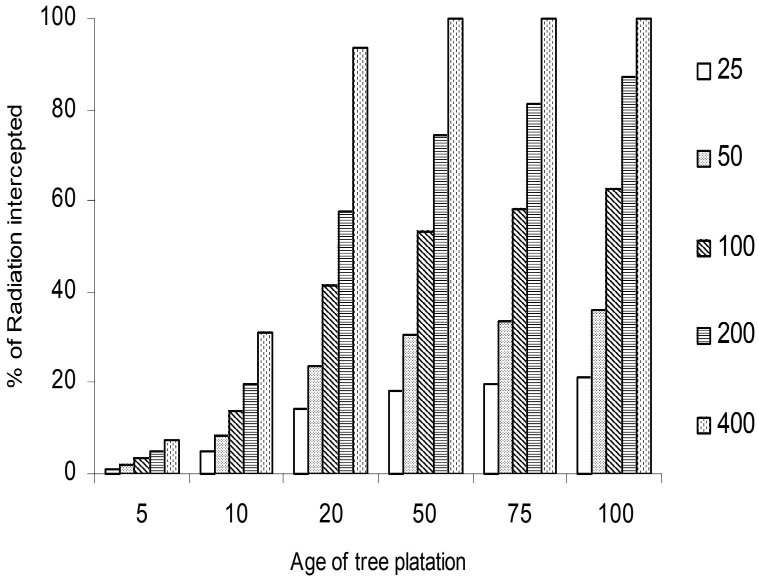


Figure 26: Percentage of intercepted radiation related to tree age for different densities of plantation (25 to 400 trees per ha)

The present model is a simple tool to determinate the light availability for understorey in Dehesas of Holm-oak from very easy measurement (DBH). The amount of available light for understorey is highly dependent of the tree age and density because light reduction is only significant in the close vicinity of the trees. These data will be used for validating the Hi-sAFe light module for Holm oak.

At CRAN

Hemispherical pictures were taken at four different periods in May, June, August and October 2003 in the Silsoe poplar experimental plot. The common SAFE protocol was applied with 18 pictures per tree to the three poplar clones.

The late leafing Gibecq clone intercepted less radiation than Beaupré and Trichobel in May (11% vs 32%). In June and August, Gibecq intercepted more radiation than Beaupré and Trichobel (60%, 56%, 43% respectively in August). Note that the slow growing Gibecq clone is no longer pruned since 2000, and this may explain its higher light interception. Trichobel started to loose its leaves later in autumn, resulting in a higher light interception in October. Significant differences in the diffuse/direct ratio were evidenced for the different clones.

From all the documented SAFE experimental sites, the Silsoe poplar experiment displays the highest light interception by the trees (mean radiation available during the crop growing season = 60%). Light interception is also almost homogeneous in the stand: this is due to the North-South orientation of the tree rows, and was also described at Vézénobres.

At CNR

Hemispherical pictures were taken in August 2004 at the Biagio experimental farm in two walnut plots. The relationship between light interception and tree stand basal area was then studied. The trees had completed their leaf area at the time of taking the pictures. In plot1, the SAFE common protocol was applied with only 9 pictures per tree (due to the high tree density). In plot2, only one picture per plot was taken at the mid-point between 4 trees (square plantation design).

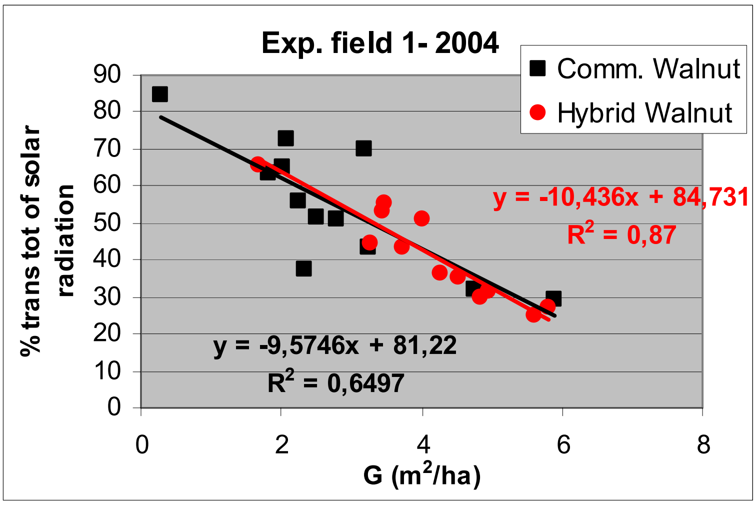


Figure 27. Relationship between walnut stand basal area (G) and the percentage of the total solar radiation transmitted below the walnut canopy (Experimental plot 1).

The relationship between light transmission and stand basal area was very significant, and similar for both common and hybrid walnuts (Figure 27). However, no significant relationship was found between the summer light reduction and the clover intercrop yield. This is not surprising, as clover is a cool season growing crop, that do not experience much light competition from the walnut trees between November and May. Clover is therefore a recommended intercrop in a mature walnut agroforestry system.

Building architectural simulation mock-ups for the three tree species

In the SAFE project, INRA-AMAP was to build detailed simulation mock-ups of trees, to help calibrate the tree-crop models. Detailed mock-ups of three important tree species for SAFE were to be provided, based on measurements in experimental situations. These mock-ups were then to be used as reference descriptors of use of space by trees, in order to test the validity of the Hi-sAFe model. The species to be studied in detail are Prunus avium, Populus sp., and Juglans nigra x regia.

AMAP methodology has been briefly described in the first year report (p 105). In the first year, data collection and parameter estimations had been performed for Wild Cherry and Hybrid Walnut. The main results of the second year concerned AMAPsim parameters. In the third year, the parameters for AMAPsim tree simulations were improved (especially for hybrid walnut), and the 3–D tree mock-ups were used for validation of more general models. Three main validation processes were implemented:

- One individual hybrid walnut tree (tree 2-16 of the Restinclières experimental plot) was completely described and digitised to serve as support for the many ecophysiological studies undertaken mainly by the INRA UMR-SYSTEM team on this same tree.
- On hybrid walnut, hemispheric photographs were compared between digitised tree mock-ups and the real trees.
- Simplified crown descriptions were tested on AMAPmod mock-ups for hybrid walnut

AMAPsim parameters for Juglans nigra x regia

In this paragraph, we present results, which will be useful to calibrate mock-ups of hybrid walnut in AMAPsim software. These results were obtained for one digitised tree (#11-33 located in forestry control plot of the Restinclières experimental farm) using AMAPmod software.

The AMAPsim parameters depend on many variables, measured in the field and tested against several relatively simple statistical laws. Hybrid walnut is a very complex species, with a high variability, and the first and second year results were still too uncertain to produce satisfactory results. Many additional observations were necessary. The field observations have now been completed, and the distributions are being studied for implementation in the AMAPsim model. The following figure shows an example of one Hybrid walnut tree, measured at 7, 8, and 9 years, where we can distinguish the different annual shoots (only the last 3 annual shoots are represented here).

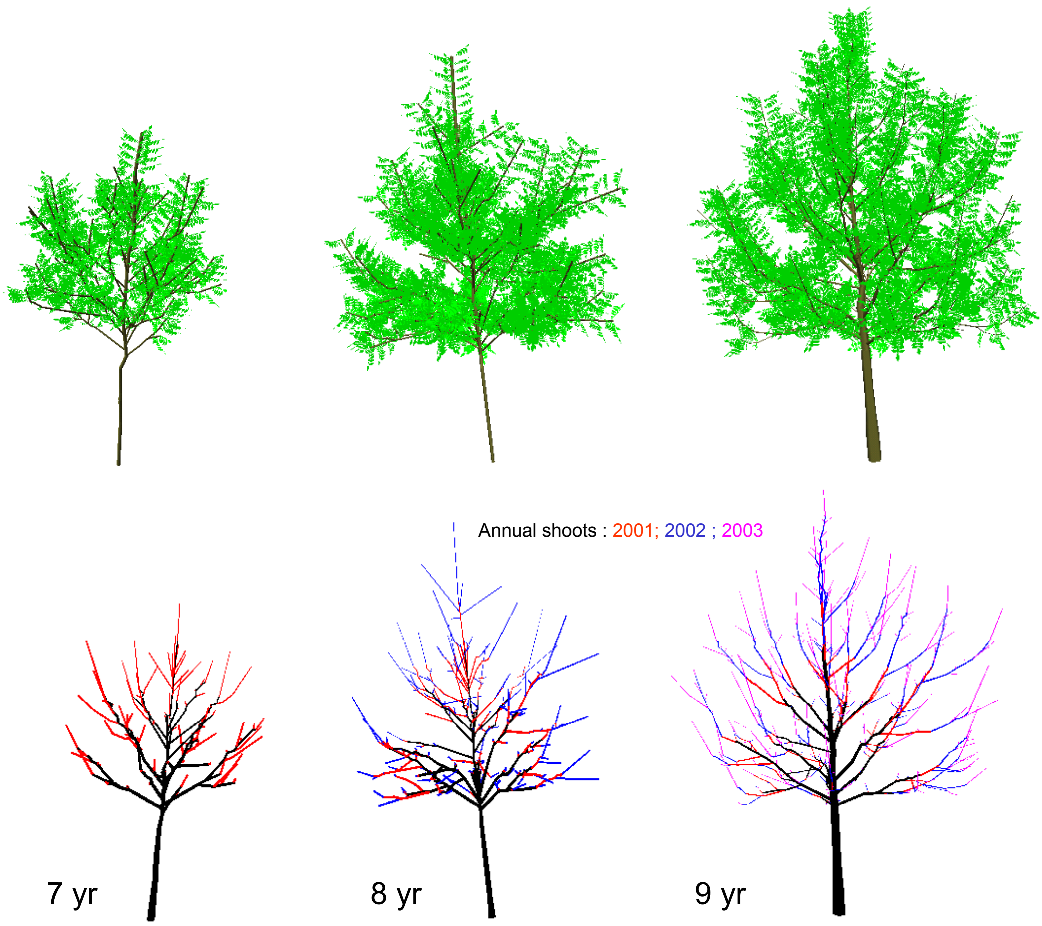


Figure 28: Digitised mock-ups of hybrid walnut 11-33 (Restinclières experimental farm) for three consecutive years (7 year = 2001)

A correct prediction of the shoot length of the walnut trees require to describe accurately the number of internodes per shoot and the internodes length. Detailed studies of these variables are available in the INRA-AMAP contractor report (SAFE third year report volume 3).

Digitised Juglans nigra x regia tree #2-16

The hybrid walnut tree # 2-16 (agroforestry plot A4, Restinclières) is an important reference tree in the experimental design. Many measurements are performed on this tree, mainly by the INRA UMR-SYSTEM team (leaf area, leaf N content, soil water content, water potential, sap flow measurement, root coring, hemispheric photographs). This year the tree was described entirely: i) topology, ii) geometric description (digitising) at the shoot scale , iii) diameter measurement of the axes.

The figures below show a photograph of tree 2-16, and the first representation of the mock-up. Some digitising errors are still to be corrected (Figure 29). The results are being coded for further interpretation and use with the physiological data.

Figure 29: Digitising the agroforestry hybrid walnut 2-16 in April 2004 and first image of the digitised tree.

Tree mock-up validation for Juglans nigra x regia

The figures below show a photograph and the digitised mock-up for hybrid walnut tree #10-33 (Restinclières). The general visual aspect of the mock-up serves as a first validation test.

Figure 30: Simple validation of the walnut trees mock-up on a different tree. Here walnut 10-33 (Restinclières forest plot A4). Left: photograph; Right: virtual mock-up

Concerning transmitted radiation, one validation technique consists in comparing observed and simulated values of light porosity under the crown. Hemispheric photographs were simulated in a similar way under the virtual crown of a tree mock-up (tree #11-33), with the POV-Ray software. These were then compared with real hemispherical pictures in terms of light porosity .

The first results show that the gap probability of the simulated mock-up is higher than measures under the real tree (Figure 31). The area and geometry of leaves should therefore still be improved. A further study of leaf geometry will be performed shortly by digitising a sample of walnut leaves.

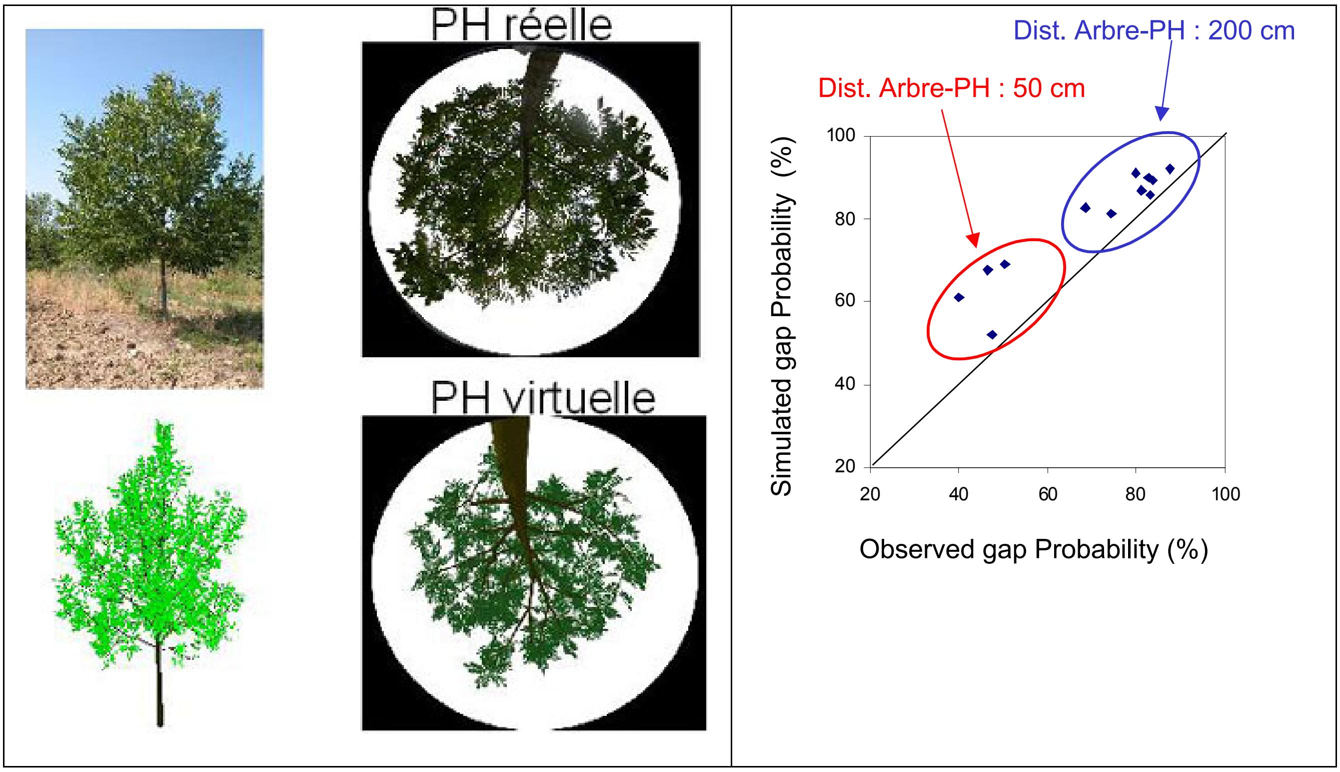


Figure 31: Comparing actual and virtual hemispherical pictures to test the value of the walnut mock-ups for light porosity

Simplifying the representation of the crown of Juglans nigra x regia

Three-dimensional architectural mock-ups of trees measured at a very fine scale (with detailed topological and geometrical description of all the shoots) can help calibrate simpler models. In Hi-sAFe the tree crowns are represented as ellipsoids. On 3-D architectural mock-ups we have compared the foliage "apparent volume" of an ellipsoidal representation of the entire crown and of several more detailed representations at various scales. We can thus estimate the potential error, and/or bias, linked to the computation of "foliage volume" when using different representations of the tree crown. This can if necessary provide correction factors, according to the level of detail required.

Several models have been tested to estimate the envelope of the crown (figure below). This work has been undertaken with the AMAPmod software (Godin et al., 1999[1]), using tools developed by Frederic Boudon (2001[2], 2004[3])

[1] Godin, C., E. Costes, Sinoquet H. (1999). "A method for describing plant architecture which integrates topology and geometry." *Annals of Botany* **84**(3): 343-357.

[2] Boudon F, Pradal C, Nouguier C, Godin C, 2001. *GEOM module manual. I. User guide*. Doc Programme Modélisation des plantes, 4-2001. CIRAD-AMAP, Montpellier, France, 600p.

[3] Boudon F, 2004. *Représentation géométriques multi-échelle de l'architecture des plantes*. Thèse de doctorat, Université Montpellier II, AMAP, 176p.

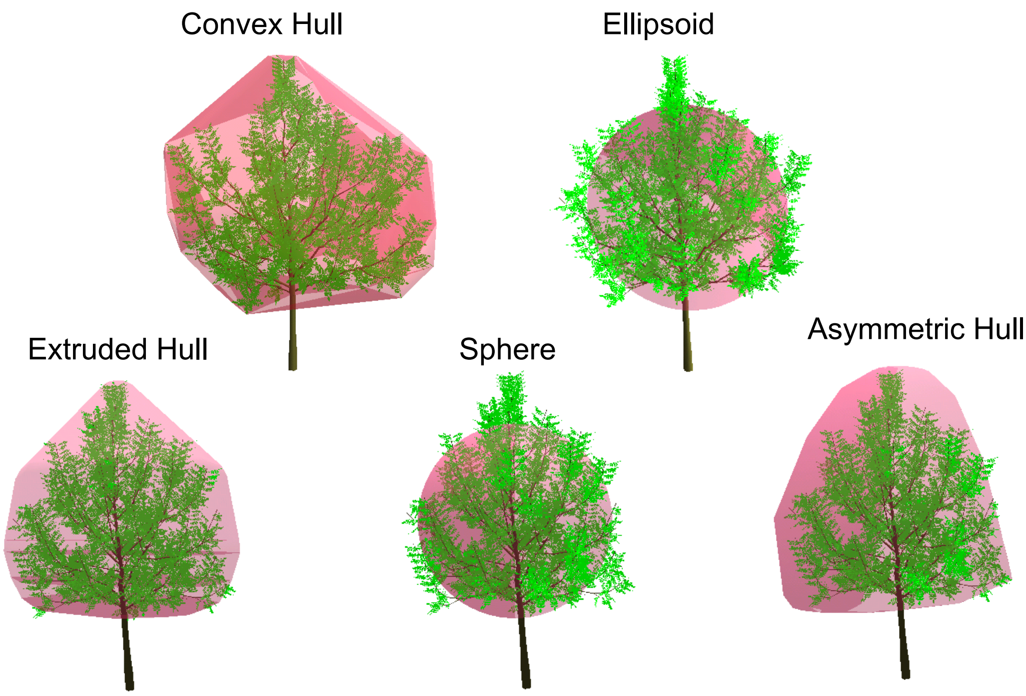


Figure 32: Various models available for defining the crown volume of a tree

According to the form chosen, the envelope of foliage can then be represented at different scales.

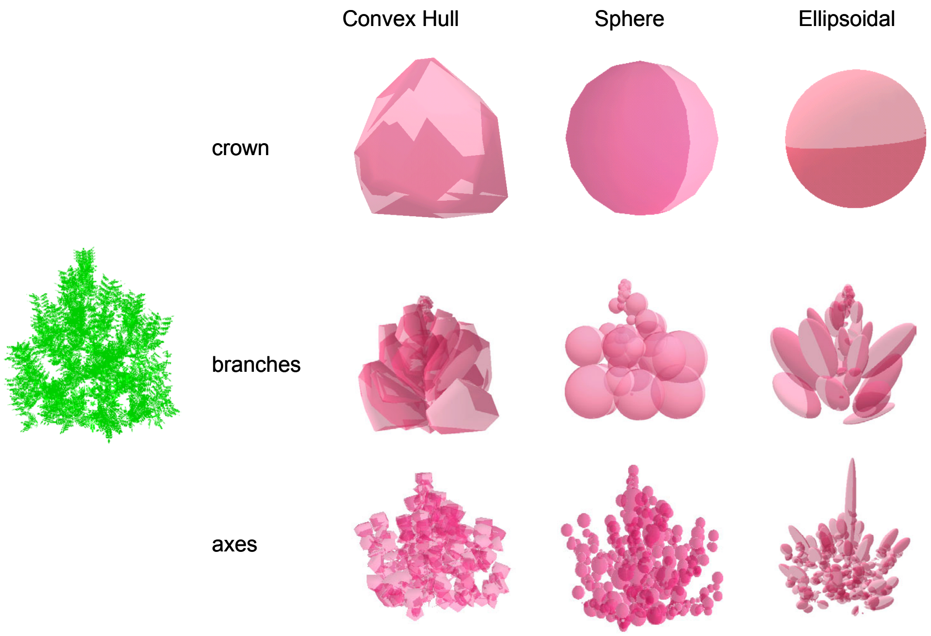


Figure 33: Simplifying the crown volume using three different unit volumes

The next figure shows the different scales of representation of a walnut tree crown, using the ellipsoidal form.

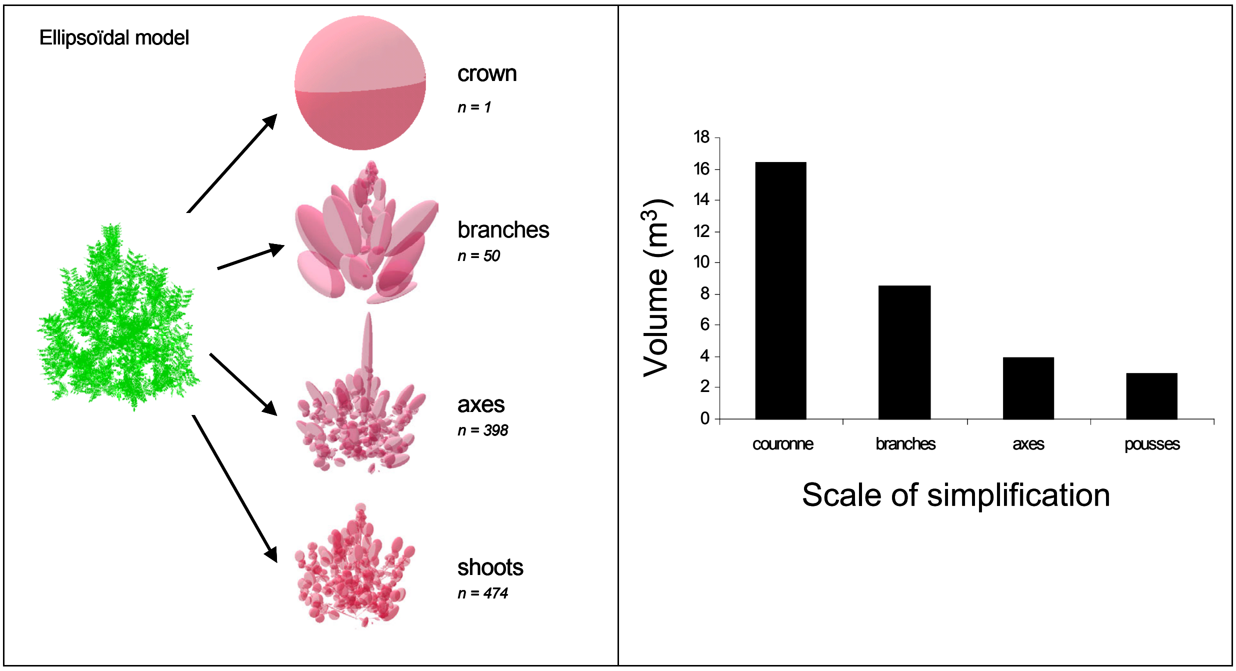


Figure 34: The actual volume of the canopy decreases with the level of decomposition in elementary units

The Hi-sAFe light competition module

The tree light interception module is fully described in Deliverable 4.1. The radiation interception module is aimed at computing:

- Incident radiation available to the crop canopy: This is the spatial distribution of the transmitted radiation below the tree canopies. The crop canopy is divided in rectangular cells in the Hi-sAFe scene. The radiation competition module compute incident radiation above each cell at the day time-step..

- Radiation intercepted by each individual tree defined in the scene: Note that the scene could include only one tree. The radiation competition module is able to predict the tree to tree competition for light as well as the tree to crop competition for light.

The radiation model provides inputs for the carbon acquisition module, the water consumption and the canopy microclimate modules.

Above-ground modules in Hi-SAFE

(Tree phenology, tree C allocation, tree light interception, microclimate)

Deliverable D.4.1 (SAFE European Research contract QLK5-CT-2001-00560)

Silvoarable Agroforestry For Europe (SAFE)

Christian Dupraz, Grégoire Vincent, Isabelle Lecomte, François Bussière, Hervé Sinoquet

August 2004

This module was derived from the Courbaud's light model (MOUNTAIN, 2003). It is written in Java. This model had been developed for spatially heterogeneous coniferous forest canopies. Based on the interception of light rays by parabolic crowns, it calculates simultaneously the energy intercepted by each tree and the distribution of light reaching the ground. Slope and exposure are taken into account as a function of the distribution of incident light rays. An optimisation process that reduces the computing time needed to find trees which intercept a ray and to manage plot boundaries was developed.

Important modifications to Courbaud's model have included:

- the use of Goudriaan's expression (1977) for the extinction coefficient. For a given beam direction Ω, the transmission T of light within a crown is computed from Beer's law as:

$$T = \exp(-K \cdot D \cdot L) \quad (1)$$

Where the extinction coefficient K is modelled as:

$$K = G \cdot \sqrt{\alpha} \quad (2)$$

D is leaf area density within the tree crown ($m^2\ m^{-3}$). L is length on the beam path within the tree crown (m). L is computed from geometry principles, from the intersection points between the crown envelope and the beam line. G is the projection coefficient of leaf area, which depends on both foliage inclination distribution and direction Ω. α is the leaf absorptance in the PAR (Photosynthetically Active Radiation) waveband (400-700 nm).

Note that beams are regularly spaced, so that a given beam represents a small area A_b. Average light interception $\bar{I}_\Omega$ by a tree is therefore expressed in square-meter, i.e. as interception area of the tree

$$\bar{I}_{\Omega} = \sum_{Beams}(1-T)\cdot A_b \qquad (3)$$

- The sky discretisation according to the turtle concept (Den Dulk, 1989) in order to shorten the number of computed directions and then time computation. The sky vault was characterised by a set of 46 directions.

- The computation of both sunlit and shaded leaf area: This is useful since the photosynthesis response to light is not linear. Computation is based on the following equation (see e.g. Sinoquet et al., 1993)

$$\bar{I}_{\Omega sun} = K \cdot D_{sun} \cdot L \qquad (4)$$

Equation (4) simply means that leaf area intercepting light in the sun direction is the sunlit leaf area.

In order to save more time, light computations are run only when:

- Trees are leafy.
- The daily sun course significantly changes, i.e. every 2-3 days near the equinox and every 10 days near solstices. Sensitivity analyses could be performed in order to fit the time interval between light computations.
- Tree structure shows significant changes, in terms of tree dimension and leaf area.

Finally the model outputs are PAR interception by each tree in the vegetation scene and PAR transmission to each crop zone, both for diffuse radiation and direct radiation at 5-11 time steps per day. As radiation variables are proportional to incident radiation, only relative values (i.e. assuming that incident diffuse and direct radiation is equal to 1) are stored in memory. They can therefore be used several days showing different conditions of incident radiation, as long as the sun course or the canopy structure does not significantly change. For each time step, sunlit and shaded areas of each tree are also computed.

The light module was modified to cope with both paraboloids and ellipsoids to represent the tree crown shape. Actually, ellipsoids are more adapted to simulate interception of light by non-symmetric crowns. In nature, these deformations appear when trees are touching neighbours on the tree line. This will enable Hi-sAFe to simulate accurately the tree-tree interaction. When two tree canopies are touching, the tree canopy will grow only in the free direction, resulting in non-symmetrical canopies (Figure 35).

Figure 35: In a mature agroforestry plot, tree canopies are heavily distorted by the tree-tree competition on the tree row. Here, the poplar canopies are 4 m wide along the tree row and 12 m wide across the tree row. Tri-axial ellipsoids are perfectly suited to represent such distorted canopies.

Further improvements were implemented, such as the possibility to compute the direct radiation interception at a variable number of times during the day. This is useful for managing scenes with narrow canopy trees (such as poplars). With such narrow canopies, some cells escaped the beams and this resulted in strange maps of daily direct irradiance on the crop.

Interactions between trees and crops through the modification of the microclimate

The current version of Hi-sAFe does include the trees and crops interaction through rainfall interception and stem-flow. But the mutual impact of plant transpirations through air humidity is not yet implemented. A lot of discussions were taking place during the third year of the project on the best strategy to achieve this. We did not reach a final conclusion yet on this very difficult issue. More details are included in the third year annual report.

The tree growth module of the Hi-sAFe model

Conceptualising a new tree growth module was a major achievement of WP4. After a thorough analysis, it was decided not to try to adapt the HyPAR tree growth module. It was considered more efficient to build a new one from scratch. This module was prepared by Dr. Grégoire Vincent from ICRAF and Dr. Christian Dupraz from INRA, and implemented in the Hi-sAFe CAPSIS shell by Isabelle Lecomte. It is presented under task 4.4

In the meantime, many other modules were also improved. The Montpellier biophysical workshop (February 2004) was a key step for implementing these modules.

The tree growth model itself is part of the Hi-sAFe agroforestry biophysical model which is designed to describe a 3-5 years growth period of the tree + crop agro system in a temperate (seasonal) climate on a daily time step. It should be capable of simulating early years of tree development as well as the functioning of large mature trees. It should address pruning or root trenching which are considered to be important management practices to orient the productive outcome of such systems.

The tree growth model predicts the tree response to pruning and models the C uptake by a simple Radiation Use efficiency approach. The maximum RUE is a species-specific constant (g/MJ of intercepted PAR) that is reduced through dimensionless modifiers to take into account water stresses, nutritional stresses and possibly temperature effect.

Two types of rules govern C allocation

- teleonomic (or goal driven) allocation rules based on allometric equations defining the relative sizes of aboveground sub-compartments and below ground sub-compartments. Allometric relationships are supposed to capture internal constraints not explicitly dealt with in the model (e.g. architectural model and structural stability constraints or hydraulic constraints) in relation to the tree dimensions.

- an optimal allocation assumption (‘functional equilibrium’) between above ground and below ground mediated through stress indices, which basically assumes that plant allocates its biomass so as to maximise it’s growth rate under the given environmental conditions.

Various tree phenological stages are considered, which govern the application of different sets of rules for C allocation by switching on and off C sinks. Phenological stage notably determines when NSC pool will act as a sink or a source of C.

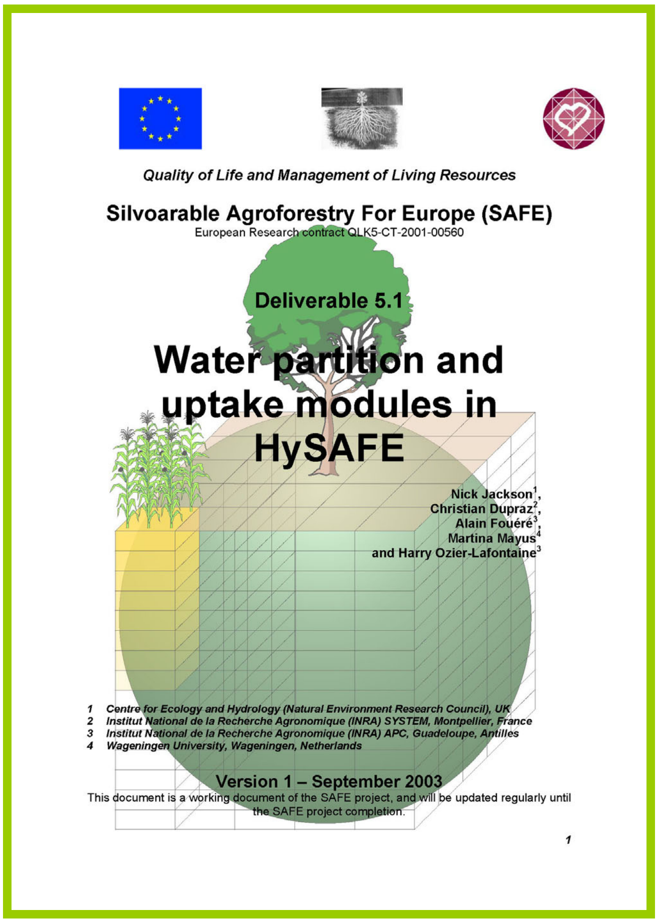
Tree parts considered are the stem, branches (distinction between stem and branches is necessary because of alteration of the branch / stem allometry following pruning), foliage, coarse (structural) roots and fine roots (feeder roots). C partitioning between fine roots and coarse roots is controlled by the root development module and is not dependent on a fixed allometric relation but depends on the tree root geometry, which is adaptive. No distinction between sapwood and heartwood is considered. C and N pools are divided into structural and non-structural pools. N is allocated to the tree parts according to target (structural) N contents.

Relative dimensions of the aboveground part of the tree are forcing functions in the model (except for crown volume which may be altered by pruning) that serve as guides to the distribution of biomass between compartments and in space within compartments.

The model also includes crown shape and crown volume alteration by pruning.

WP5: Modelling below-ground tree-crop interactions

WP5 produced two deliverables: Deliverable 5.1 describes the below-ground competition modules for water and nitrogen, and deliverable 5.2 includes the scientific papers produced about below-ground competition between trees and crops.



Quality of Life and Management of Living Resources

Silvoarable Agroforestry For Europe (SAFE)
European Research contract QLK5-CT-2001-00560

Deliverable 5.1

Water partition and uptake modules in HySAFE

Nick Jackson[1], Christian Dupraz[2], Alain Fouéré[3], Martina Mayus[4] and Harry Ozier-Lafontaine[3]

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Version 1 – September 2003
This document is a working document of the SAFE project, and will be updated regularly until the SAFE project completion.

1

Field evidence calling for a new approach to below-ground competition modelling in silvoarable systems

Most of the results below are obtained from the two following papers produced by the SAFE project

- *Moreno G., Obrador J.J., Cubera E., Dupraz C., 2005. Root distribution in Dehesas of Central-Western Spain. Plant and Soil, accepted for publication*
- *Mulia R., Dupraz C., (2005). Unusual fine root distributions of two deciduous tree species in southern France: what consequences for modelling of tree root dynamics? Submitted to Plant and Soil*

The spatial distribution of fine roots of two deciduous and one evergreen tree species was investigated in contrasting growing conditions in southern France and western Spain. Hybrid walnut trees (*Juglans nigra x J. regia* cv. NJ203) and hybrid poplars (*Populus euramericana cv. I214*) were both cultivated with or without annual winter intercrops for 10 years on deep alluvial soils. Holm oak (*Quercus ilex*) was either intercropped or intergrazed. Fine root distribution of both trees and crops was measured by soil coring down to 2-3-metre depth at several distances and orientation from the tree trunks. The observed root systems of trees were very patchy, and unexpected root profiles were found. In the tree-only stands, fine root profiles followed the common decreasing pattern with depth and distance from the tree trunk. But most intercropped tree root profiles were uniform with depth (Figure 37, Figure 37), and sometimes-inverse profiles were found (i.e. significantly more roots at depth than next to the surface).

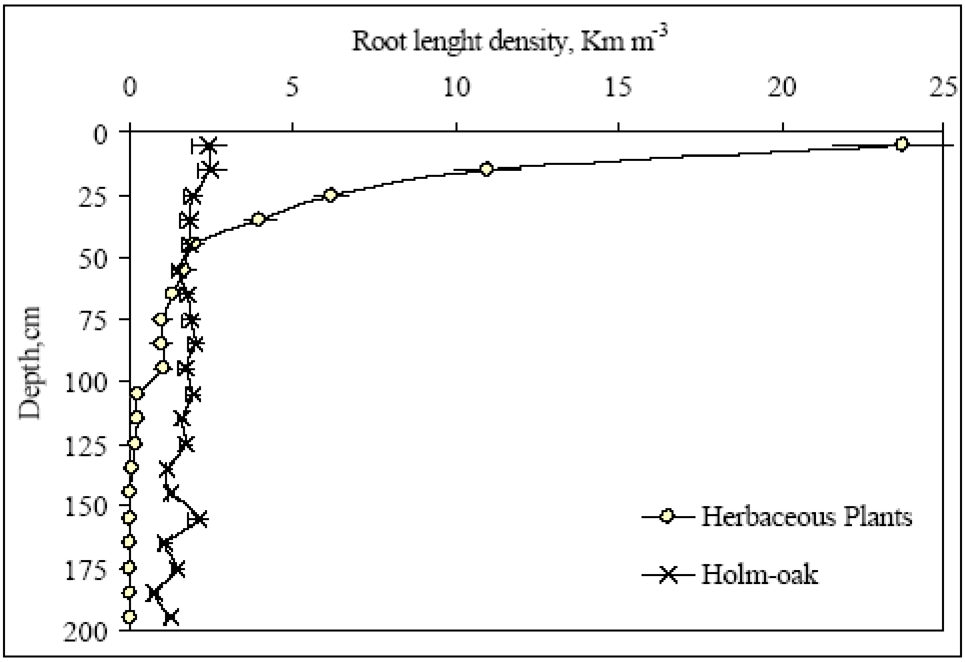

Figure 36: variation of Holm oak and herbaceous plant (oats and natural grasses) root length densities (RLD) by soil depth in Dehesas of central Western Spain

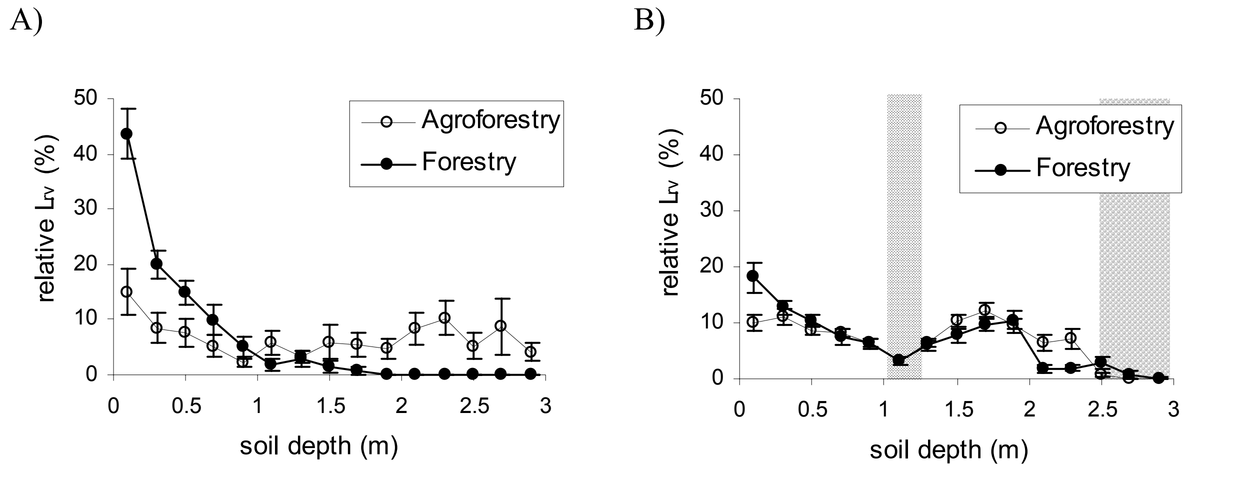

Figure 37: Root distribution profiles of walnut (A) and poplar (B) in the agroforestry and forestry plots. The vertical bars indicate one standard error. The shaded areas indicate the 1.1 m deep sand horizon and the 2.5 m – 3 m deep gravel layer in the poplar stand.

In the cropped alleys, the root distribution of the trees was significantly modified by the crop (Figure 38 for poplars, Figure 39 for walnut trees).

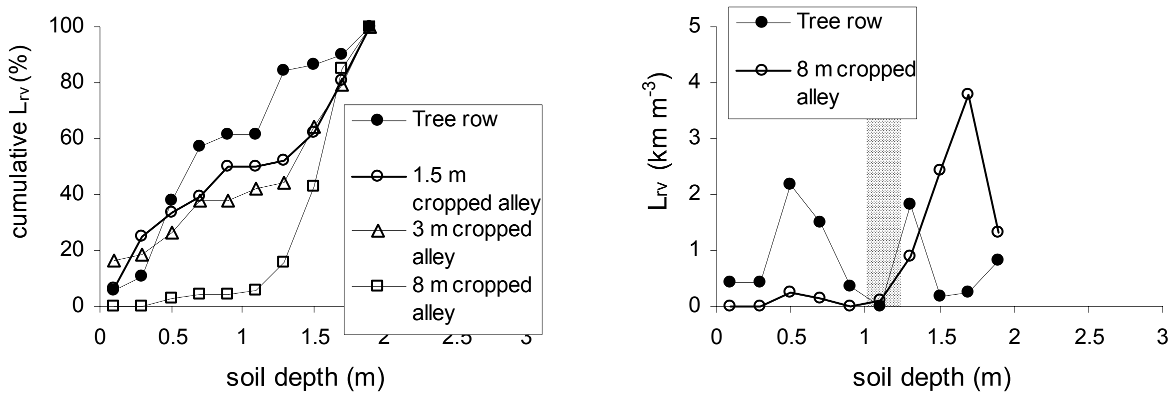

Figure 38: Fine roots in a poplar agroforestry stand in July 2003. Left: Cumulative fine roots of poplars at various distances from the tree stem; Right: L_{rv} on the tree row and in the centre of the cropped alley.

A) 2002 and 2003 data

B) 2004 data

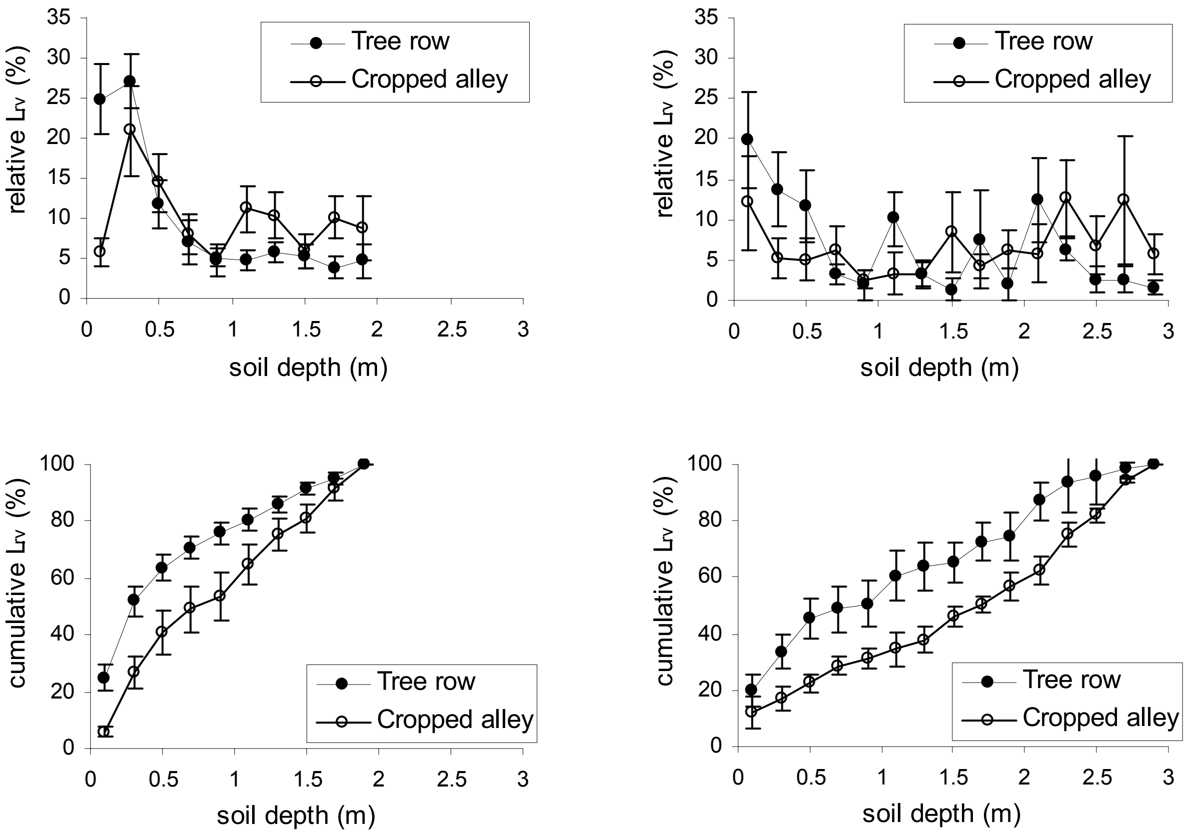

Figure 39: Absolute and cumulative root distribution profiles of walnut trees with soil depth within tree row and in the cropped alley based on the root observations in year 2002 – 2003 (A) and 2004 (B).

These distributions may result from a high degree of plasticity of tree root systems to sense and adapt to fluctuating and heterogeneous soil conditions. Heterogeneous 3D soil conditions resulted from both vertical gradients due to soil properties and horizontal gradients due to the varying extraction dynamics by the plants. The distortion of the tree root system was more pronounced for the oak trees and the walnut trees that only partially explored the soil volume: in the tree-only stand, the walnut rooting pattern was very superficial, but in the intercropped stand walnut trees developed a deep and dense fine root network below the crop rooting zone (Figure 40). The larger poplars explored the whole available soil volume, but the intercrop significantly displaced the root density from the topsoil to layers below 1 m depth.

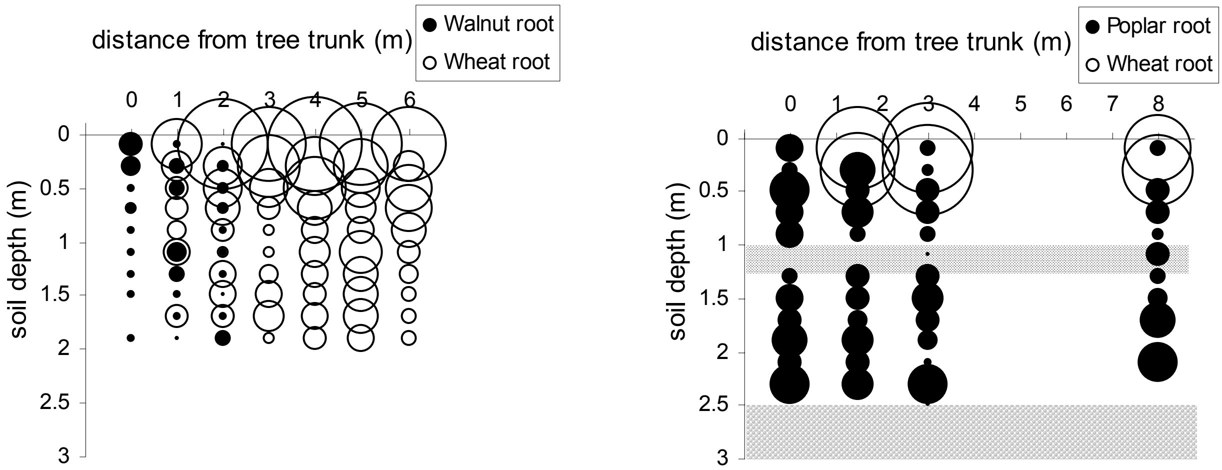

Figure 40: Compared root distributions of durum wheat and trees in the walnut intensive agroforestry plot observed in spring 2002 (left, Grazzia variety) and in the poplar agroforestry plot observed in spring 2004 (right, Allure variety). The bubble sizes are proportional to the observed root length densities.

Most tree root growth models assume a decreasing fine root density with depth and distance from the tree stem. These models would not predict correctly tree-tree and tree-understorey competition for water and nutrients in 3D heterogeneous soil conditions that prevail under low-density tree stands. To account for the integrated response of tree root systems to such transient gradients in soils, we need a dynamic model that would allow for both genotypic plasticity and transient environmental local soil conditions.

An innovative dynamic model of tree fine roots

These results are based on the following paper produced by the SAFE consortium:

☞ *Dupraz C., Mulia R., van Noordwijk M., (2005) A 3D model with voxel automata to simulate plant root growth in a heterogeneous soil condition. In preparation for New phytologist.*

Prior simulation models of plant root growth in heterogeneous soil conditions where based on root architecture and often-required detailed parameterisation, but no parsimonious 3D simulator with continuum representation was available as yet. Simplified models usually assume a fixed pattern that is not relevant for our silvoarable systems (Figure 41).

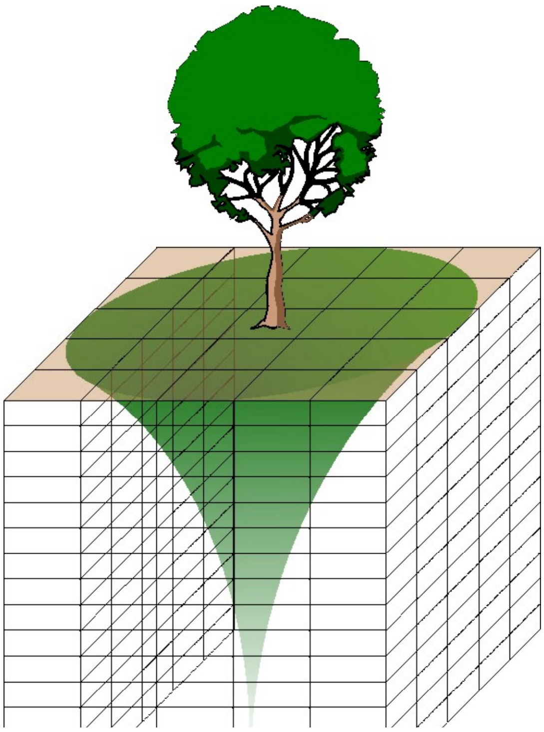

Figure 41: The classical hypothesis of decrease in root length density with depth and distance that we could not include in our model of tree-crop interactions

During the SAFE project, we proposed to model the dynamic three-dimensional root growth of trees with a voxel automata approach.

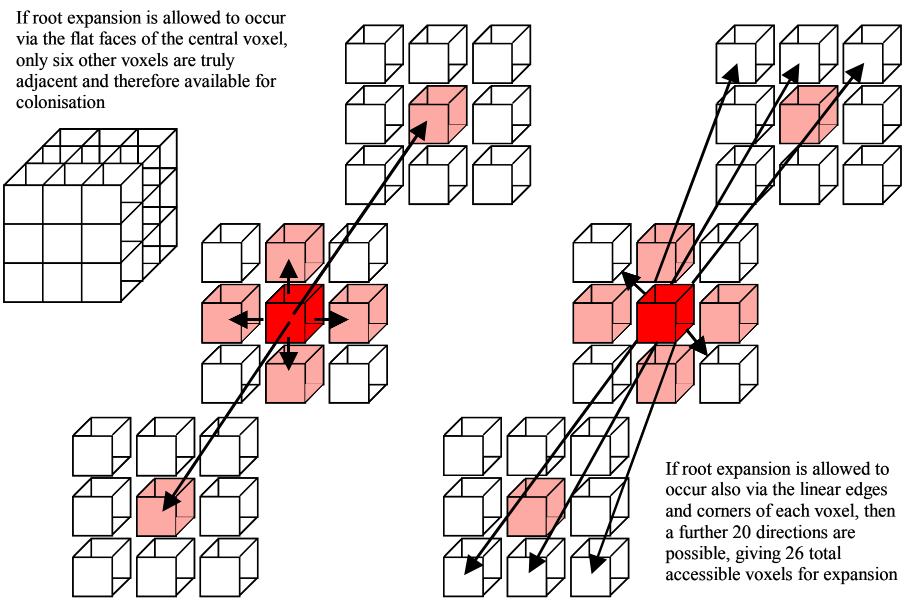

Figure 42: Voxel colonization by tree root growth in two different voxel automata. The simple approach with 6 neighbour voxels was retained in Hi-sAFe

Root system grows within voxel spaces according to an automaton mechanism and responds to local soil conditions. Both fine and coarse root growth are simulated. Six parameters are involved including two parameters, which describe preferential growth directions.

Parameter	Symbol and value	Unit
A weighting factor to regulate the effect of local water uptake	$-\infty < \varphi < \infty$	-
A weighting factor to regulate the effect of root dry matter source-voxel distance	$-\infty < \rho < \infty$	-
Threshold of root colonisation	$\alpha \geq 0$	$m\ m^{-3}$
Proliferation rate	$0 \leq \beta \leq 1$	-
Plagiotropism factor	$0 \leq \lambda \leq 1$	-
Geotropism factor	$0 \leq \eta \leq 1$	-

Table 9: The six parameters of the dynamic tree root model

The voxel level allocation of the total fine root growth responds to the relative success of roots in water uptake on the preceding day and to the distance between each voxel and the shoot-root interface situated at the soil surface. Coarse root system growth is allocated in proportion to the previous day local fluxes of soil water in any part of the system, based on coarse root topology. Fine root growth in any voxel is allocated to proliferation within the voxel and colonisation of neighbouring voxels (Figure 43). Preferential growth directions control the latter.

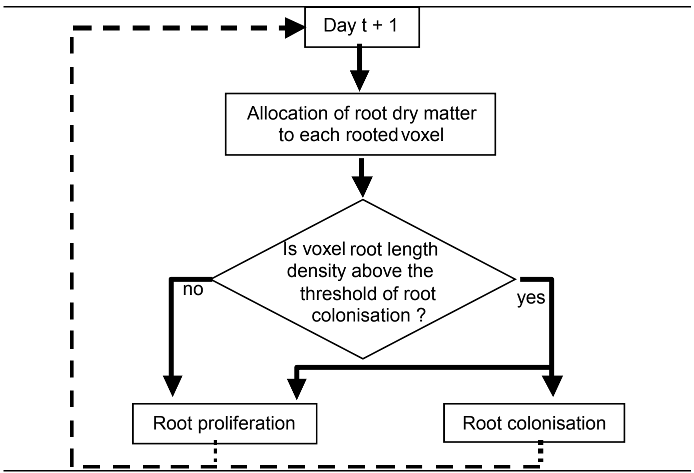

Figure 43. Fine root growth process and the automaton mechanism applied in the root model

The resultant root distribution pattern is sensitive to the parameter values, across the spectrum of decreases with distance from the plant base, uniform distributions and increasing fine root length density with distance from the plant base. The voxel-based root model is affected by voxel dimensions. A scaling rule is introduced to adjust parameter values when the model applies to different voxel shapes and sizes. Container experiments were used by INRA-System to parameterise and validate the root voxel automata with walnut trees and wild cherry trees (Figure 44). Similar experiments are currently performed by the university of Extramadura for poplars and oaks.

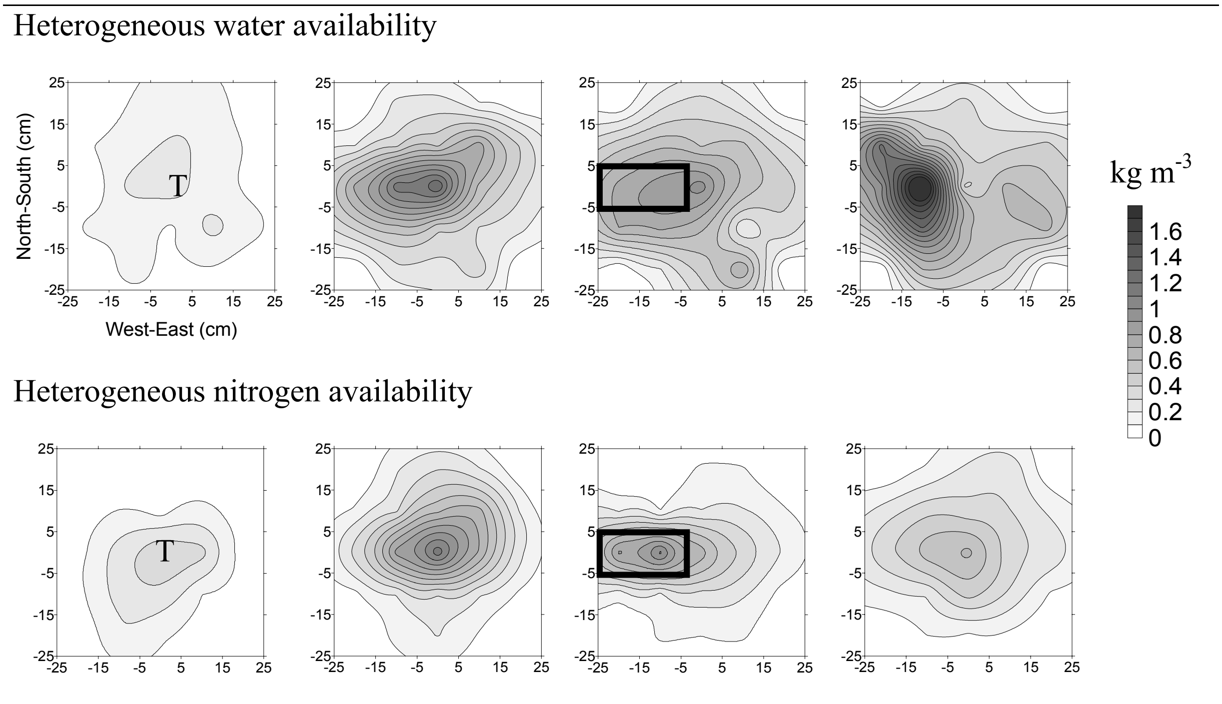

Figure 44. Distribution of fine root density of walnut in containers with 3D heterogeneous patterns of water and nitrogen availability. The black rectangles in the third layers indicate the positions of water or nutrient-enriched patch. The letters 'T' indicate the position of tree trunk.

An innovative water and nitrogen competition model between trees and crops

These results are based on the following paper produced by the SAFE consortium:

☞ van Noordwijk M., de Willigen P., Lusiana B., Mulia R., Ozier-Lafontaine H., Radersma S. and Dupraz C. (2005). A process-based algorithm for water uptake by roots of mixed vegetation. *In preparation for plant and Soil.*

Water uptake by monospecific or mixed vegetation at seasonal scale tends to be dominated by net supply to the soil (rainfall minus soil evaporation) and evaporative demand (determined by the energy balance), rather than by details of root distribution. The time course of uptake (and related processes of yield formation) and the sharing of total resource capture between plant components of mixed vegetation, however, depend on the daily adjustment of demand to supply (and hence to relative root lengths of the various plants) and the adjustment of root length distribution during the season. An understanding of competition at this short and medium time scale requires details of the root systems. Competition for water by roots of different plants with access to a common volume of soil may for time steps of say 1 day involve 'interference' in the potential rate of uptake per unit root, as well as simple interactions via depletion of the resource, similar to the scaling rules for considering root length density in a volume of soil rather than single roots in a cylinder of soil. A simple algorithm is presented that makes uses of the linearity of transport equations for water in soil if the 'matrix flux potential' concept is used (Figure 45, rather than volumetric soil water content or water potential.

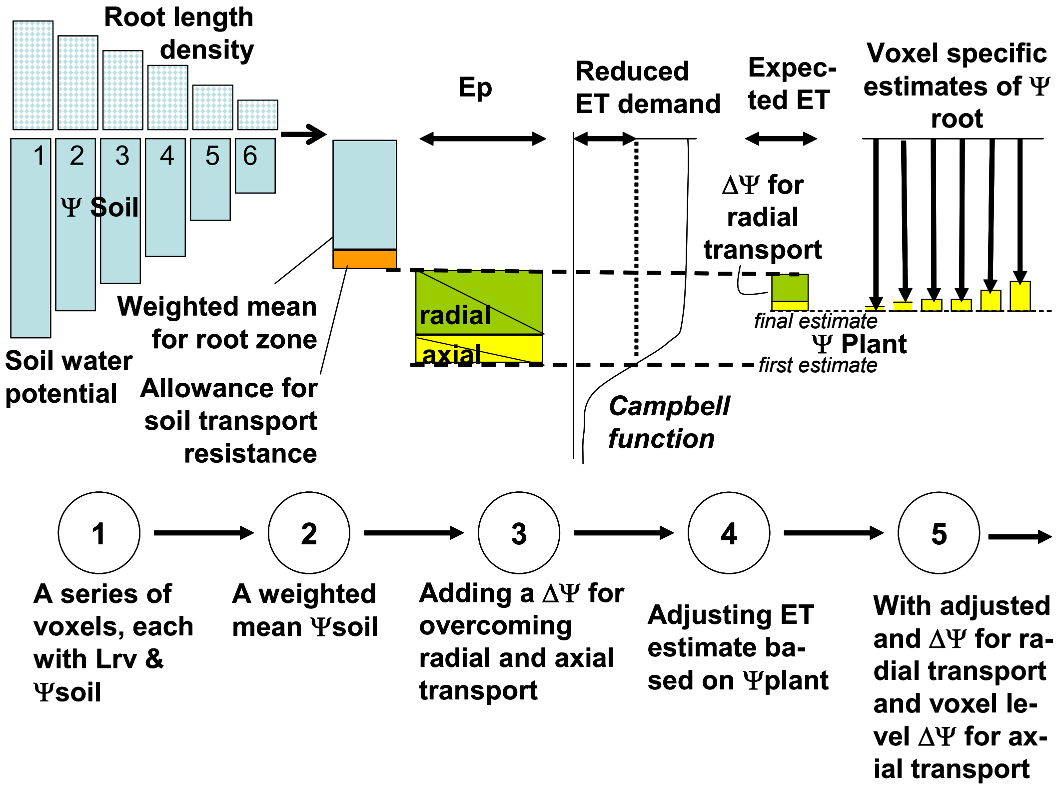

Figure 45: **Steps (1…5) in daily cycle of calculations of water uptake for each plant in the simulation, deriving the plant water potential at the root surface in every voxel of the soil on the basis of a reduced transpiration demand.**

Sorting the plant roots concurrent in a voxel (volume element) of soil yields a matrix flux potential range where only the root with the lowest (most negative) rhizosphere potential operates and the ranges that it shares with other plants. Bi-directional flow of water through root systems can be considered as a process of 'hydraulic equilibration' that can redistribute water from wetter to drier layers of soil (regardless of their position) during night time periods of low transpiration demand. Adjustment of root length densities to local supply can be simulated by adjustments of the parameters of an exponential (in 1 or 2D) distribution, or at voxel level by a form of modified 'cellular automata' algorithm that includes global information of overall growth rates (functional equilibrium response) and local response based on the relative voxel-level success rate of uptake per unit root length in the previous time step. Using a pipe-stem logic, the requirements for adjustment of woody root tissue to the local increase in fine roots can be derived, and root systems can be constructed that are, in hindsight, compatible with fractal branching theory, without being rigidly constrained in the rules for formation of the root system. Interactions between these processes and other determinants of plant growth in mixed vegetation can be assessed in the WaNuLCAS (water, nutrient and light capture in agroforestry systems) model, while the algorithm is also implemented in Java script in the Hi-sAFe model. Examples and sensitivity tests are presented that show how uptake by each plant component responds to changes in its own root length density or that of the companion plant. Mutual adjustment of root distribution can be evaluated as a 'game strategy', with the success of adjustment strategies depending on how the companion plants respond, as the root length densities required for effective uptake in competitive situations far exceed those that are optimal in a monoculture.

WP6: Production of integrated models of tree-crop interactions

WP6 was split in two: WP6a produced the detailed process-based Hi-sAFe model that can be run on a year period, while WP6b produced the simple Yield-sAFe model that can be run on the life cycle of the trees (60 years)

The Hi-sAFe model

WP6 was focusing on integrating the different competition modules produced by WP4 and 5.

The Hi-sAFe model aims at predicting crop behaviour in different ambient conditions as a result of the presence of trees, and at predicting the tree growth resulting from the interaction with the crop. This was achieved by running concurrently the crop model under different conditions resulting from the tree functioning. We conceptualise the plot by dividing it in homogeneous crop cells. The crop model runs concurrently on each cell occupied by the crop, allowing us to simulate the tree-crop interactions at different distances and directions from the tree.

As we need to model original below ground process as asymmetric tree root growth, it was necessary to have a 3D discretisation of soil component.

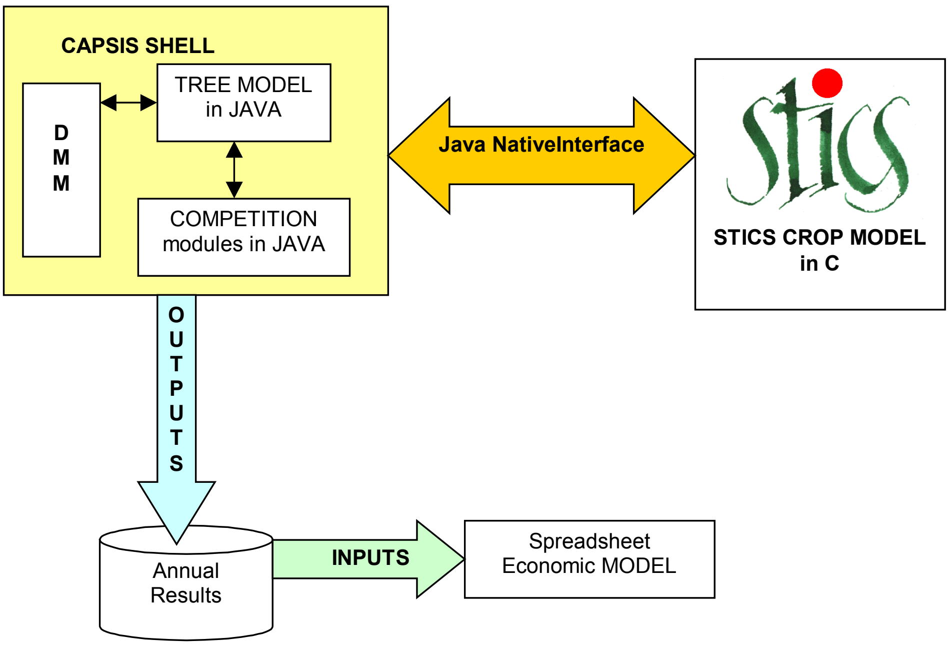

Figure 46: Hi-sAFe technical implementation resume with reference to WP1 decisions

More detailed information can be found on "**Deliverable D1.1**" document available on the SAFE web site.

Between August 2002 and January 2005, we had 5 modelling meetings:

- Clermont Ferrand (France): 3-6 December 2002
- Plasencia (Spain): 4-15 April 2003
- Porano (Italy): 15-16 October 2003
- Petit bourg (Guadeloupe): 24 Oct -3 November 2003

- Montpellier (France) 4-5 February 2004

All presentations and synthesis of these meeting are available on safe web site.

During Clermont-Ferrand modelling workshop, we decided to develop two models: **Hi-sAFe** that could be used on a yearly basis for the simulation of the interaction between trees and crops and **Yield-sAFe** an oversimplified model for the long term simulations (more than 50 years long) the uncertainty analysis and the connection with the economic modules. A description of Yield-sAFe model is presented in deliverable 6.2.

The Hi-sAFe prototype is implemented under the CAPSIS modelling platform and includes:

- A **light competition module** adapted from Mountain model, computing tree light interception

- A new tree module with **phenology** and **C allocation** computation

- A **tree fine root growth** module based on original cellular automata algorithm

- Two different **water and nitrogen repartition modules**: the INRA one is based on water potentials, while the ICRAF one is based on the matrix flux potential.

- Communication modules with **STICS crop module** to simulate daily interaction between trees and crop

Detailed descriptions of these modules are presented in deliverable 4.1, 4.2, 5.1 and 5.2 available on safe web site.

Hi-sAFe spatial discretisation

The Hi-sAFe scene is a rectangular grid divided in homogeneous squared cells. Each cell supports a different crop that can be bare soil. Thanks to a toric symmetry system, agroforestry plot can be simulated with an average tree localised in the middle of the grid. Hi-sAFe soil is composed of homogenous pedologic layers, divided in 3 dimension voxels.

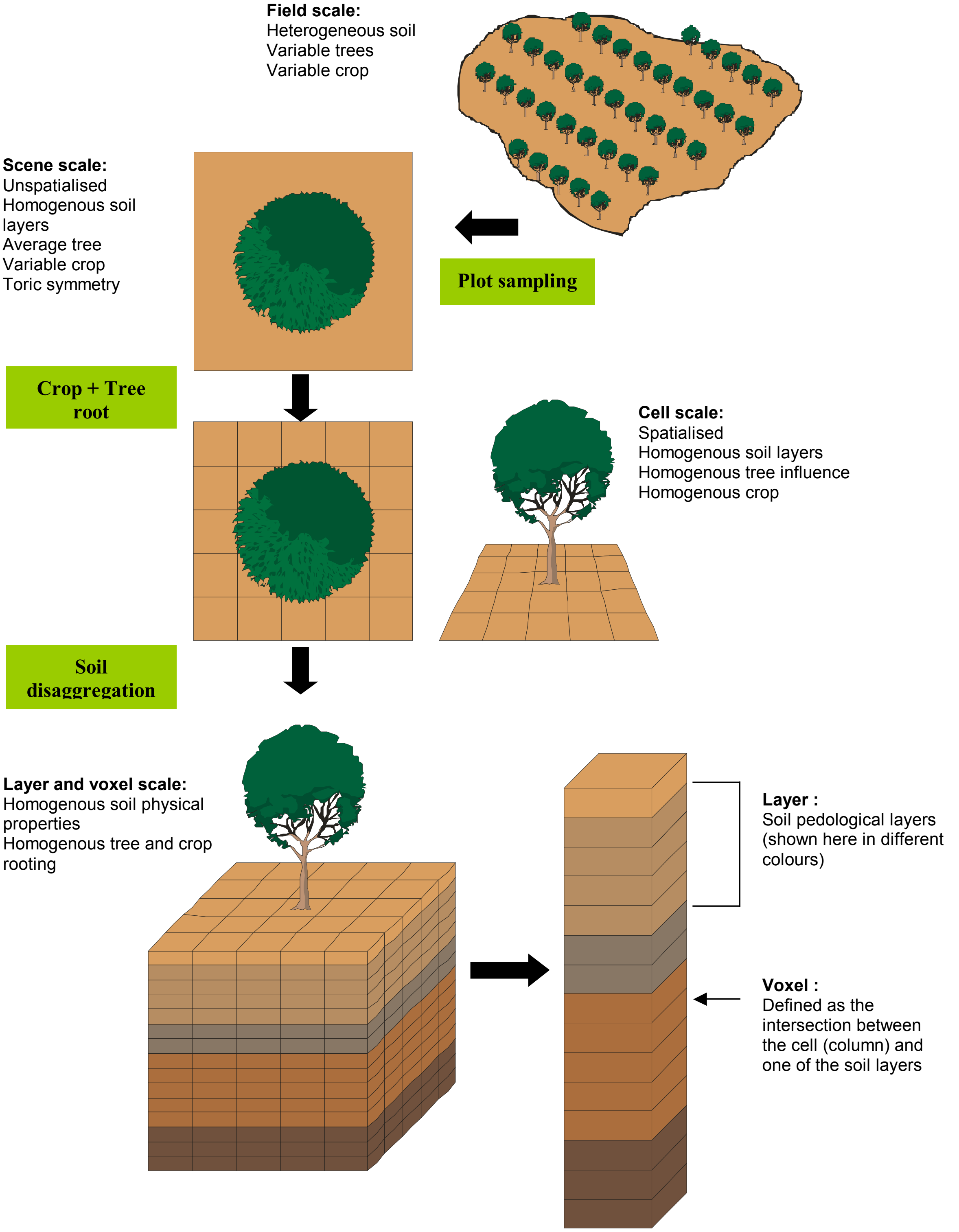

Figure 47: Spatial resolution – from the field scale to the voxel scale in the Hi-sAFe model

Communication with STICS crop model

STICS crop model is originally written in FORTRAN, but a C version of STICS V5 has been automatically generated by a translator program developed by an INRA scientist (Jean-Claude Poupa). Specifically for the SAFE project, some important improvements have been incorporated in the FORTRAN version of STICS by Nadine Brisson and Dominique Ripoche (INRA-Avignon) to rearrange state variables and parameters in separate memory blocks.

During the working visit in Guadeloupe computer scientists studied the STICS algorithm and decided to:

- Remove input reading modules that will be implemented in Hi-sAFe (macro-climate, soil description, crop species parameters)

- Remove the seasonal loop to allow daily communication between Hi-sAFe and STICS (exchange of daily results such as soil or crop state variables).

- Interrupt the STICS daily loop just after the crop water demand calculation to integrate a water and nitrogen repartition module to share ground resources between trees and the crop.

Moreover, for this purpose, data from STICS soil mini-layers (1 cm thickness) have to be aggregated to match with Hi-sAFe voxels sizing, and resulting data have to be back-distributed into mini-layers.

These developments were necessary but very penalising because it generate a lot of work on the STICS code, that was not scheduled at the beginning of the project, and involve delays in model achievement. It avoids also upgrading on future versions of STICS.

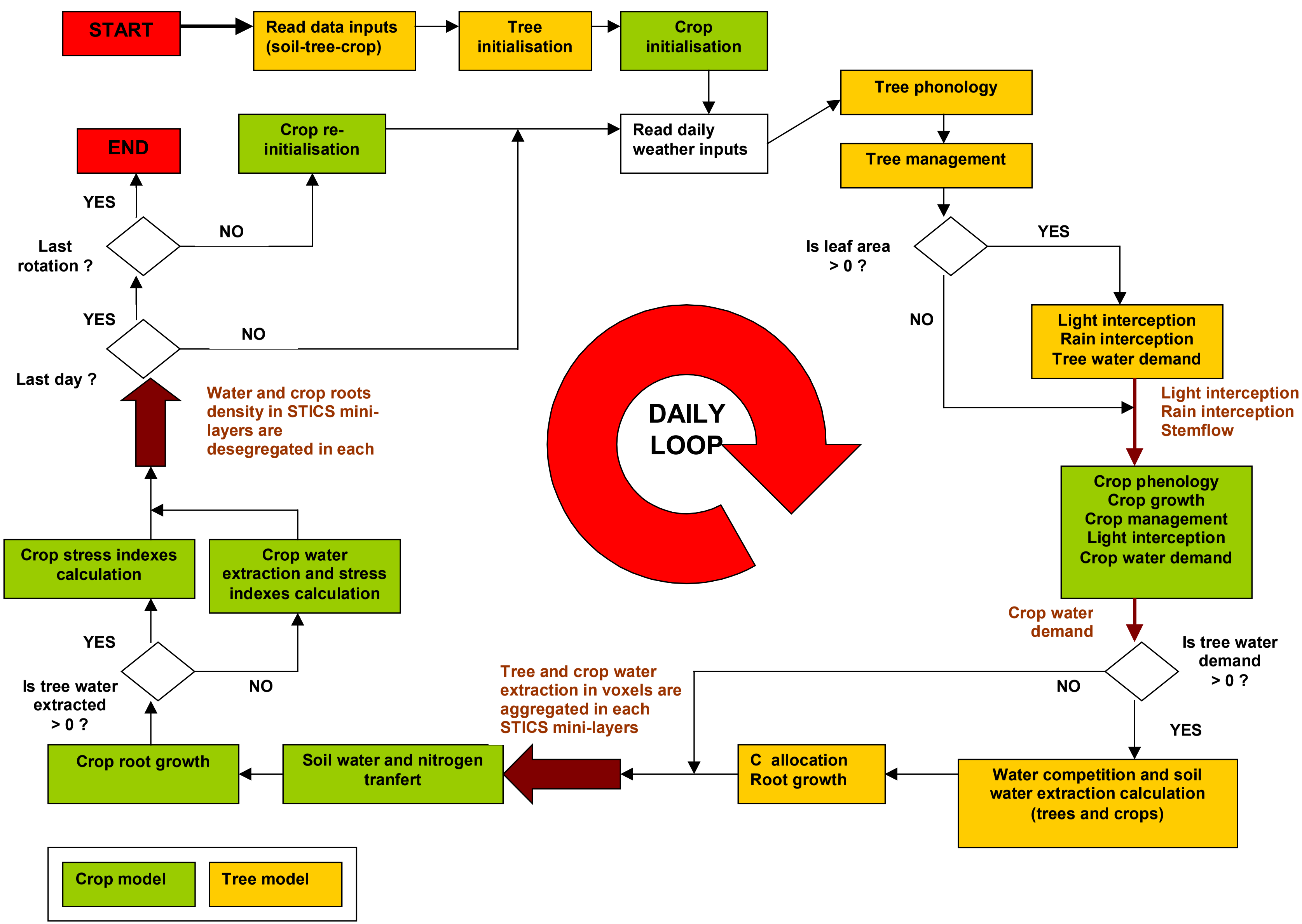

Figure 48: Hi-sAFe daily loop showing interaction with STICS crop model

Some Hi-sAFe results

Even if some module are still missing (nitrogen competition, water table and capillary rise) the Hi-sAFe prototype is running. Above ground, crop development is influence by trees (light and rain interception) in each cell of the simulated scene.

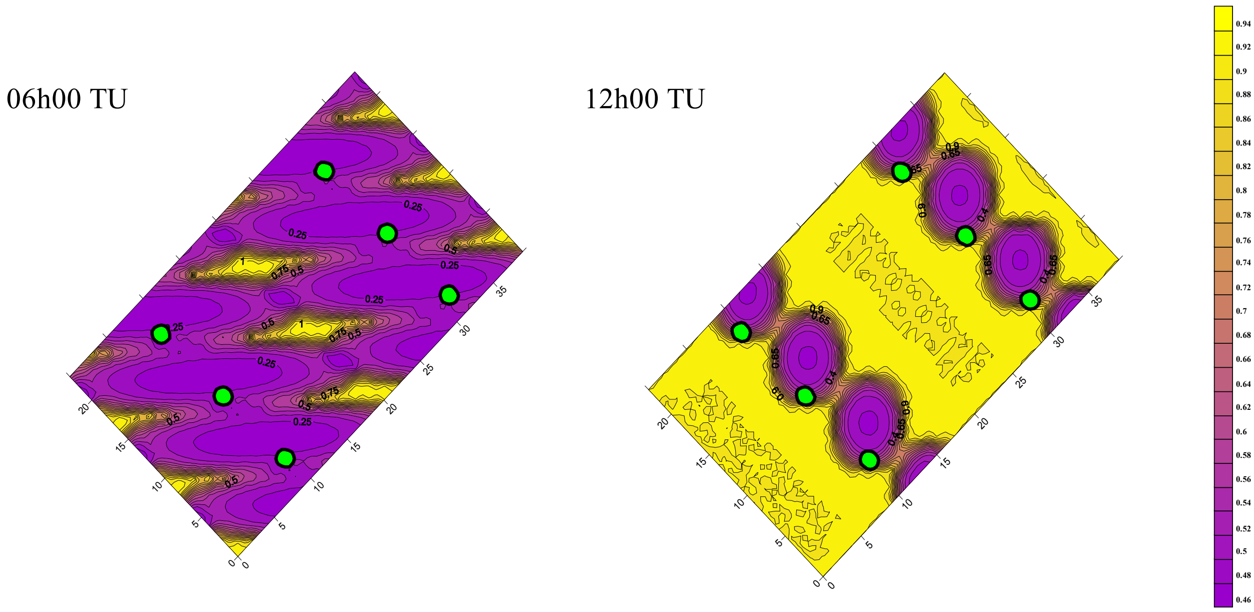

Figure 49: Influence of identical trees (NW-SE orientation, 8X20 spading) on direct light available on crop. Computation is done 5 to 11 time a day and daily integrated.

For the below ground, the competition module shared water resources between plants in each rooted voxels of the soil.

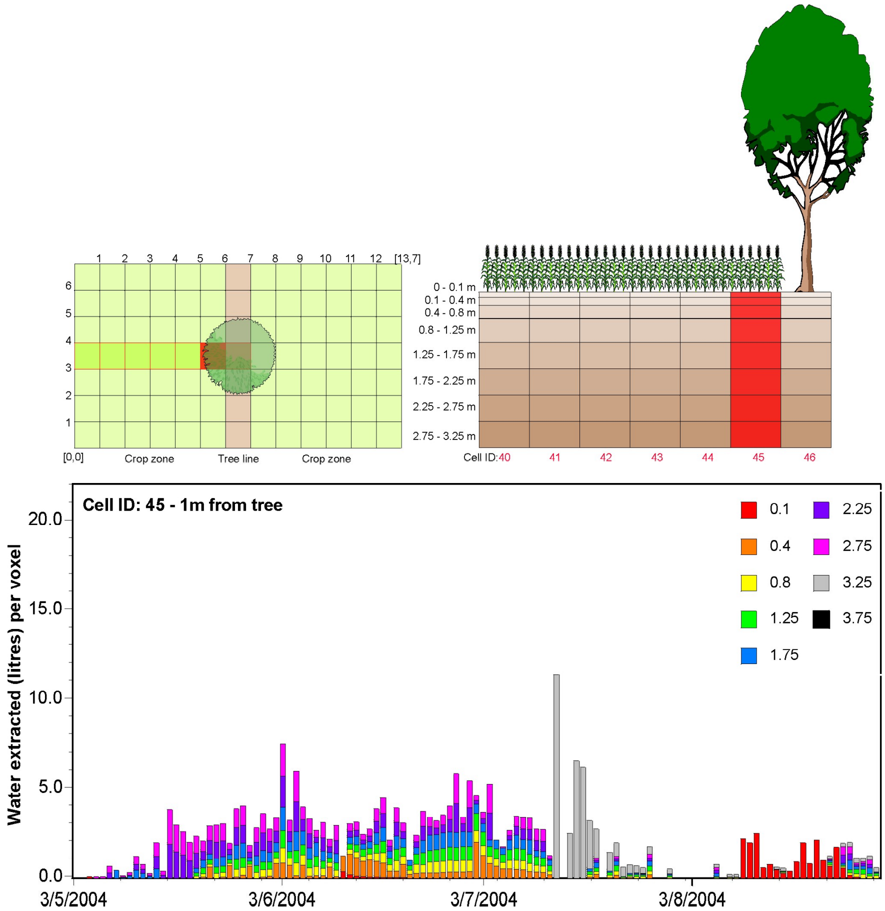

Figure 50: Cumulated water extracted per voxels along a transect across the cropped alley during a cropping season

Finally the model predicts how the crop yield is affected by the presence of trees. Future work will concentrate on validating the model with field data collected during the SAFE project at several experimental sites.

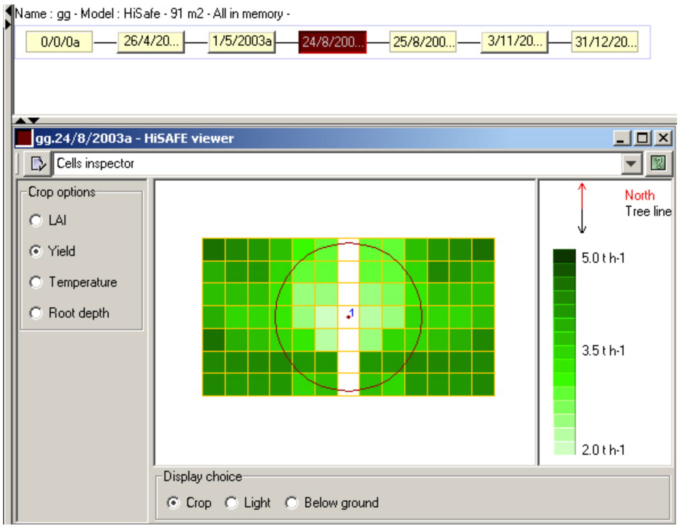

Figure 51: Hi-sAFe model graphical viewer under CAPSIS shell, showing how a 7 meter height walnut tree influences the durum wheat crop yield in the Restinclières farm conditions for year 2004.

The Yield-sAFe model

Agroforestry systems are complex biological systems with distributed character in space and time. Within SAFE there is a need to evaluate economic and regional performance of these systems. Hence, the required model properties are: (i) Simple to allow fast simulation (including uncertainty characterisation), (ii) Conceptual to preserve insight and (iii) "Control-oriented" to evaluate control/management strategies.

Conceptualisation of the minimal biophysical model

During the project the major achievement was the concept and implementation of two silvoarable biophysical models, i.e. a complex model (for explaining tree-crop interactions) and a simple model (for long term predictions, economic analyses, up-scaling). The simple model is not the result of a simplification of the complex model, but was developed individually.

This task was difficult. First, the development of a silvoarable model is a complex and challenging task. Secondly, using existing validated models as the basis of the silvoarable model is a very good decision in terms of accuracy and robustness of the implemented process parts, but on the other hand their use is accompanied with restrictions and problems in linking the various model components (e.g. STICS 'minicouches' see this report WP5 part). In addition the study of the model descriptions and code of the chosen models HyPAR and STICS were rather laborious. Moreover, the required STICS version in ANSI-C became available only at the end of the second project year, delaying the implementation of HySAFE. Third, due to the twofold aim of the HySAFE model, i.e.

1) To explain tree-crop interactions as determined by environmental conditions and management actions

2) To predict the productivity of silvoarable systems over their complete life cycle, as determined by environmental conditions, management actions and subsidy and prices.

Finally the modelling team was split into two groups: One group preferred to invest all modelling time in the development of one biophysical silvoarable model and another group preferred to do develop two models in parallel, a complex model for aim 1 and a simple model for aim 2. For convenience, the complex model is called HySAFE and the simple model LoSAFE.

For a better comparison of the two modelling approaches (mono or dual) a position paper and a draft concept of the LoSAFE was written in addition to the draft concept for HySAFE. The two approaches were presented and discussed at the modelling workshop in Clermont Ferrand (December 02). The discussion resulted in the development of a concept of a super simple agroforestry model, BeloSAFE, by the WU team during the workshop. The WU team, in charge of uncertainty analysis is in particular interested in a fast and simple model (First annual report - WP6 part). A consensus could be taken to follow the dual modelling way with HySAFE and BeloSAFE. It was agreed that further development of LoSAFE has to start not before HySAFE and BeloSAFE are running and only if these two models would not satisfactorily fulfil the modelling objectives.

During the project the name of the minimal model was changed from BeloSAFE (Dec. 02) to SAFE-RESULT (Nov. 03) and finally to Yield-sAFe (May 04).

Model description

Yield-sAFe is a simple agro-forestry model, considering the system as spatially homogeneous Hence, the effect of competition for light and water on tree and crop production is simulated as an average of the silvoarable plot with a given tree and crop density (see Figure 52 and Figure 53).

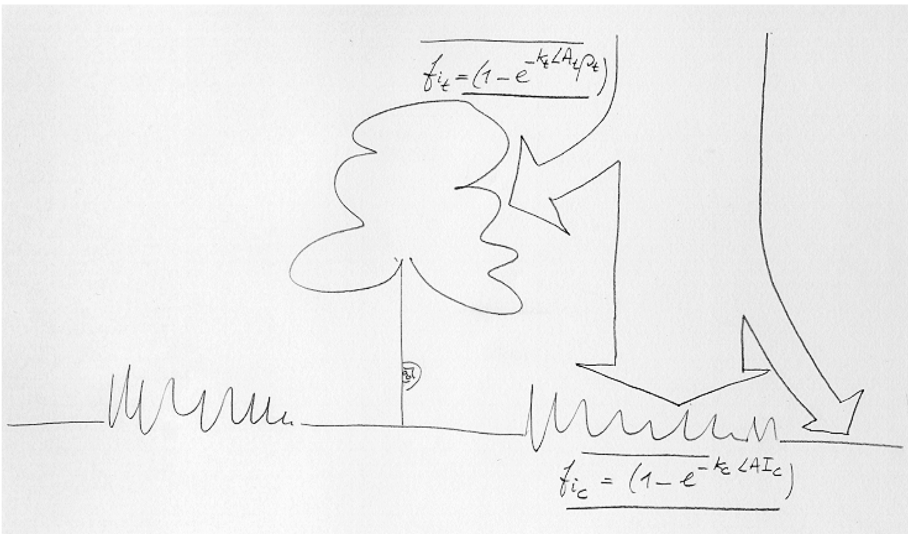

Figure 52: Light distribution modelling in Yield-sAFe

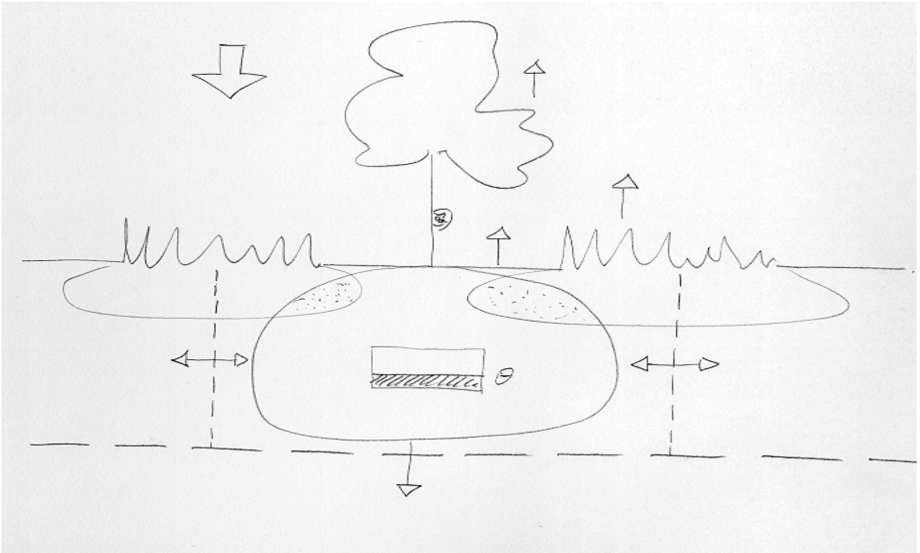

Figure 53. Water distribution modelling in Yield-sAFe.

Each of the processes is described using few equations and parameters. Most parameters can be found in literature.

The properties of YIELD-SAFE can be summarized as:

- Discrete time (daily time step)

- No spatial distribution

- 7 difference equations: biomass tree/crop, leaf area tree/crop, partitioning leaf crop, number shoots tree, soil water content

- 22 "physical" parameters

- 6 control/management inputs: sowing/planting dates, crop cover/tree density, crop rotation, pruning, thinning, irrigation

- 3 disturbance inputs (forcing): radiation, temperature, and precipitation

- Simulation time 50 years (approx. 5 sec.)

See for further details Stappers *et al.* (2003). Initially, Yield-sAFe has been implemented in a Matlab/Simulink environment, but in a later stage Burgess et al (2004) implemented it in an Excel-environment.

Evaluation of the performance of the model with information from experimental plots

Preliminary analysis

A first calculation (Dec. 03), using Yield-RESULT with default parameter values, of the LER of an agro-forestry system gives:

Full crop cover: yield (year=30) = 3.45 t/ha and 80% cover: yield (year=30) = 2.76 t/ha

168 trees/ha: yield (year=30) = 608 kg/tree

4*168 trees/ha: yield (year=30) = 344 kg/tree

10*168 trees/ha: yield (year=30) = 176 kg/tree

Hence, LER = 608/(4*344) + 2.76/3.45 = 1.24 or for the case with very high tree density: LER = 608/(10*176) + 2.76/3.45 = 1.15.

Again, this is a first indication of the LER of an agroforestry system and can be easily repeated for a calibrated version of the model.

So far, Yield-sAFe aims to be easily implementable and robust to give reasonable long-term biomass predictions of trees and time-series predictions of tree and crop yields.

Whether YIELD-SAFE misses some aspects that are crucial for realistic predictions of silvoarable bio-economic outputs has to be answered by comparison with Hi-sAFe.

Notice that so far nitrogen competition is ignored. Consequently, N non-limiting biomass predictions will be calculated. On the basis of soil properties the amount of nitrogen supplied from 'natural sources' ('indigenous nitrogen supply') can be calculated, and in combination with the yield data, from which the nitrogen requirements can be estimated, estimates can be made of the nitrogen fertilizer requirements, using the so-called "three-quadrant" method (van Keulen, 1982)

Sensitivity analysis

Recently, in addition to the uncertainty analysis reported by Metselaar et al. (2004), to test the final reliability of the calibrated model a sensitivity analysis has been performed. The following remarks and conclusions, related to a sensitivity analysis of Yield-sAFe for three experimental sites, have been made (for details see Keesman et al, 2005a).

For the Silsoe experiment the following remarks can be made:

- after a 10% change in individual parameter values the LER remains on the interval [1.30, 1.39].

- evaluating the main effects (differential quotient: dLER/d*p* with *p* the parameter) shows that especially gamma_c and gamma_t are dominant. However, this effect can be fully attributed to the very small values of these parameters.

- the normalized main effects show that, as more or less expected, Kt_0, epst, nShoots0 and LAssmax (see article Keesman et al. (2005b) and results Martina Mayus, Zurich meeting 2004) are dominant. These tree parameters define to a large extend the shading of the tree on the crop.

- notice that in Keesman et al. (2005b) nShootsMax is a dominant parameter, because there the sensitivity analysis was based on full-grown trees with maximum leaf area.

- interactions between these dominant parameters can be further analysed, but for the time being we focus on main effects only.

For the Vézénobres experiment one may notice that:

- after a 10% change in individual parameter values the LER remains on the interval [1.34, 1.38].

- the normalized main effects show that again Kt_0, epst, nShoots0 and LAssmax are dominant. However, the crop parameters epsc, Tsumharvest and the soil parameters gammac, pF_crit_tree are becoming dominant as well. Especially epsc is crucial here.

- in the Silsoe experiment the ratio LER tree/LER crop = 2.2, while in Vézénobres this ratio becomes 1.3. In other words, in Vézénobres the crop yields contribute relatively more to the final LER than in Silsoe.

- in the Vézénobres experiment soil water plays some role, while in Silsoe this did not.

For the Dehesa Boyal site (AF = 113/50/16 trees ha^{-1}, continuous wheat and oak):

- after a 10% change in individual parameter values the LER for AF = 113/50/16 remains on the interval [1.04, 1.33], [1.09, 1.18] and [1.01, 1.08], respectively.

- for decreasing tree density the midpoint and width of the intervals of the LER decrease. For even lower densities the LER will tend to 1.

- for AF = 113, the normalized main effects show that Kt_0, epsc, Tsumharvest and especially pF_crit_tree and pF_crit_crop are dominant, where pF_crit_tree is most dominant.

- for AF = 50, the normalized main effects show that especially Kt_0, Tsumharvest, pF_crit_tree and pF_crit_crop are dominant, where again pF_crit_tree is most dominant.

- for AF = 16, the normalized main effects show that Kt_0, pF_crit_tree and pF_crit_crop are dominant, where again pF_crit_tree is most dominant.

- as expected, in the Dehesa Boyal experiment soil water parameters plays a key role.

An additional sensitivity analysis (SA) of Yield-sAFe for the Leeds experimental site can be found in the paper: "Yield-sAFe, A parameter-sparse process-based model for calculating growth, yield and resource use in agro-forestry systems (Van der Werf et al., 2005). The analyses refer to a poplar - winter wheat system under optimum growth conditions. Due to the low tree density (156 trees/ha), tree-to-tree competition does not occur. During the course of the model application it became evident that the tree factor responsible for light interception (kt) was sensible and rather uncertain. Therefore, the SA was performed for two different values of kt, that is kt = 0.4 and kt = 0.8. Overall, the results are similar, namely: the tree factors have the largest influence on the land equivalent ratio (LER) and factors influencing the light interception and light use are in this simple model of major importance. However, in case of scenario kt = 0.8, the crop parameters kc and epsc play a large role in years 20 and 25 compared to the other scenario. The reason is that tree light interception is double of that with kt of 0.4. As expected, during the entire period of 25 years, higher poplar and wheat yields as well as a higher LER are predicted with simulation scenario kt =0.4 than with scenario kt =0.8.

Calibration and validation of the minimal silvoarable model

The following calibration approach for YIELD-SAFE will be aimed at: use regional data (yield tables and regional yield statistics) to develop a region-specific version of the model for further economic analyses and up scaling activities. This regional version will be used to generate time series with associated production uncertainty for use in the policy document. In addition, a version that is calibrated on site/year-specific data will be developed for site-specific applications. The site-specific data can subsequently be used to validate the regional version.

Calibration method Yield-sAFe at regional scale

A major task was related to calibration of the model Yield-sAFe for the crops: durum/winter wheat, forage/grain maize, sunflower and oilseed rape, and for the trees: cherry, poplar, walnut, oak given data from the following Euro-regions: Atlantic region, Continental region and Mediterranean region (SAFE project CMC5 Toulouse Report and associated Working Documents on SAFE website disk space, and Metselaar et al., 2004). See for further details the working documents, named Calibration of ..., by Klaas Metselaar and distributed under the name SAFEcalibration.zip (June 2004). For the crops data has been generated by STICS and the experts within the consortium have provided regional tree data. The collection and pre-processing of experimental plant/tree and weather data to allow calibration and evaluation of the model was a difficult and very time intensively task involving all experts of the consortium. and (iv) calibration of this model using (Matlab) optimisation functions at regional and field scale

After the calibration for three different climatic regions in Europe, we continued with the implementation of Yield-sAFe, a tool for long-term yield predictions to be used in economic analyses (WP7) and up scaling (WP8). In this context some additional calibration was required (see modified tree calibration results by Karel Keesman, distributed under the name Tree_calibration.zip, July 2004). The calibration results are also summarized in the report of WP7.

Three working visits have been organised in this context of the calibration of the Yield-sAFe model using regional data: a) Wageningen, comparison and testing of model implementations, May 2004, b) Plasencia, calibration of oak, cherry and poplar in Mediterranean regions using potential and realistic yield data, July 2004, and c) Montpellier, calibration of walnut, cherry and poplar in Atlantic/Continental regions using potential and realistic yield data, July 2004.

In summary, given potential yield data for the crops the following parameters have been adjusted: light use efficiency, specific leaf area coefficient, harvest index and the heat sum parameters defining the plant phenology. For trees, it appeared that adjustment of only light use efficiency and initial number of shoots was sufficient to obtain good fits. To calibrate the model for real yields it has been proposed to adapt the water use efficiency of crops and trees. However, one has to realize that the estimated water use efficiency also contains the effects of diseases, nutrient limitation and mismanagement in general only the yields.

Some more details on the tree calibration at the France LTS's are needed here. For these sites DBH (tree diameter at breast height), height and volume were available for calibration. Consequently, the following procedure has been suggested:

- modify the form factor F given the realistic data of height, DBH and volume. (at site-specific age and tree density)

- find a least-squares solution of the `water use efficiency`, including all effects of miss-management leading to the realistic yield, minimising the sum of squares of (DBH-DBH(model)) and (volume-volume(model)), given pFcrit = 4.0.

A further modification to the calibration procedure for realistic yield has been proposed in Dec. 2003. Recall that in a first step Yield-sAFe has been calibrated on the basis of potential yields, *i.e.* from yield tables and outputs from detailed crop growth models. In a second step realistic yields have been taken into account to estimate, in particular, soil water parameters. However, one should realize that (for all tree and crop species) only one measurement of realistic yield is available. Consequently, in general only one parameter can be uniquely estimated. If two parameters, eps (light use efficiency) and gamma (water use efficiency) say, are estimated an infinite number of eps-gamma combinations (see bold line in Figure 52), that produce a yield from Yield-sAFe that coincides with the realistic (measured) yield, will be found.

If, however, we fix eps such that eps=eps0, which was the case in our initial calibration procedure (working visit Plasencia, July 2004), an estimate of gamma outside the box (representing feasible intervals) can be obtained (see Figure 52). Since we did not know any of the bounds on the parameters, as yet this estimate of gamma was accepted (till October 2004). However, further analysis showed that this estimate of gamma affected the predicted yields of some crops/trees to strongly.

A calibration procedure that estimates more than one parameter needs bounds on the parameters, but as mentioned before it should be realized that no unique combination of parameter values could be found (bold line in Figure 54)! In general, constrained search algorithms will find estimates on some of the bounds (circle at intersection of curved line and box).

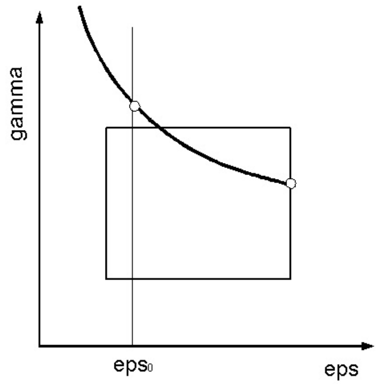

Figure 54: Constrained estimation procedure.

Consequently, finally the following procedure has been proposed:

- Initially, select eps and gamma for the estimation step.
- If the estimated combination eps-gamma is not a vertex of the box (in Figure 54: estimated gamma (see circle right) is not at its boundary, where estimate eps is at its upper bound) the procedure can stop. (under some additional conditions it can be proven that in this case an "optimal" estimate is obtained)
- If the estimated combination is a vertex of the box, an additional parameter should be added, e.g. HI (harvest index), pFcrit (critical pF value related to the water uptake factor) or the box should be enlarged till step 2 can be fulfilled.

Calibration method Yield-sAFe at field scale

In a first step the parameters for calibration have been selected based on expert knowledge and sensitivity analysis. Subsequently, the parameters used in the crop sub-model are calibrated using field observations, corresponding to the crop species, climatic and soil conditions, from Randwijk (The Netherlands) and Rothamsted (UK). The calibration of the crop part does not take into account crop rotations, because: i) we assume that an effect of water limitation over two seasons can be ignored, ii) N limitation is performed outside the dynamic model part and iii) pests and diseases are not considered.

A mathematical automatic calibration approach was applied, namely a non-linear least-squares fitting method (MATLAB function lsqnonlin). The function lsqnonlin scales parameter types that differ in magnitude of value. The residuals have been implemented such that the deviation between simulated and observed measures (i.e. LAI and Biomass) is scaled. Before running the calibration, the start values and the lower and upper boundary values of all parameters that will be fitted have to be pre-determined. During one calibration cycle (i.e. same start values and ranges for parameters), the parameter values were varied consecutively or simultaneously. The least-squares fitting method stops when the discrepancy measure has reached a local minimum.

Since the initial parameter values (from which the function starts searching) have an impact on the calibration output (Metselaar, 1999), we repeated the calibration cycle for various starting values. These sets have been redefined partly systematically and partly based on former calibration output. The best parameter set was then chosen visually by comparing model output and field observations and expert knowledge with respect to plausible parameter values. The calibration cycle was repeated until further possibilities for significant improvements were exhausted, given the conceptual constraints of the model and the model accuracy of the available data (Van Keulen and Seligman, 1987) The calibration was performed first for potential crop growth in North Europe, where radiation and temperature are the only growth-defining factors (Van Ittersum and Rabbinge, 1997).

Yield-sAFe has only few (10 physical and 6 control/management) crop parameters. They can be classified in physical parameters that depend on species and/or environmental conditions, but which should be conservative after calibration for well-defined crop-types (Group A) and parameters that depend on the crop and site (specific) management actions (Group B). Of the 10 physical parameters 4 have been chosen for calibration, because of their importance for light interception and leaf development, both are key processes in estimating aerial biomass production.

In what follows we will focus on the different steps in the calibration procedure, i.e. i) pre-calibration, ii) sensitivity analysis with initial crop parameter values and iii) calibration winter wheat for North Europe using data on seasonal growth pattern

- Pre-calibration

Symbol	Unit	Definition	Valid Range	Ro1	Ro2
kc	-	Radiation extinction coefficient	0.5-1.1	0.7	0.7
εc	g biomass MJ intercepted-1	Potential growth rate	0.8-1.5	1.5	1.5
sc	m2 leaf g –1 leaf	Specific leaf area	0.01-0.03	0.02	0.02
pl0	initial g leaves g-1 actual biomass	Initial partitioning fraction to the leaves	0.7-0.9	0.8	0.8
TsumLeavesStop	oC d	Reduction factor of partitioning fraction to leaves	250-700	250	250
T0	oC d	Temperature threshold	-	0	0
γc	mm g-1	mm water needed to produce 1 g dry matter of crop biomass	0.1-0.3	0.15	0.15
KpFc	log (cm)	Theta above which epsc is reduced by 50%			
TsumEmergence	oC d	Temperature sum from sowing to emergence	160	160	160
DOYsowing	DOY	Day of year of sowing	-	263	
DOYharvest	DOY	max DOY of harvest,	-		
TsumHarvest	oC d	Temperature sum from sowing to harvest	ca, 2500	28668	2726
Bc0	g m-2	Initial crop biomass	10 - 25	20	20
LAIc0	m2 m-2	Initial leaf area index	0.01*Bc0	0.14	0.14
CropSwitch	DOY	Crop rotation			
Cropfraction covered	-	Crop soil cover fraction			

Physical crop parameters – group A: to calibrate (grey field) and fixed (green field)

Table 10: Lists the crop parameters for calibration and user settings. The reference crop parameter values for winter wheat in Rothamsted (Ro) and its plausible range are also given.

Crop parameters to set by model user, since referring to region and/or management – group B: white field. Ro1, Rothamsted season 1, Ro2, Rothamsted season 2.

- Sensitivity analysis with initial crop parameter values

The sensitivity analysis was performed on total aboveground biomass production and maximum LAI of winter wheat for the data set of Rothamsted, 1979/1989 under potential growth conditions using the reference parameter values. Depending on the type of parameter, its value was varied within a given range of values that refers to their plausible variability. Conclusion from the sensitivity analysis:

The parameter Bc0 is almost not, but the parameter LAI0 is slightly sensitive.

The parameters epsc and sc are highly sensitive for, both, Bc and LAImax.

The parameter kc is not very sensitive above a value 0.8 for, both, Bc and LAImax

The parameters pl0 and TsumLeavesStop are slightly sensitive for Bc and highly sensitive for LAImax.

The parameter TsumLeavesStop is more sensitive than pl0. Simulation test runs showed that the calibration of TsumLeavesStop provided more accurate LAI predictions than fitting pl0. At first sight, the introduction of the additional parameter TsumLeavesStop might appear useless for long-term yield estimations. However, for the silvoarable situation, when light competition plays a major role, a reasonable simulation of crop LAI and light interception becomes more important.

Consequently, for the calibration of the crop part of YIELD-SAFE we selected: epsc, sc, TsumLeavesStop and kc. The parameter pl0 was only tested occasionally. LAI0 was not selected since it will be set as a certain fraction of Bc_0. The latter is in fact a management parameter and depends on sowing density (or seeding rate).

- Calibration winter wheat for North Europe using data on seasonal growth pattern

The calibration was performed first on the experimental results from Rothamsted (UK) for the growing seasons 1979/80 and 1980/81 (each 6 intermediate harvests). Secondly, the seasonal calibration was done for Randwijk for the growing seasons 1982/83 and 1983/84 (10 intermediate harvests). The model was separately calibrated for each season and then over the two seasons of a site combined. The seasonal values of aboveground biomass (Bc) and LAI were used for fitting the model. However, we gave priority to a good fit of Bc, because this is the major output of the crop sub-model. Moreover, the experimental data on total aboveground biomass are probably more accurate than the measurements of LAI. The best parameter sets have been chosen visually, i.e. those with the best agreement between simulation results and field observations and close to the biological range. The corresponding simulation results are given in Figure 55 and Figure 56.

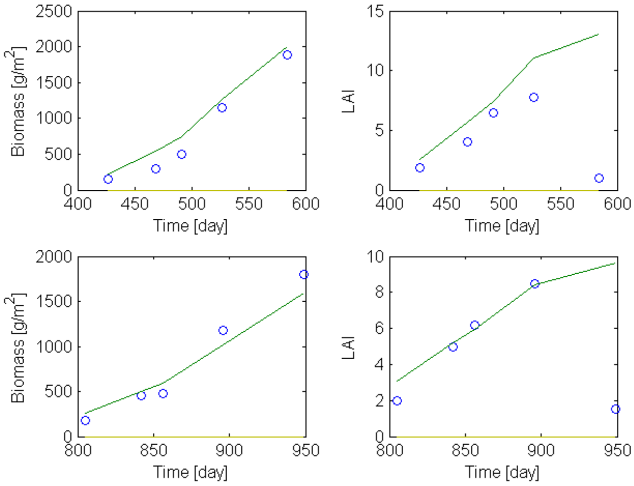

Figure 55: Winter wheat Rothamsted: results of fitting simultaneously kc (0.64) and epsc (1.81) using set 3 (kc,epsc, sc, plo, TLstop of: 0.7; 1.5; 0.02; 0.8 and 250) and experimental data of the growing seasons 1979/80 and 1980/81

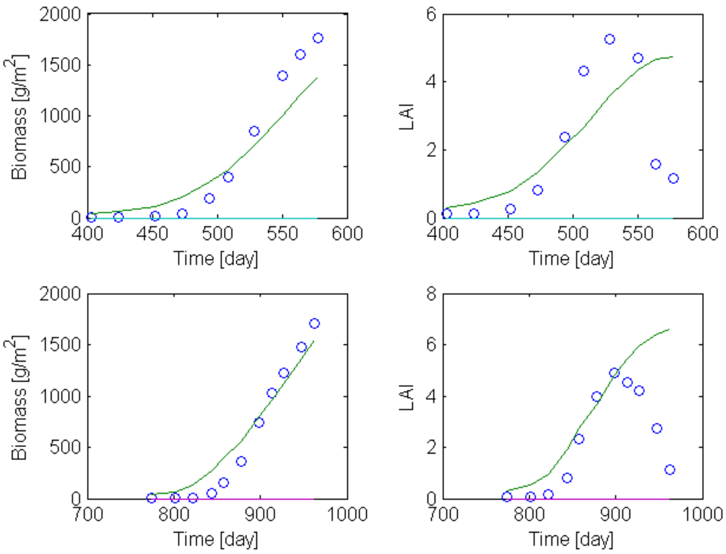

Figure 56: Winter wheat Randwijk: results of calibrating TsumLeavesStop (436) with start set 6 (kc,epsc, sc, plo, TLstop of: 0.74; 1.7; 0.011; 0.8 and 700) and experimental data of growing seasons 1982/83 and 1983/84.

Parameterisation of the model for a range of tree and crop mixtures, suitable for different parts in Europe

Model adjustments

A difficult task was the model application to a silvoarable experimental site in Mediterranean France, i.e. the poplar - durum wheat stand at Vézénobres. The first problem was the weather file, since the radiation data of Vézénobres covered only several months. Therefore, first simulation tests were performed with radiation data of the 30 km southwest located experimental site Restinclières. The parameter set calibrated for Mediterranean region (Team WP6b, 7 and 8 on 5.7/ 04) has been used as base, and was adapted to the site with respect to management factors as tree densities and harvest dates. The simulations for potential growth conditions show reasonable estimates for potential durum wheat yields and tree growth. Also the simulations mimicking lower growth conditions as for water stress (using site factor), showed satisfactorily results. However, it seems that the competition effect of trees was underestimated. This discrepancy was even higher when using radiation data obtain from a weather station close to the experimental field.

Apparently, it is not possible to achieve good Yield-sAFe predictions for the poplar-wheat site at Vézénobres when using the parameter set for Mediterranean region. The results suggest that the parameter value of kt has to change with time.

Following initial evaluation of the use of the model on selected Landscape Test Sites, four changes were proposed. See for details Burgess et al. (2005).

1. The use of phased kt for the tree component reduces the relative size of the tree at low densities and increases relative crop yield. The function of phased kt to be used for the trees comprises an “a” value of 10 and a “b” value of 0.4.

2. The relative yield of the tree and the crop is sensitive to the choice of the critical pF values for the tree and the crop. For future analysis, it was decided that a critical pF value of 4.0 for the trees and 2.9 for the crops.

3. Increasing the gamma of one component of the system decreases the yield of both components of the system. The converse is also likely to be true. The gamma values of crops and trees need to be in sensible ranges to allow for correct competition for water between the tree and the crop.

4. The cropped area for the 50 and 113 tree ha-1 systems were assumed to be 85.7% and 90% respectively

Final implementation of Yield-sAFe for long-term predictions

Table 11 summarizes the conditions for predicting the tree and crop yields for each of the Landscape Test Sites.

Site	Unit	Rad (%)	Soil type	Soil depth (cm)	Tree species	Crop rotation
Spain						
Alcala	LU1	97	Medium	140	Oak	Wheat/wheat/fallow
Alcala	LU2	86	Medium	50	Oak	Wheat/wheat/fallow
Torrijos	LU1	101	Medium	140	Oak	Wheat/fallow
Torrijos	LU2	100	Medium	140	Oak	Wheat/wheat/fallow
Ocana	LU1	100	Medium	140	Oak	Wheat/wheat/fallow
Almonacid	LU1	97	Medium	140	Oak	Wheat/fallow
Almonacid	LU2	83	Fine	140	Oak	Five years of sunflower/wheat/fallow
Cardenosa	LU1	93	Medium	140	Oak	Wheat/wheat/wheat/fallow
Cardenosa	LU2	101	Fine	140	Oak	Wheat/wheat/wheat/fallow
Fontiveros	LU1	99	Coarse	140	Oak	Wheat/wheat/wheat/wheat/fallow
Fontiveros	LU2	98	Coarse	140	Pinus	Wheat/wheat/wheat/wheat/fallow
Olmedo	LU1	100	Coarse	140	Pine	Wheat/sunflower/fallow
Olmedo	LU2	100	Medium	140	Oak	Wheat/sunflower/fallow
Olmedo	LU3	99	Coarse	140	Oak	Wheat/sunflower/fallow
Campo	LU1	99	Coarse	140	Pine	Wheat/wheat/wheat/fallow
Campo	LU2	99	Medium	140	Oak	Wheat/wheat/wheat/wheat/wheat/fallow
Paramo	LU1	100	Medium	140	Oak	Wheat/wheat/wheat/sunflower/fallow
Paramo	LU2	100	Medium	140	Oak	Wheat/wheat/wheat/sunflower/fallow
Paramo	LU3	101	Medium	140	Oak	Wheat/wheat/wheat/sunflower/fallow
France						
Champdeniers	LU1	100	Fine	80	W.cherry	Wheat/wheat/sunflower/wheat/oilseed/sunflower
Champdeniers	LU2	100	Medium	120	Walnut	Wheat/wheat/sunflower/wheat/oilseed/sunflower
Chateauroux	LU1	102	Fine	80	Walnut	Wheat/wheat/oilseed/wheat/oilseed/sunflower
Chateauroux	LU3	102	Medium	120	Walnut	Wheat/wheat/oilseed
Chateauroux	LU2	102	Fine	40	W.Cherry	Wheat/wheat/oilseed/wheat/oilseed/sunflower
Chateauroux	LU4	100	Fine	40	W.cherry	Wheat/wheat/oilseed/wheat/oilseed/sunflower
Fussy	LU1	101	Fine	40	W cherry	Wheat/oilseed
Fussy	LU2	103	Medium	80	Poplar	Wheat/wheat/oilseed
Fussy	LU3	102	Fine	120	W. cherry	Wheat/oilseed
Sancerre	LU1	103	Fine	40	W. cherry	Oilseed/wheat/sunflower/wheat/wheat/wheat/oilseed
Sancerre	LU3	101	V fine	120	W. cherry	Oilseed/wheat/sunflower/wheat/wheat/wheat/oilseed
Sancerre	LU4	100	Coarse	80	W. cherry	Oilseed/wheat/sunflower/wheat
Sancerre	LU2	102	V fine	140	Poplar	Oilseed/wheat/sunflower/wheat/wheat/wheat/oilseed
Champlitte	LU1	103	Medium	140	W. cherry	Wheat/wheat/oilseed
Champlitte	LU2	103	Md-fine	35	Walnut	Wheat/wheat/wheat/wheat/wheat/grain maize
Dampierre	LU1	98	Medium	140	W. cherry	Wheat/wheat/grain maize
Dampierre	LU2	97	Fine	35	W. cherry	Wheat/wheat/wheat/grain maize
Dampierre	LU3	95	Md-fine	60	Poplar	Wheat/grain maize
Vitrey	LU1	103	Medium	60	W. cherry	Wheat/wheat/oilseed
Vitrey	LU2	103	Md-fine	60	Poplar	Wheat/wheat/grain maize
Netherlands						
Balkbrugg	LU1	100	Coarse	140	Poplar	Forage maize
Bentelo	LU1	100	Coarse	140	Walnut	Wheat/wheat/forage maize
Scherpenzeel	LU1	100	Coarse	140	Poplar	Forage maize

Table 11. Description of the 44 different land units and the respective assumed tree species and crop rotation.

The detailed outputs for each of the Landscape Test Sites, with the tree/crop parameterisations, are described in Burgess et al. (2005), i.e.

a) Reference calibrations

b) Management regime for the two land unit scenarios

c) Management regime for the three tree scenarios.

d) Predicted tree and crop yields and LERs in the two monoculture and two silvoarable systems.

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Burgess, P., Metselaar, K., Graves, A., Stappers, R., Keesman, K.J., Mayus, M. and van der Werf, W., 2004. The SAFE-RESULT equations in Excel, Version 10: April 23 2004. SAFE Working document.

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Stappers, R., Keesman, K.J. and van der Werf, W. The SAFE-RESULT Equations: an Agro-Forestry Model. Systems & Control and Crop & Weed Ecology Group, Wageningen University, The Netherlands. October 2003.

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Van Keulen, H., 1982. Graphical analysis of annual crop response to fertiliser application. Agr. Syst. 9: 113-126.

Van Keulen, H. and Seligman, N.G., 1987. Simulation of water use, nitrogen nutrition and growth of a spring wheat crop. Simulation Monographs, Pudoc, Wageningen, The Netherlands.

Werf, W. v.d., K. Keesman, R. Stappers, M. Mayus, H. van Keulen, M.J. Kropff, C. Dupraz., 2004. Uncertainty analysis of agroforestry models. 1st Agroforestry World Congress, Orlando, USA, June 2004.

Werf, W. v.d., Keesman, K.J., Metselaar, K., Mayus, M., Stappers, R., Burgess, P., Graves, A., Incoll, L.D., Pilbeam, D., Dupraz, C. and H. v. Keulen. (2005) Yield-sAFe: A parameters-sparse process-based model for growth, yield and resource use in agro-forestry systems. (In preparation; will be submitted to Ecological Modelling)

WP7: Economic modelling at the plot scale

The work completed in work-package 7 is described in relation to the five tasks of the work-package. Task 7.1 covered the review of existing financial models, and task 7.2 covered the selection and development of a plot- and a farm-scale economic model. The third task related to the use of templates to identify and quantify inputs, outputs, costs and revenues for the silvoarable systems at selected network sites, and for existing arable and forestry enterprises for different parts of Europe. Task 7.4 related to the use of the model to identify the profitability of the agroforestry systems at the network sites and their sensitivity to changes in prices and grants. Task 7.5 related to the same analysis for 42 land units across 19 landscape test sites which are used in the up scaling analysis in work-package 8. An additional piece of work, labelled in this report as task 7.5b, was also completed by Borrell et al. (2005) who investigated the effect of different tree densities in France, using a model called the LER-based-generator. Each task is reviewed in turn.

Review of existing financial models

The review of existing economic models of agroforestry systems undertaken in Task 7.1 has been written up as two papers. These are also presented in Deliverable 7.4.

A paper entitled "Development and use of a framework for characterising computer models of silvoarable economics" will be published during 2005 by the journal Agroforestry Systems (Graves et al. 2005b). A Microsoft® Powerpoint presentation of this paper was also presented by Paul Burgess at the World Agroforestry Congress in Florida, USA in June 2004 (Table 12). The paper develops a framework for comparing five computer models of silvoarable agroforestry: POPMOD, ARBUSTRA, the Agroforestry Estate Model, WaNuLCAS, and the Agroforestry Calculator. Key characteristics described for the models are the background, the systems modelled, the objective of the economic analysis, economic viewpoint, spatial and temporal scales, generation and use of biophysical data, model platform and interface, and input requirements and outputs.

The second paper is entitled "Evaluating agroforestry investments" (Table 12). The paper reviews the difficulties of integrating long-term and short-term crops within the same economic system and discusses and develops the basis for economic analysis of such systems. The paper also reports several criteria that have been used to evaluate agroforestry and forestry projects including, for example, the maximisation of mean annual timber volume, annual receipts, land revenue, and discounted benefits.

Table 12 Key outputs from the review of existing models (Task 7.1)

Title of presentation	Comment
Graves, A.R., Burgess, P.J., Liagre, F., Terreaux, J.P., and Dupraz, C. (2005b). Development and use of a framework for characterising computer models of silvoarable economics. Agroforestry Systems (in press)	In press

Graves, A.R., Burgess, P.J., Liagre, F., Terreaux, J.-P., and Dupraz, C. (2004b). A comparison of computer-based models of silvoarable economics. In: Book of Abstracts, 1st World Congress of Agroforestry. p241. 27 June-2 July 2004. University of Florida, Florida, USA.	Conference presentation
Terreaux, J.P., Chavet, M., Graves, A.R., Dupraz, C., Burgess, P.J. and Liagre, F. (2004). Evaluating agroforestry investments.	Draft paper

Selection and development of a plot- and farm-scale economic model

The criteria for the economic model were reported as milestone 7.1 in September 2002 (Table 13). This included agreement that the economic model was needed to work at both plot- and a farm-scale. In 2002, Anil Graves and Paul Burgess developed an initial plot- and farm-scale economic model (Burgess and Graves, 2002). This model, which ran on Microsoft® Excel was circulated to consortium members in November 2002 together with a 24 page description of the model and some sample exercises (Table 2). This constituted Deliverable D7.1. The financial templates for the economic model were placed on the project website in November 2002 (Milestone 7.2).

During 2003 and 2004, various modifications were made to the economic model including the addition of routines to calculate an infinite net present value and an equivalent annual value. During October 2003, at a workshop at Orvieto, Italy it was apparent that it would be useful to develop a plot-based model with an integrated biophysical model for use in Work-package 7, and a farm-based model for use in Work-package 8 (Figure 57). These models were called “Plot-sAFe” and “Farm-sAFe” respectively.

Table 13 Key outputs from the selection and development of the economic models (Task 7.2)

Name of presentation or file	Date
Criteria for the model (Milestone 7.1)	
Graves, A. & Burgess, P. (2002). The development of an economic plot- and farm-scale model for SAFE. Unpublished workshop paper: Cranfield University. 6 pp	Apr 2002
Burgess, P.J., Liagre, F., Mayus, M., Lecomte, I., Reisner, Y., Palma, J., Jackson, N. & Graves, A.R. (2002). Report on workshop session on the criteria and structure for the economic model. Unpublished report. Cranfield University. 3 pp.	Sept 2002
Initial model development (Deliverable 7.1)	
Graves, A.R., Burgess, P.J., Liagre, F., Dupraz, C., Terreaux, J-P. & Thomas T. (2002). SAFE Economic model v01.xls	Nov 2002

Burgess, P.J. & Graves, A.R. (2002). HySAFE economical model. Deliverable D.7.1. Unpublished Report. Silvoarable Agroforestry for Europe contract — Nov 2002

Burgess, P.J. & Graves, A.R. (2002). HySAFE economical model: Sample exercises. Unpublished Report. Silvoarable Agroforestry for Europe contract — Nov 2002

Graves, A. & Burgess, P. (2002). Description of the SAFE economic model (version 0.1). Unpublished report: Cranfield University 25 pp. — Nov 2002

Graves, A. & Burgess, P. (2002). Sample exercises with the SAFE economic models. Unpublished report: Cranfield University 14 pp. — Nov 2002

Development of Plot-sAFe

Burgess, P.J., Graves, A.R., Metselaar, K., Stappers, R., Keesman, K., Palma, J, Mayus, M., & van der Werf, W. (2004b). Description of the Plot-sAFe Version 0.3. Unpublished document. 15 September 2004. Cranfield University. 52 pp. — Sept 2004

Development of Farm-sAFe

Graves, A.R., Burgess, P.J., Liagre, F., Dupraz, C. & Terreaux, J.-P. (2003). The development of a model of arable, silvoarable and forestry economics. Unpublished draft paper. Silsoe: Cranfield University. 30 pp — Dec 2003

Graves, A.R., Burgess, P.J., Liagre, F., Dupraz, C., Terreaux, J-P., Borrel, T. & Thomas T. FarmSAFE.xls — Apr 2004

Graves, A.R., Burgess, P.J., Liagre, F., Dupraz, C., and Terreaux, J.-P. (2004). The development of an economic model of arable, agroforestry and forestry systems. In: Book of Abstracts, 1st World Congress of Agroforestry. p242. 27 June-2 July 2004. University of Florida, Florida, USA. — Jun 2004

Development of the LER generator

Borrell, T., Dupraz, C. and Liagre, F. (2005). Economics of silvoarable systems using the LER approach. Unpublished report. Montpellier, France: Institut National de la Recherche Agronomique. 37 pp. — March 2005

Plot-sAFe model

During 2004, a plot-scale model called Plot-sAFe was developed that combined the parameter sparse biophysical model (Yield-sAFe; see work-package 6b) with a plot-scale economic model (Figure 2) in Microsoft® Excel. Plot-sAFe Version 0.2 of this model was placed on the project website in June 2004. Some corrections to the model were made following a workshop at Wageningen in May 2004. The full description of version 0.3 of the Plot-sAFe model is provided by Burgess et al. (2004a).

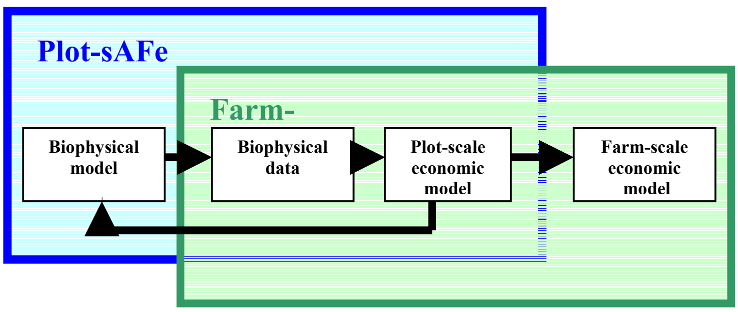


Figure 57 Diagram showing the components and interrelationship between a plot-based model called Plot-sAFe and a farm-scale model called Farm-sAFe

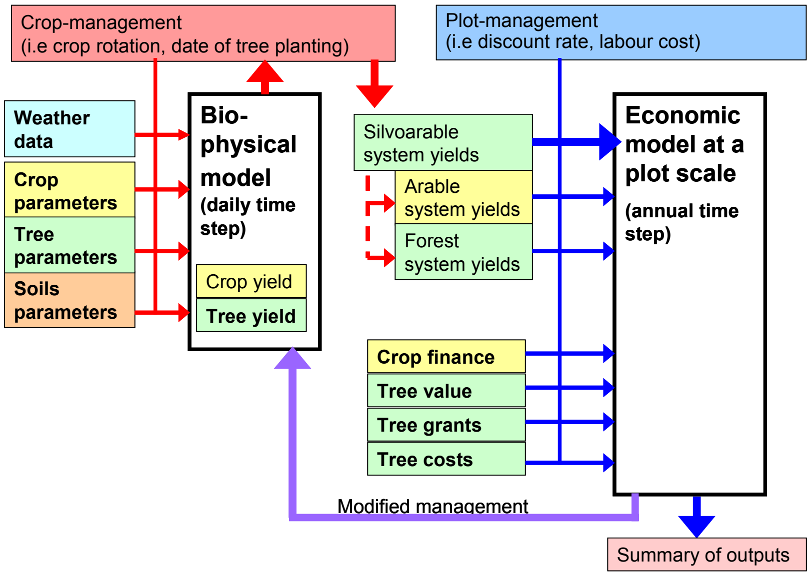


Figure 58 Outline of the Plot-sAFe model

Farm-sAFe model

Farm-sAFe, a "Financial And Resource-use Model for Silvoarable Agroforestry For Europe", was chosen as the name for the farm-scale economic model. A paper describing the development of the Farm-sAFe model is due to be submitted to Agroforestry Systems (Table 2). A poster describing the development of Farm-sAFe was presented at the World Agroforestry Congress at Florida, USA (Table 2). The current Farm-sAFe model (version 0.2) matches most of the initial criteria stated in November 2002 (Table 3).

For most of the farm-scale analysis, the biophysical data for the Farm-sAFe model was obtained the Plot-sAFe model. However a "LER-based-generator" biophysical was also developed for use at selected French sites (Borrell et al. 2005).

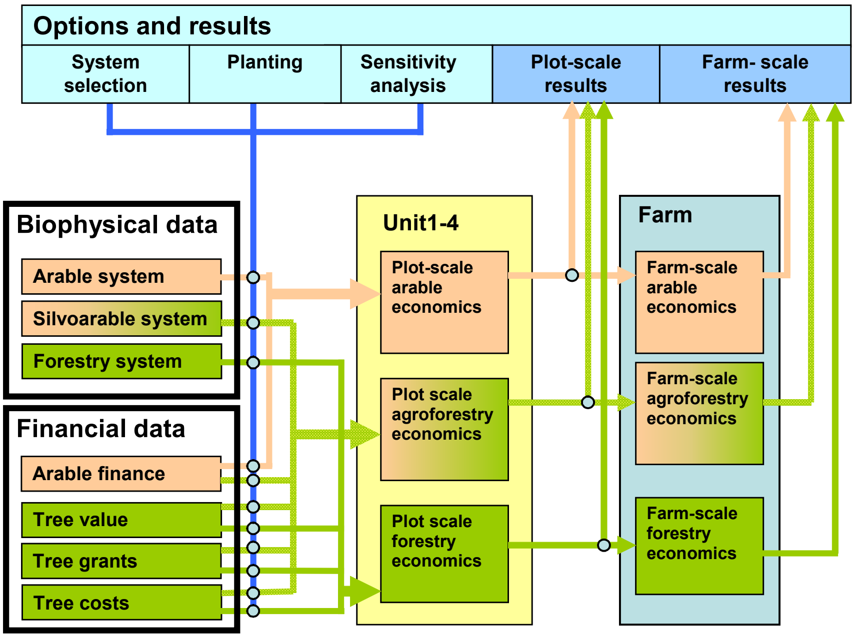


Figure 59 Outline of the Farm-sAFe model

Table 14 Criteria for the SAFE economic model agreed on 12 September 2002, and the capacity of Plot-sAFe version 0.3 and Farm-sAFe version 0.2 to meet each criterion

Criterion number	Criterion The model should be able to:	Does Plot-sAFe 0.3 meet this criterion?	Does Farm-sAFe 0.2 meet this criterion?
1	model arable and forestry alongside silvoarable agroforestry	Yes	Yes
2	use cost benefit analysis to calculate net present values (NPV)	Yes	Yes
3	operate on an annual-time step	Yes	Yes
4	model the economics at a plot-scale and farm-scale	No	Yes
5	cope with land heterogeneity within a farm	No	Yes
6	calculate the effect of different management decisions on net farm income, taking into account farm fixed costs and taxation	No	Yes
7	calculate the effect of ownership on farm costs and taxation	No	Yes
8	compare the effect of the farmer using his own or contract labour	Yes	Yes
9	simulate introducing proportions of agroforestry on the farm	Yes	Yes
10	simulate the effect a phased introduction of agroforestry	Yes	Yes
11	model sensitivity of systems to costs, revenue, and discount rate	Yes	Yes
12	determine sensitivity of the systems to governmental support	Yes	Yes
13	be used by the greatest number of users (i.e. be transferable)	Yes	Yes
14	accept input data through “electronic templates”	Yes [a]	Yes [a]
15	derive the revenue from the arable component of the silvoarable system from estimated yields determined from biophysical calculations, and to model reductions in the planted area in an agroforestry system	Yes	No [b]
16	allow the use of aggregate costs of arable production	Yes	Yes
17	model production for several crops within a rotation	Yes	Yes
18	calculate timber revenue using the annual increase in standing timber volume and the use of price-size curves	Yes	Yes
19	model the cost of returning agroforestry back to arable production.	No	No
20	model the cost of obtaining professional advice	No	No

[a]The options are stored within worksheets held within the workbook

[b] In Farm-sAFe the biophysical inputs are obtained from Plot-sAFe

Use of templates to identify and quantify inputs, outputs, costs and revenues for the silvoarable system network systems, and existing arable and forestry enterprises for different parts of Europe

The costs of inputs and the value per unit of output were determined from previous studies and through a series of workshops and visits related to each network site and landscape test site region (Table 15). For the network sites these are reported by Graves et al. (2003a; 2003c) and Burgess et al. (2003). For the landscape test sites, the workshops are reported by Reisner (2004), Palma and Reisner (2004), and Herzog (2004). The final description of the inputs and the outputs at the respective sites are described by Graves et al (2005a; 2005c) and Borrell et al. (2005).

Table 15 Reports describing the output from task 7.3

Authors, year of production, title and origin of reports
Network site reports
Graves, A.R., Bertomeu, M., Burgess, P.J. & Moreno, G. (2003a). Work Package 7 visit trip report to Plasencia for collection of economic and management data on Spanish Network sites 9-11 April 2003. Unpublished report. Silsoe, Bedfordshire: Cranfield University 35 pp.
Graves, A.R., Liagre, F., Dupraz, C., and Terreaux, J.-P. (2003c). Working visit report for work-package 7 in Montpellier. 2-7 June 2003. Unpublished report. Silsoe, Bedfordshire: Cranfield University. 10 pp.
Burgess, P.J., Incoll, L.D., Hart, B.J., Beaton, A., Piper, R.W., Seymour, I., Reynolds, F.H., Wright, C., Pilbeam & Graves, A.R.. (2003). The Impact of Silvoarable Agroforestry with Poplar on Farm Profitability and Biological Diversity. Final Report to DEFRA. Project Code: AF0105. Silsoe, Bedfordshire: Cranfield University. 63 pp.
Landscape test site workshop reports
Palma, J. & Reisner, Y. (2004). Work visit report on the upscaling of the seven landscape test sites in France. Unpublished report. Zurich: FAL 15 pp.
Reisner, Y. (2004). Work visit report: upscaling for three landscape test sites in the Netherlands. 24-28 May 2004. Unpublished report. Zurich: FAL. 9 pp.
Herzog, F. (2004). Work visit report on upscaling for nine landscape test sites in Spain. Workshop at Plasencia, Spain 5-8 July 2004. Unpublished report 2004.
Final reports
Graves, A.R., Burgess, P.J., Bertomeu, M., Moreno, G., Liagre, F., Palma, J.H.N., Herzog, F., Terreaux, J.P., Thomas, T., Keesman, K., van der Werf, W., and Dupraz, C. (2005a). Plot-scale economics of silvoarable systems at the network sites. Unpublished report. Cranfield University at Silsoe. 24 February 2005. 43 pp.
Graves, A.R., Burgess, P.J., Palma, J.H.N., Herzog, F., Moreno, G., Bertomeu, M., Dupraz, C. and Liagre, F. (2005c). Economic feasibility of silvoarable in target regions report. Cranfield University at Silsoe. 24 February 2005. 43 pp.
Borrell, T., Dupraz, C. and Liagre, F. (2005). Economics of silvoarable systems using the LER approach. Unpublished report. Montpellier, France: Institut National de la Recherche Agronomique. 37 pp.

Use of the model to identify the most profitable agroforestry systems for the network sites and their sensitivity to changes in prices and grants

Background

Between August 2004 and January 2005, the biophysical tree and crop yields for forestry, arable and silvoarable systems for selected network sites were modelled using the Yield-sAFe model within Plot-sAFe (Burgess et al. 2005). These were then used, with the economic data collected in task 7.3, to assess the effect of different tree management regimes and grant scenarios on the plot-scale economics of forestry, agricultural and silvoarable systems at five network sites. A full description of the analysis is provided by Graves et al. (2005a). However for clarity the key results are also summarised in this report.

Selection of network sites

Five network sites were chosen: three sites in western Spain (Sotillo, Cerro Lobato and Dehesa Boyal), and one in southern France (Vézénobres) and in eastern England (Silsoe) (Figure 60). Some of the originally planned sites, for example Restinclières and St Jean d'Angely in France and Eratyra and Sisani in Greece, were excluded because of insufficient input data. Although there was also a network site at Leeds in the UK, the tree and crop yield responses were broadly similar to those at Silsoe and therefore the results are presented for only one site. An initial analysis was also undertaken for a walnut site at Biagio in Italy and is reported separately by Lhouvum (2004).

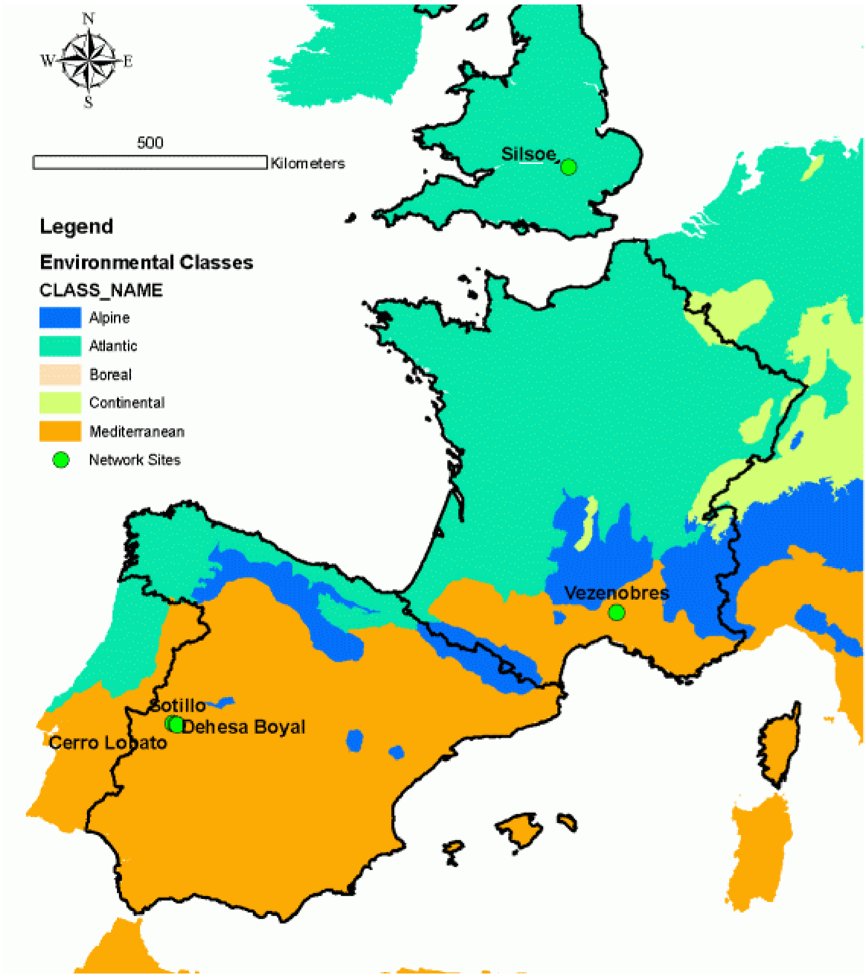


Figure 60 Location of selected network sites in Spain, France and the UK

Description of network sites

In order to use the Yield-sAFe biophysical model, it was necessary to provide daily values of temperature, total short-wave radiation and rainfall for a complete tree rotation (i.e. 15, 30 or 60 years) at each network site. The assumed mean air temperature, annual total short-wave radiation and annual rainfall at each site is presented in Table 16. The soil types were classified as medium or fine (Wösten et al. 1999).

Table 16 Description of the network sites

Site name	Mean temp. (°C)	Annual solar radiation (MJ m^{-2})	Annual rainfall (mm)	Soil type	Modelled soil depth (mm)	Tree species	Crop species
Sotillo	16.4	5830	510	Medium	700	Oak	Oats & grass
Cerro Lobato	16.4	5830	510	Fine	1200	Oak	Oats & grass
Dehesa Boyal	16.4	5830	510	Fine	1200	Oak	Wheat, oats & grass
Vézé-nobres	14.7	5120	1000	Medium	4000	Poplar	Durum wheat
Silsoe	9.7	3620	790	Fine	1500	Poplar	Wheat, barley & oilseed

At the Spanish sites, measurements of the height and diameter of trees in an agrosilvopastoral (i.e. crops, livestock and trees) and a silvopastoral (livestock and trees) system were taken during the project (Figure 61). At Vézénobres, forestry and silvoarable treatments were planted in 1996. Tree height and diameter was measured in each treatment for the first nine years and estimates of the relative crop yield in the silvoarable treatment were provided. The experiment at Silsoe is part of the UK silvoarable network, which includes sites at Leeds and Cirencester (Burgess et al. 2003; 2004b). The Silsoe and Leeds network sites have a silvoarable and a forestry treatment and an arable control. Measurements of crop yield, and tree height and diameter in each treatment were recorded for eleven years from planting.

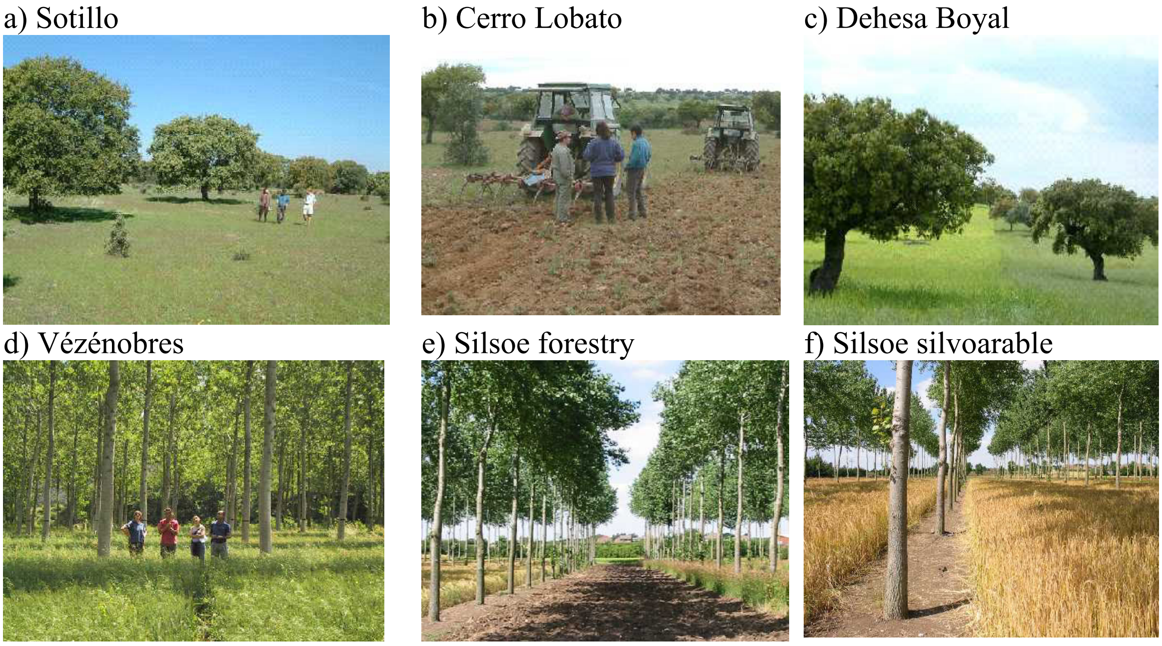


Figure 61 Photographs showing a) oaks and oats planted at Sotillo; b) land preparation at Cerro Lobato; c) a wheat (light green) and oats (dark green) crops at Dehesa Boyal; d) poplar at Vézénobres, and e) a forestry treatment and f) a continuously-cropped treatment with poplar at Silsoe

Validation of the Yield-sAFe model

Because of the limited nature of the field measurements, a biophysical model was needed to estimate tree and crop yields for a full tree rotation and for different tree spacing. The Yield-sAFe model is a biophysical empirical model for describing tree and crop growth in forestry, arable and silvoarable systems. It was developed in the final part of the SAFE project once it became clear that the Hi-sAFe model would be unable to provide the necessary data for the economic analysis. The model is described by Burgess et al. (2004a) and van der Werf et al. (2005). The parameterisation of the model is described by Burgess et al. (2005).

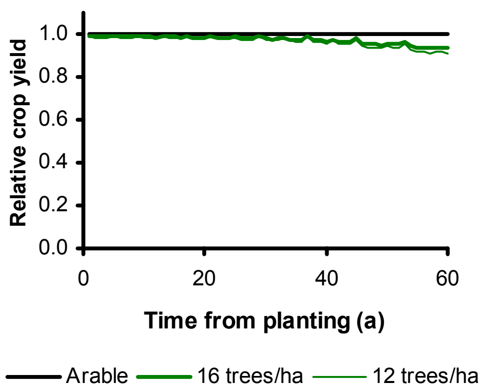
The Yield-sAFe model was used to determine tree and crop yields for the current systems at the five network sites. For each site, the Yield-sAFe model was calibrated for a reference yield in the forestry and arable treatments. The model was then used to predict the interaction between tree and crop yields in the silvoarable treatment.

At the Spanish sites, the model appeared to provide an acceptable description of tree and crop yields, although it was unable to predict difference in tree growth between an agrosilvopastoral and the silvoarable system (Figure 62). A similar response was also apparent at Sotillo and Cerro Lobato (Graves et al. 2005a). The poor growth of the trees in the silvopastoral system, relative to the sites with cropping, could have been due to unaccounted site differences.

At Vézénobres, the model predicted relative crop yields similar to those assumed by the experiment manager. Although the increase in timber volume initially lagged that measured by one or two years, the tree volumes were similar at the end of the rotation of 15 years (Figure 63). Moreover the model also predicted that the silvoarable and forestry timber yields would diverge in a similar way to that predicted by the experiment manager. At Silsoe, the model provided a good description of relative crop yields and the increase in timber yield in the forestry treatment (Figure 64).

From these site analyses there would appear to be some benefit from further refining the calibration of the tree-component of the model. This would require calibration of the outputs of the model against measured tree volumes at a range of densities and ages. However in January 2005, the decision was taken that it was valid to use the Yield-sAFe model to predict the timber and crops yields of silvoarable systems at moderate tree densities. Because of a lack of field data, it was not possible to validate the model at low tree densities, for example 50 trees ha^{-1} and therefore the results for such low densities should be treated with caution. However it is noteworthy that the profitability of such systems is less sensitive to changes in predicted tree volume than densely planted silvoarable systems (see Figure 110).

a) Relative crop yield



b) Timber volume

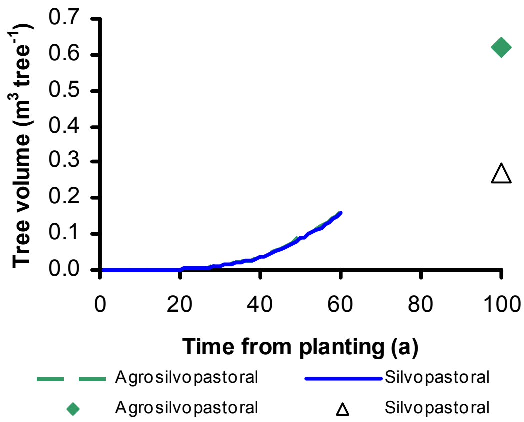


Figure 62 Comparison of a) the relative crop yields and b) the predicted tree size as estimated by Yield-sAFe with measured values at Dehesa Boyal

a) Relative crop yield b) Timber volume

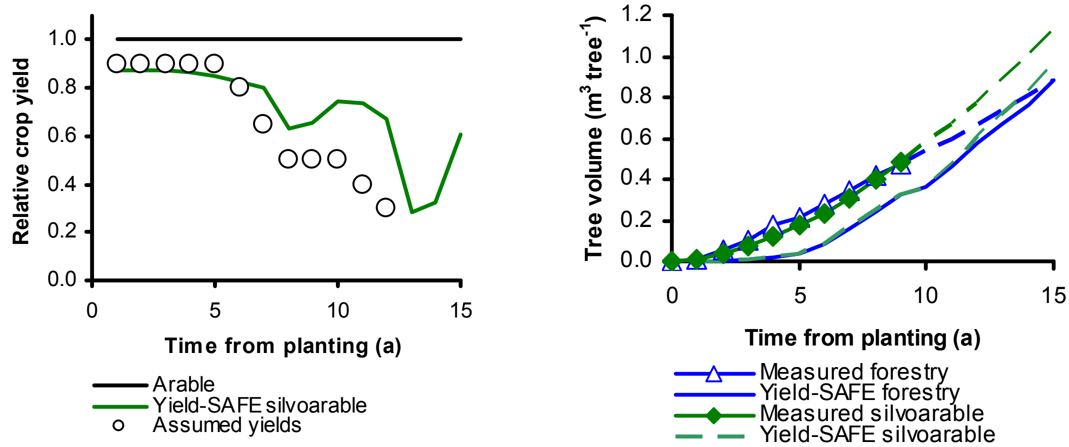


Figure 63 (a) Predicted Yield-sAFe relative crop yield with that estimated by the experiment manager and b) the predicted and calculated timber volumes within the forestry (204 trees ha^{-1}) and silvoarable (138 trees ha^{-1}) treatment at Vézénobres

a) Relative crop yield b) Timber volume

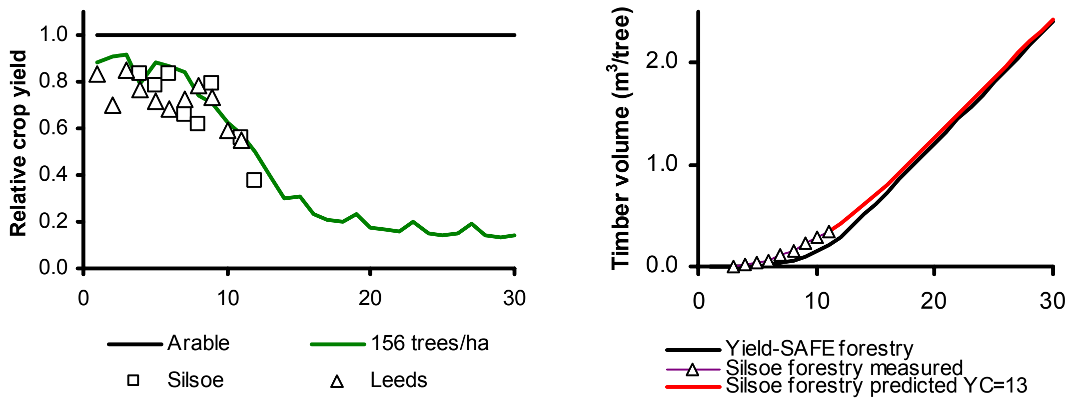


Figure 64 Predicted and measured a) relative crop yields within the silvoarable (156 trees ha^{-1}) treatment and b) timber volumes for the poplar forestry (156 trees ha^{-1}) treatment at Silsoe

Using Yield-sAFe to predict network site yields

Following the initial validation, the Yield-sAFe model was used to predict the tree and crop yields for silvoarable systems with densities of 113 and 50 trees ha^{-1}. In theory for any tree density there is a range of possible tree spacing. For the purpose of the initial yield calculations it was assumed that the area cropped was 95% and 90% at densities of

50 and 113 trees ha^{-1} respectively (Table 17). However in estimating the land equivalent ratio, it was assumed that the rectangularity of the tree planting arrangement should not be greater than about 2: 1. Therefore for these calculations a more uniform tree spacing was assumed with the area of arable crop occupying a lower proportion of the total area (Table 17).

Table 17 Summary of tree densities and proposed orientation and cropped area

Tree density	Original calibration			Land equivalent ratio calculations		
	Tree spacing (m)	Crop width (m)	Proportion of area cropped (%)	Tree spacing (m)	Crop width (m)	Proportion of area cropped (%)
50 trees ha^{-1}	40 x 5	38	95.0	20 x 10	18	90.0
113 trees ha^{-1}	22 x 6.3	20	90.0	14 x 6.3	12	85.7

For each network site, the Yield-sAFe model had already been calibrated for the reference yields in the forestry and arable treatments. The model was then used to predict tree and crop yields in the silvoarable system at densities of 50 and 113 trees ha^{-1}.

In Spain, the calibrated model predicted that the increase in the timber volume of the oaks was slow and hence the effect on crop yields was relatively small (Figure 65). At Vézénobres, the timber volume per poplar was relatively insensitive to tree densities below 200 trees ha^{-1} (Figure 66). The mean relative crop yield over the 15-year-rotation in the 113 tree ha^{-1} systems was predicted to be 71% of that in the arable control. The yields declined from 86% in the initial year to 36% of the arable control 14 years after planting. The yield reduction in a particular year was sensitive to the assumed rainfall pattern. At Silsoe, the timber volume per poplar after 30 years was predicted to be sensitive to a decrease in the tree density below 100 trees ha^{-1}. This may be a result from choosing a rotation of 30 years. The mean relative crop yield over the 30-year rotation at tree densities of 113 and 50 trees ha^{-1} was predicted to be 50% and 65% respectively (Figure 66). In the silvoarable system with 113 trees per hectare, the relative crop yield was predicted to decline from about 90% in the initial years to 30% in year 17.

a) Sotillo (oak; 70 cm medium soil; oats/grass/grass/grass)

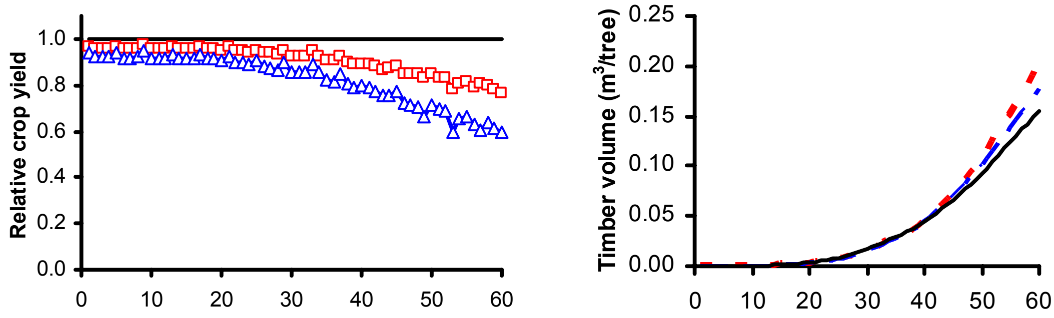
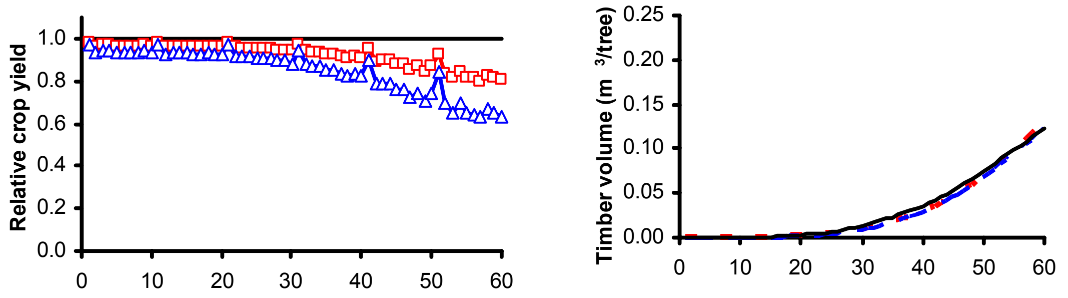
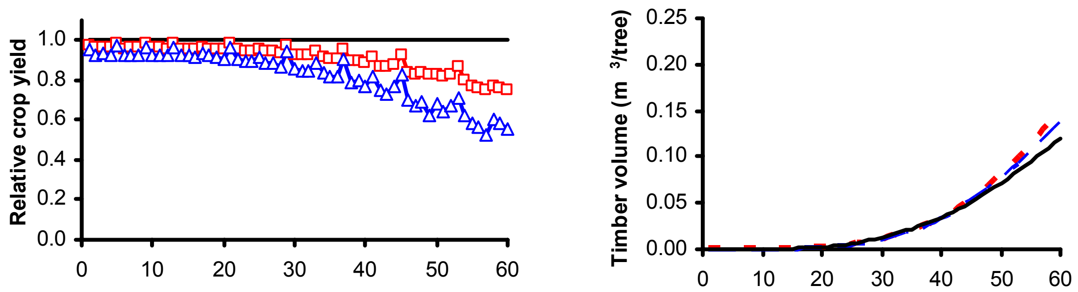


Figure 65 Predicted relative crop yield and timber volume using Yield-sAFe for arable, forestry and two silvoarable systems (50 and 113 trees ha^{-1}) at Sotillo

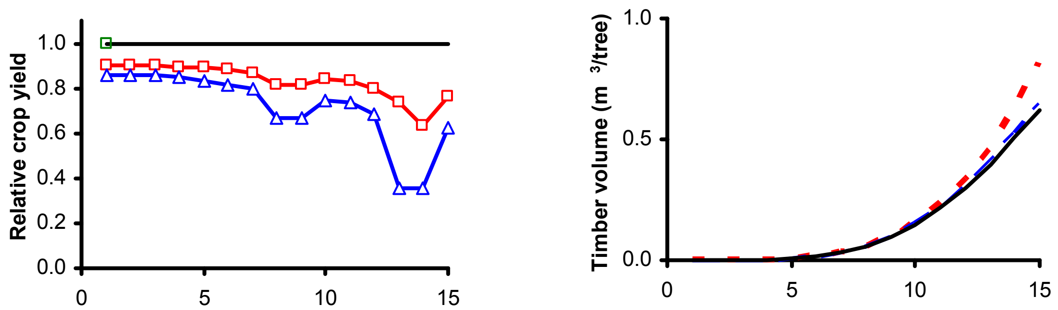
a) Cerro Lobato (oak; 120 cm fine soil; oats/nine years grass)



b) Dehesa Boyal (oak; 120 cm fine soil; wheat/three years grass oats/three years grass)



c) Vézénobres



d) Silsoe

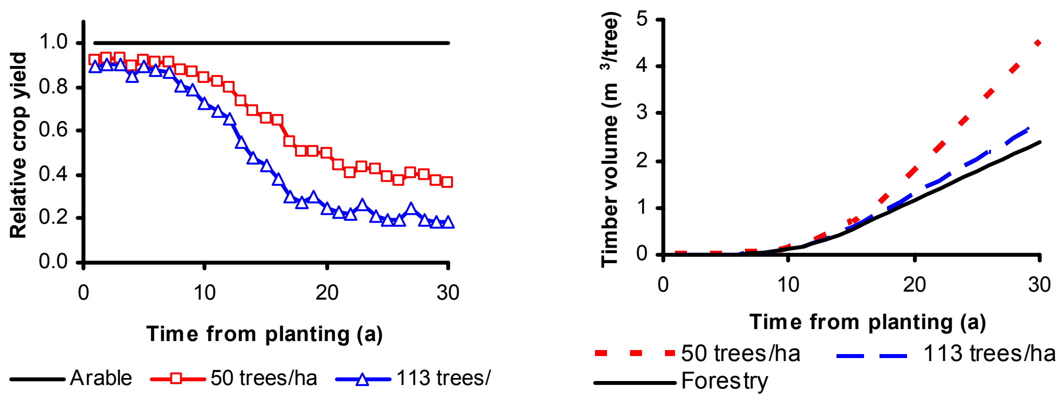


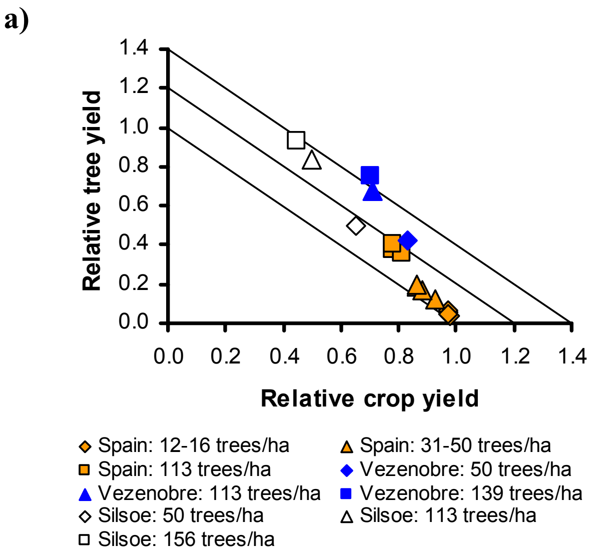
Figure 66 Predicted relative crop yields and timber volumes using Yield-sAFe for a forestry system and two silvoarable systems (50 and 113 trees ha^{-1}) at a) Cerro Lobato, b) Dehesa Boyal, c) Vézénobres and d) Silsoe

Land equivalent ratios for the network sites

From the biophysical yields, it was possible to estimate a land equivalent ratio (LER) for each system. This is defined as "the ratio of the area under sole cropping to the area under the agroforestry system, at the same level of management that gives an equal amount of yield" (Ong, 1996). The LER can therefore be expressed as:

$$LER = \frac{Tree\ silvoarable\ yield}{Tree\ monoculture\ yield} + \frac{Crop\ silvoarable\ yield}{Crop\ monoculture\ yield} \qquad \textbf{Equation 1}$$

Because some of the crop rotations contained more than one species, the yield ratio of each crop type was determined separately and then weighted to provide an overall value. The LER for each system was then calculated. Ong (1996) notes that the choice of the denominator or the monoculture yields for the tree and the crop should be the optimal for that site. One of the potential advantages of the Yield-sAFe model is the possibility of determining if this is the case. The chosen initial tree density of the forestry system ranged from 600 trees ha^{-1} at the Spanish sites to 204 and 156 trees ha^{-1} at Vézénobres and Silsoe respectively.



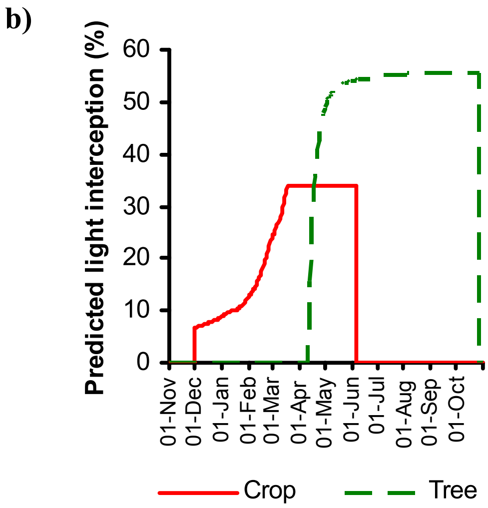


Figure 67 a) Effect of site and tree density on the predicted mean tree and crop relative yields at each network site, and b) the predicted light interception by Yield-sAFe of the tree and crop component of the silvoarable system (139 trees ha^{-1}) at Vézénobres in year 15

In Spain, the predicted land equivalent ratio increased from 1.02-1.04 for tree densities of 12-16 trees ha^{-1}, to 1.05-1.06 for a density of 31-50 trees ha^{-1}, and 1.16-1.17 for a density of 113 trees ha^{-1} (Figure 67a). The dominant component of the silvoarable system was the crop because of the slow growth of the oaks. At Vézénobres, the Yield-sAFe model predicted that the land equivalent ratio would increase from 1.24 at a density of 50 trees ha^{-1}, to 1.45 at a density of 139 trees ha^{-1}. This is the highest value recorded across both the network and the landscape test sites in this project. However similar values of about 1.4 have been reported in agroforestry systems in India (Corlett et al. 1992). The reasons for the high land equivalent value at Vézénobres include: the complementary light interception pattern between the autumn-planted crop and the poplar (Figure 67b), a relatively low tree density in the forestry treatment, and a relatively deep soil which minimises competition for water

At Silsoe, the Yield-sAFe model predicted that the land equivalent ratio would increase from 1.25 at a density of 50 trees ha^{-1} to 1.38 at a density of 156 trees ha^{-1}. Again these high values were partly a result of the complementary light interception pattern of the autumn-planted crops and the poplar. However the value was also inflated because the forestry control yield was obtained from a tree density of 156 trees ha^{-1}. If a forestry control yield were taken at a tree density of 625 trees ha^{-1}, the predicted land equivalent ratio for the silvoarable system at a density of 113 trees ha^{-1} would have been between 0.93 and 1.18 (Graves et al. 2005a).

Approach used for the economic analysis

The aim of the economic analysis was to compare the net returns over a period of years from arable, silvoarable and forestry enterprises, and to express this as a single value. Cost benefit analysis provided a convenient way of making such comparisons through the comparison of aggregated revenue and costs, and the expression of these in terms of a net present value.

In Europe, arable farms are typically composed of a range of "enterprises", such as wheat, barley and oilseed rape production, which generate revenue (*R*; units: € ha^{-1}) and costs expressed on a per unit area basis. Those costs, which are directly related to the area of an enterprise, such as the costs of fertilizer, seed and sprays in an arable enterprise, are termed variable costs (*V*; units: € ha^{-1}) (Nix, 2001; UK Ministry of Agriculture, Fisheries and Food, 1983). For annual-crop enterprises, the net value of enterprises to the farm can be compared on the basis of their gross margins (units: € ha^{-1}) (revenue minus variable costs):

$$\textbf{Gross margin} = R - V \qquad \textbf{Equation 2}$$

Two other costs associated with most enterprises are labour and machinery. Such costs can be termed 'assignable fixed costs' (*A*; units: € ha^{-1}) in that they are "fixed" over short time periods but they can nevertheless be assigned to specific enterprises. Because agroforestry systems exist over a long time period and because labour and machinery costs are typically included in analyses of forestry systems, the economic comparison of forestry, arable and silvoarable was calculated on the basis of their net margins (units: € ha^{-1}) (revenue minus variable costs minus assignable fixed costs) (Equation 3) (Willis et al., 1993; Burgess et al., 1999; 2000).

$$\textbf{Net margin} = R - V - A \qquad \textbf{Equation 3}$$

Whereas an economic comparison of arable crops can be undertaken on an annual basis, the economics of a forestry plantation need to be considered over the rotation of the tree, which may last many years. Within the model, the aggregation of the benefits and costs from each enterprise over time was based on discounted cost benefit analysis (Faustmann, 1849). Discounting is a method that allows the user to directly compare money realised at different periods of time. Most people have a preference for immediate income, because of inflation, the opportunity cost of money and flexibility. Hence a net "present" value of future benefits and costs was determined by dividing them by a pre-determined discount rate (*i*; typically a value between 0.0 and 0.1). At a plot scale, the net present value (*NPV*; units: € ha^{-1}) of an arable, forestry or silvoarable enterprise can therefore be expressed as (Equation 4):

$$NPV = \sum_{t=0}^{t=T} \frac{(R_t - V_t - A_t)}{(1+i)^t} \qquad \textbf{Equation 4}$$

Where: *NPV* is the net present value of the arable, forestry or silvoarable enterprise within a unit (€ ha^{-1}), R_t is the revenue from the enterprise (including subsidies) in year *t* (€ ha^{-1}), V_t is the variable costs in year *t* (€ ha^{-1}), A_t is the assignable fixed costs in year *t* (€ ha^{-1}), *t* is the time horizon (years), and *i* is the discount rate.

In order to compare systems with different rotation lengths, it is possible to calculate an infinite net present value. This is defined as today's value of an infinite system in which each replication has a rotation of *n* years. The infinite *NPV* was defined as:

$$Infinite\ NPV = NPV \frac{(1+i)^n}{(1+i)^n - 1} \qquad \textbf{Equation 5}$$

The infinite net present value can also be expressed as an equivalent annual value (*EAV*). This is the infinite net present value converted to an annual payment at the end of year for the life of the investment. It is calculated at an appropriate discount rate using the following formula:

$$EAV = \text{infinite } NPV \times i \qquad \textbf{Equation 6}$$

Financial analysis of the network sites

The financial analysis was undertaken using Plot-sAFe (Task 7.2). The revenues, costs and grants associated with tree and the arable component at each network site were determined during workshops in Spain and France (Graves et al., 2003a; 2003c), and in the UK by reference to Burgess et al. (2003). Full details are provided by Graves et al. (2005a). In addition at the Spanish network sites, the livestock value of the grass was also included in the analysis (Graves et al. 2003a). The profitability of each system to a farmer is also dependent on the governmental support available for arable, livestock, forestry or silvoarable production. To determine the effect of grants, six scenarios were considered. These were no grants, the 2004 grant scenario and four grant scenarios termed the "2005 grant scenario", arising from the reforms to the Common Agricultural Policy in September 2003.

Network site profitability with no grants

In the no grant scenario, the net present value (*NPV*) and an equivalent annual value (*EAV*) were calculated for the forestry and arable rotation for the duration of the tree crop. The profitability of the silvoarable system was determined using the same crop duration as for the 2004 grant scenario (Table 20) and for an optimised duration with no grants (Table 18).

Table 18 No grants: net present value (*NPV*) (discount rate of 0%) and equivalent annual value (*EAV*) (discount rate of 4%) of the forestry, arable and a silvoarable system at each network site

	Forestry			Arable[a]		Silvoarable[a] (113 trees ha^{-1})			
	Tree period (a)	*NPV* (€ ha^{-1})	*EAV* (€ ha^{-1} a^{-1})	*NPV* (€ ha^{-1})	*EAV* (€ ha^{-1} a^{-1})	Crop period (a)	Stock period (a)	*NPV* (€ ha^{-1})	*EAV* (€ ha^{-1} a^{-1})
Sotillo	60	1180	-37	-2480	-45	60	60	-520	-43
						5[b]	5[b]	1390	-14
Cerro Lobato	60	1370	-37	-1540	-29	60	60	180	-31
						5[b]	5[b]	1350	-12
Dehesa Boya	60	1300	-37	6110	116	60	60	6640	104
						60	5[b]	8010	128
Vézénobres	15	5410	190	910	59	15	na	3690	143
						5[b]	na	6025	265
Silsoe	30	9120	97	3150	109	18	na	9290	110
						12	na	11560	179

[a]: Arable and silvoarable systems in Spain include grass for potential livestock production

[b]: The minimum rotation allowed for the livestock and crop component of the silvoarable system was five years.

In the no grant scenario, at the low productivity sites of Sotillo and Cerro Lobato, the *EAV* (at a 4% discount rate) of the forest, arable or silvoarable systems was negative (i.e unprofitable) (Table 18). Hence, assuming stated prices and costs, none of the systems would be undertaken commercially without governmental support. By contrast at Dehesa Boyal, where crop yields were higher, an integrated system of crops and livestock had an *EAV* (at a 4% discount rate) of 116 € ha^{-1} a^{-1} without grants. This profitability was totally due to the crop and hence, without grants and assuming current prices and costs, it is proposed that the livestock component would be curtailed. Because the tree component of the silvoarable system was unprofitable without grants, it is likely that an "optimised" arable system without livestock would be more profitable than the optimised silvoarable system.

At Vézénobres, without grants, the forestry system (204 trees ha^{-1}) had a greater predicted *EAV* (190 € ha^{-1} a^{-1}) than the arable system (59 € ha^{-1} a^{-1}) (Table 18). This was due to the high value of the poplar timber from a relatively short rotation and low crop yields. However the predicted *EAV* of the optimised silvoarable system was even higher (265 € ha^{-1} a^{-1}). Without grants, the profitability (at a 4% discount rate) of the tree component within the silvoarable system was very high (274 € ha^{-1} a^{-1}) whilst the net margin from the crop component was negative. The high value of the tree component arose because the predicted timber revenue was about 93% of the value predicted for the forestry system whilst the tree-related costs were about half that in the forestry system.

At Silsoe, without grants, the *EAV* (at a 4% discount rate) of the optimised silvoarable system (179 € ha^{-1} a^{-1}) was predicted to be greater than that for the forest (97 € ha^{-1} a^{-1}) or arable (109 € ha^{-1} a^{-1}) system. The improved profitability of silvoarable agroforestry was due to both the crop component and a larger final timber volume per tree. As at Vézénobres, the model predicted an economic benefit from reducing the tree density from that in the forestry treatment, irrespective of the presence of a crop.

Network site profitability with 2004 grants

The actual level of grants within the 2004 grant scenario ranged from 3470 € ha^{-1} for forestry at Vézénobres to 16700 € ha^{-1} for the arable system, including livestock, at Dehesa Boyal (Table 19). The estimated grants for silvoarable agroforestry were always less than for the arable system, and at Sotillo they were less than that for forestry.

In the 2004 grant scenario it was assumed that the arable area compensation payments were only received if a crop was grown. Hence the optimal duration of arable cropping, where it could be extended, increased relative to the no grant scenario (Table 18). For example, crop and livestock production remained profitable for a full-tree rotation of 60 years within the silvoarable systems at each Spanish site.

Table 19 Actual value of the 2004 grants for the forestry, arable and silvoarable (113 trees ha^{-1}) system at each network site

Network site	Time period (a)	Forest (€ ha^{-1})	Arable[a] (€ ha^{-1})	Silvoarable[a] (113 trees ha^{-1}) Crop period (a)	Livestock period (a)	(€ ha^{-1})
Sotillo	60	9380	8050	60	60	6360
Cerro Lobato	60	9380	13500	60	60	11510
Dehesa Boyal	60	9380	16970	60	60	13790
Vézénobres	15	3470	8960	15	na	8660
Silsoe	30	6320	11390	18	na	6560

[a]Arable and silvoarable systems at the Spanish network sites include a livestock component

The grants for forestry, where available, are particularly generous in Spain. Hence at Sotillo and Cerro Lobato, the predicted *EAV* (at a 4% discount rate) of forestry was greater than that for the arable and silvoarable system (Table 20). By contrast, at Dehesa

Boyal, the low variable and machinery costs associated with arable production meant that the arable system was more profitable than forestry and silvoarable agroforestry.

Table 20 Scenario with 2004 grants: net present value (*NPV*) (discount rate of 0%) and the equivalent annual value (*EAV*) (discount rate of 4%) of the forestry, arable and silvoarable system at each network site

	Forestry			Arable		Silvoarable (113 trees ha^{-1})			
	Tree (a)	*NPV* (€ ha^{-1})	*EAV* (€ ha^{-1} a^{-1})	*NPV* (€ ha^{-1})	*EAV* (€ ha^{-1} a^{-1})	Crop period (a)	Stock period (a)	*NPV* (€ ha^{-1})	*EAV* (€ ha^{-1} a^{-1})
Sotillo	60	10550	289	5560	101	60	60	5850	83
Cerro Lobato	60	10740	290	11960	221	60	60	11700	195
Dehesa Boyal	60	10680	289	23070	428	60	60	20430	378
Vézénobres	15	8880	477	9870	680	15[b]	na	12350	754
Silsoe	30	15440	417	14540	504	18[b]	na	15840	392

[a]: Arable and silvoarable systems at Sotillo, Cerro Lobato and Dehesa Boyal includes livestock component

[b]: Cropping period optimised to maximise net present value; na = not applicable.

At Vézénobres, the silvoarable system continued to be more profitable than the considered forestry and arable systems, in part due to the crop remaining profitable for the full rotation. By contrast with the silvoarable system at Silsoe, because it was only profitable to maintain cropping for about 18 years of the 30-year rotation, the loss of arable area payments led to the *EAV* (at a discount rate of 4%) being less than that for the arable system. The lack of compensation payments associated with the poplars also meant that the silvoarable system was less profitable than the forestry system.

Network site profitability with 2005 grant scenario

Four grant scenarios termed the “2005 grant scenario” were determined to determine the relative profitability of silvoarable agroforestry following the reforms to the Common Agricultural Policy agreed in September 2003 (Table 21).

Table 21 Summary of the four 2005 grant scenarios

Grant scenario	Description	Arable payment	Tree payment
1.1	% arable; 0 tree	Cropped area	None
1.2	full arable; 0 tree	Total area	None
2.1	% arable; full tree	Cropped area	Specified level
2.2	full arable; full tree	Total area	Specified level

The key changes with the 2005, compared to the 2004, grant scenario were predicted to occur in Spain. The introduction of the single farm payment was predicted to reduce the per hectare grant payment on those parts of a farm where crop production occurred. There was also a large predicted decrease in forestry grants. Hence in practice the relative profitability of the forestry, arable and silvoarable systems at Sotillo and Cerro Lobato remained the same (Figure 68) as in the 2004 grant scenario. By contrast, the *EAV* of forestry, arable and silvoarable systems became similar at Dehesa Boyal.

a) 2005 grant scenario 1.1

b) Change from 2004 to 2005 grant scenario 1.1

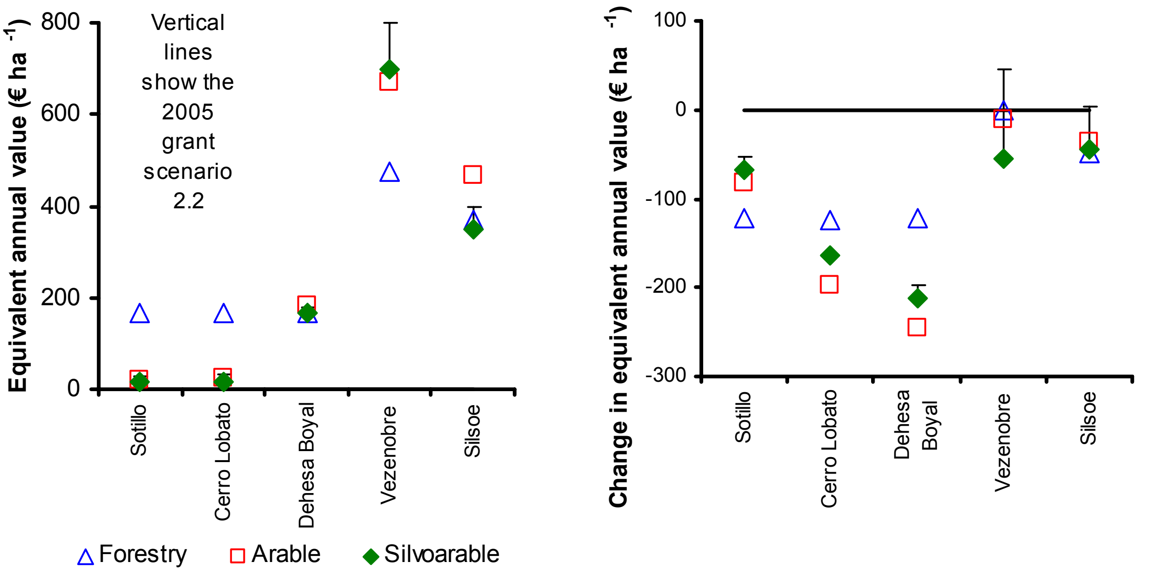


Figure 68 a) Equivalent annual value of the arable, forestry and a silvoarable system (113 trees ha^{-1}) at a discount rate of 4% at each network sites assuming the 2005 grant scenario 1.1, and (b) the change in the equivalent annual value from the 2004 scenario

In general, the relative profitability of the systems at Silsoe and Vézénobres under the 2005 grant regimes was similar to those predicted for the 2004 grant regime (Figure 68). In the case of the silvoarable system, this is primarily because it was assumed that the single farm payment would be forfeited if annual arable cropping were stopped. The profitability of the silvoarable system at Vézénobres and Silsoe was predicted to decline relative to the 2004 scenario, if the singe farm payment was only paid on the cropped area and there were no tree grants (Scenario 1.1). Three other scenarios under the 2005 grant regime were studied. The inclusion of the single farm payment to the whole area increased the equivalent annual value of the 113 tree ha^{-1} system by 24-55 € ha^{-1} a^{-1}, and the inclusion of the tree grants increased the value by an additional 24-46 € ha^{-1} a^{-1}. If the single farm payment was paid on the full area and tree grants were also available, the benefit would result in an increase in the equivalent annual value of 48-102 € ha^{-1} a^{-1}.

Use of the Yield-sAFe model to determine the optimum silvoarable system for high potential locations

Aim

The aim of task 7.5 was to undertake a plot-scale economic analysis of the 42 land unit sites, based at 19 landscape test sites to be used in the farm-scale analysis in Work-package 8 (Figure 69). The choice of the landscape test sites is described in work-package 8. An analysis of each of the sites was completed using Yield-sAFe and the Farm-sAFe model (Graves et al., 2005c). An additional study was also completed in France, which looked at the effect of different silvoarable densities using the LER-generator (Borrell et al. 2005). This described under task 7.5b.

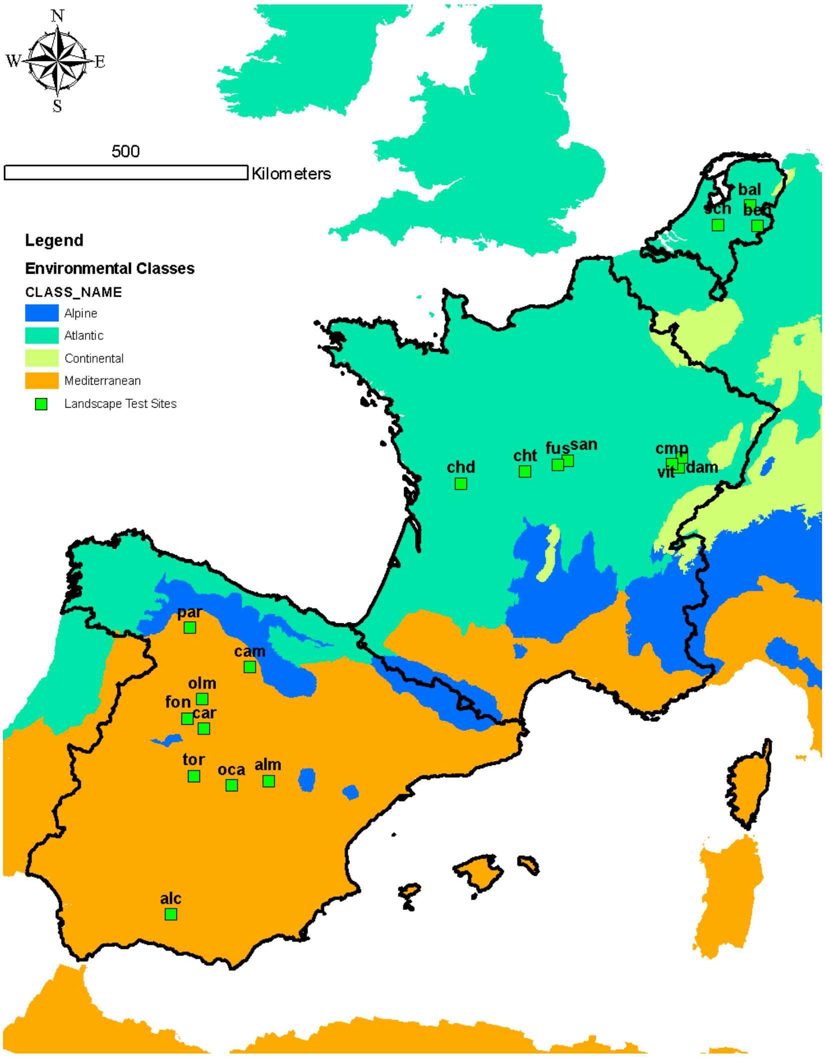


Figure 69 Location of the landscape test sites in Spain, France and the Netherlands

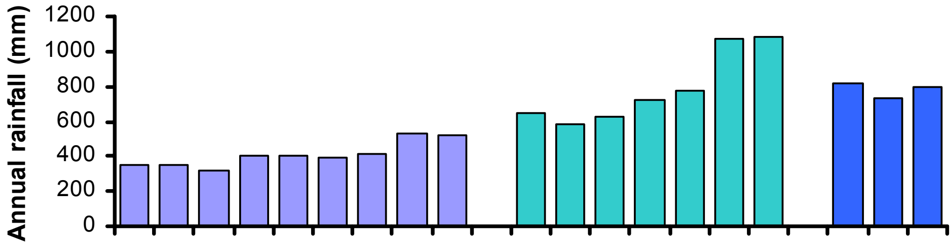
Meteorological data

The use of the Yield-sAFe model required daily values of temperature, solar radiation and rainfall to be determined at each site for the duration of the crop rotation. The mean air temperatures at the sites ranged from about 9°C in the Netherlands to 15.5°C at Torrijos in central Spain. The annual rainfall ranged from 316 mm at Ocaña in central Spain to 1084 mm at Vitrey in eastern France (Table 22; Figure 70).

Table 22 Summary of the annual rainfall, solar radiation and mean temperature at each site

Country and region	Site name	Latitude	Long.	Altitude (m)	Mean temp (°C)	Solar radiation (MJ m^{-2})	Annual rainfall (mm)
Spain							
Andalucia	Alcala la real	37.36N	3.88W	1000	15.3	5490	355
Castilla La Mancha	Torrijos	39.89N	4.39W	500	15.5	5560	348
	Ocaña	39.94N	3.44W	700	14.7	5780	316
	Almonacid de Zorita	40.23N	2.61W	900	12.6	6610	404
Castille-Leon	Cardenosa El Espinar	40.78N	4.53W	1000	12.0	5700	404
	Fontiveros	40.86N	5.00W	900	12.0	6170	393
	Olmedo	41.28N	4.80W	750	12.5	5480	410
	St Maria del Campo	42.11N	3.91W	800	na	5630	530
	St Maria del Paramo	42.44N	5.69W	800	10.2	6600	519
France							
Poitou Charentes	Champdeniers	46.41N	0.02E	200	11.0	4740	648
Centre	Chateauroux	46.92N	1.65E	150	11.0	4750	587
	Fussy	47.18N	2.47E	200	10.6	4800	626
	Sancerre	47.30N	2.72E	400	10.7	4590	724
France Comté	Champlitte	47.64N	5.58E	300	8.5	4940	773
	Dampierre	47.61N	5.82E	300	10.0	5090	1072
	Vitrey	47.81N	5.78E	400	9.5	4900	1084
The Netherlands	Balkbrugg	52.57N	6.34E	0	8.9	4830	818
	Bentelo	52.22N	6.67E	0	8.8	3690	729
	Scherpenzeel	52.57N	6.34E	0	9.0	3710	801

a) Rainfall



b) Temperature

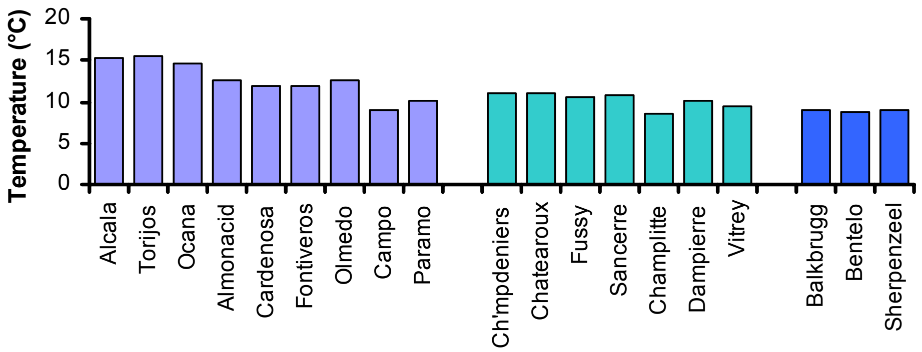


Figure 70 Summary of the (a) rainfall and (b) temperature across the landscape test sites

Selection of modelled forestry, arable and silvoarable systems

During 2004, workshops were held in each of the three countries to determine the optimum forestry system for each land unit (Palma and Reisner, 2004; Reisner, 2004 ; Herzog, 2004). The forestry systems in Spain were based on either Holm oak (*Quercus ilex*) or stone pine (*Pinus pinea*). The forestry systems considered in France and the Netherlands were wild cherry (*Prunus avium*), walnut (*Juglans* spp.), and poplar (*Populus* spp.) (Figure 71).

a) Holm oak b) Stone pine c) Wild cherry d) Walnut e) Poplar

Figure 71 Photos of a) Holm oak, b) stone pine (Arboretum de Villardebelle, 2003), c) wild cherry, d) walnut and e) poplar

At the same workshops, an agricultural system was also selected for each land unit (Table 23). The agricultural systems in Spain were assumed to be based on wheat, sunflower and fallow. The systems in France were based on wheat and sunflower in the Poitou Charentes and Centre regions, and wheat, oilseed and grain maize in the eastern Franche Comté region. The systems in the Netherlands were based on wheat and forage maize. Full details of the rotations assumed at each site are presented in Deliverable 6.4 (Burgess et al. 2005)

Selection of reference yields for the forestry and arable systems

For each landscape test site, a reference tree and crop yield was selected assuming 100% radiation and a specified depth of soil. The reference tree yield related to an individual tree volume at the end of a rotation with a specified forestry system. For example in Spain, the reference yield for the Holm oak and stone pine at 60 years was assumed to be 0.22 m^3 and 0.26 m^3 per tree respectively. In France, the reference timber volume of wild cherry, after 60 years, was 1.04-1.06 m^3 per tree. The corresponding volume for walnut was assumed to 1.04 m^3 per tree in France and 0.80 m^3 per tree in the Netherlands. The timber volume of the poplar, after 20 years, was assumed to be 1.46 and 1.51 m^3 per tree in France and the Netherlands respectively (Burgess et al. 2005)

Reference arable yields were also determined for each crop at each land unit assuming 100% radiation and a specified soil type and depth. In Spain, reference wheat and sunflower yields ranged from 1.62 to 3.71 t ha^{-1} and 0.60 to 1.09 t ha^{-1} respectively. Unlike the network site analysis, the landscape site analysis did not include a livestock component. In France, in the western and central regions, the reference sunflower yield was 2.3-2.5 t ha^{-1}. Wheat yields ranged from 6.5 to 8.0 t ha^{-1} and oilseed yields ranged from 3.2 to 4.0 t ha^{-1}. In the eastern part of France, the reference grain maize yield was 7.5-8.0 t ha^{-1}. In the Netherlands, the mean yield of wheat and forage maize (dry weight basis) was assumed to be 7.8 and 12.0 t ha^{-1} respectively. Full details of the reference yield at each site are presented again by Burgess et al. (2005).

Table 23 Description of the 42 different land units and the respective assumed tree species and crop rotation

Country and region	Site	Code	Rad-iation (%)	Soil type	Soil depth (cm)	Tree species	Crop rotation
Spain							
Andalucia	Alcala	ALC1	97	Medium	140	Oak	w/w/f
	Alcala	ALC2	86	Medium	50	Oak	w/w/f
Castilla La Mancha	Torrijos	TOR1	101	Medium	140	Oak	w/f
	Torrijos	TOR2	100	Medium	140	Oak	w/w/f
	Ocaña	OCA1	100	Medium	140	Oak	w/w/f
	Almonacid	ALM1	97	Medium	140	Oak	w/f
	Almonacid	ALM2	83	Fine	140	Oak	s/s/s/s/s/w/f
Castille-Leon	Cardenosa	CAR1	93	Medium	140	Oak	w/w/w/f
	Cardenosa	CAR2	101	Fine	140	Oak	w/w/w/f
	Fontiveros	FON1	99	Coarse	140	Oak	w/w/w/w/f
	Fontiveros	FON2	98	Coarse	140	Pine	w/w/w/w/f
	Olmedo	OLM1	100	Coarse	140	Pine	w/s/f
	Olmedo	OLM2	100	Medium	140	Oak	w/s/f
	Olmedo	OLM3	99	Coarse	140	Oak	w/s/f
	Campo	CAM1	99	Coarse	140	Pine	w/w/w/f
	Campo	CAM2	99	Medium	140	Oak	w/w/w/w/w/f
	Paramo	PAR1	100	Medium	140	Oak	w/w/w/s/f
	Paramo	PAR2	100	Medium	140	Oak	w/w/w/s/f
	Paramo	PAR3	101	Medium	140	Oak	w/w/w/s/f
France							
Poitou Charentes	Champdeniers	CMD1	100	Fine	80	W. cherry	w/w/s/w/o/s
	Champdeniers	CMD2	100	Medium	120	Walnut	w/w/s/w/o/s
Centre	Chateauroux	CHT1	102	Fine	80	Walnut	w/w/o/w/o/s
	Chateauroux	CHT2	102	Fine	40	W. cherry	w/w/o/w/o/s
	Chateauroux	CHT3	102	Medium	120	Walnut	w/w/o
	Chateauroux	CHT4	100	Fine	40	W. cherry	w/w/o/w/o/s
	Fussy	FUS1	101	Fine	40	W. cherry	w/o
	Fussy	FUS2	103	Medium	80	Poplar	w/w/o
	Fussy	FUS3	102	Fine	120	W. cherry	w/o
	Sancerre	SAN1	103	Fine	40	W. cherry	o/w/s/w/w/w/o
	Sancerre	SAN2	102	V fine	140	Poplar	o/w/s/w/w/w/o
	Sancerre	SAN3	101	V fine	120	W. cherry	o/w/s/w/w/w/o
	Sancerre	SAN4	100	Coarse	80	W. cherry	o/w/s/w
France Comté	Champlitte	CMP1	103	Medium	140	W. cherry	w/w/o
	Champlitte	CMP2	103	Md-fine	35	Walnut	w/w/w/w/w/gm
	Dampierre	DMP1	98	Medium	140	W. cherry	w/w/gm
	Dampierre	DMP2	97	Fine	35	W. cherry	w/w/w/gm
	Dampierre	DMP3	95	Md-fine	60	Poplar	w/gm
	Vitrey	VIT1	103	Medium	60	W. cherry	w/w/o
	Vitrey	VIT2	103	Md-fine	60	Poplar	w/w/gm
Netherlands	Bentelo	BAN1	100	Coarse	140	Walnut	w/w/fm
	Balkbrugg	BAL1	100	Coarse	140	Poplar	fm
	Scherpenzeel	SHR1	100	Coarse	140	Poplar	fm

Crop rotation key: w = wheat; s = sunflower; f = fallow ; o = oilseed; fm = forage maize; gm = grain maize

Effect of site on predicted tree and crop yields

Using the reference yields, the Yield-sAFe model was calibrated for each landscape test site. The number of land units per landscape test site varied between one and four (Table 23). The individual radiation levels, soil types and depths within each land unit were then used to determine a specific forestry and arable yield for each land unit.

The yields predicted by the Yield-sAFe model for the arable and forestry systems could have been modified by changes in soil type, solar radiation level and soil depth. In practice, there were minimal changes in predicted yield due to soil type because the available water contents of different soils as predicted by Wösten et al. (1999) were relatively similar. The level of solar radiation within a land unit was assumed to range from 83% for northerly-facing slopes (Almonacid Land Unit 2) to 103% for southerly-facing slopes (Fussy land unit 2, Sancerre land unit 2, Champlitte land units 1 and 2, and Vitrey land units 1 and 2). However the effect of these differences was confounded by other factors. The major changes in tree and crop yields across the sites appeared to result from differences in soil depth. For example in France, the predicted yield from wheat was predicted to decline by 20 kg ha^{-1} per 1 cm decrease in soil depth (Figure 72). Similarly the timber yield of cherry was predicted to decline by 0.31 m^3 ha^{-1} per 1 cm decline in soil depth (Figure 72).

a) Cherry **b) Wheat**

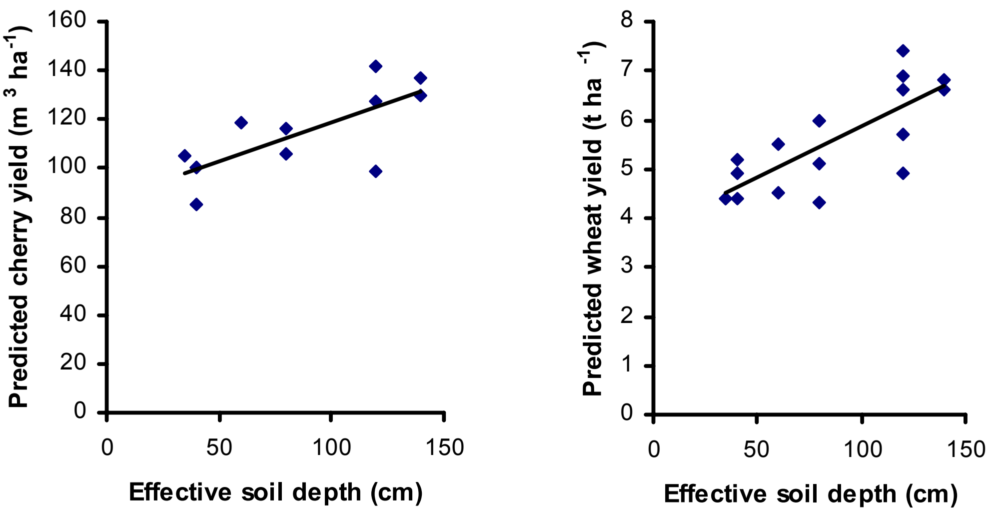


Figure 72 Effect of soil depth (*d*) on the predicted yield (*Y*) monoculture a) wild cherry ($Y = 0.32\ d + 87$; $R^2 = 0.56$) and b) wheat yields ($Y = 0.021\ d + 3.8$; $R^2 = 0.62$) at the land units in France

Selection of modelled silvoarable systems

The assumed silvoarable system at each land unit integrated the tree species in the forestry system with the crop rotation used in the arable system. The tree and crop yields from two silvoarable systems (50 and 113 trees ha^{-1}) were then established for each land unit using the Yield-sAFe model. As for the network site analysis, for the initial yield calculations the proportion of the total area cropped was assumed to be 95% and 90% at densities of 50 and 113 trees ha^{-1} respectively (Table 17). As for the network site, for the calculation of the land equivalent ratio, the assumed cropping areas were reduced to 90% and 85.7% respectively.

Predicted silvoarable yields

The full set of results from the Yield-sAFe model is presented by Burgess et al. (2005) in Deliverable 6.4. As an example, the results are presented for an oak system, a wild cherry, a walnut and a poplar system (Figure 75).

The Yield-sAFe model predicted different growth patterns for the five tree species. In France, the initial growth of the cherry was generally slow, and hence the level of crop yields tended to be greater than in the walnut system, where initial tree growth was more rapid (Figure 73). Although the poplars showed the fastest growth rate, the relative crop yields over the tree rotation were intermediate because it was assumed that the tree would be harvested after 20 years.

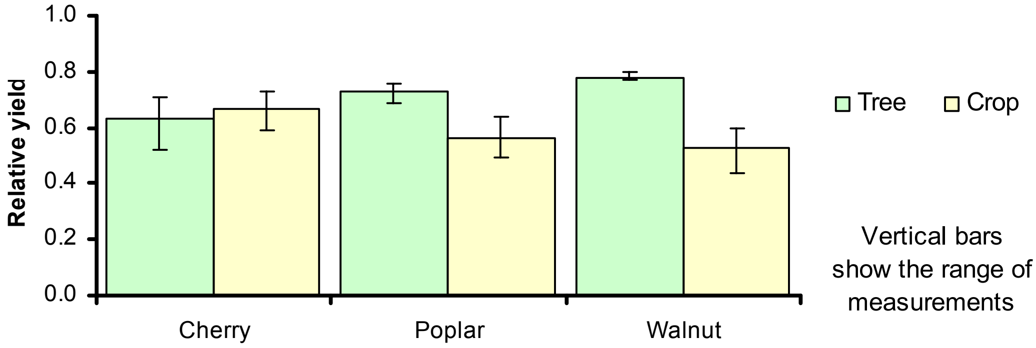


Figure 73 Predicted effects of tree species in a silvoarable system (113 trees ha^{-1}) on the yield of the tree and the crop components (over a complete tree rotation) relative to a monoculture

In Spain, the relative yield of autumn-planted wheat tended to be greater than that for spring-planted sunflower (Figure 74a). As the trees were evergreen, it is assumed that this is a result of the greater competition experienced by the spring-planted crop for water. Within the silvoarable systems with deciduous trees in France, the difference in the relative yield of the autumn- (i.e. wheat and oilseed) and spring-planted (sunflower and grain maize) crops was greater (Figure 74b). This is because of the reduced shading of the autumn-planted crops, which can be harvested before or soon after the trees have fully unfurled their leaves.

a) Crop yields in Spain b) Crop yields in France

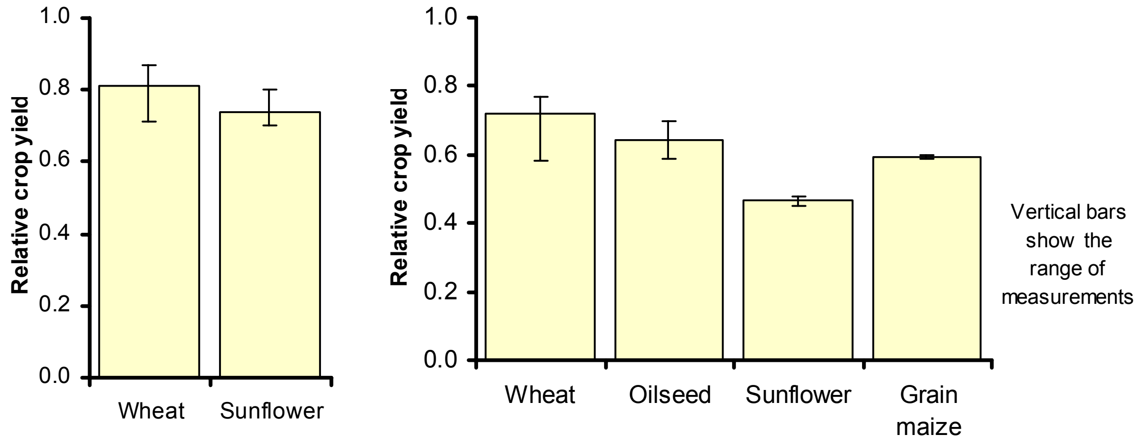


Figure 74 Effect of crop species on the relative crop yield (over a complete tree rotation) below (a) oak in Spain and (b) cherry trees in France at 113 trees ha^{-1}

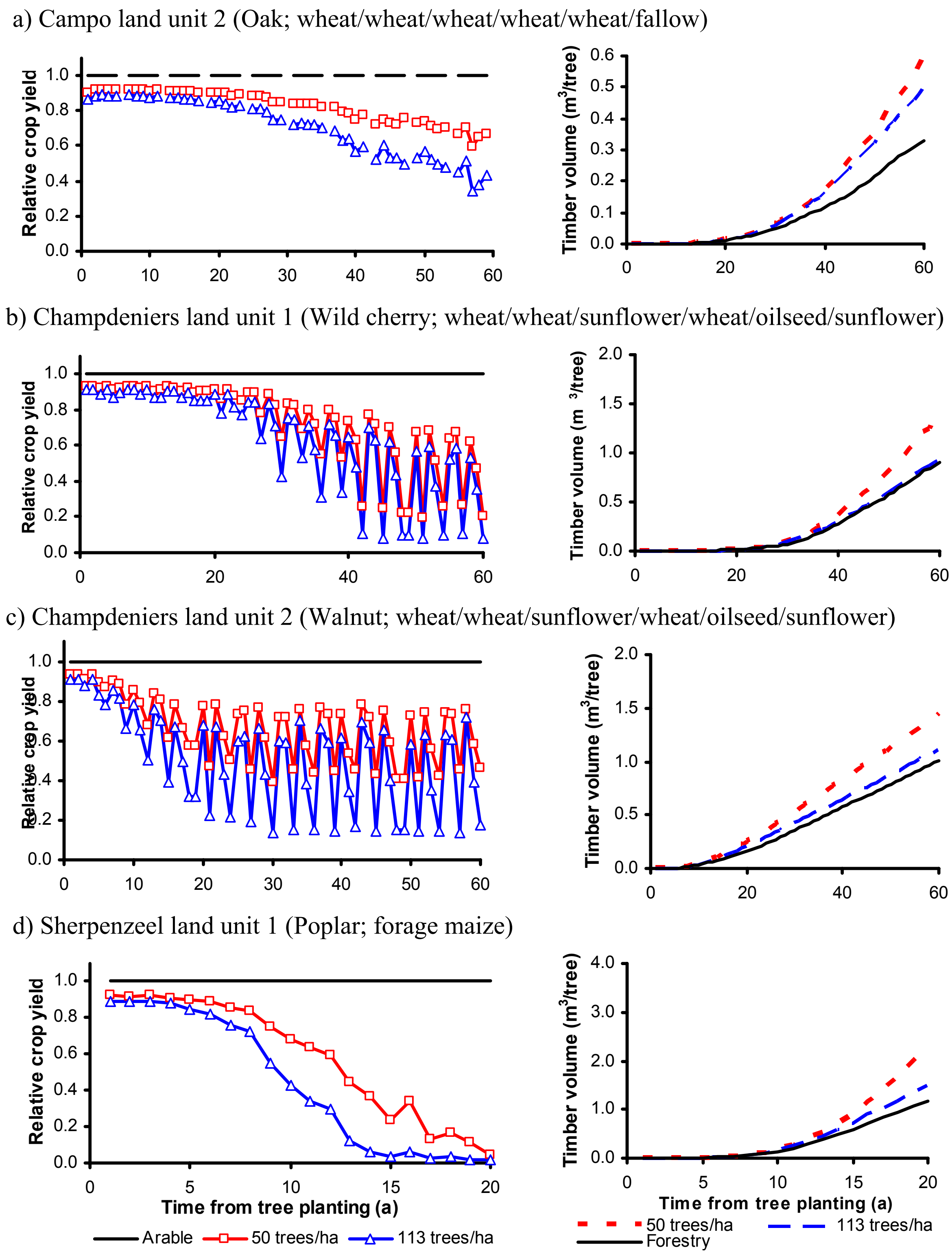


Figure 75 Relative crop yields and the timber volume for (a) an oak, b) a wild cherry, c) a walnut and d) a poplar silvoarable system at selected land units

Land equivalent ratios at landscape test sites

The land equivalent ratio of each silvoarable system in each land unit was determined in the same way as for the network sites. Across the 42 land units, the land equivalent ratio was calculated to show a convex pattern, equal to 1 within the forestry and arable systems, and in general values above 1 in the silvoarable treatments. The land equivalent ratio with a density of 113 trees ha^{-1} was greater than that at 50 trees ha^{-1} (Figure 76). The land equivalent ratio for cherry, poplar and walnut also tended to higher than those for the oak and pine (Figure 77).

a) 113 trees per hectare **b) 50 trees per hectare**

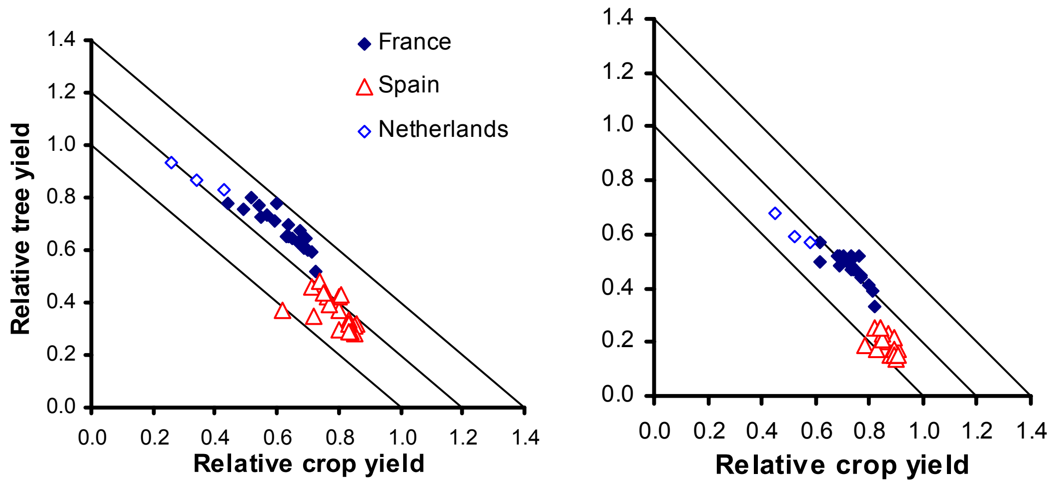


Figure 76 Effect of country of the predicted land equivalent ratio at the 42 land units at a tree density of a) 113 and b) 50 trees ha^{-1}

a) 113 trees per hectare

b) 50 trees per hectare

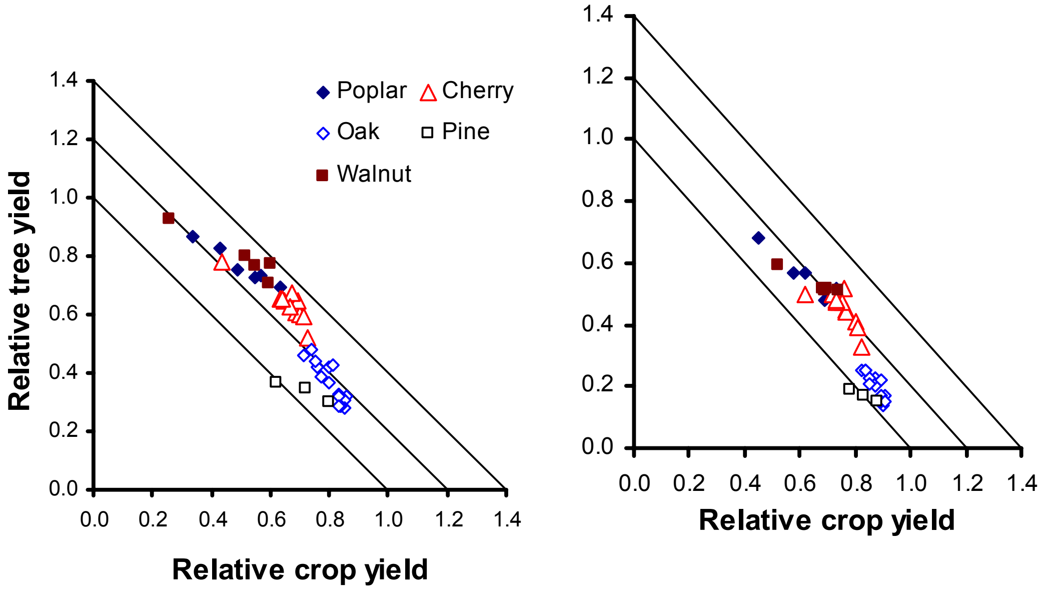


Figure 77 Effect of tree species on the predicted land equivalent ratio at 42 land units at a density of a) 113 and b) 50 trees ha^{-1}

Approach used for the landscape test site economic analysis

The basis of the economic analysis was the same as used for the network sites. The financial data for the crop components were obtained from the Farm Accountancy Data Network (European Commission, 2003) or ROSACE. Full details of the financial data used for the tree and crop components are presented by Graves et al. (2005a). However for clarity, the tree-related grants for the 2004 grant scenario are described for each location (Table 24).

Table 24 a) Forestry and b) agroforestry grants in the 2004 grant scenario

Country	Region	System	Planting		Compensation		Maintenance	
			Year	Grant (€ ha^{-1})	Year	Grant (€ ha^{-1})	Year	Grant (€ ha^{-1})
a) Forestry grants								
Spain	Andalucia	Oak (400 ha^{-1})	1	1149	1-20	225	1-5	240
	Castilla La Mancha	Oak (600 ha^{-1})	1	1593	1-20	325	1-5	258
		Pine (800 ha^{-1})	1	1262	1-20	312	1-5	180
	Castille-Leon	Oak (800 ha^{-1})	1	1017	1-20	320	1-5	288
		Pine (800 ha^{-1})	1	849	1-20	313	1-5	180
France	Poitou Charentes	Broadleaf	1-4	50% costs	1-10[b]	300	0	0
	Centre	Broadleaf	1-4	50% costs	1-10[b]	240	0	0
	Franche Comté	Broadleaf		0		0	0	0
Netherlands		Broadleaf	1	1500[a]	1-5	100	1-18	545
b) Agroforestry grants								
Spain	All regions	All systems		0		0		0
France	Poitou Charentes	Broadleaf	1-4	50% costs		0		0
	Centre	Broadleaf	1-4	50% costs		0		0
	Franche Comté	Broadleaf		0		0		0
Netherlands		Broadleaf		0		0		0

[a]: 95% of total costs not exceeding 1500 € ha^{-1};

[b]: compensation payments for poplar in France, where paid, are only paid for 7 years

The woodland grants tended to be based on a planting grant and a compensation payment. In the 2004 grant scenario and dependent on the tree species, Spanish farmers could receive a woodland planting grant of 849 to 1593 € ha^{-1}. Farmers could also receive a compensation grant of 225-325 € ha^{-1} a^{-1} over the first 20 years and a maintenance grant (180-288 € ha^{-1} a^{-1}) for the first five years. In the Poitou Charentes and Centre regions of France, the woodland planting grant was assumed to cover 50% of the costs incurred over the first four years. Farmers were also eligible to a compensation grant of 240-300 € ha^{-1} over 10 (walnut and cherry systems) or 7 years (poplar). In the French region of Franche Comté, where there is already a substantial area of woodland, there were no woodland grants. In the Netherlands, a woodland planting grant of 95% of costs was available up to a maximum of 1500 € ha^{-1}. Farmers were also eligible to a planting grant of 240 € ha^{-1} a^{-1} for five years and a maintenance payment of 545 € ha^{-1} a^{-1} for the first 18 years.

Local experts were used to determine the status of agroforestry grants related to the tree component in 2004. In Spain and the Netherlands, the experience was that no grants were available for the tree component of the agroforestry system. However a woodland planting grant was available in the Poitou Charentes and Centre regions of France (Table 24).

Landscape test site profitability with no grants

In the no grant scenario, the *EAV* (at 4% discount rate) of the forestry systems at each site in Spain and the Netherlands was negative (Figure 78). The *EAV* of each wild cherry forestry system in France was also negative. The only forestry systems showing a positive return were the walnut and poplar systems in France. In Spain, the *EAV* of the arable system were positive in Alcala, Cardenosa, Fontiveros, Olmedo and Paramo, and negative in Torrijos, Ocaña and Campo. In France, the profitability of the arable system was positive in Poitou Charentes and Centre, but negative in the majority of sites in the Franche Comté region. In the Netherlands the arable system showed positive returns without grants.

There were no sites in Spain where silvoarable agroforestry (without grants) showed a positive return that was greater than the arable system. By contrast in France, silvoarable agroforestry with walnut in each of the three regions, agroforestry with poplar in the Centre region, and agroforestry with cherry in the Poitou Charentes and the Franche Comté regions were predicted to be more profitable (4% discount rate) than the arable and forestry systems. In the Netherlands, the poplar silvoarable systems were predicted to have a marginally greater *EAV* (140-216 € ha^{-1} a^{-1}) than that (131-187 € ha^{-1} a^{-1}) for the arable system. However the walnut silvoarable system was unprofitable because of the relatively low value of walnut timber in the Netherlands.

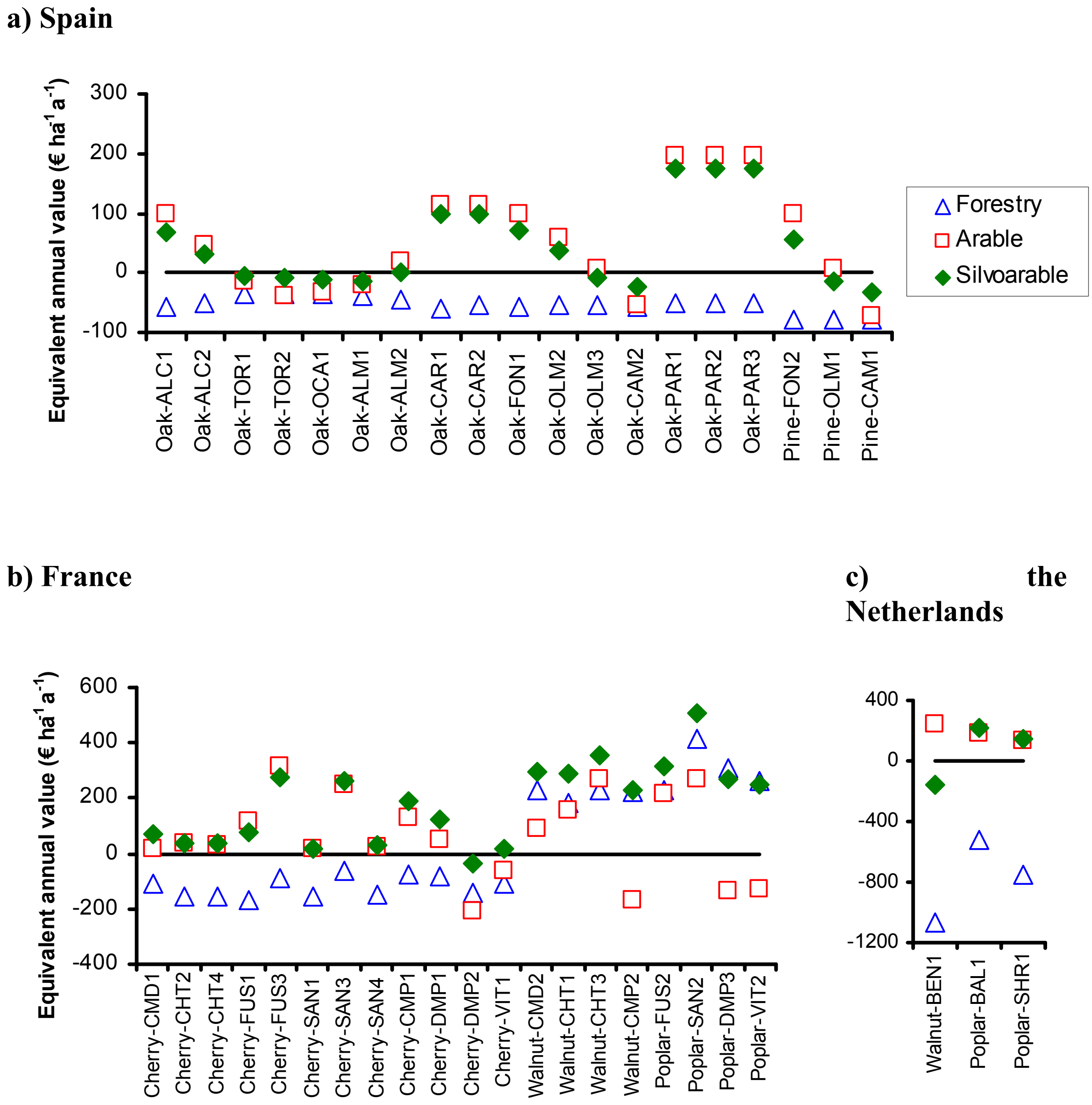


Figure 78 Equivalent annual value (discount rate of 4%) without grants of the arable, forestry and silvoarable (113 trees ha^{-1}) system in a) Spain, b) France and c) the Netherlands

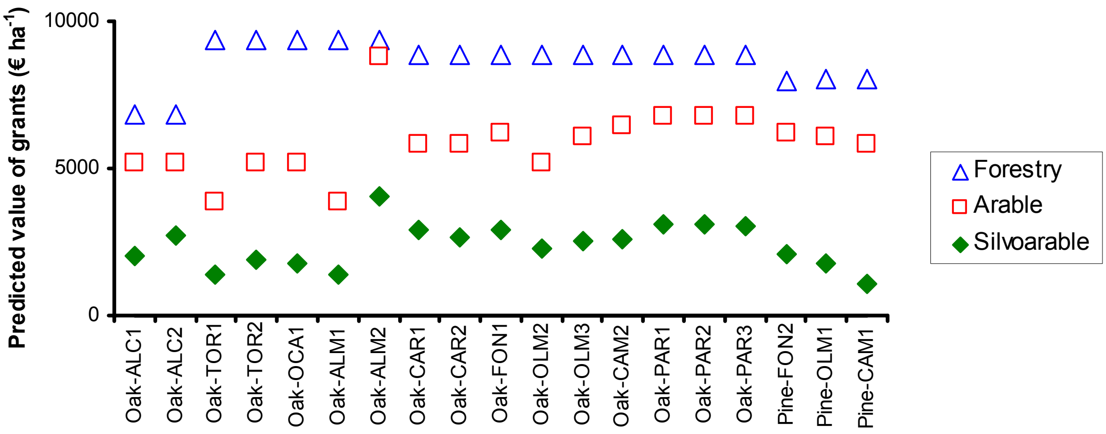
Value of grants with the 2004 grant scenario

In Spain, the predicted level of forestry grant, where available, (6860-9380 € ha^{-1}) was greater than that predicted for the arable (3870-8770 € ha^{-1}) systems (Figure 79). At each site, the lowest level of grant was predicted for the silvoarable system (1380-4080 € ha^{-1}).

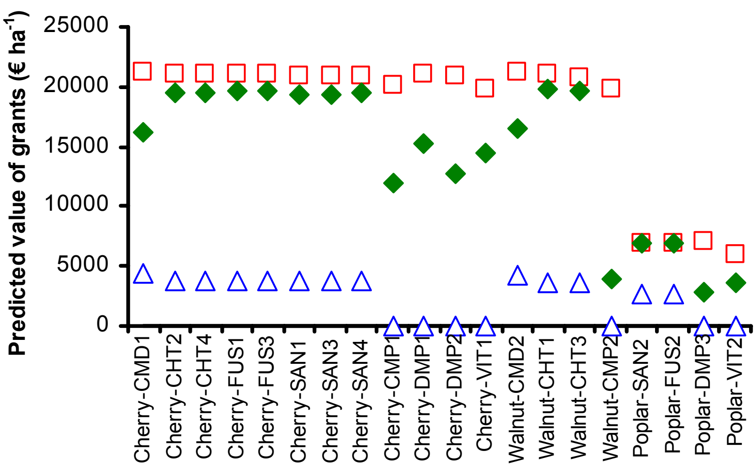
In the Poitou Charentes and Centre regions of France, the predicted level of grant available for the arable system, predicted forward over 60 years based on 2004 levels, was at least five-times available for forestry (Figure 79). The level of grant for the silvoarable systems in these regions was broadly similar to, but still less than, that for arable agriculture. At Champlitte, Dampierre and Vitrey in the Franche Comté region, there were no forestry grants and hence the greatest level of support was for arable agriculture. The predicted level of arable grants for the poplar system is low because a 20-year, rather than a 60-year, time period was assumed.

In the Netherlands, the support for forestry was similar for the walnut and poplar systems, and that for agriculture was dependent on the assumed rotation of the tree species. In each case the support for silvoarable agroforestry was less than for forestry and arable agriculture.

a) Spain



b) France



c) the Netherlands

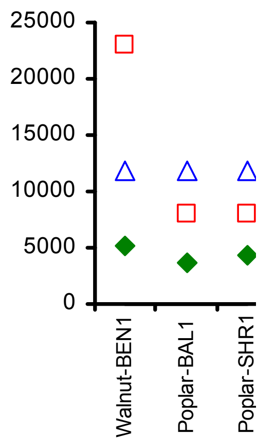


Figure 79 Predicted actual value of grants (2004 grant scenario) for the forestry, arable and silvoarable (113 trees ha^{-1}) system in a) Spain and b) France and c) the Netherlands

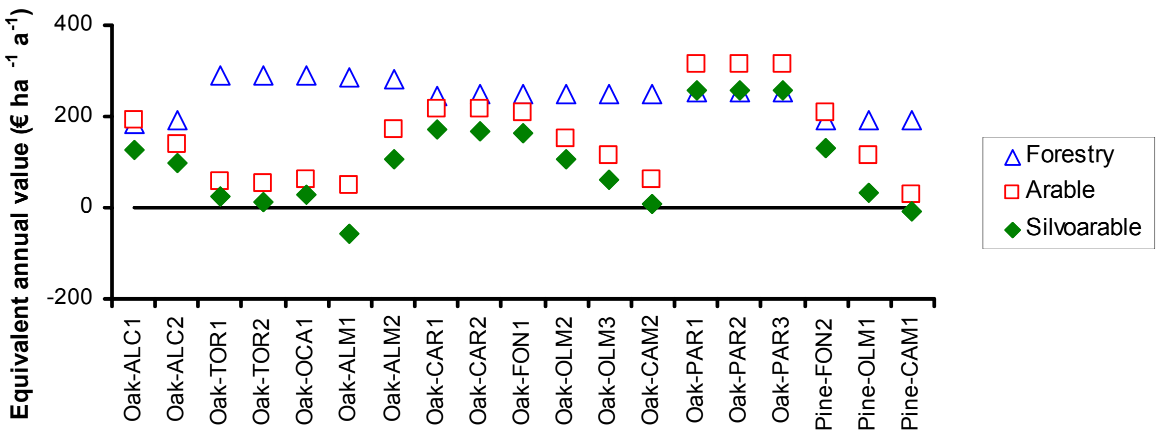
Landscape test site profitability with the 2004 grant scenario

Under the 2004 grant regime, in Spain and the Netherlands, there were no land units where the 113-tree ha^{-1} silvoarable system had a higher equivalent annual value (at a 4% discount rate) than both the forestry and the agricultural system (Figure 80).

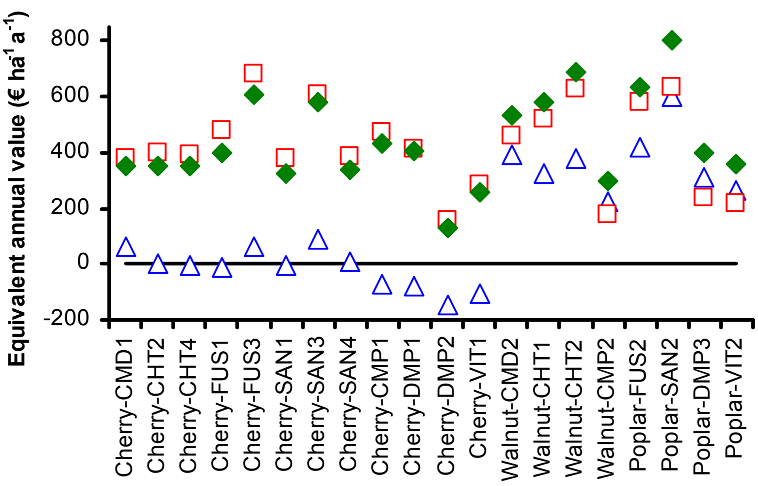
In France, at those sites where the chosen tree species was cherry, the arable system was predicted to be more profitable than both the forestry and the silvoarable system.

However it is apparent that silvoarable agroforestry offers the most profitable means of establishing cherry trees at these sites. By contrast, both the poplar and the walnut systems in France produced a greater return than both the forestry and the arable system.

a) Spain



b) France



c) the Netherlands

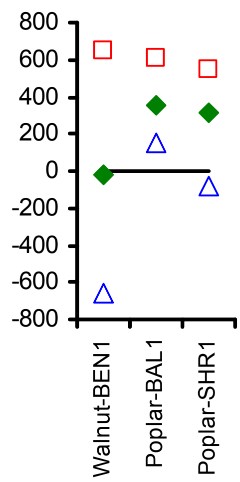


Figure 80 Equivalent annual value (4% discount rate) of the arable, forestry and silvoarable (113 trees ha^{-1}) system in a) Spain and b) France and c) the Netherlands, assuming the 2004 grant regime

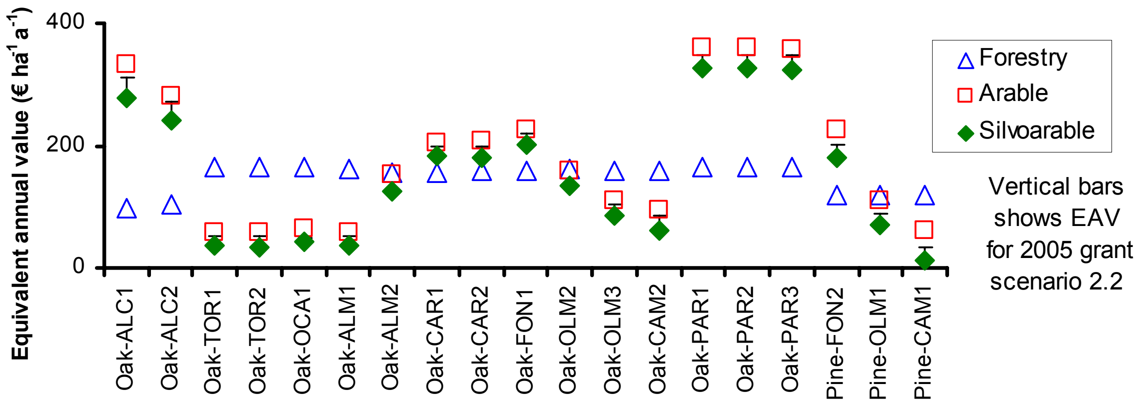
Value of grants with the 2005 grant scenario

For the forestry systems in the 2005 grant scenario, it was assumed that the planting grant at each site would be on a 50% cost basis (except in Franche Comté where no tree-related grants are available), and that the compensation grant would only be paid over ten years. The maximum level that could be obtained for a maintenance payment was also assumed to be 500 € ha^{-1} a^{-1} over ten years. For the tree component of the silvoarable system, it was assumed that the planting grant at each site would be based on 50% of costs (except in Franche Comté) and that there would be no compensation or maintenance payments. The arable system and the arable component of the silvoarable system were assumed to be eligible for the appropriate level of a single farm payment.

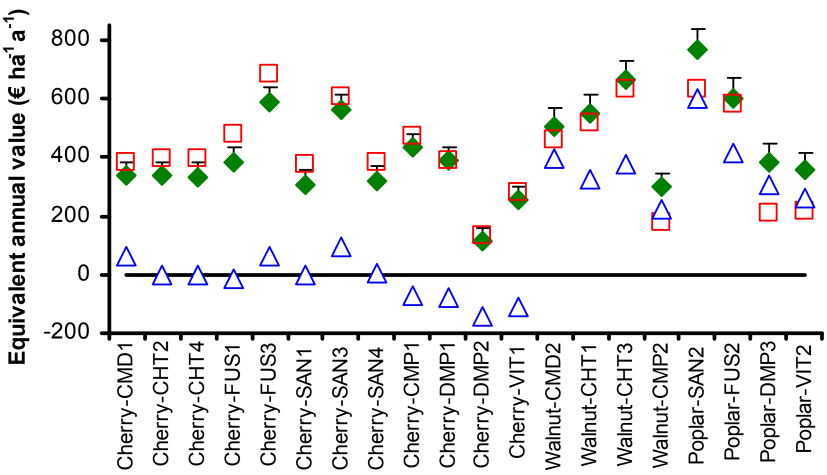
Landscape test site profitability with the 2005 grant scenario

Under the 2005 grant regime, in Spain the profitability of the arable systems at Alcala and Paramo were predicted to increase because of the assumed value of the new single farm payment were particularly high at these sites (Figure 81). However at the other Spanish sites and in France and the Netherlands, the *EAV* of each system was generally similar to that for the 2004 grant scenario. The effect of the different 2005 grant scenarios (Table 21) on the predicted *EAV* was relatively small.

a) Spain



b) France **c) the Netherlands**



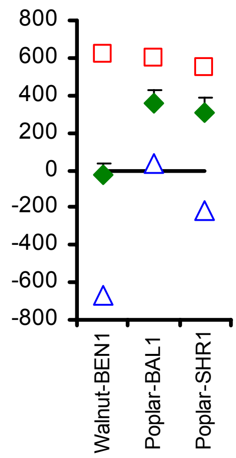


Figure 81 Equivalent annual value (4% discount rate) of a forestry, arable, and silvoarable (113 tree ha^{-1}) system in a) Spain and b) France and c) the Netherlands, assuming the 2005 grant scenario 1.1

Use of an LER-based-generator model to determine the optimum silvoarable system for high potential locations in France

Some of the French partners in the SAFE-project also undertook an additional piece of work with the aim of determining the optimum silvoarable system for high potential locations in France (Borrell et al. 2005). These analyses were presented to the "Chambres de Agriculture" at three regional meetings.

The reference tree and crop yields used for this analysis were similar to those reported for Yield-sAFe model. However for the silvoarable systems, the relative tree and crop yields throughout the tree rotation were determined by the LER-based-generator model described by Borrell et al. (2005). With this model, the relative yields of the walnut, wild cherry or poplar component were determined directly from a linear relationship with the tree density and the assumption that the timber volume of an agroforestry tree could not be greater than 120% of that for a forestry tree (Figure 82). Because the relative tree yield is fixed by the tree density, different values for the land equivalent ratio can only be attained by changing the mean relative yield of the crop component.

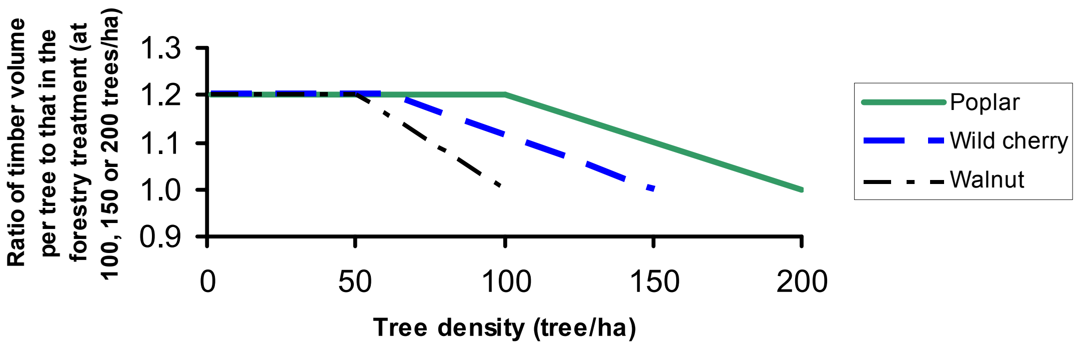


Figure 82 Assumed relationship in the LER-based-generator of the effect of agroforestry tree density on the relative timber volume of an agroforestry tree relative to that in a forestry system (at 100, 150 or 200 trees ha^{-1})

Scenarios examined and biophysical results

The tree and crop rotations assumed in the analysis were generally similar to those described for France in the preceding section. The effect of tree density was examined for two scenarios: 50 trees ha^{-1} (40 m spaced tree-lines) and 120 trees ha^{-1} (22 m spaced tree-lines). The tree strip was assumed to be 2 m wide, creating an intercropped alley-width of 38 m and 20 m respectively. Thus the corresponding maximum crop area represented 95% or 91% of the total area (Table 25).

Table 25 Effect of tree species and density and three relative crop yield scenarios on the predicted land equivalent ratio (LER) of biomass (including thinning) and products (crop yields and final fell), calculated using the LER-based-generator

	Initial tree density (ha^{-1})	Width between tree rows (m)	Width of cropped alley (m)	LER biomass[a]			LER products[a]		
				Low	Medium	High	Low	Medium	High
Walnut	50	40	38	1.00	1.15	1.30	1.12	1.27	1.42
	120	22	20	1.00	1.20	1.40	1.20	1.40	1.60
Wild cherry	50	40	38	1.00	1.07	1.15	1.10	1.17	1.25
	120	22	20	1.00	1.15	1.30	1.19	1.34	1.49
Poplar	50	40	38	1.00	1.10	1.20	1.00	1.10	1.20
	120	22	20	1.00	1.20	1.40	1.00	1.20	1.40

[a]: "Low", "medium", and "high" are equivalent to "pessimistic", "probable" and "optimistic" respectively

The relative yield of the crop was calculated for two scenarios: "optimistic" and "pessimistic", and a third scenario "probable" which was a mean of the other two values. The calculated land equivalent ratio (including thinning) in the "pessimistic" and "optimistic" scenario was 1.0 and 1.15-1.40 respectively (Table 25). An example of the assumed decline in crop yield for a wild cherry silvoarable system is shown in Figure 83. The general pattern is similar to that predicted by the Yield-sAFe model for autumn-planted crops, and more optimistic than that predicted by the Yield-sAFe for spring-planted crops (i.e. Figure 75b).

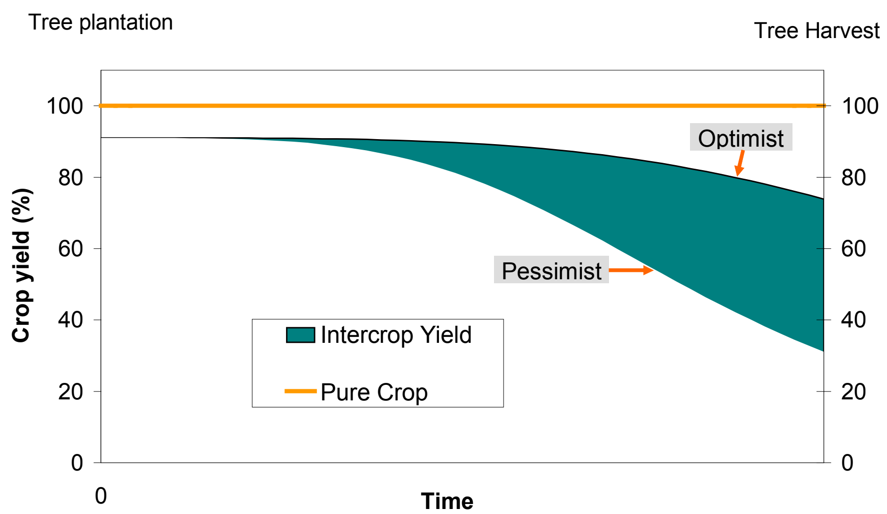


Figure 83 Assumed change in the relative crop yield according to a "optimistic" or "pessimistic" view using the LER-based-generator, for a wild cherry silvoarable system with an initial density of 120 trees ha^{-1} and a final density of 80 trees ha^{-1}

Financial analysis

The effect of different tree species and densities on farm net margin were examined for three farm types corresponding to three regions: high yields and low fixed costs (Centre region); high yields and high fixed costs (Poitou Charentes), and low yields and low fixed costs (Franche Comté). The arable data came for the ROSACE database produced by APCA. These are described in detail by Borrell et al. (2005). Unlike the Yield-sAFe analysis, labour costs were not taken into account. However the overall profitability is relatively insensitive to the cost of labour.

For each arable crop a threshold yield was determined below which it was assumed that no further cropping took place. The assumed grant regime was similar to the 2005 grant scenario used in the Yield-sAFe analysis. The model was then used to determine the effect of three tree species, two densities, two land unit types, and three cropping scenarios (36 runs) for each of the three regions.

The results indicated that, assuming "probable", and "optimistic" crop yields and the 2005 grant scenario, the introduction of a silvoarable agroforestry with walnut always increased farm net margin (Figure 84). However, assuming "probable" crop yields, introducing a silvoarable system with poplar or cherry had a marginal effect on the farm net margin. The particular benefit of the walnut system was also apparent with the Yield-sAFe results (Figure 81).

Borrell et al. (2005) also investigated the effect of tree density on relative profitability. The density at which the maximum land equivalent ratio was attained was predicted to greater than the most profitable density. For the "probable" scenario, the optimum tree density for profitability was predicted to be 60-90 trees ha^{-1} for the walnut and wild cherry and 100-130 trees ha^{-1} for the poplar (Table 26). The high density for the poplar is due in part to the fact that the assumed critical density was higher than for the other two species (Figure 82).

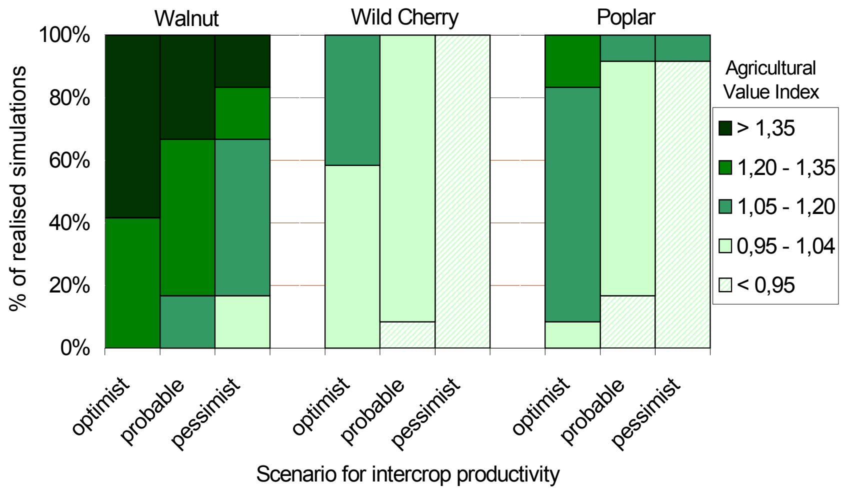


Figure 84 Frequency of silvoarable agroforestry (for two densities, and two land types) increasing or decreasing the farm net margin relative to agriculture, for three tree species and three cropping scenarios as estimated by the LER-based-generator

Table 26 Predicted optimum tree densities (trees ha^{-1}), using the LER-based-generator, for three tree species to maximise the value of the land equivalent ratio and profitability in France

	Optimum tree density to maximise the land equivalent ratio	Optimum tree density to maximise profitability
Walnut	80 - 120	60-90
Wild cherry	80 - 120	60 - 90
Poplar	130 – 200	100-130

WP8: Up-scaling to the farm and region scale

The main tasks developed in WP8 during the SAFE project were

1. to select landscape test sites (LTS) and to acquire and/or digitise the spatial data needed

2. to assess how and were soil erosion, nitrate leaching and carbon sequestration can be mitigated by silvoarable systems.

3. to integrate environmental and economic criterion at the landscape scale in order to define target regions for silvoarable agroforestry for Europe (for five tree species *Populus* ssp.*, Pinus pinea, Juglans* ssp.*, Quercus ilex, Prunus avium*)

Assessing the environmental effects of agroforestry at the landscape scale

These results are based on the following paper produced by the SAFE consortium:

☞ *Palma J, Bunce R, De Fillippi R, Herzog F, van Keulen H, Mayus M, Reisner Y, (2005). Assessing the environmental effects of agroforestry at the landscape scale. Submitted to Ecological Engineering.*

Silvoarable Agroforestry, the deliberate combined use of trees and crops on the same area of land, can potentially improve the environmental performance of agricultural systems in Europe. Four major potential benefits are identified: soil water erosion reduction, nitrate leaching reduction, carbon sequestration enhancing and landscape diversity improvement.

The application of existing, and state of the art, models at landscape scale for each of the environmental impacts is described and applied to three landscape test sites (Champlitte in France, Torrijos in Spain and Scherpenzeel in the Netherlands).

The assessment demonstrates the applicability of existing models at the landscape scale for the evaluation of SAF and the results showed that SAF systems could improve the environmental performance in comparison with monocropping practices.

Assessment of Soil Erosion

Erosion rates are similar in Champlitte and Torrijos and lower in Scherpenzeel but agroforestry had a similar impact in the reduction of soil loss. When the farm is biophysically homogeneous, there is no best/worst land and presence of agroforestry can only be evaluated by its conversion percentage (Figure 85 – Scherpenzeel). The comparison of this particular LTS with more heterogeneous farms, enables to observe the impact of having better quality land in the farm and the how agroforestry have different impacts depending on farmer criteria on where to plant the trees. In the case of Scherpenzeel, the farmer doesn't have to decide on which quality of land he should plant agroforestry, while in Champlitte or Torrijos, the farmer have to make decisions.

Although plot results not being the scope of this article, they can be the key to understand some farm/landscape results. Based on the results of Palma *et al.* (2005a), the best land in Champlitte has approximately 2.4 while the worst land has 0.7 tons ha^{-1} $year^{-1}$ for non contouring practices. When relating the correct proportions of the land units to the whole farm, the weighted mean value for the farm/landscape is around 1.5 tons ha^{-1} $year^{-1}$ (Figure 85 – Champlitte). This information of different parts of the farm/landscape makes easier to understand the approximate 60% reduction in erosion when agroforestry is planted 50% in the best land with intensive rotations. The value of 60% reduction is not the direct relation with the 50% conversion, as demonstrates Torrijos, and is related to the interaction of the different factors (Equation 1) where the crop rotation has the most influence in these three LTS.

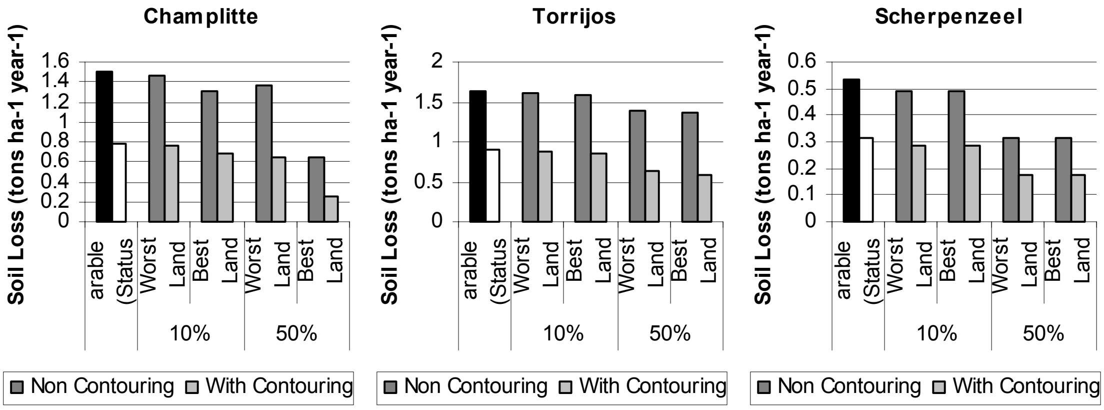


Figure 85: Soil erosion results for the scenarios evaluated at farm scale in the Landscape Test Sites

If the current farming practices do not account for contouring practices and, when converting 50% of the farm into agroforestry in the best land, there is the opportunity to introduce contouring practices, the current rates of soil loss can drop to 80%. This reduction is due to a similar approach when doing strip cropping based on Morgan (1995) which is more effective when there is more slope involved.

This erosion assessment does not account for gully erosion and, if the agroforestry project is implemented without contouring, the possibility for gully erosion in the junction of the alleys and the tree strips might become a problem. This phenomenon can increase the relative values of soil loss (Figure 85 - non contouring figures) which, in some cases (10% worst land) might become a higher soil loss with an agroforestry scenario. However, this could not be modelled and observed in this occasion.

Assessment of Nitrogen Leaching

Some plot results need to be interpreted in order to understand the outputs of this assessment.

Previous page : Figure 86a represents the effect of tree competition (light and water) on crop yield predicted by Yield-sAFe. In this plot scale example, the total yield after 60 years (the tree rotation period) is about 40% less.

When the impact of trees reduce yield, the main limiting factor of crop growth are light and water and, therefore, nitrogen becomes a surplus if not reduced to match yield reduction. Although there is an increase of N uptake by the tree during time, it doesn't compensate the uptake reduction in the arable component and consequently, the whole SAF system uptake, in this case (113 trees ha^{-1}), is less than the arable system (Previous page : Figure 86c). Nevertheless, although the uptake is less, there is more evapotranspiration by the whole system leading to a lower ground water recharge (Previous page : Figure 86d), thus reducing the vector for N leaching.

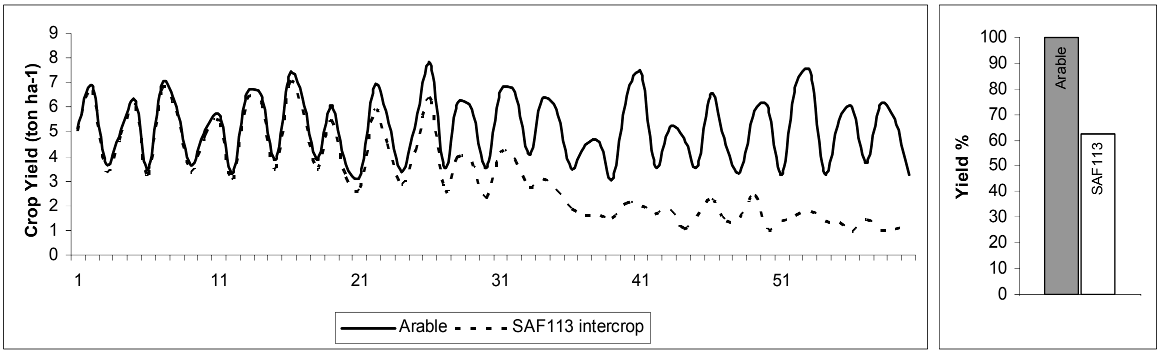
The triple quadrants method for the calculation of the N fertilizer has the "inconvenience" of retrieving an ideal application given a yield predicted by Yield-sAFe. The method reduces the N application if the yield is reduced over time in the AF system (Previous page : Figure 86b). The accompanied reduction on rhythm of N application (Previous page : Figure 86b) is probably too optimistic regarding real situations leading to about 65% reduction in leaching after 60 years and can be considered as a theoretical maximum impact of agroforestry on leaching in this situation (East France).

The 65% reduction in leaching, as a sum of the impacts of lower ground water flow and reduced fertilization, can have a high variance depending on the climate and implemented agroforestry system, where differences in fast/slow growing trees systems and the time to stop rotation (economic optimisation) take an important role in differences in fertilizer application and evapotranspiration.

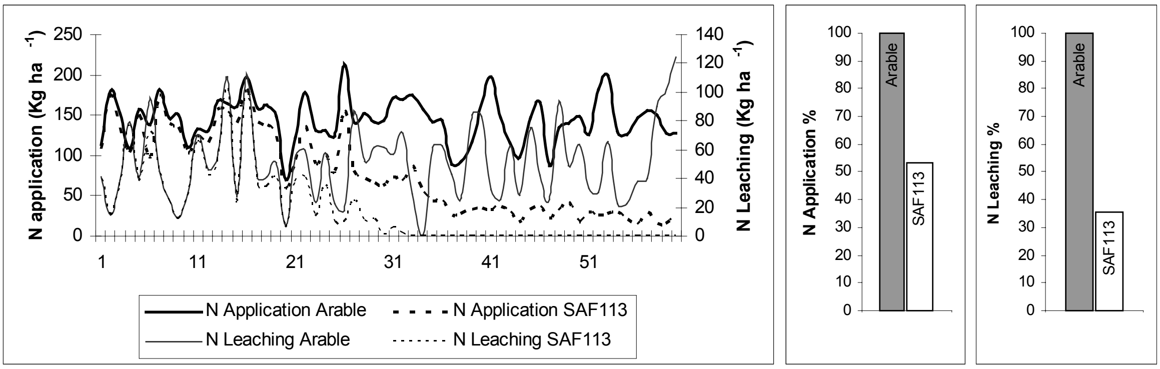
In real situations the farmer does not know how the weather will be and he cannot control the ideal N application as in the triple quadrants approach. If the fertilizer is considered to be applied as an average based on the arable system, not only the leaching increases but also the N leaching is higher in SAF systems (Figure 87). This is due to the lower uptake in the SAF systems previously explained and, therefore, if the N application continues the same since the beginning, the system loses the recovery capacity of the N applied and, consequently, leaches.

From Previous page : Figure 86a a simple rule could be raised: What could happen if a simple rule of reducing the N application by 40% (because yield is reduced by 40%) from half the tree rotation?

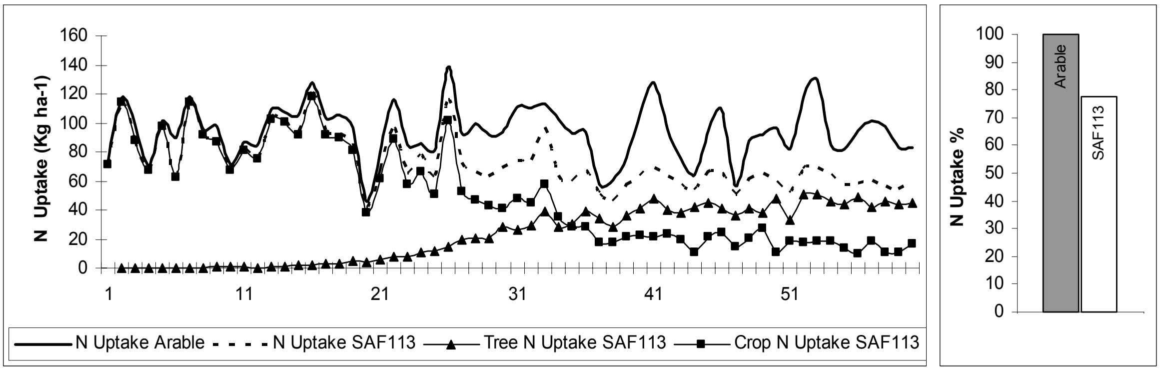
Figure 88 shows that, when applying this rule, the leaching is reduced about 20%. Other options can explored that will make the leaching float between the optimum (65%) and the worst (140%) in this example. However the scope of this article is to demonstrate the applicability of environmental modelling knowledge to SAF assessment and further explorations are in the future scope of the authors.


Crop Yield (ton ha-1)
Arable
SAF113 intercrop
Yield %
Arable
SAF113

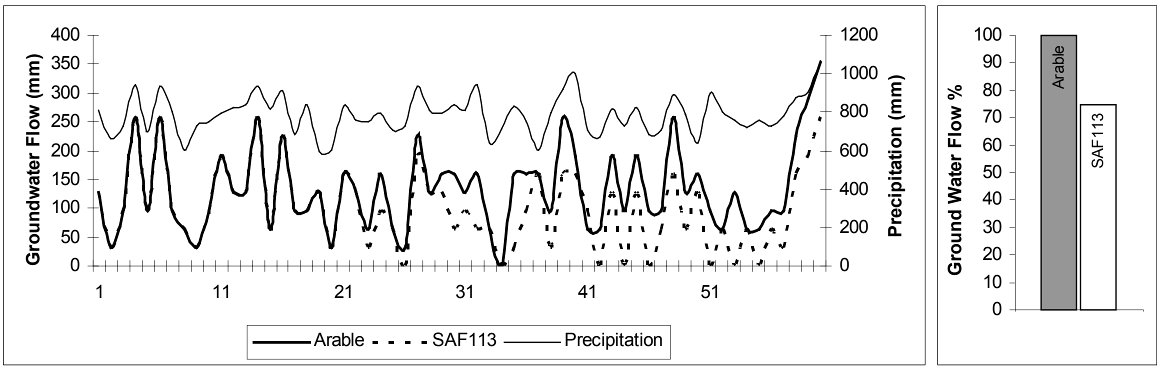
a)


N application (Kg ha -1)
N Leaching (Kg ha -1)
N Application Arable
N Application SAF113
N Leaching Arable
N Leaching SAF113
N Application %
Arable
SAF113
N Leaching %
Arable
SAF113

b)


N Uptake (Kg ha-1)
N Uptake Arable
N Uptake SAF113
Tree N Uptake SAF113
Crop N Uptake SAF113
N Uptake %
Arable
SAF113

c)


Groundwater Flow (mm)
Precipitation (mm)
Arable
SAF113
Precipitation
Ground Water Flow %
Arable
SAF113

d)

Previous page : Figure 86: Comparison, at plot scale, between Monocropping and Agroforestry (113 trees ha^{-1}) in Champlitte Landscape Test Site, East France. Tree: Wild Cherry; Crop Rotation: Wheat-Wheat-Oilseed. Soil texture: Medium; Soil Depth: 140 cm. a) Crop Yield; b) N Fertilization and N Leaching; c) N uptake; d) Precipitation and Ground Water Flow. Bar Graphs: Relative cumulative results for 60 Years.

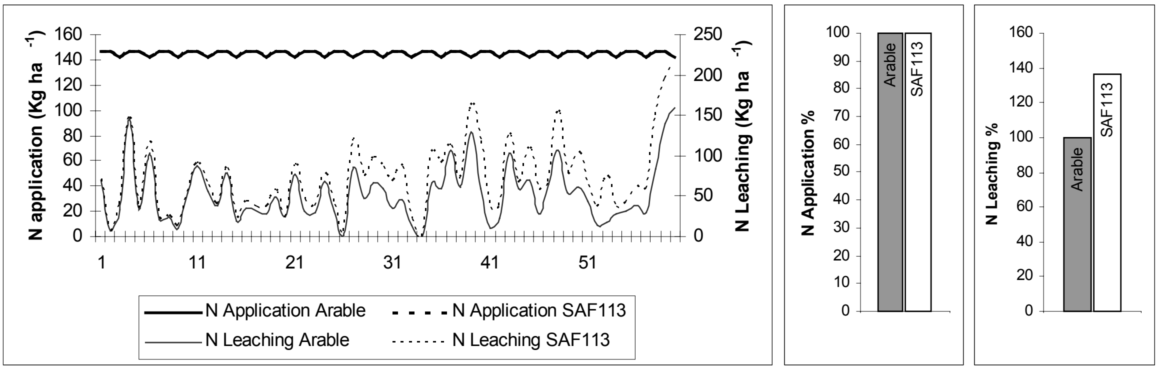


Figure 87: Same as Previous page : Figure 86 but applying every year the average fertilizer for wheat and oilseed as in an arable system

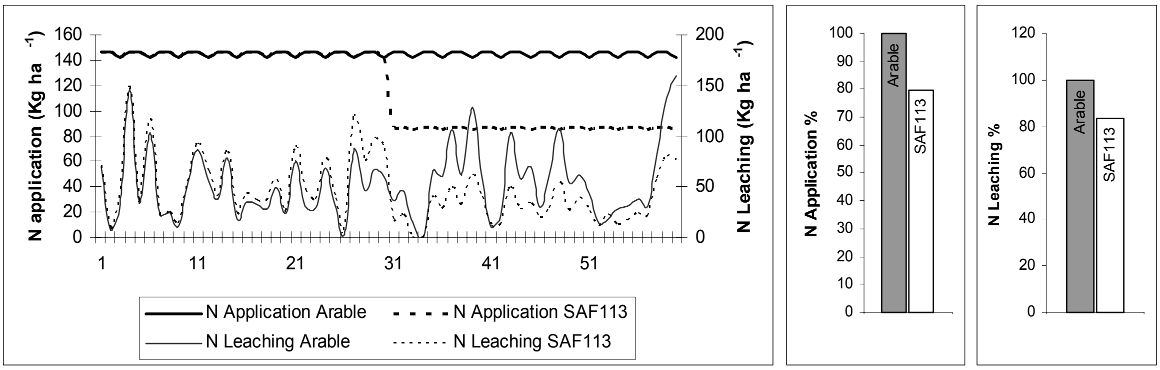


Figure 88: Same as Previous page : Figure 86 but with the simple rule of reducing the N application by 40% from the middle of the tree rotation

In Champlitte, if the farmer chooses to plant agroforestry in the best land, the differences in leaching reside not only in the difference between crop rotations (thus different N application rates) but also in different tree specie to plant. In this case, the tree specie chosen for the best land was walnut, which has a higher resource demand, therefore more competitive, leading to an earlier impact on intercrop yield. Consequently, the effects previously described for Previous page : Figure 86 start earlier, and cumulative leaching is more strongly reduced. This leads to agroforestry having more impact when the best land is chosen (Figure 89 - Champlitte).

In Scherpenzeel, similarly to erosion interpretation, there is no differentiation between worst/best land and the differences occur only between 10% or 50%. Here, with a fast growing tree (Poplar), the leaching can be reduced in the farm/landscape by 30% by converting 50% of the farm into agroforestry. Results of leaching in forage maize systems in this farm/landscape in The Netherlands found the same magnitude trend (150 Kg ha^{-1} $year^{-1}$) as Schröder (1998) which strengths the methodology applied for leaching calculation.

In Torrijos, a Mediterranean LTS, the leaching is very low due to the inexistence of ground water recharge. These leaching results can be found similarly to those observed by Seligman & van Keulen (1989) and Seligman *et al.* (1992) under these climatic conditions.

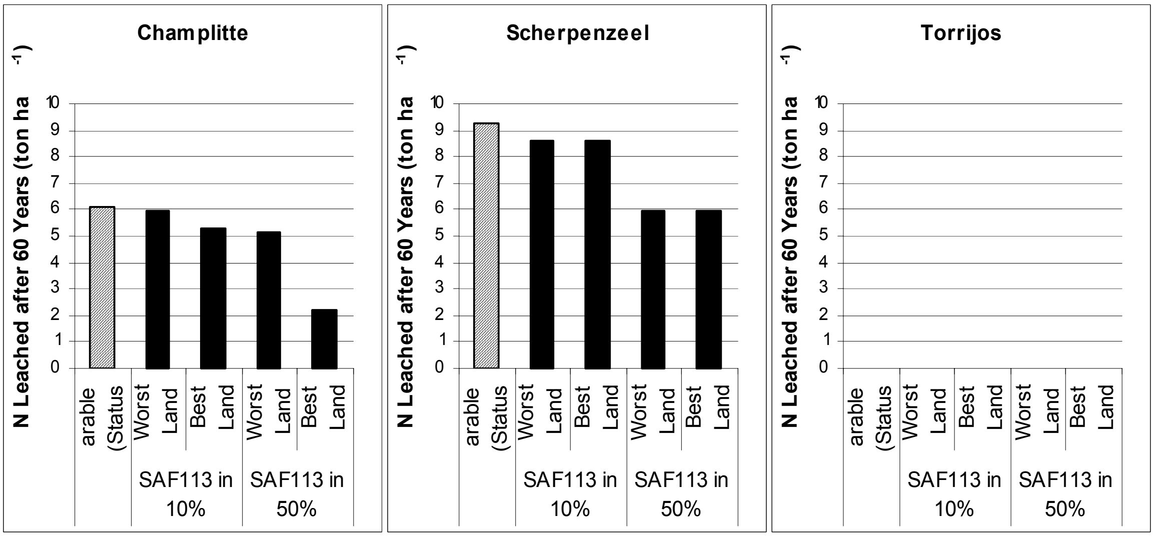


Figure 89: Farm/Landscape scale comparison of 60 years accumulated N leaching between the status quo (arable system) and different SAF scenarios

Assessment of Carbon Sequestration

Carbon is quantitatively differently sequestered depending on the tree specie selected. The modelled poplar have 3 rotation in 60 years which makes this fast growing tree accumulate more carbon than slow growing trees like wild cherry, walnut or Holm oak with the same tree density (Figure 90). Even differences between slow growing trees are evident. Wild cherry and walnut are more demanding trees than Holm oak and have higher growth rates. An average agroforestry walnut and wild cherry merchandisable wood volume (with 60 years) is around 1 m^3 while Holm oak is around 0.2 m^3. This means that walnut and wild cherry can sequester approximately 5 times more carbon than Holm oak in the same period of time (Figure 90).

Naturally, when more agroforestry is implemented (50%), more carbon is sequestered, as it is a straight relation to the amount of trees planted in the farm/landscape.

Behind the less sequestration in the best land (Champlitte and Torrijos), is the fact of the best land usually receiving a more exigent crop rotation. As a consequence, more crop competition with the tree leading to lower tree growth, thus less carbon sequestration.

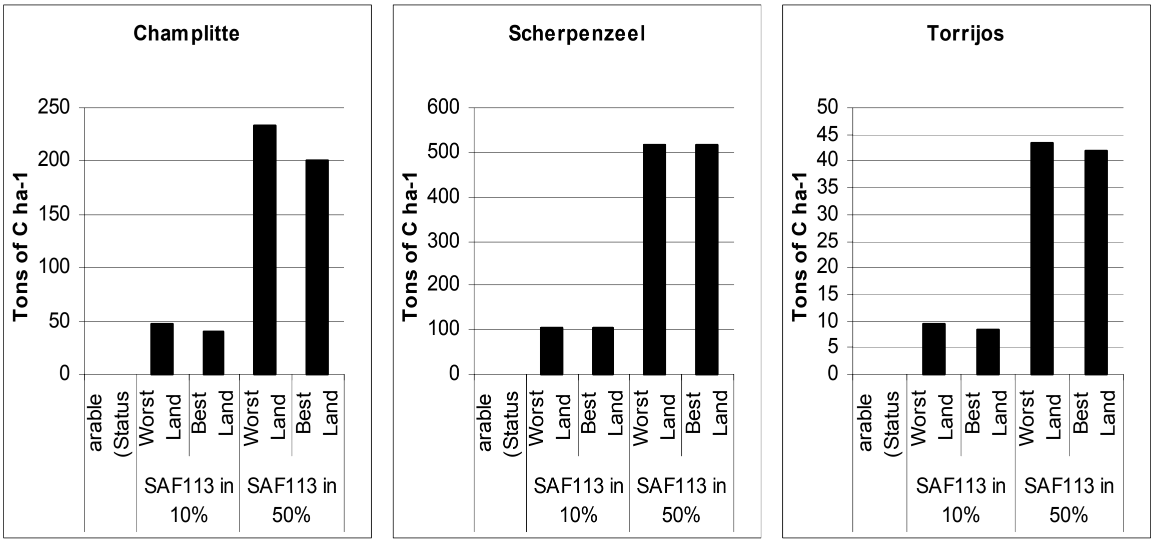


Figure 90: Carbon sequestered (per farm basis) after 60 years in different scenarios of 113 trees ha^{-1} SAF. Champlitte - Wild Cherry (worst land) and Walnut (best land); Scherpenzeel - Poplar; Torrijos - Holm Oak (both qualities of land)

Assessment of landscape (bio)diversity

Agroforestry is not meant to be the best land use to increase biodiversity nor never has been the purpose of this article to propose that. Similarly to carbon sequestration, and previously described, there is experimental evidence of agroforestry harbouring more biodiversity than common agricultural monocropping practices. The research done and existing tools provide a way to observe how agroforestry can change the current situation.

The results evidence the importance of introducing trees in monotonous intensive agricultural landscapes with low heterogeneity. Figure 91 illustrates Equation 16 and relates the different effects of converting different portions of the arable land (10 to 90%) into agroforestry and the different importance (slope) of that conversion depending on the existent greenvein elements. The slope, is proportionally inverted to the area to which the farm/landscape is to be converted into agroforestry which means that when comparing the introduction in two different landscapes, e.g. one with 5% and the other with 60% of greenvein elements, the difference between converting 10% and 40% into agroforestry is much higher in the less greenveined landscape (43-14.5=28.5%) than in the more greenveined landscape (76-64=12%).

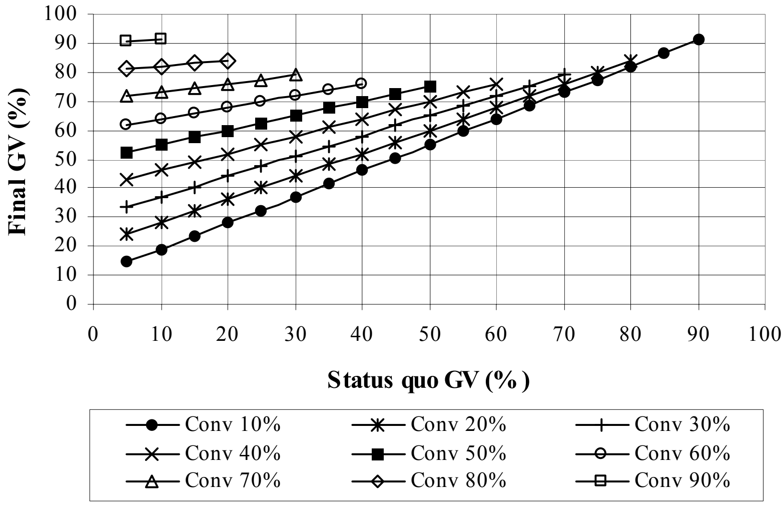


Figure 91: Relation between Status quo Greenveins and final Greenveins by converting different percentages of arable land into agroforestry in the farm/landscape

In real situations, in the LTS, the theory previously described is observed. The introduction of agroforestry had more impact in landscapes with low greenvein elements (Scherpenzeel). In Champlitte and Torrijos the conversion of 50% of the farm into agroforestry approximately duplicates the current greenveining status, while in Scherpenzeel, the same farm conversion into agroforestry pentiplicates the landscape diversity (Figure 92).

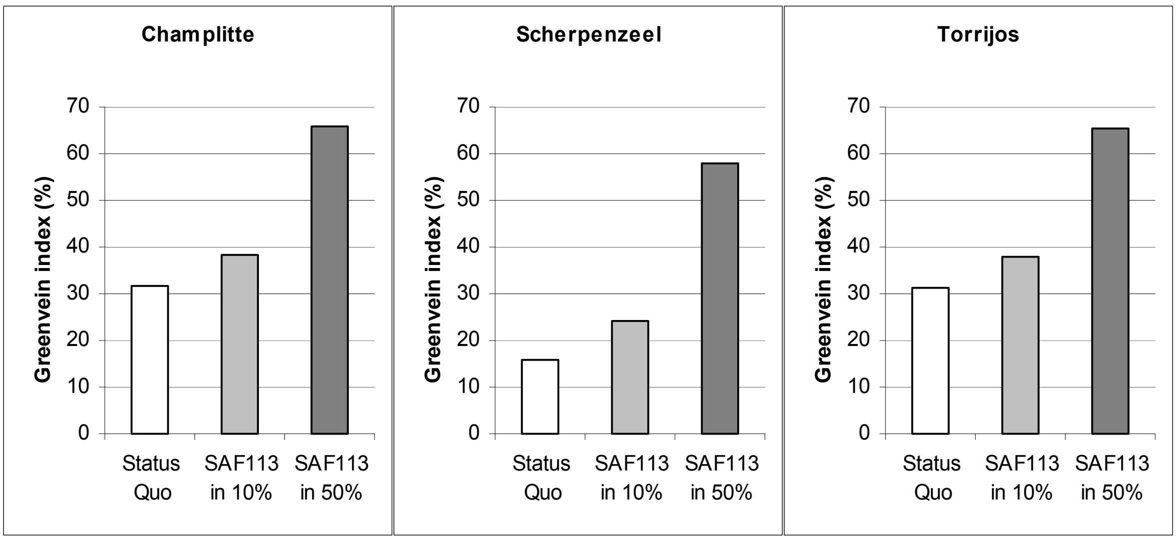


Figure 92: Effect of agroforestry introduction in the farm/landscape diversity

If Billeter's *et al.* (2004) regression equations relating landscape greenveinning to number of group individuals are to be applied, this would mean that, by converting 10% of the farm/landscape into agroforestry, the number of herbaceous plants, birds and arthropods would increase around 12, 2, and 2 respectively in Torrijos and Champlitte, and 14, 2 and 3 respectively in Scherpenzeel. If 50% were converted, the figures would increase to 59, 10 and 11 in Torrijos and Champlitte, and 72, 12 and 13 in Scherpenzeel. However the experimental test sites from where these relations were developed, did not took in consideration Mediterranean agricultural areas where is documented higher biodiversity than in northern latitudes of Europe (Mittermeier *et al.*, 2005) and these relations could be different.

				Erosion (Kg ha^{-1})		N Leaching (Kg ha^{-1})	CO_2 Seq (Tons C ha^{-1})	Greenvein Index (%)
				N con	Con			
Spain LTS	Scenarios	Status Quo		1.64	0.91	0	0	31
		10 %	Worst Land	1.60	0.88	0	21	38
			Best Land	1.58	0.85	0	20	38
		50%	Worst Land	1.38	0.63	0	101	66
			Best Land	1.35	0.59	0	98	66
France LTS	Scenarios	Status Quo		1.12	0.44	6121	0	31
		10 %	Worst Land	1.11	0.4	1972	21	38
			Best Land	1.05	1.05	1698	17	38
		50%	Worst Land	1.05	0.44	1624	106	66
			Best Land	0.75	0.19	963	98	66
Netherlands LTS	Scenarios	Status Quo		0.53	0.31	9274	0	16
		10 %	Worst Land	0.49	0.29	8606	42	24
			Best Land	0.49	0.29	8606	60	24
		50%	Worst Land	0.32	0.17	5937	164	58
			Best Land	0.32	0.17	5937	224	58

Table 27: Resumed table of environmental effects under different scenarios of silvoarable agroforestry in three Landscape Test Sites (Spain, France and the Netherlands)

Defining target regions for silvoarable agroforestry for Europe

These results are based on the following paper produced by the SAFE consortium:

☞ *Reisner, Y.; Herzog, F. and De Filippi, R. (2005): Target regions for silvoarable Agroforestry in Europe. Submitted to Ecological Engineering.*

Silvoarable Agroforestry (SAF) has recently been proposed as an alternative land-use system for Europe. In a geographic information system (GIS) data on soil, climate, topography, and land cover were integrated to identify agroforestry target regions where (i) productive growth of trees (*Juglans* spp., *Prunus avium, Populus* spp., *Pinus pinea*, and *Quercus ilex*) in SAF systems could be expected and where (ii) SAF systems could potentially reduce the risk of soil erosion, contribute to groundwater protection and increase landscape diversity.

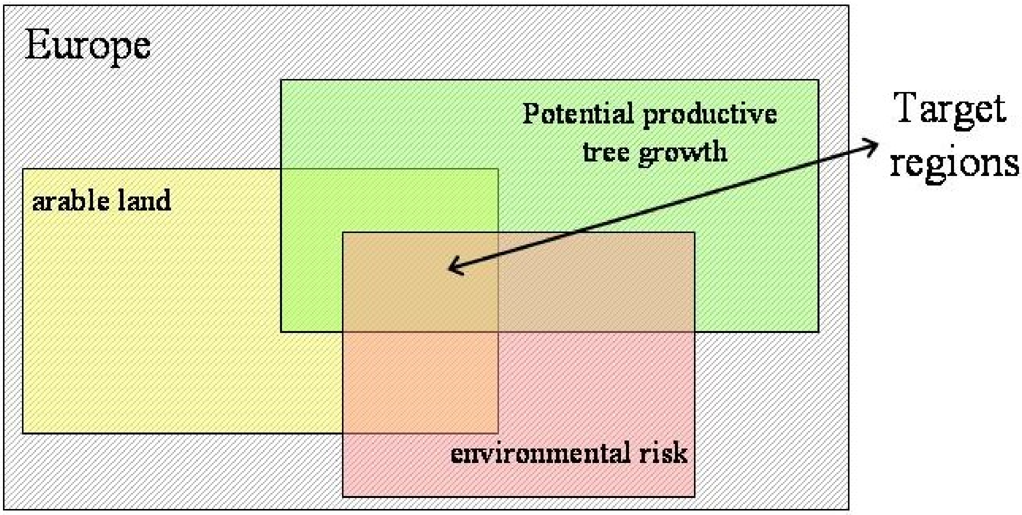


Figure 93: Concept to identify target regions for silvoarable agroforestry at the European scale.

The analysis shows that the investigated tree species could grow productively in SAF systems on 56% of the arable land throughout Europe (potential productive tree growth area). 80% of the European arable land were classified as potential risk areas for soil erosion, nitrate leaching and/or landscape diversity. Overlaying potential productive tree growth areas with the arable land, which were considered as environmental risk areas yielded target regions. They were found to make up about 40% of the European arable land and thus SAF could contribute to soil protection on 4%, to mitigate nitrate leaching on 18% and to increase landscape diversity on 32% of European arable land.

Although limited by constrained data availability, the study shows that SAF could be implemented in a productive way throughout Europe and that it could contribute to resolve some of the major land-use problems. The environmental benefits could justify the support of SAF by subsidies.

Potential productive tree growth area

All together, the tree species investigated can potentially grow and produce economically viable wood yield on 906 887 sqkm. This corresponds to 55.8% of the arable land of Europe (Table 3).

Walnut (*Juglans *spp.)

Walnut trees are economically important because of their fruits and the decorative, valuable timber (Becquey, 1997). The definition of the potential productive growth area of walnut trees (*Juglans* hybrids) is based on the requirements of *Juglans regia*, which is found today in most of Europe except for northern and northeastern regions (Norway, Finland, Poland). It grows well on fertile, deep, and well-drained soils (CABI, 2003).

Figure 94 shows the potential productive growth area of walnut (*Juglans* hybrids). It covers an area of 242 961 sqkm. This is 14.9% of the European arable land. The main potential distribution is in flat regions of Germany, France, Italy, and the eastern part of Austria.

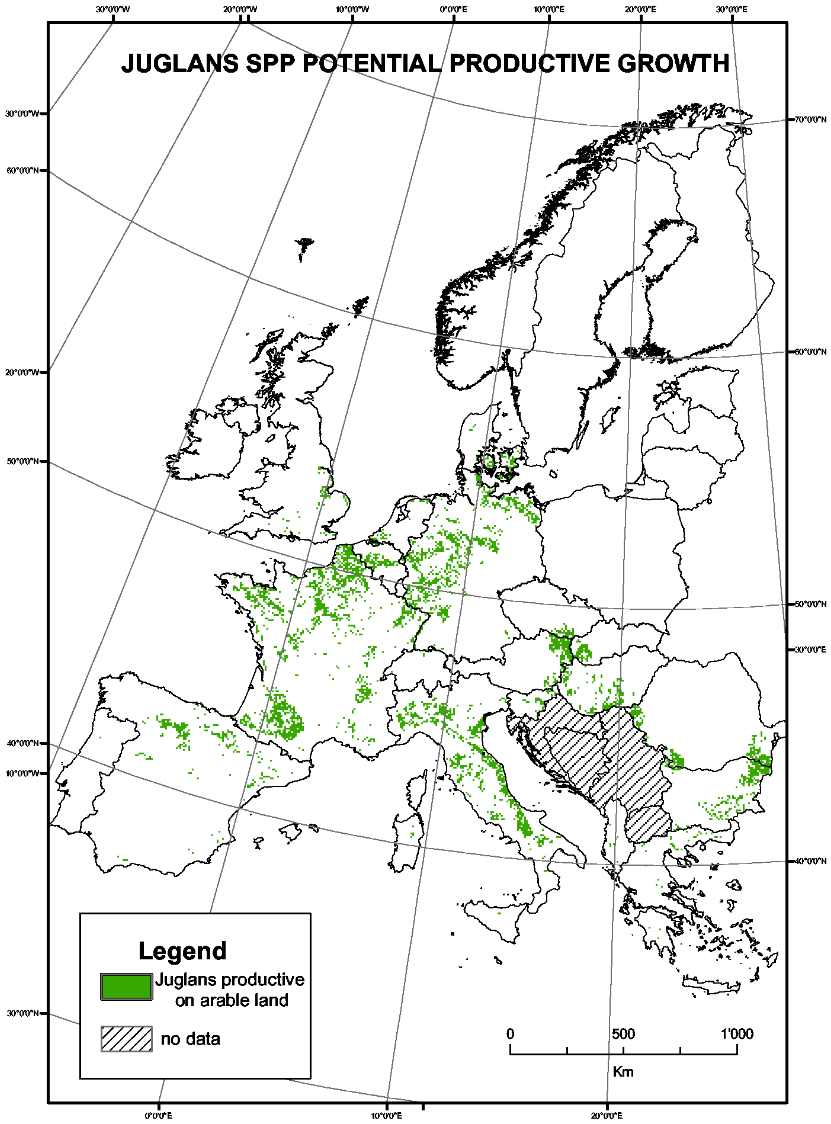


Figure 94: Walnut (*Juglans* spp.): potential productive tree growth area on arable land

Wild Cherry (*Prunus avium*)

Prunus avium is found on lowland plains, and also on slopes and hills over most of Europe. It grows scattered along moist river valleys, or in the edges of woods and in hedgerows (Ducci et al., 1988). In general it needs a deep moist soil for good growth (Teissier, 1980; Savill, 1991). Current interest in wild cherry wood production in natural forests and in plantations in Europe is high, as it produces an attractive, patterned wood (Zimmermann, 1988; Schalk, 1990).

Figure 95 shows the potential productive growth area of *Prunus avium,* which covers an area of 296 335 sqkm (18.2% of the European arable land, see Table 3). In some areas it has the same distribution as *Juglans regia*, but it stretches to colder regions and to regions with a more continental climate.

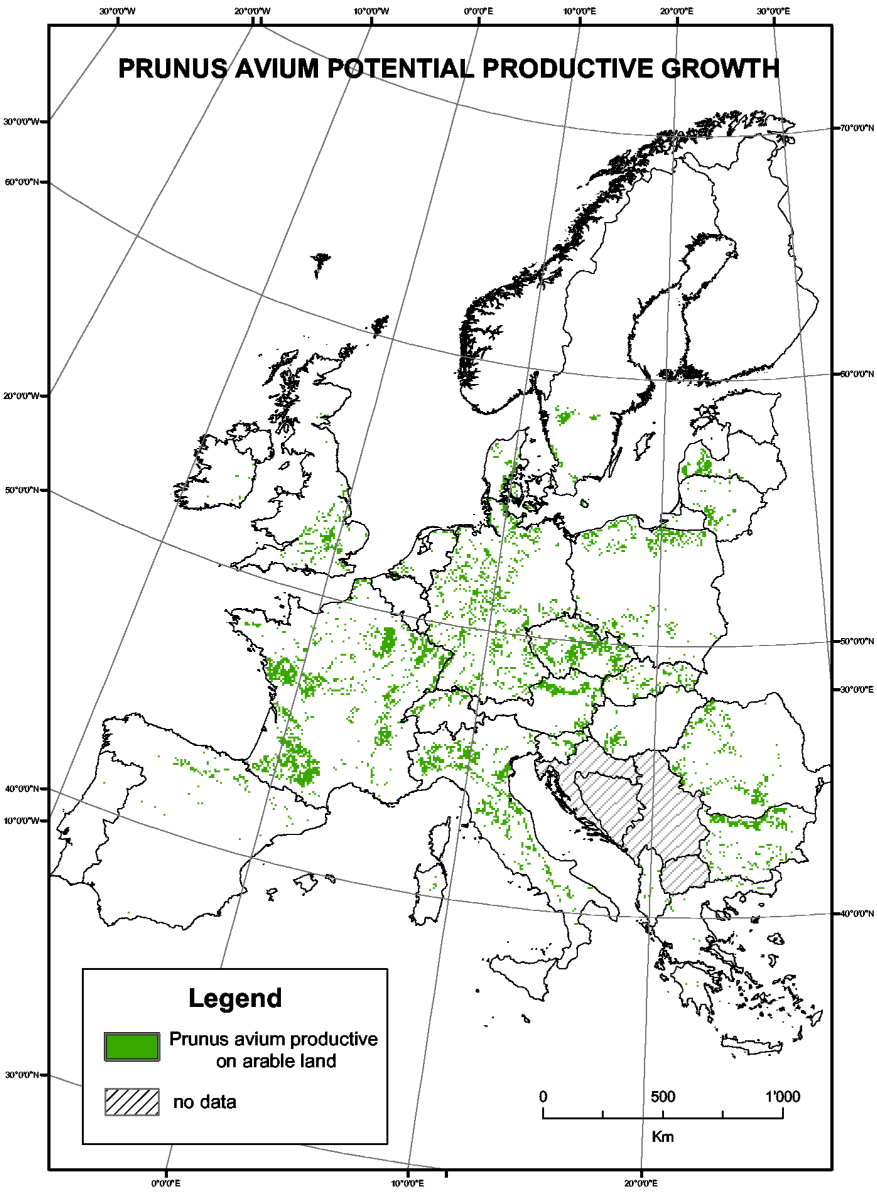


Figure 96: Wild Cherry (*Prunus avium*): potential productive tree growth area on arable land.

Poplar (*Populus *spp.)

The definition of target areas for poplar was based on the tree requirements of *Populus deltoides,* because it has been extensively used in poplar hybridisation programmes throughout the world, producing fast-growing clones.

Populus deltoides primarily grows on the moist alluvial soils along streams and on sandy or well-drained soils with a high water table which provides year-round moisture (Albertson and Weaver, 1945; Dickmann and Stuart, 1983; Hupp, 1992; Kaul, 1995). The wood of poplar is commonly used for the manufacture of a number of products, including pallets, furniture, matches, and packing cases.

The potential productive growth area of poplar hybrids covers 547 054 sqkm (33.6% of the European arable land). The potential productive tree growth area is very large. In reality it would be even larger, mainly in the Mediterranean region, as the resolution of the maps (1100x1100 metres) do not allow for the inclusion of smaller areas (e.g. along rivers and streams) into the analysis. Moreover, irrigation would allow the extension of poplar planting into areas where rainfall was the limiting criterion.

***Italian Stone Pine (*Pinus pinea)**

Pinus pinea has a distribution limited to the Mediterranean basin (Richardson and Rundel, 1998). It can grow on almost all soil types, including very poor soils, but it grows best on sandstone and sandy substrates (Barbéro et al., 1998). *Pinus pinea* is cultivated for different purposes such as fruits (seeds), solid wood, wood-fibre and environmental protection (e.g. erosion control, drift sand control) (Maitre, 1998).

The potential productive growth area of *Pinus pinea* covers an area of 65 405 sqkm. This corresponds to 4.0% of the European arable land.

Holm Oak (*Quercus ilex*)

Quercus ilex is a typical Mediterranean tree. It is more important in the western part of the Mediterranean Basin than in the eastern part (Barbéro et al., 1992). *Quercus ilex* can grow on a large range of soil types, ranging from littoral sandy soils to granite soils, but it does not tolerate waterlogged conditions (CABI, 2003). The wood is used for firewood and to produce good quality charcoal. The acorns of subsp. rotundifolia are also collected and fed to animals (CABI, 2003).

The potential productive growth area of *Quercus ilex* covers 155 957 sqkm (9.6% of the European arable land).

Environmental risk on arable land

Soil erosion

The erosion map does not cover all selected countries (section 2.2). The following countries were excluded because of insufficient data: Albania, Finland, Norway, Sweden, and Switzerland (Figure 8). The analysed countries cover $3.5*10^6$ sqkm, with an area of $1.53*10^6$ sqkm arable land. 5.2% of the arable land has a high or very high risk of soil erosion with more than 5 t/ha/year.

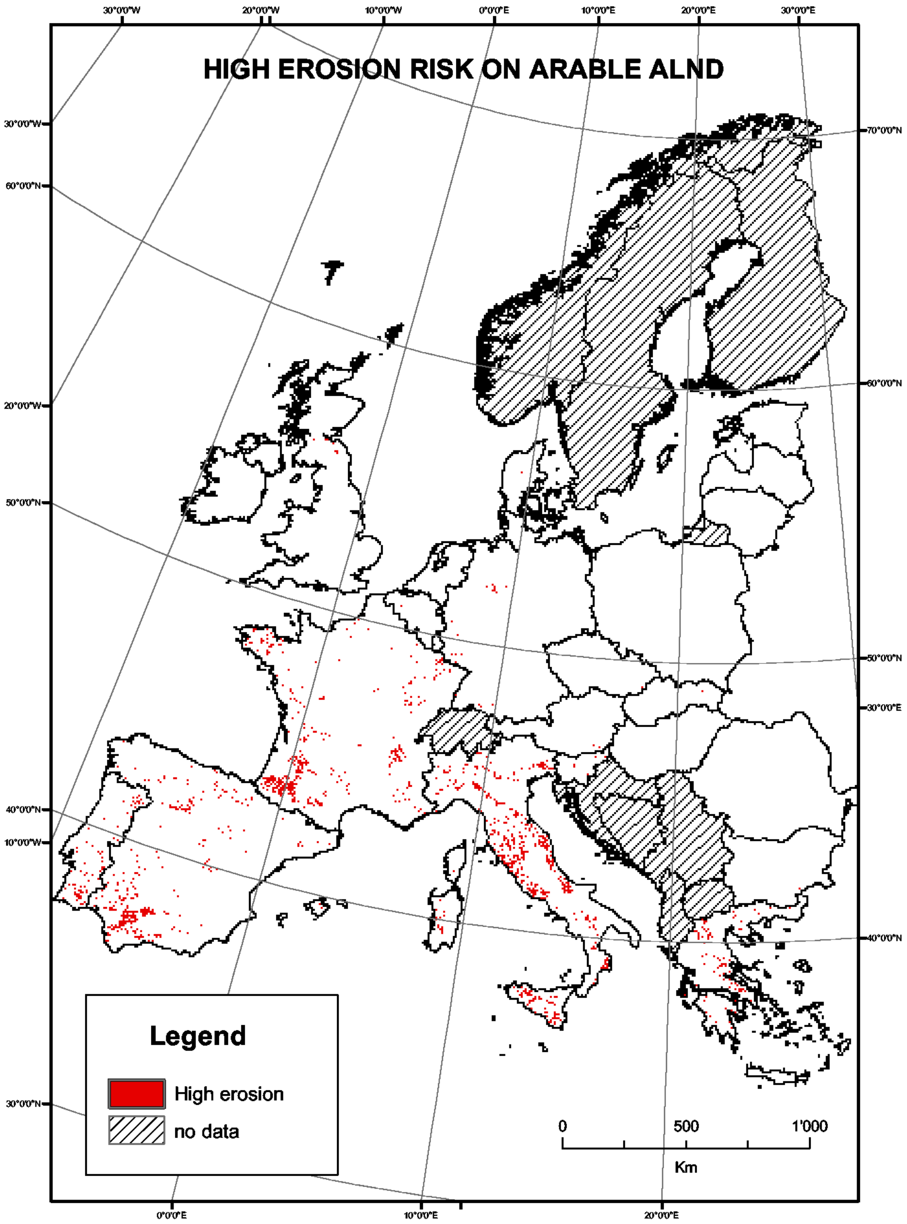


Figure 97: High soil erosion (>5 t/ha/year). ***Source:*** **Gobin and Govers (2003).**

Nitrate vulnerable zones

Nitrate Vulnerable Zones (NVZ) (European Commission, 2002) have been defined for Austria, Belgium-Luxembourg, Denmark, Finland, France, Germany, Greece, Italy, Netherlands, Portugal, Slovenia, Spain, Sweden, and the United Kingdom (see the countries in Figure 98). 984 383 sqkm in the analysed countries are arable land, of which 51.6% were assessed as NVZ with a high risk of nitrate leaching into the groundwater.

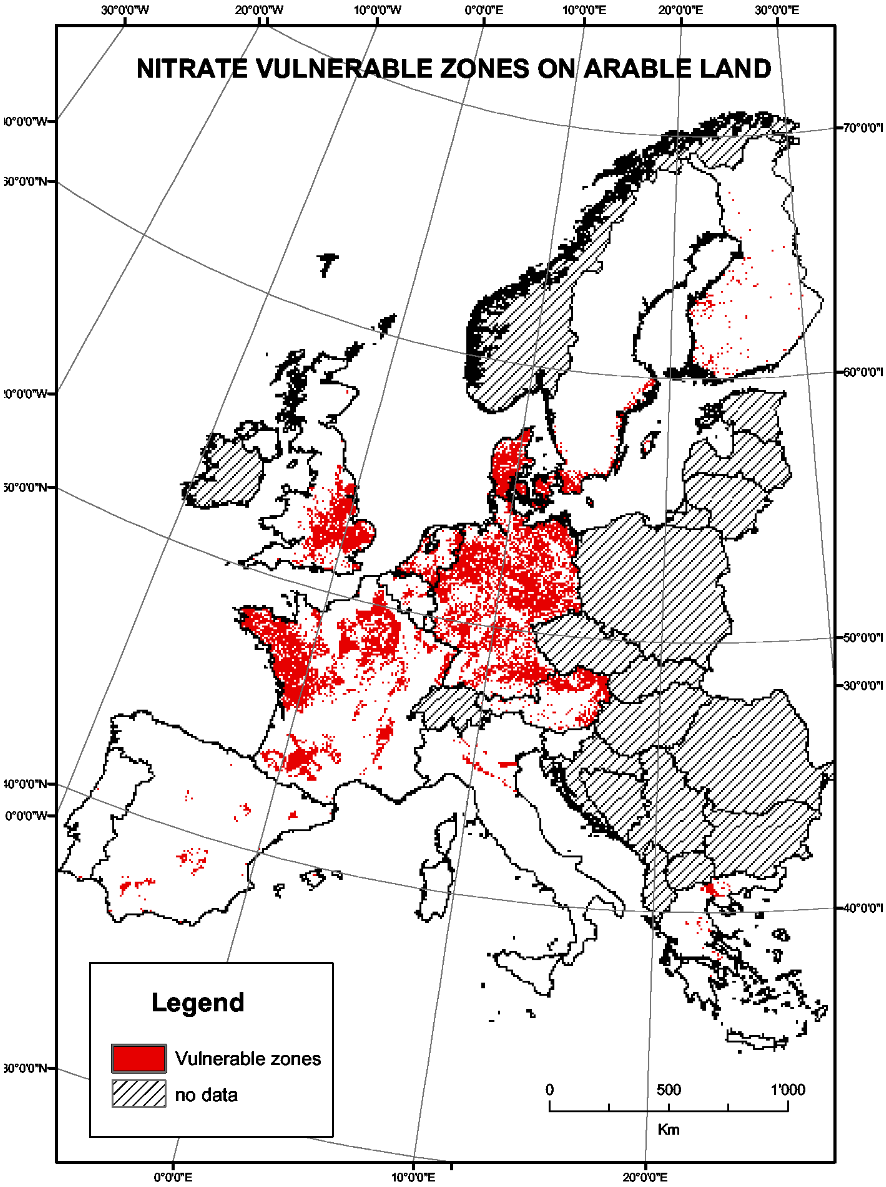


Figure 98: Nitrate Vulnerable Zones (NVZ).*Source:* European Commission (2002).

Landscape diversity

All countries from the list in section 2.2 were included. From the $1.63*10^6$ sqkm arable land, $1.08*10^6$ sqkm were assessed to have a low landscape diversity (Figure 10). This represents 66.3% of the European arable land (Table 4).

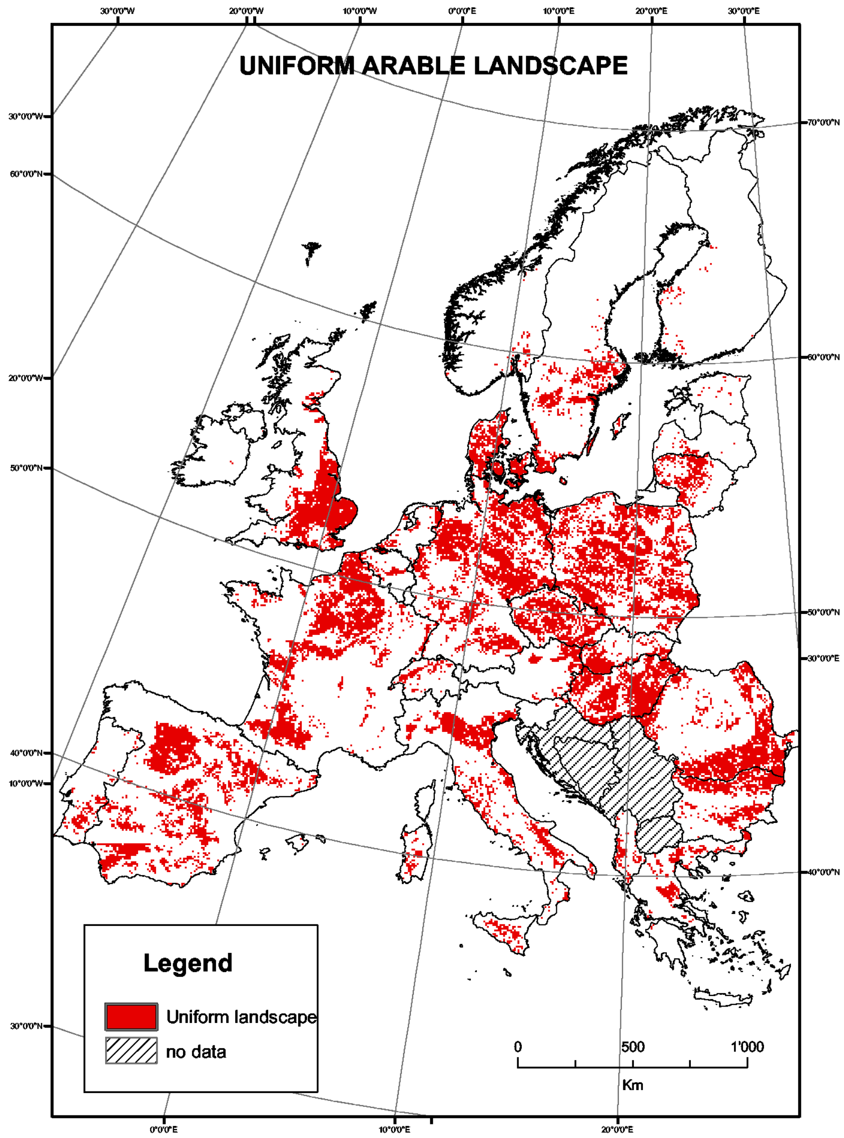


Figure 99: Low landscape diversity in Europe.

Target regions for Silvoarable Agroforestry (with Juglans spp., Prunus avium, Populus spp., Pinus pinea, and Quercus ilex)

Target regions resulted from overlaying the trees' potential growth areas with areas for which environmental problems were identified (Figure 99). These target regions cover 652 185 sqkm (Table 28). This means that around 40.1% of the arable land in Europe was defined as a target region for at least one of the five tree species under investigation. Of this area, 7% were classified as being in danger of erosion with an erosion rate of more than 5 t/ha/year. 34% of the target regions were categorised as nitrate vulnerable zones and 59% were found to have a uniform arable landscape.

Table 28: Potential productive tree growth area and target regions for silvoarable agroforestry in Europe (for *Juglans* spp., *Prunus avium*, *Populus* spp., *Pinus pinea* and *Quercus ilex*).

Tree species	Potential productive tree growth area		Target regions	
	sqkm	% of European arable land	sqkm	% of European arable land
Juglans spp.	242 961	14.9	197 308	12.1
Prunus avium	296 335	18.2	222 604	13.7
Populus spp.	547 054	33.6	402 763	24.8
Pinus pinea	65 405	4.0	37 667	2.3
Quercus ilex	155 957	9.6	88 098	5.4
Area where at least one of the selected tree species can grow [1)]	906 887	55.8	652 185	40.1

[1)] because of overlaying, the area is smaller than the sum of the potential distribution area of the single tree species.

If in the target regions for productive silvoarable agroforestry would be implemented, soil erosion could be reduced on 4% of the total area of European arable land. Similarly, nitrate leaching could be reduced on 18% of the arable land area in Europe and 32% of the arable European landscape could be diversified by trees.

Target regions cover large parts of central Europe. In many areas of Germany, Poland and the Czech Republic integrating walnut, wild cherry and/or popular based agroforestry systems could reduce nitrogen leaching from arable agriculture. The same is true of the arable landscapes along the river Danube in northern Austria and the agricultural areas near Bucharest. At the same time these rather monotonous agricultural landscapes would benefit from landscape diversification that the agroforestry system affords. Walnut, wild cherry and poplar silvoarable agroforestry could also mitigate nitrate leaching in southern England, northern (Brittany, Champagne) and central France (Paris basin, Loire region) and reduce soil erosion in the steeper zones of these regions. In southern France (Aquitaine, Pyrenees), walnut and cherry based agroforestry systems could have the same beneficial effects. In Italy, the Po valley would qualify for poplar agroforestry systems with the benefit of reducing nitrate leaching and increasing landscape diversity. This target region stretches all the way down the Italian peninsula on the eastern flank of the Apennine mountains. In this region, silvoarable agroforestry using walnut could be used mainly to reduce soil erosion.

In comparison to central Europe, less target regions were identified in the Mediterranean regions. This is partly due to the fact that the maps (1 sqkm) are unable to locate small, narrow valley bottoms where e.g. Poplar could take advantage of the water table. Nevertheless, in southern Portugal, in Spain (Saragossa, Valladolid, Sevilla), in Sardinia and in Sicily, the use of silvoarable agroforestry with poplar, oak and pine could contribute to the reduction of soil erosion and also enhance landscape diversity.

WP9: Developing European guidelines for policy implementation

WP9 results are covering 4 aspects:

- The problems met by farmers establishing new silvoarable plots in 5 European countries.
- The eligibility of silvoarable systems for Government financial support
- Proposals for changes in policy to favour agroforestry based on scenario testing using models.
- The establishment of silvoarable plots as a 'social experiment' by user participants in 3 countries.

Documenting the problems of farmers establishing new silvoarable plots in 5 European countries.

Anecdotal evidence was gathered during end-user meetings (between January and March 05) in several countries on the perceptions of officials and farmers. In summary, officials have difficulties with agroforestry for several reasons.

- There is no EU Forest Policy (or mention of forestry in the Constitution)
- There is little knowledge that knowledge that agroforestry is mentioned several times in 1999 EU Forest 'Strategy'
- There is lack of experience of old or new agroforestry systems, or willingness to be flexible with grant rules in order to benefit experimental trials of agroforestry.
- Agroforestry presents complications to calculating grant levels, which are most easily solved by making it ineligible.
- Agroforestry has complicated effects on the 'cadastral' and local tax status of land.
- Responsibility for agroforestry falls between agriculture, forestry and environment departments (the Agriculture Department wants to hang on to agricultural land, the Forestry Department doesn't believe its possible to grow good quality timber at wide spacing, the Environment Department doesn't like regimented rows, intensive management and control of weeds).
- Finally, there is a perception that EU doesn't allow it!! (e.g. it is frequently stated that 'EU insists that afforestation grants must reduce agricultural surpluses').

Farmers are reluctant to introduce agroforestry plantations because of technical difficulties, such as:

- uncertainties over management, time consumption and yield;
- likely damage to field drains;
- perception of increased pest problems;
- incompatibility with machinery & potential tree-damage;
- little knowledge of timber markets;
- possible lower timber quality;
- trees owned by landlord and not tenants.

Or because of disincentives due to current regulations:

- low or no subsidies following 1257/99 (no or lower arable area payments, no or pro-rata reduced planting grants, no income support payments, ineligible for agri-environmental payments);
- classification as permanent forest land (lower tax but lower land value & irreversible planning control);
- time and bureaucracy for grant application process;
- scepticism of professionals and advisors.

Comparing eligibility of silvoarable systems for Government financial

Support in EU member states

A Report on Deliverable 9.2 was prepared during just after the reporting period (Annex 2). More detailed appendices have been prepared for the UK, France and Spain, and are under production for other SAFE member countries. Rules and regulations in many countries are changing and it is hoped that these country reports can be updated after the end of the project. Results are presented in the Work package 9 report, and are summarised in Table 29.

Presentations focusing on eligibility of agroforestry systems for current arable area payments, for tree-planting grants, and for future single-farm-payments were made following the formal end of the project at end-user meetings in three countries (Paris -26th January 05, Madrid - 11th March 05, and Brussels - 30th March 05).

Table 29: Eligibility of Agroforestry Systems for Agricultural and Forestry Grants under current Pillar I and Pillar II rules

Country	**Agricultural Payments** (First Pillar)		**Forestry Grants for Agroforestry Spacing** (Second Pillar)			**Agri-environmental** (Second Pillar)
	Arable Area Payment	**Livestock payments in silvopastoral systems (if declared as 'foreage areas').**	**Planting**	**Tree-maintenance (usually for 5 years)**	**Income support (for 8-20 years)**	
France	Yes on cropped area. (with young trees) or area reduced for crown area (mature trees)	Yes in grazed woodland if forage area >50%	Yes, proportion of total cost. But strong restrictions in practice (such as follow up of the plantation by a research institute)	Yes, proportion of total cost	Yes, on non-cropped area. But not yet applied for	Yes, specific AF measure, but only applied in two Departments
Germany	Yes on cropped ares, but so far no references with mature trees	Yes in grazed woodlands if forage area >50%	No	No	No	Possible but untried
Greece	Yes on cropped area reduced by crown area	Yes in grazed woodlands if forage area >50%	No	No	No	Possible but untried
Italy	Yes usually reduced by crown area but can vary	Yes in grazed woodlands if forage area >50%	No	No	No	Possible but untried
Netherlands	Yes on cropped Ares, but so far no references with mature trees	Yes in grazed woodlands if forage area >50%	No	No	No	Possible but untried
Spain	Arable payments usually reduced by more than crown area.	Yes in grazed woodlands (e.g. Dehesas) if forage area>50%	Proportion of total cost (density as low as 278t/ha for some species	Yes, proportion of total cost	No	Small grants in some Regions but only for maintaining existing trees[4]
Switzerland	?	Yes in grazed woodlands	No	No	No	Possible if AF recognised as Ecological Compensation Areas
UK	Yes on cropped area, provided connected to larger field.	Yes in grazed woodlands (tho'area is reduced to account for trees & grazing should be possible for 7 months per year)	Pro-rata reduction from 1200t/ha for poplar (only). No income support	Pro-rata reduction	No	Possible (e.g. hedges) but untried

[4] E.g. support for traditional agroforestry in Andalucia; maintenance of non-productive trees (Aragon, Madrid); maintenance of windbreaks and setos (Asturias, Canarias, Cataluna, Rioja; Pais Vasco; soil protection through lines of trees and scattered trees (Pais Vasco);

Proposing changes in forestry and agroforestry policy based on scenario testing using models.

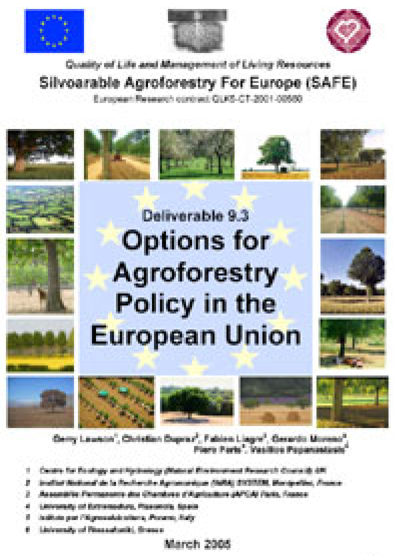


Figure 100: The cover page (left) of Deliverable 9.3 that was presented at the final Conference of the project (announcement, right)

Partners in WP6, 7 and 8 have collaborated to develop plot and landscape models of agroforestry growth which allow the effects of subsidies for tree, crop and environmental to be varied. Standard scenarios are being tested using the FARMSAFE model within Landscape Test Sites in Spain, Netherlands and France, and to a lesser extent in other countries. These scenarios form part of the final milestone for the SAFE Project (Milestone 15), and have been described in the WP7 and WP8 final reports.

A final conclusion on the profitability of agroforestry within the reformed CAP depends on the whether agroforestry is considered eligible for Single Farm Payments, and whether countries implement Article 41 of the draft Rural Development Regulation 2007-20013. This regulation, for the first time, provided for tree-planting grants to be paid for trees at agroforestry spacing. The SAFE Project has identified 7 policy issues.

Regulation 1782/03 introducing the move to the ‘decoupled’ Single Payment Scheme (SPS) indicates that ‘woods’ (Article 43) and ‘forests’ (Article 44) are ineligible for the SPS. But confusion exists because the Regulation does not define either ‘woods’ or ‘forests’. Already there are examples of farmers removing trees from farmland (e.g. traditional orchards in England, hedges in Poland or Dehesa systems in Spain) because they fear the loss of SPS payments.

Guidance Document AGRI-2254-2003 recommends that the threshold of 'woodland' is > 50 stems per ha, but does allow countries to define exceptions in the case of ‘mixed cropping’.“ In accordance with Article 5(1)(a) of Regulation (EC) No 2419/2001, areas of trees – particularly trees with a potential use only for wood production inside an agricultural parcel with density of more than 50 trees/ha should, as a general rule, be considered as ineligible. Exceptions may be envisaged for tree classes of mixed cropping such as for orchards and for ecological/environmental reasons. Eventual exceptions must be defined beforehand by the Member States.” We propose replacing ‘tree classes of mixed-cropping’ with ‘agroforestry systems’ and include a simple definition of agroforestry.

Farmers obtaining the Pillar I SPS are obliged to demonstrate that they maintain the farm in ‘Good Agricultural and Environmental Condition' (GAEC). Annex IV of Regulation 1782/03 gives one GAEC condition as ‘avoiding encroachment of unwanted vegetation on agricultural land'. EU countries differ in their definition of GAEC but it should be clear at the EU level that well managed Agroforestry Systems fulfils GAEC requirements.

The draft Rural Development Regulation includes support for new planting of agroforestry (Article 41) but NOT the 5-year maintenance element received by conventional plantations. However, good maintenance during the 5 first years of a low-density tree stand is crucial for the success of the plantation. Tree protection, weed control, and stem pruning are essential.

Existing Agroforestry systems can be managed to maximise environmental benefits. These traditional management costs could be included as an option within the agri-environmental measures proposed by the draft RDR.

Regulation 2237/03 Chapter 5 sets levels and conditions for subsidies to nut plantations. • It sets minimum densities (125/ha for hazelnuts, 50/ha for almonds, 50/ha for walnuts, 50/ha for pistachios, 30/ha for locust beans) but indicates that payments to nut trees orchards will NOT be made if these are intercropped. • This condition is reflected in national legislation, but is an unreasonable condition provided that SPS is not claimed.

The 1998 EU Forest Strategy emphasised Agroforestry in the context of: ‘sustainable and multifunctional management of forests … including optimisation of agroforestry systems’ (p15); – research to concentrate on ‘… diversification (no wood uses, agro-sylvo-pastoral systems)’..(p16); – maintenance of traditional management of silvopastoral systems with high levels of biodiversity which may be lost of these areas area abandoned (p23); – the importance of agroforestry for carbon sequestration (p23) Yet agroforestry is hardly mentioned in national forestry strategies, or current EU or national rural development strategies, or in the recent publication on ‘Sustainable Forestry and the European Union’.

The SAFE project has produced 4 key policy proposals.

Proposal 1: A definition of agroforestry is suggested that includes isolated trees, tree hedges and low-density tree stands, which clearly distinguishes between agroforestry and forestry.

Proposal 1: Agroforestry systems refer to an agriculture land use system in which high-stem trees are grown in combination with agricultural commodities on the same plot. The tree component of agroforestry systems can be isolated trees, tree-hedges, and low-density tree stands. An agroforestry plot is defined by two characteristics: a) at least 50% of the area of the plot is in crop or pasture production, b) tree density is less than 200/ha (of stems greater than 15 cm in diameter at 1.3 meter height), including boundary trees.

Proposal 2: This proposal is compatible with existing Regulations, removes the contradiction between the two pillars of the CAP on rural trees (farmers will no longer be stimulated to remove trees to get CAP payments), and simplifies controls, and therefore saves a lot of European money

Proposal 2: The total area of an agroforestry parcel should be eligible for the Single Payment Scheme

Proposal 3: The draft RDR for 2008-2013 includes a welcome and innovative Article 41 that introduces support for the establishment of new agroforestry systems. It could be

supplemented: a) to include maintenance costs for agroforestry planting in the same way as in Article 40 for forest plantations; b) to support the eligibility of existing agroforestry systems for improvement and environmental payments.

Proposal 3: Agroforestry systems should be backed by the Rural Development Regulation (RDR, CAP second pillar)

Proposal 4: The 1998 EU Forest Strategy refers to agroforestry several times, but it was not mentioned in the Commissions recent review of implementation of the Strategy. This omission could be corrected in: a) the proposed Action Plan for Sustainable Forest Management (2006), b) The EU Rural Development Policy Document (2006).

Proposal 4: The EU Action Plan for Sustainable Forest Management (2006) should emphasise the need to maintain or increase the presence of scattered trees in farmed landscapes (agroforestry)

Co-ordinating the establishment of silvoarable plots as a 'social experiment' by user participants in 3 countries.

Trials have been established: a) in Luebeck, Germany by the FINIS Group; b) in , Gelderland, Netherlands by the GPG group, and at the Municipality of Askio in Greece.

Germany

A silvoarable trial was established at Gross Zecher, Schleswig-Holstein in spring 2003. The design of the silvoarable system is unusual: trees are planted in half circles in a way that combines functionality and landscape aesthetics (). The circles match the contours of the land and have been designed to match existing paths and landscape features (Figure 101).

The landscape aspect is important for the field owner. The planted trees were perceived to bring environmental and potential financial benefits, but also to provide an attraction for tourists to visiting her restaurant and/or guesthouse. Crop yield and timber production and fruit production were also of interest, and species were chosen to represent a range of artisan uses. Additionally, an herb garden was established within the smallest crop ring – which was too small to plant with crops. Last but not least FINIS is interested that the public becomes interested and attracted by the silvoarable system. Their objective is the establishment of multifunctional interdisciplinary land use systems that fulfils the local requirements in terms of ecology, landscape aesthetics, recreation and work opportunities.

Figure 101: Aerial view of design showing use of a depression to create a regional cycle path which eliminates a dangerous bend and attracts visitors into the site for visitors.

As in the Netherlands, the effect of drought differed between tree species. Moreover, some species disappeared/ died completely, because they were not adapted to the rather poor soil conditions. (It was the purpose of FINIS to experiment with tree species); these species have been replaced by others. In total about 30 % of the trees have been replanted.

Despite the small size of the trees the design of the plantation has attracted interest from locals, tourists, academics and local policy makers.

Greece

The exceptionally dry summer period in 2003 resulted in a number of dead trees in the three experimental plots established in 2003. Specifically, the first plot (Siargas' Figure 102) intercropped with maize did not have any dead trees due to drought because it was irrigated during the summer period (July 2003-October 2003). It had only 2 dead trees out of the 43 planted destroyed by the harvest machine. The second plot (Tsatsiadis') intercropped with wheat had 3 dead trees and 7 trees with dead leaves out of the 28 planted. Finally, the third plot (Strebas') intercropped with wheat had 27 dead trees and 12 trees with dead trees out of the 63 planted. All the dead trees were replaced during March 2004 with cherry and walnut trees sent by the coordination centre of Montpellier. In addition, a new experimental plot was established at the Kaloneri village during March 2004 (by the farmer D. Moustakas).

Figure 102: Siargas' experimental plot (January and August 2004)

Netherlands

The silvoarable field was set up in spring 2003 at Veluwe, in the Province Gelderland. The system comprises 4 tree species: *Robinia pseudoacacia, Castanea sativa, Prunus avium, Juglans nigra.* A fifth species *Picea abies* was planted in spring 2004 within the trees rows, at intermediate spacing between existing trees. In the first year the crop was starch potato (Figure 103). A 5-year rotation scheme will be followed, i.e. the potato crop will be followed by a summer cereal (barley), a winter cereal (wheat, triticale), fallow and maize. More details are given in the SAFE 2nd annual report.

Figure 103: ***Veluwe agroforestry trial showing difficulties of harvesting potatoes close to the tree strip***

The tree establishment was satisfactorily, but several drought spells caused the death of almost all trees. The yield of the potato crop was reduced by 30 % due to drought. Unfortunately irrigation of trees was not possible, since that would have damaged the crop. No weed control was performed following tree planting, and this could have alleviated the effect of water stress. The affect of the drought varied with tree species, but the *Robinia* planting stock appears to have been of poor quality.

Around 80% of the trees appeared to require replacement. The advantage of planting in early Spring is that the trees profit from the moisture of the winter period at a moment when root activity starts. Planting in autumn was also considered, but this is less favoured amongst foresters in the Netherlands. Volker Repelear decided to replant in spring, with regular weeding applied round the trees. Planting and weeding methods, and timing of canopy pruning were discussed (Figure 4).

Figure 104: Discussing advisable length of planting material with owner – Volker Repelear

In addition the experiment includes a control crop adjacent to the silvoarable field. Due to the machinery width used by the farmer for cultivation, the distance between two tree lines is 30 m. The distance between trees in the lines is 4 m and 8 m between trees of the same species. After tree planting a starch potato crop was interplanted up to 1 m from the tree lines. Thus the intercrop zone is 28 m. The largest machine (sprayer) has a width of 26 m.

The choice of tree species was discussed with a local forestry officer. On each tree line four species - *Robinia pseudacacia, Castanea sativa, Prunus avium, Juglans* - were planted. Each line consists of 25 trees, with blocks of 2 alternating species. In November 2003, the fifth specie *Picea abies* will be planted in between the already planted trees – in total 120 spruce trees. The latter will be harvested after 6 years as Christmas trees. The main purpose of the other species is wood production. Locust tree in particular is becoming a very popular wood for outside furniture in the Netherlands.

Replanting of dead trees and maintenance of crops has continued in the 'social agroforestry plantings' in Netherlands, Germany and Greece.

Discussion

WP1: A platform for modelling silvoarable systems

Not relevant. This WP did not produce results that deserve a discussion, but proposals that drove further recommendations (see conclusion)

WP2: Extant silvoarable systems in Europe

The extant silvoarable systems in Europe database

Despite the limitations of our review, it is clear that there are two distinct geographical and climatic zones with respect to European silvoarable agroforestry –northern Europe and the Mediterranean. The latter contains a broader range of systems, reflecting the higher diversity of commercial crops and plant resources. In general, the form and structure of systems in northern Europe are determined by light limitation, whereas in the Mediterranean water is the key resource.

In their review of agroforestry practices in temperate regions around the globe, Newman and Gordon conclude that the most successfully optimised systems are those for which there is a clearly defined market for a tree product (Newman & Gordon, 1997). In assessing the prospects for the preservation of traditional silvoarable systems, and the scope for novel and innovative approaches to combinations of trees and crops, we should therefore focus upon the economic value of the trees.

Although extant silvoarable practices in Europe are mostly residual elements of formerly widespread systems, there is still a considerable diversity in existence. As well as the systems based on timber trees and oaks that were studied experimentally in the SAFE project there are tree-crop systems with fruit trees, olives and, to a limited extent, fodder trees. The precise quantification of silvoarable systems in Europe is difficult due to lack of documentation. The application of a consistent definition of silvoarable agroforestry in land use surveys and recognition of their unique characteristics would go some way towards an accurate appraisal of their present extent and importance in the landscape of Europe. Their productive role in the European countries studied is not yet fully understood and deserves more attention, especially in the context of the diversification of farm income and the development of sustainable farming systems, two issues of immense strategic importance to the future of European agriculture. There are economic, environmental and aesthetic reasons to encourage their adoption in all regions of the European Union.

Survey of farmers' reaction to modern silvoarable systems

Can we trust our results?

In France, the results of the interviews have been presented to extension officers and farmers in each target region. Three local meetings have been organised in Prahecq (Poitou-Charentes), Orleans (Centre) in December 04 and in February 05 in Besançon (Franche Comté). These meetings were the opportunity to discuss all the results with the technicians who helped to design the sample and the farmers who were interviewed.

The results observed for France were quite surprising. Both in the very productive region (Centre) and in the contrasting region where it is difficult to maintain the agricultural area in the face of forest development (Franche Comté), the reaction of the farmers to the idea of silvoarable agriculture was enthusiastic (see Figure 105). If many farmers pointed out all the technical difficulties, they showed a deep interest to be informed about the potential of these systems – 80% wanted to be contacted again.

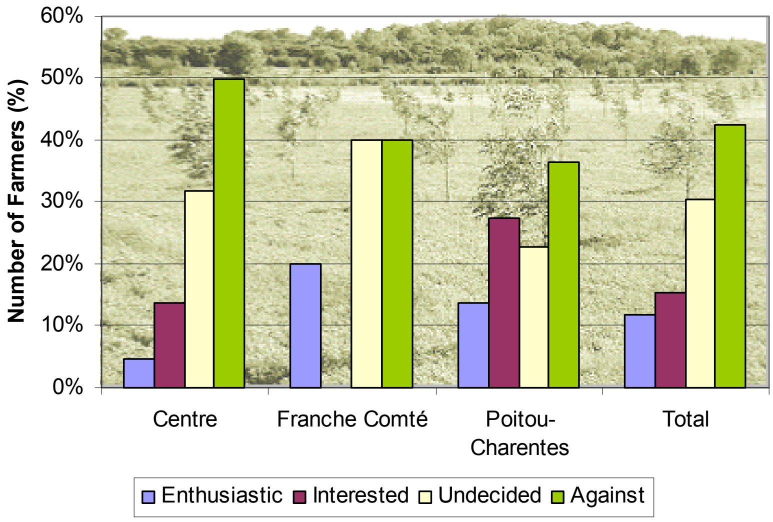


Figure 105: Are the French farmers interested in creating some silvoarable project? A third of them said that it could be an option in a short-term future. And 12 % seemed to be really motivated.

Even if the percentage of farmers interested in attempting some silvoarable projects is less important than in the European study, almost 30% of the French farmers said they would think about it. In the Region Centre, we found a large number of farmers against this possibility.In contrast, we have more possibility of finding an interested farmer in Poitou-Charentes.

This result was a strong surprise for the Chambers of Agriculture. Faced to this result, we realised an opinion poll with all the people who worked in the Farmer's reaction study. We wanted to know their opinion before showing them the results. Almost 50 questionnaires were sent to them to sound up their opinion about the farmers' reaction. And we received 25 answers. After the analysis of these questionnaires, we should be able to say that a few technicians were able to forecast these final results.

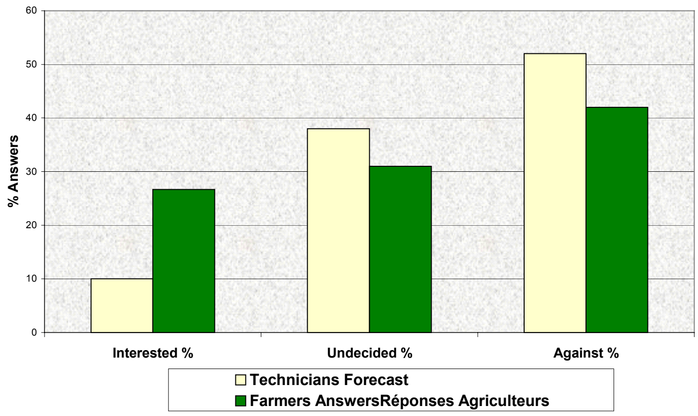


Figure 106: Technicians forecast about the answers of the farmers according to their interest in creating or not a silvoarable project. If the technicians share the same interest as the farmers concerning the possibilities of development of agroforestry, they nonetheless think that not so many farmers would be interested in this option.

Before each regional meeting, we phoned each farmer, two years after the interviews, to sound out again if they were thinking about a silvoarable project,and if they had changed their mind about agroforestry (see Figure 107).

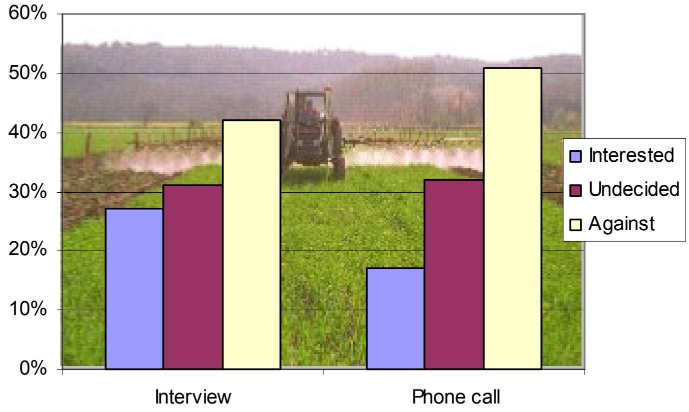


Figure 107: Evolution of the interest in creating a project for the French farmers who have been interviewed in 2003.

After 2 years, the farmers interested in attempting a project are less important than the first time, although we have still 10 farmers who are still enthusiastic. Finally, only half of those interviewed do not imagine to plant trees in their cropping area, although some of them do not close the door to this eventuality… In case of great subsidy, they can adopt their farming system!

We must also underline that 7 farmers have initiated some discussions with their technicians to see how to set up their silvoarable plot for 2005 (2 in Poitou-Charentes, 2 in Centre and 3 in Franche Comté)! From these 7 farmers, 5 had said that they were interested, one that he was undecided and the last one was against any project… This last farmer changed his mind about some environmental goal. In fact, his village decided to protect their water catchment area and to adopt some agro-environmental measures to maintain good water quality. Therefore he himself proposed a silvoarable measure. This programme will concern many farmers in this area. We can add that, again with this environmental approach, another farmer we interviewed could propose an agroforestry measure for the same reason in his village. The rest of the farmers who want to plant trees in their crop gave some economic reasons (diversification and inheritance) or just wanted to improve the landscape.

One of them told us during the interviews: "**Your system is fantastic! But if you don't succeed to change the European regulations to take into account the agroforestry specifications, you are an idiot! Sorry to tell you that!!**"

How many European farmers will take the plunge?

We saw in the French case that if the number of farmers interested has decreased, we still have a large part of them who are ready to study setting up a silvoarable plot on their farm. At the European scale, how many farmers from the 48% who declared being interested are ready to take the plunge?

To answer this question, we designed an indicator of interest for the silvoarable technology that could then be compared with the answer to the question: "Do you consider a silvoarable project in the near future on your farm?». This indicator was built by mixing several questions and weighting the answers (Table 30:).

Question	Answer	Weight
97. Do you envisage a collective project?	Yes No Doesn't know	1 0 0.5
98. Would you be ready to share machine costs?	Yes No Doesn't know	1 0 0.5
99. Would you be ready to share worker cost?	Yes No Doesn't know	1 0 0.5
104. If a neighbour proposed an intercropping area for you to use, would you accept?	Yes No Doesn't know	2.5 0 1
105. If your landlord proposed to make an agroforestry project on the land you rented from him/her, would you agree?	Yes No Doesn't know	3 0 1.5
106. If the investment were between 1000 to 1600 euros/ha, what proportion would you be willing to pay?	0 1-25 % 25-50 % 50-75 % 75-99 % 100 %	-1 0 0.5 1 1.5 2
114. What is your opinion on agroforestry? (Mark from 0 to 10)	Mark 0-3 Mark 4-6 Mark 7-10	0 1 2
44a. What tree species would you choose for a project on your farm?	Couldn't name species Named 1 specie Named > 1 specie Named trees in general	0 0.5 1 0.5
24. Have you heard of the word "agroforestry"? 26. If yes, what's your definition of agroforestry?	Yes with right definition Yes with wrong definition No	1 0.5 0
24. Have you heard of the word "agroforestry"? 25. If "yes" how have you heard of it?	Yes, personal experience Yes, demonstrated origin (article filed…) Yes, origin well defined Other	1.5 1 0.5 0
31. Do you have trees in the cropped area of your farm? 1 none, 2: <10 trees/ha, 3: 10-20 trees/ha, 4: 20-30 trees/ha, 5: >30 trees/ha	1 2 3 4 5	0 0.5 1 1.5 2
32. Who planted them? 1 parents, 2 grandparents, 3 yourself, 4 don't know	Parents Grand Parents Himself Doesn't know	1 1 2 0
Agroforestry Interest Indicator		Mark / 20

Table 30: Calculation of the farmer Agroforestry Interest Indicator.

This indicator is clearly linked to the motivation of the farmer. The answers given for the possibility of setting up a project in the near future can therefore be compared to the indicator. This resulted in different profiles of farmers accounting for their motivation for a silvoarable plantation.

The Agroforestry Interest Indicator will allow the identification of 4 classes of farmers according to their interest:

1. High motivation, ready to invest in a project in the near future
2. Motivated but cautious. Defines conditions first (such as payment eligibility).
3. Without definite opinion but the concept is considered attractive. Wonders if it could apply to his farm.
4. Reluctant, but still open in case of very high grants…

It was a surprise to find evidence that many European farmers are open to the possibility of introducing trees back into their cropped area. Trees disappeared because of mechanical adaptation, land regrouping and because farmers didn't want to lose CAP payments.

But if tree plantation is well adapted to the mechanical conditions, trees are not more considered to be an obstacle. After 30 minutes of discussion and a slide show of traditional and modern silvoarable systems, half of the farmers concluded the interview saying that they would be interested to set up some agroforestry plots on their own farm. With more agroforestry experience, Mediterranean farmers are more open to this eventuality than the farmers of the Northern Countries. But even in some intensive agricultural regions, where man can observe no trees in the fields, one third of the farmers are interested. This was a big surprise for the SAFE consortium, which was not expecting such an interest from the cereal farmers. And it was not expected at all by the extension services in the different countries, which are still a little suspicious about this result…

Different advantages have been underlined by the farmers. The main advantages that farmers have pointed out are more economic than environmental. The most important one is the possibility to diversify farm production. Faced with the possible decreasing of the Single Farm Payment in the future by the modulation effect, farmers search for new opportunities. Agroforestry could be one of them. Another stimulus for agroforestry was the possibility of complying with the new CAP conditions (Good Agricultural Environmental Conditions). But above these CAP considerations, agroforestry is seen as a possibility for improving the agro-environmental performance of the farm (nitrogen leaching, soil erosion, biodiversity), with a system that can make money for the future contrary to most of the AEM, which are not profitable and depend on an unstable subsidy.

But as one French farmer said, "farmers don't mind about photos, they need to visit some experiment". And the majority of the farmers set some conditions for the adoption of agroforestry. What kind of impact will the trees have on the crop yield? How many trees will they have to plant? 80% of the farmers want to be contacted again.

Farmers required two main conditions before taking some decision:

1. They want to know more about the agronomic performance of such a system. They need results from the research programmes. They wish to visit some existing experimental plots and to see for themselves if wheat can grow between the trees (in quantity and quality). They also want to be sure about the economic results of these systems (investment level, cash flow evolution, timber price).

2. CAP regulations should be adapted to agroforestry. All the farmers agreed that if this kind of system complies with the GAEC, it must not penalize the farmers regarding the CAP payment. Tree area should be eligible for the SFP payment. And a subsidy of 50% of the investment costs is considered by the farmers as a minimum aid to support an agroforestry

project. At the very least, farmers underlined the point that with the new aerial control system, farmers who have scattered trees will be penalized. They asked therefore for a simplification of this control system.

If the 2 conditions of adoption are set up, as is almost the case in France, we can expect that a large number of farmers will adopt agroforestry (more than 100 projects in 4 years in France). This future increase of the agroforestry area will be the concrete expression of the farmers' interest we observed during our interviews. For example, in France, 12 % of the farmers we interviewed have initiated some projects for 2005, 2 years after being interviewed.

This important interest from the farmers and the eventuality that in the near future farmers will adopt agroforestry on a large scale, pose some questions about the political consequences:

- The interview results open some doors for Research Development. During the discussions, various questions have been made by the farmers that can help the National Research Institutes to define some topics.

The interview results also challenge the extension services in each country to think about the best way to supervise the future development of agroforestry and to train not only the farmers but also the technicians about agroforestry.

WP3: European silvoarable experimental network

A discussion about the value of the very numerous field measurements obtained during the SAFE project is not possible in a few pages. This will be done in the many scientific papers that are expected after the end of the SAFE project.

However, a common problem that was encountered on most experimental sites was the value of the pure crop and pure tree control treatments, when available. These control treatments are essential to compute the value of the Land Equivalent Ratio of the silvoarable plot. The LER is the most powerful integrator of the production efficiency of the silvoarable system. This calls for very careful design of future experiments on silvoarable agroforestry. Common problems encountered were as follows: border effects due to the small size of the control plots; poor control of the soil variability due to the small number of replications; unsuitable control treatments due to variations in management not planned.

The project used data from a high proportion of the long-term field experiments on silvoarable agroforestry in Europe. Only a few such experiments exist because of the difficulty in obtaining long-term funding for such work, and if future development work on the subject is to occur more secure funding will be required.

WP4: Modelling above-ground tree-crop interactions

Most scientific papers expected from this WP are still in preparation. They will include discussions on the value of the modelling approach, and of the field activities to validate the models. The final structure of the aboveground modules of Hi-sAFe is now more consistent than the intermediate versions developed during the project.

About the consistency of the above-ground modules in Hi-sAFe

The tree growth and development module is part of the tree growth model (which as a whole also includes simulation of water and N uptake mediated through a spatially explicit root growth model and C uptake via a light interception and photosynthesis module). The tree growth module more specifically covers C and N allocation to (and from) the different compartments identified, and provides a spatially explicit representation of the above-ground parts of the tree.

The tree growth model itself is part of the Hi-sAFe agroforestry biophysical model, which is designed to describe a 3-5 year growth period of the tree + crop system in a temperate (seasonal) climate on a daily time step. It should be capable of simulating trees in the early years of development as well as the functioning of large mature trees. It should address pruning or root trenching, which are considered to be important management practices to improve the productive outcome of such systems. The design of the tree growth modules was backed by the following analysis:

Is carbon supply limiting tree growth?

Recent evidence, based on repeated measurements of above-ground tree non-structuralcarbohydrate stocks which have been conducted in a variety of climates, suggests that growth of mature trees in natural stands may never be limited by carbon availability (Hoch, Richter et al. 2003; Korner 2003). This may reflect the fact that trees have not yet adapted to the elevated ambient CO_2 levels and that the limiting step is integration of carbon into functional tissues rather than carbon uptake *per se*. For example, it has been argued that at high elevations temperature may limit growth more than C uptake (Korner 1998) as "growth as such, rather than photosynthesis or the carbon balance, is limited. In shoots coupled to a cold atmosphere, meristem activity is suggested to be limited for much of the time, especially at night". The same type of restriction may play a substantial role at high northern latitudes.

This idea that tree growth is not intrinsically limited by C-uptake is apparently contradictory to the extensive experimental data that prove that access to light is of paramount importance in determining relative competitive success of individual trees in a forest stand.

More probably in most environments tree growth is co-limited by a number of factors. The *most* limiting step may indeed not be C-uptake rate but biosynthesis rate of new tissues, particularly so under cold climates or low nitrogen fertility.

In any case, in low-density tree stands, like those we are dealing with, light availability is unlikely to limit C uptake as severely as in denser forest stands. Hence we put the emphasis on N and H_2O limitations to growth, be it at the C-uptake step or the step of biosynthesis of new functional tissues.

Tree response to pruning

The few reviews found on the subject (Geisler and Ferree 1984; Stiles 1984; Richards 1986) focus on fruit trees and are not recent. A quick Internet search was also conducted to complement the information reported in the above-mentioned horticultural reviews.

Overall, the literature consulted supports the view that response to pruning depends on the timing of pruning and that the general response will be towards a redistribution of growth to the pruned compartment. The extent to which remobilisation of NSC is involved in fuelling compensatory growth and how this may relate to pruning severity is unclear.

C-uptake modelling

It was finally decided to replace the initially preferred Farquard type infra-daily time step photosynthetic module a by a simple Radiation Use efficiency approach ((Bartelink, Kramer et al. 1997). A number of reasons can be put forward to justify this simplification

- So much uncertainty exists in terms of C-allocation patterns that it would not make much sense to use a large amount of computer resources to try and estimate C uptake to a great level of detail if further accounting of C the various pools is so grossly done.
- The candidate photosynthesis model (which includes a Jarvis model of stomata functioning) - which was developed for plants growing *without* water limitation - would be relevant if the evaporative demand were to be computed on an infra-daily time step. This again would imply a significant additional cost in term of computer time (and would not be consistent with the crop daily time step yielding a number of additional complications).
- No human resources were available to calibrate this photosynthetic model for the tree species under consideration.
- RUE approach to simulate C-uptake and daily time step are congruent with the STICS crop model.

The maximum RUE is assumed in Hi-sAFe to be a species-specific constant (g/MJ of intercepted PAR), which is reduced through dimensionless modifiers to take into account water stresses, nutritional stresses and possibly a temperature effect.

Should respiration processes be explicit in the tree model?

There was considerable discussion about whether respiration should be explicitly computed in the model. The model is meant to run under a variety of climate types. The contribution of respiration fluxes to total C budget is considerable (as much as half of the integrated daily net foliage carbon gain can be lost to respiration by the whole plant) and largely influenced by temperature. Therefore it seemed justified to consider including respiration in the model (as done in Hypar).

However as a Radiation Use Efficiency approach to C-uptake modelling implicitly includes the growth and maintenance respiration costs by relating intercepted radiation with net Carbon accumulation no explicit respiration modelling seemed warranted. However, it should be stressed that doing so, NSC accounting is done on a 'Structural carbon unit' base as no conversion cost from NSC to SC is considered.

Root phenology

Root and shoot growth are highly coordinated and patterns of root vs. shoot growth appear to vary among species. Generally fine root production is halted during winter, resumes with leaf expansion in spring and stops with leaf fall (Pregitzer, King et al. 2000; Cote, Belanger et al. 2003).

The failure to provide a micro-climate module

We may conclude that we are not able to provide a satisfactory air humidity interaction module. This should not be taken as a failure of the project: the task was difficult, and all previous modelling approaches of agroforestry systems failed to solve the issue correctly (the Hy-Par solution was theoretically consistent, but proved not applicable as it required computing times an order of magnitude above the rest of the model). If Hi-sAFe does not take into account this aspect of the microclimate interaction, it will still be very powerful with all the other interaction aspects incorporated. We cannot exclude that this microclimate issue may be solved after the end of the SAFE project.

Future Improvements and potential issues

Suggested future improvements to the C allocation

- Temperature effects

Calibrating impact of temperature on RUE and partitioning to reserve pool (reflecting change in rate of C incorporation into functional or structural C) and remobilisation rate will be uneasy though it may be important in explaining between-site and between-year variations in tree growth.

Both the rate of conversion of NSC to new tissues and the RUE are temperature dependent. The latter may be roughly estimated from a bibliographic search. The former (much like the respiration parameters) is more elusive but should have marginal effects on overall growth and may be neglected in first approximation.

From (Jones 1993) the following shape of temperature response may be used (where k is the reduction in the rate under concern at a given temperature)

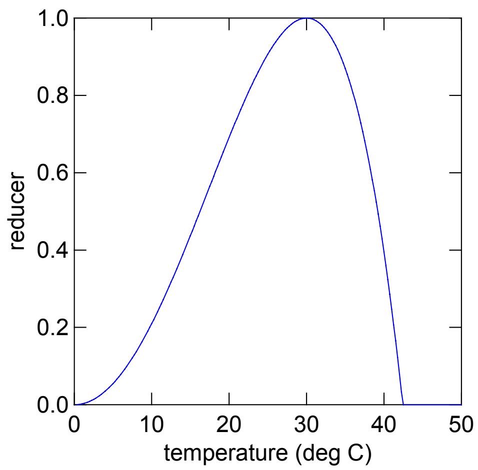


Figure 108: Proposed temperature response curve

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K(t) = max((2*(t+Tmin)^2 *(Tmax+Tmin)^2 -(t+Tmin)^4)/(Tmax+Tmin)^4,0)
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(e.g. Tmin=0, Tmax=30)

- Branch volume calculations – Pipe model application

Allometric relations between leaf surface (and crown volume) and branch biomass may be derived by application of the pipe model theory. The next version may include this functional constraint in the model, allowing parameterising this allocation fraction to woody biomass according to the type of wood (diffuse porous, semi-diffuse or ring porous).

- Long term non-stomata water stress

We may also need to introduce a water stress index to take into account the nonstomatal limitation of photosynthesis during drought. According to Kozlowski and Pallardy (Kozlowski and Pallardy 1996), the relative importance of stomatal and non-stomatal inhibition of photosynthesis during drought varies with the drought tolerance of the species, increasing in xeric plants under drought but decreasing in mesic plants. Non-stomatal inhibition of photosynthesis is considered by those authors to be especially important in the long term and under severe water deficit. Some species show after-effects of water deficits on photosynthesis that may last for weeks or months after irrigation resumes. This calls for the introduction of a water stress index which could be used to further reduce photosynthesis under severe drought, and from which recovery could be made time dependent.

Such an index could be based on accumulated days of water deficit above a certain threshold. An explicit time recovery function could be introduced (based on a daily recovery fraction, for example as done in Noordwijk and Lusiana (2000).

Potential issues

Even though we have tried to keep the number of parameters to a minimum some calibration problems will undoubtedly arise.

The root:shoot equilibrium assumption combined with fixed allometric ratios within above ground and belowground compartments may prove awkward. If there is solid evidence in support of the functional equilibrium assumption, it seems that this is best expressed when dissociating foraging organs from structural organs e.g. stem and branch fraction are affected differently by limiting light availability (Korner 1994; Poorter and Nagel 2000).

Linking phenology to extreme events e.g. early frost impact on N remobilisation and leaf shedding, leaf fall triggered by water stress (a common reaction in black walnut and poplar according to (Kozlowski and Pallardy 1996)).

N balance is based on average values per compartment. However, nitrogen content in woody tree parts decreases with age and therefore the N balance as it is computed at present is biased.

WP5: Modelling below-ground tree-crop interactions

About the characterization of the root systems of trees in silvoarable fields

The SAFE project was innovative in being able to manage non-destructive soil coring to a 3 m depth to document the rooting patterns of various tree species grown either as pure stands, or in mixture with crops. Appropriate calibration curves were obtained for converting the root counts in L_{rv}. The observed root systems of most trees were very patchy at the 10 cm scale. Deep and unusual vertical profiles were documented: evidence for uniform, decreasing, or increasing root distribution patterns with depth or distance was found. Such variability was interpreted as the result of a high degree of plasticity to sense and adapt to heterogeneous soil conditions that resulted mainly from crop competition.

The root system of walnuts was the most sensitive to crop competition, and developed towards deeper soil layers or extended laterally below the crop-rooting zone. The poplar root system was less distorted, but was influenced by sandy or gravel layers. The need for a model that could correctly predict the root growth of a perennial plant in a 3D heterogeneous soil environment was underlined. Existing models assume a fixed shape of the rooted volume and they predict L_{rv} as a function of depth and distance to the tree. In our conditions, L_{rv} could not be predicted as a function of depth and distance: significantly different profiles were observed at the same distance on the tree row and in the cropped alley. A 3D model of root dynamics is therefore required. Natural environments are indeed always patchy rather than uniform (Hutchings and John, 2004), and such a model could have a large spectrum of use.

The ability of walnut and poplar root systems to adapt to the wheat competition by distorting their root architecture appears to be an essential feature in order to achieve efficient agroforestry systems with a high degree of complementarities between trees and crops (Cannell et al., 1996). While minimising competition, deep tree root systems provide environmental benefits: a 'safety-net' service by capturing nutrients such as nitrates leached from the top soil and a capture of nutrients from deep soil alteration, which is often referred to as a 'nutrient-pumping' effect (Cannel et al., 1996; van Noordwijk et al., 1996). Most of the alluvial soils in Europe are intensively cultivated, and both effects are welcome to avoid the pollution of alluvial water tables.

About novel approaches to modelling the dynamics of tree root systems in heterogeneous soils

There have been various propositions to model dynamic fine root dry matter (FRDM) allocation to soil layers/cells for root growth. The fraction of FRDM input for each layer is usually calculated as a function of existing root length density, distance between each layer and the plant base, or local soil conditions. However, taking into account both the effect of existing root length density and soil water condition in terms of local water uptake is a novel approach. Pertaining to the modelling of coarse root dry matter (CRDM) allocation process, Mobbs et al (1999) and van Noordwijk and Lusiana (2000) consider the effect of distance between each layer and the plant base. It is assumed that fractions of CRDM input decrease exponentially with lateral and vertical distance from the plant base. As far as we are aware, only these two models simulate a coarse root system growth. It is pertinent to mention here that a more physical–based and dynamic process has been proposed but an adequate voxel dimension should be imposed when we simulate a coarse root growth with the root model. For example, when simulating root growth of perennial trees for a number of years, we have to use voxels which are relatively large; otherwise, a tiny voxel beneath the plant base might be modelled to contain more than volume-filling coarse root biomass. From the modelling side, a possible way to overcome this problem is to impose a threshold of maximum coarse root biomass density; but we see no urgency to apply this strategy in the current model version.

Some models use a geotropism factor and define it as a preference to perform a horizontal rather than vertical colonisation (Acock and Pachepsky, 1996). Some others assume that a downward root extension does not have a deterministic vertical component and may or may not occur depending on the state of soil variables in the upper layers. In the root model, it has been described that we include two parameters describing preferential growth directions. The purpose was to allow us to test various hypotheses of root system growth behaviour. Indeed, until now, whether a root system has a preferential growth direction or not, is still a debatable issue. However, it has been claimed in the literature (e.g. Huxley, 1999; van Noordwijk et al., 1996) that the observed plant root distributions are the result of a 'genotype x environment interaction'. This indicates that a preferential growth orientation presumably exists. Van Noordwijk et al (1996) claimed that limited evidence of the role of genotype difference in plant root distribution might be due to the lack of suitable observation methods rather than the genotype variation itself. In the subsequent paper, we would describe a proposition to observe the role of genotype difference in root distribution through a pot experiment.

The existing root models also have different hypotheses about a saturation threshold of root length density (Acock and Pachepsky, 1996). Some authors consider that a maximum root concentration exists and growth ceases when such limit is achieved. Other authors assume that root concentration does not limit root growth. Pierret et al. (2005) suggest that fine root lengths may in fact be larger than usually assumed as standard root washing procedures lead to losses of fine roots.

In an optimal condition where soil resource availability is not limited, we assumed that root growth rate is not limited by root concentration. In a heterogeneous condition, root growth strongly depends on the local soil water conditions. Soil water availability in voxels with high root length densities may be rapidly depleted and if fractions of FRDM input are calculated proportional to local water uptakes (i.e. $\varphi > 0$), this would also rapidly reduce local root growth rate. In the current model version, we only take into account the effect of local soil water condition in the allocation process of root dry matter input. However, the model can be surely developed to include the effect of other important soil factors.

Before the SAFE project, no model simulated an upward extension of root system. Such a root system growth behaviour has been reported in the literature (e.g. Huxley, 1999; Singh et al., 1989; Von Carlowitz and Wolf, 1991). Indeed, specifically in the agroforestry systems, it is important to simulate a negative-geotropism growth of tree root system. The ability of a tree root system to grow upward determines the effective time span of the application of some root management options such as the installation of root barriers or root pruning at a specified distance from the stem, aimed at reducing tree root lengths in the main crop root zone. Basically, such practice is less efficient if tree roots can rapidly grow upward from beneath the barrier so the tree-crop interaction will start again (Schroth, 1999). From the modelling side, the distance between voxels situated further than root barrier position to the plant base may depend on the depth of the installed root barrier. Therefore, the calculation of SRI-voxel distance is not simple. In the root model, it has been described that we have anticipated this by deriving the way of calculating SRI-voxel distance from the rules used to establish a coarse root topology.

About container experiments to validate the root voxel automata

Container experiments contributed to our knowledge about the growth behaviour of a tree root system in homogeneous and heterogeneous soil resource conditions. Indeed, most existing studies concerned themselves with the root system of non-woody plants. The response of a root system to soil resource heterogeneity was verified by comparing and testing statistically root distribution patterns observed in uniform and heterogeneous soil conditions. This is a novel approach since most (if not all) existing studies merely compared root densities observed in a 'poor' and 'rich' patch.

Walnut root system responded rapidly to soil resource heterogeneity. This produced a distortion compared to the reference root distribution observed in a homogeneous condition. We rejected the null hypothesis that the difference between root distribution patterns observed in a homogeneous and heterogeneous condition is due to a natural variation. Intriguingly, walnut root system went upward with or without a vertical gradient of nutrient quality. Nonetheless, more roots were found in the upper layers with a higher nutrient quality. More results are expected for poplar trees and oaks from experiments currently performed at the University of Extremadura.

The root density data obtained with the pot experiment would be used in the validation of the root voxel automata model that simulates the growth of a plant root system in a 3D heterogeneous soil condition. A coupling of the root model with process-based soil models and soil water and nutrient uptake models is being prepared. The observed and the calculated root densities would be compared whilst verifying the dynamic of soil water and nutrient content over time.

About the novel approach to water and nitrogen competition introduced in Hi-sAFe

The new algorithms that we propose for predicting water and nutrient uptake on the basis of root architecture have the following properties:

1. consistency between the description at the level of interacting root systems and the known transport processes at individual root level as they relate to root structural (diameter, root-soil contact via root hairs, mycorrhiza) and physiological (selectivity, regulation of uptake) characteristics,
2. applicable in situations where external supply limits uptake and in situations where down-regulation of uptake processes reduces net uptake in accordance with 'plant demand',
3. response to the predicted distribution of roots over the profile, that may change on a daily basis, partly in response to the uptake,
4. potential symmetry in the sense that predicted uptake for all components will be equal if the parameters are the same (i.e. there is no hardwiring of different treatments for different groups of plants),
5. applicability to any number of soil volume elements and plants,
6. response to the level of resources and its distribution over the soil profile,
7. response to conditions that affect the overall rate of transport through soil, especially the soil water content in its influence on diffusion of nutrients as well as hydraulic conductivity for water,
8. flexible response of each organisms adjusting the rate of uptake by each part of the root system to the overall level of supply – and through this mechanism potentially complex and non-linear or non-monotone responses of any individual plant to changes in supply in any particular part of the soil profile,

In the ***long term*** (seasons, years) ***water*** availability for plant growth is largely determined by the annual (seasonal) rainfall, the frequency and intensity of rain events. The latter is to be understood relative to the short term absorption and buffer capacity of the soil and the radiation and energy balance that drive evapotranspiration -- with relatively small differences between plants and vegetation types beyond the concept of 'effective rooting depth'. If we are more interested in the growth of specific plants (e.g. crops rather than weeds or trees) or plant organs (yield formation) rather than total water use, however, a more detailed understanding of the underlying short and medium term processes is needed (Smith et al., 2004). The issues to be resolved in modelling water uptake for mixed vegetation, such as found in agroforestry, revolve around the 1) ***short-term*** (day, hour or minute) reconciliation of the plant (any of the trees or crops in the simulation) scale processes of 'demand' (and its reduction due to stomata closure during water stress) and voxel (unit soil volume) level determinants of 'supply' such as local root length density, soil water content and diffusivity, and 2) the ***medium-term*** response of the development of the respective root systems in response to plant level resource allocation and local soil conditions.

Similarly, for nutrients the total stock of nutrients at the start of a growing season plus the net effects of immobilization and mineralization during the growing season govern total uptake by the vegetation, regardless of the details of the daily uptake pattern – except under the high rainfall and leaching conditions mentioned before where 'synchrony' of supply and demand at a weekly timescale may matter (van Noordwijk and Cadisch, 2002). In situations where multiple root systems share access to the same volume of soil, however, daily uptake rates matter.

We therefore presented algorithms for the short-term responses to water and nutrients, and the medium term responses in growing and interacting root systems. In principle, these models apply equally to trees and crops, grasses or weeds and can be applied to any number of voxels (regardless of their spatial position in 1D, 2D or 3Dimensional representations). De Willigen et al. (2000) discussed how models at the level of root systems in a volume of soil can use equations that were primarily derived for the concentration profiles around individual roots, using a steady-rate solution to the equations describing diffusion in a cylindrical coordinate system. The algorithms for uptake discussed here extend the approach by De Willigen et al. (2000) to multiple plants sharing access to the same volume of soil.

This approach is a major step forward in the modelling of plant interactions, and could find applicability not only in agroforestry modelling, but also in many other plant communities (orchards, natural vegetation, mixed cropping of annual plants, etc..)

WP6: Integration of biophysical models of tree-crop systems

About the detailed Hi-sAFe model.

This model is not yet validated at all. Efforts should now be concentrated on validating the model, and producing the final documentation of the model. A founding paper for the model is now in preparation, and will include a discussion on the limits of the current model and its applicability.

However, Hi-sAFe has already proved useful for exploring some patterns of biophysical processes in a silvoarable plot. This was clear for providing Kt values for the Yield-sAFe simple model. It also perfectly predicted patterns of crop yields in the experimental plots. Much more work is now needed to explore all the possibilities of this model.

About the simple Yield-sAFe model.

Compared to existing biophysical agroforestry models (e.g. Mobbs *et al.*, 1999; van Noordwijk & Lusiana, 2000), the Yield-sAFe model proposed here is very simple. In support of this approach the following arguments can be given: a simpler model is often easier to parameterise and may produce more robust results; it is less work to build; and it is easier to explain and understand. This results in a shorter learning curve when the model is used in up-scaling studies, and this may favour its inclusion in higher-level studies, e.g. explorations of land use. Of course, a simple model may be under parameterised and unable to represent real situations using the few equations that were chosen as essential. We have not encountered data sets in which this is the case. This model was built with the philosophy that it could be extended when simulation of realistic situations required further detailing. This might be necessary, for instance, when agroforestry at different nutrient levels and nutrient limitation is simulated. However, the current set of parameters can represent many realistic situations without expanding the set of variables or equations, by simply adjusting values of parameters to specific conditions. For instance, the effect of nutrient limitation on growth rates can be captured in the value of the light efficiencies ε_c and ε_t. Our philosophy with Yield-sAFe is that the model should keep its present simple structure until it is unable to represent real situations due to lack of structure or degrees of freedom. In this sense we follow Peters' (1991) plea for simple, useful and predictive models in ecology.

In the current model version, the leaf area of the trees was assumed to spread out over the whole of the agroforested area, without explicitly accounting for clumping of tree leaf area in the tree crowns. Reasoning from existing literature on light distribution in crops (e.g. Goudriaan & van Laar, 1994) indicates that the extinction coefficient might change at low tree densities, as the canopy is more heterogeneous. Initial use of the model has suggested that it may be necessary to modify the light extinction coefficient in such situations. An alternative approach is to use detailed models on light distribution (e.g. Pronk et al., 2002) to estimate parameters for Yield-sAFe. Likewise, detailed models for root distribution and activity in agroforestry might be used to parameterise Yield-sAFe functions for water capture by crops and trees.

During the same project an elaborate model was built for agroforestry system performance, based on details of resource use processes in agroforestry systems. This model is called Hi-sAFe to indicate the high level of process detail contained in it. The applications of Hi-sAFe are more geared towards shorter time scales, and detailed questions regarding spatial configuration in agroforestry designs, whereas Yield-sAFe focuses on issues of production and resource use in the longer term. For both models, parameter estimation is an issue. Yield-sAFe requires long-term data on tree growth for parameter estimation and validation of model results. Such data are not yet available for agroforestry systems, but they may be come available in the future as the experiments that have been planted in the 1990s mature and accumulate timber. It is quite important that minimal data are collected in such experiments to allow estimation of parameters of the model proposed here. In this respect it would be very helpful if records were taken of leaf area index and/or soil cover by the crop as well as the trees at different times during the season. Moreover, allometric relationships for widely spaced trees are needed. At the present time, for studies on *future* land use, there is a pressing need for models that can be built with the limited information on agroforestry that is now available, as very few agroforestry systems have yet been planted in Europe. A simple model like Yield-sAFe can play a pivotal role in land use explorations by predicting production in agroforestry systems by integrating the vast information on forestry and arable systems, based on well proven eco-physiological principles, that – as this study shows – hold up as well in agroforestry as in agriculture and forestry.

About the sensitivity analysis of the silvoarable systems

The sensitivity of the forestry, arable and silvoarable systems to the discount rate, tree and crop production, grants, and production costs was examined using the example of Vézénobres, at both 113 trees ha^{-1} and 50 trees ha^{-1}. The baseline scenario was a full crop rotation and the 2005 grant scenario 2.2 at a discount rate of 4%; this was the most optimistic scenario for silvoarable agroforestry.

The net present value of the forestry, arable and silvoarable systems showed different sensitivities to the discount rate. The forestry and silvoarable systems at Vézénobres, where the value of the trees is only realised at the end of a 15-year rotation, were more sensitive to the discount rate than the arable system where a return is obtained each year (Figure 109).

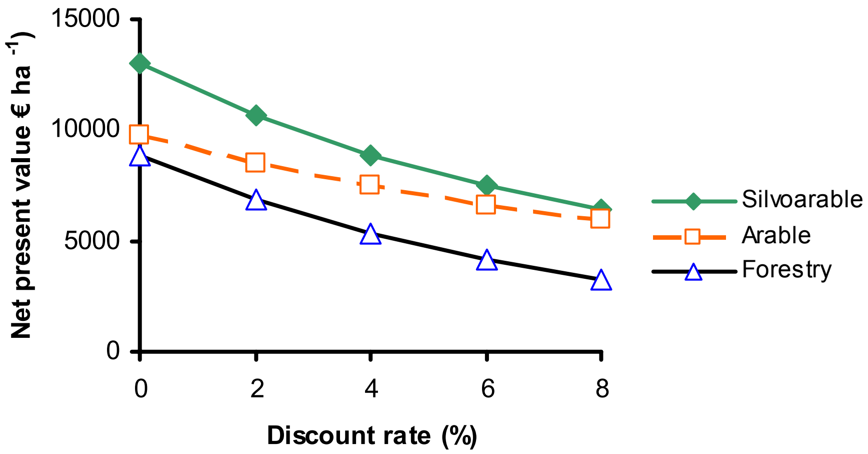


Figure 109 Sensitivity to the discount rate of the net present value of the arable, forestry and silvoarable (113 trees ha^{-1}) system at Vézénobres assuming the 2005 grant scenario 2.2

An analysis of the effect of changes in tree and crop revenue for a density of 113 trees ha^{-1}, showed that the sensitivity of the silvoarable system to tree and crop revenue were additive (Figure 110 a, b and c). The system, assuming constant cropping, was more sensitive to changes in crop value than tree value. With a 100% increase in tree and crop values, the increase (5310 € ha^{-1}) in the *NPV* (at 4% discount rate) from the increase in tree value was 75% of that (7050 € ha^{-1}) from the increase in crop value (Figure 110 a and b). In terms of a 100% decrease in tree and crop values, the decrease (-3630 € ha^{-1}) in the *NPV* from the decrease in the tree value was about half of that (-7052 € ha^{-1}) for the decrease in crop value. The greater sensitivity to crop rather than tree value is primarily a result of the greater production costs of the crop component. However in practice if cropping was unprofitable, the farmer could stop growing a crop and thereby reduce costs.

The sensitivity of the timber revenue calculations for the 50-tree ha^{-1} silvoarable system was also calculated because of concerns regarding the lack of field data to validate the outputs of the model at such densities. At a tree density of 113 trees ha^{-1}, a 100% increase in tree revenue was predicted to increase the *NPV* (at a 4% discount rate) by 5310 € ha^{-1} or 60% (Figure 110a). In contrast for a stand of 50 trees ha^{-1}, a 100% increase in tree revenue was predicted to increase the *NPV* (at a 4% discount rate) by only 3010 € ha^{-1} or 34% (Figure 110a). Hence the profitability of the 50-tree ha^{-1}

silvoarable stand is substantially less sensitive to the predicted tree value or production than a stand with 113-tree ha^{-1} or the forestry stand.

At Vézénobres, the net present value of the silvoarable and the arable system was also more sensitive to changes in the levels of grants than the forestry system (data not shown). Overall the forestry, arable and silvoarable systems were equally relatively insensitive to the labour input. However, as indicated in the above analysis, the arable and the silvoarable systems were more sensitive to costs than the forestry system.

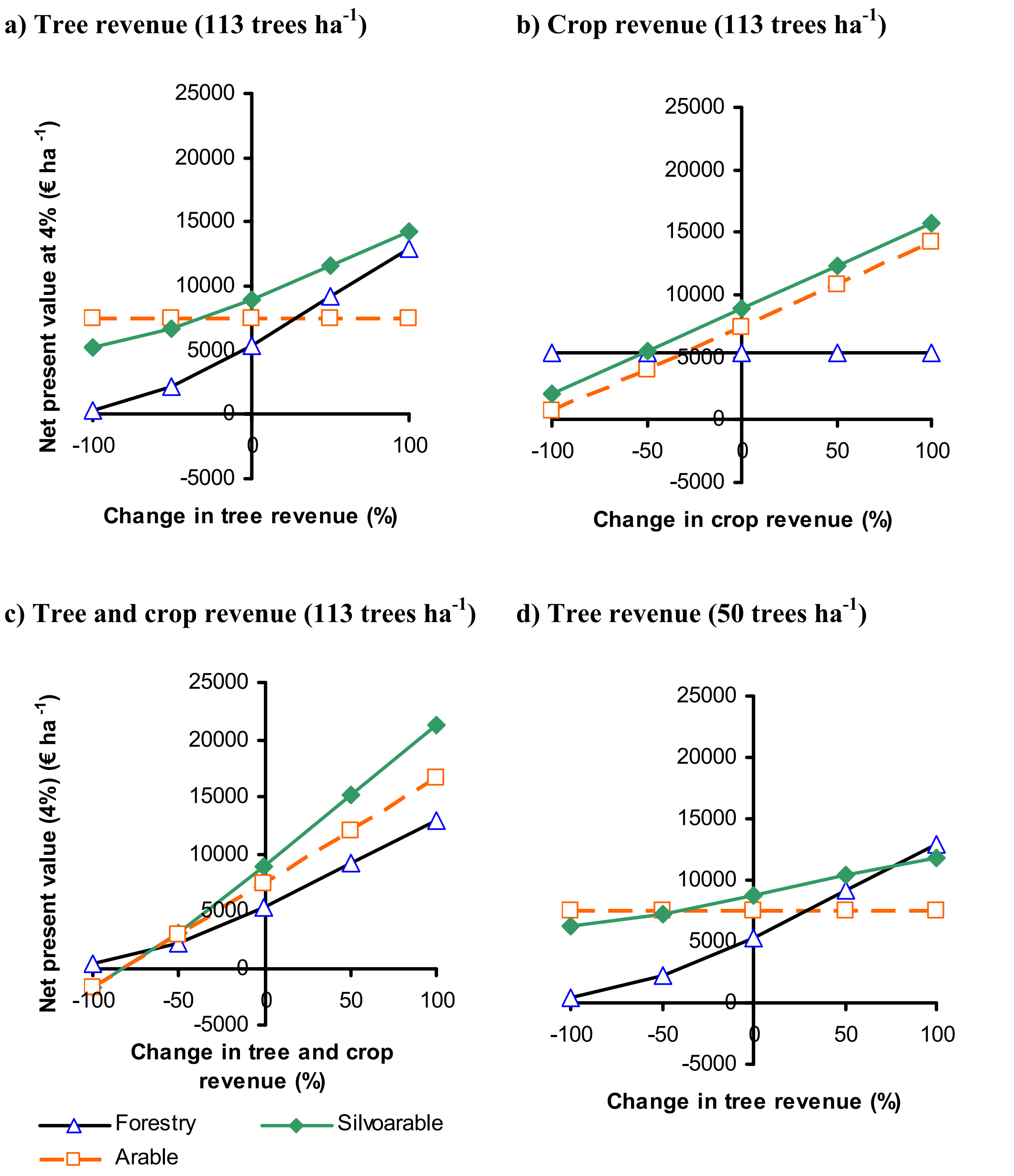


Figure 110: Sensitivity to a) tree production, b) crop production and c) combined tree and crop production of the net present value (at 4% discount rate) of the arable, forestry and silvoarable system at Vézénobres at 113 trees ha^{-1}, and d) tree production at 50 trees ha^{-1}

About the use of an LER-based-generator model to determine the optimum silvoarable system for high potential locations in France

Evolution of the cash flow at the plot scale

The cash flow will depend of the crop yield evolution and the LER level we have selected and the final density. Figure 111 illustrates the cash evolution for two different densities and a medium LER level.

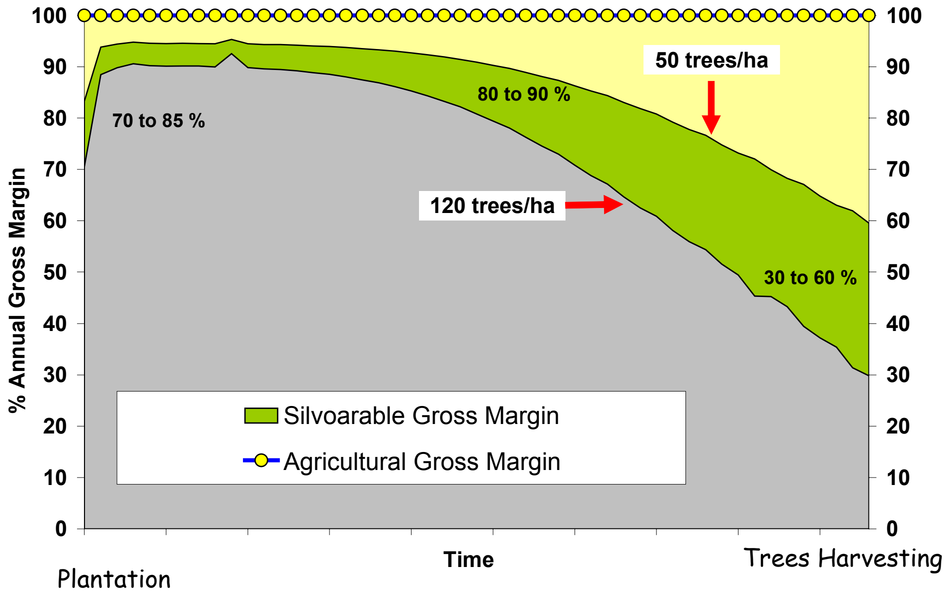


Figure 111: Evolution of the annual cash flow for the most probable scenario with wild cherry (LER=1.07 for a density of 50 trees/ha and 1.15 for a density of 120 trees).

Our hypothesis is very conservative (in the INRA experimental plots, LER values of 1.3 were observed with an initial density of 120 trees/ha). We notice nonetheless that at half of the rotation, the gross margin still represents 80 to 90 % of the agricultural gross margin. We assumed that the crop payment area was reduced progressively by the tree area. If the silvoarable plot was totally eligible for crop payments (including the tree row), the impact on the cash flow would be more reasonable, above all in some regions with poor crop yields and where the crop payment is essential in the gross margin calculation (Franche Comté for example).

Influence of the CAP payment policy

We compare here two options: payments are due on the whole plot area (Suggestion of the SAFE consortium) or only on the actual intercrop area (the case in France in 2005).

The impact of giving the grant for the whole plot on profitability is not that important. In all our simulations, the profitability increases by 3% in the best option for agroforestry. The impact is more at a cash flow level, when the crop gross margin is low. That is typically the case for farms where:

- The crop component is lower than the payment component in the gross margin calculation (Mediterranean area or farm with high cost of production)
- The yield is decreasing faster in the silvoarable scenario (high density of plantation or strong impact of the trees on the crop RA) (see Figure 112)

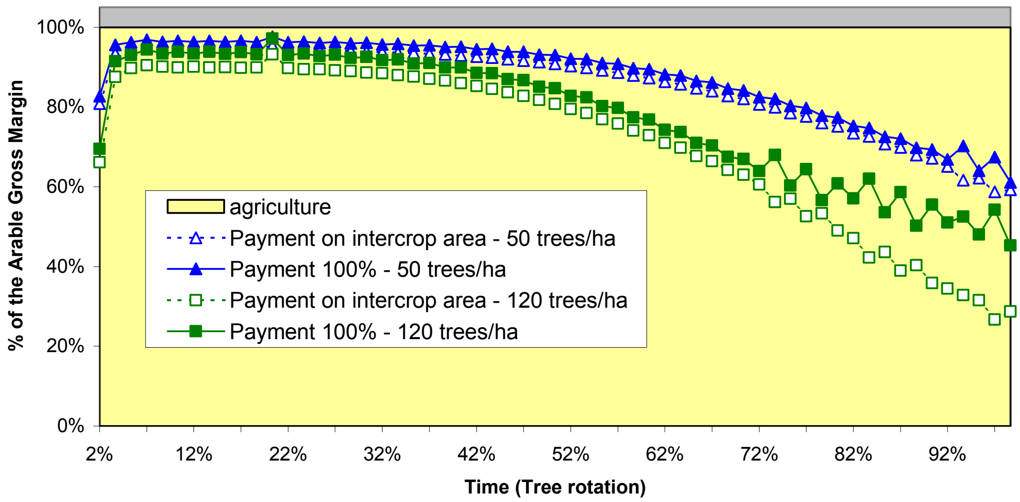
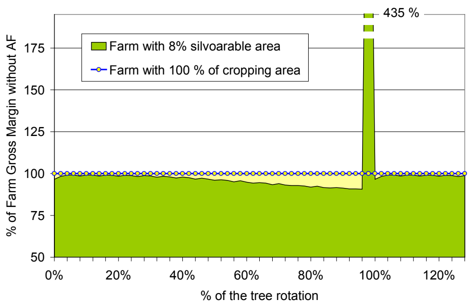


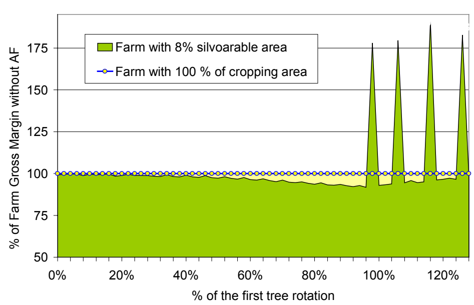
Figure 112: Influence of the different CAP payment policies in agroforestry on the annual cash flow evolution.

Evolution of the cash flow at the farm scale

At the farm scale, one of the first questions of the farmer is about the size of the area to plant. How large the area to plant? In several plots or in a single plot? All at the same time or progressively? According to the strategy of the farmer, a large range of scenarios may be considered. The choice will depend ton the cash flow constraints, on the ability to self-finance the investment costs, and above all on the intention to reduce progressively his crop activity. The labour availability is also a key aspect to decide which area to plant. According to our simulation and experimental experience, we often recommend not planting more than 10 % of the cropping area. In that case, the impact on the farm gross margin is less than 3 % in average on the first half of the tree rotation. A gradual plantation will mitigate the reduction on the annual cash flow (see Figure 113).



a. Case of a single plantation



b. Case of a gradual plantation

Figure 113: Cash flow series when the farmer plants 8 % of his cropping area (50/50 Walnut/Wild cherry). In the gradual plantation, 2 % of the farm is planted every 5 years during 20 years.

A gradual plantation will also allow a regular distribution of the timber income in the time from the moment where the owner begins to harvest the first mature trees (case b). In our example he can harvest the trees every 5 years and the farm gross margin increases by 15 %. According to the importance of the plantation and of the species he planted, a farmer could increase his long-term farm income between 10 to 100%.

Profitability of a silvoarable investment

The impact of the quality of the pruning regime is essential on the profitability (Figure 114). Reducing the knotty core of the timber log by an appropriate intensive pruning management reduces the duration of the tree rotation.

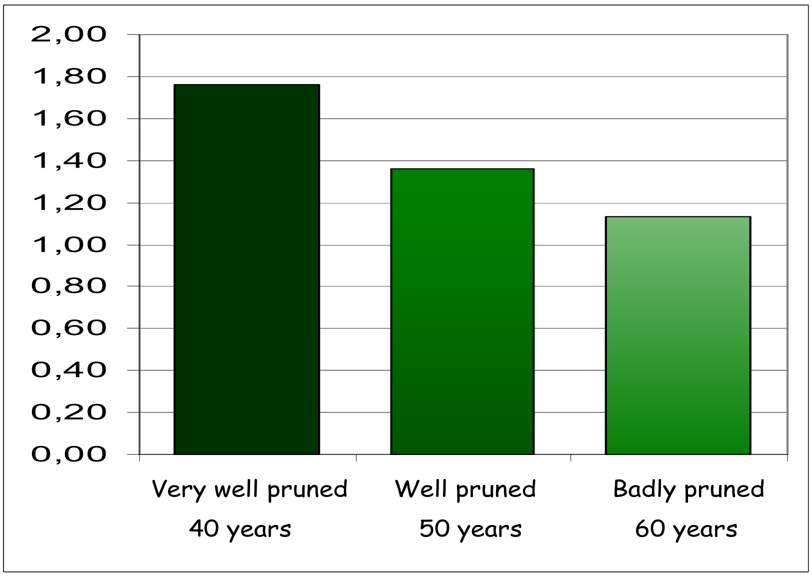


Figure 114: Influence of the maintenance quality on the profitability.

A delay in the pruning management can delay the harvest date by 10 or 20 years, above all for some sensitive species such as hybrid walnut. In this example, a delay of 20 years means a reduction of 60% of the profitability in comparison with the agricultural profitability.

Influence of the tree growth acceleration in agroforestry on the Agricultural Value

The value of the Tree Growth Acceleration has a strong impact on the profitability of the silvoarable scenarios. This impact is stronger for the scenario with higher densities of plantation. In the following figure, we noticed that the scenario with a density of 120 ha react much quicker than a scenario with 50 trees.

In our simulations, we used a conservative TGA of 1,20. At the Jollet farm, the agricultural value would have been increased by 10 to 15 % (see Figure 115).

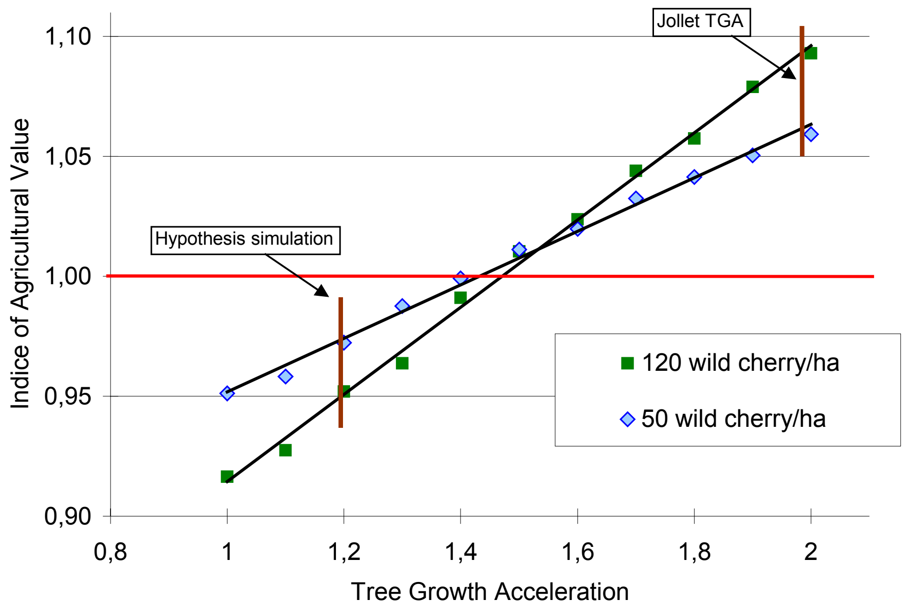


Figure 115: Influence of the acceleration of the growth of trees in silvoarable plots on the Agricultural Value of the system for the Jollet farm

What density to plant to maximize profitability?

A consistent question by farmers is the density of trees to plant. Farmers often prefer to maintain a profitable crop yield during the whole tree rotation. Some prefer to plant more trees with the aim to decrease the agricultural activity, and don't mind if the crop has to be suppressed after some years.

For each species, Walnut, Wild cherry and Poplar, according to our production hypothesis, we simulated the impact of the density to the LER but also to the Agricultural Value (see Figure 116).

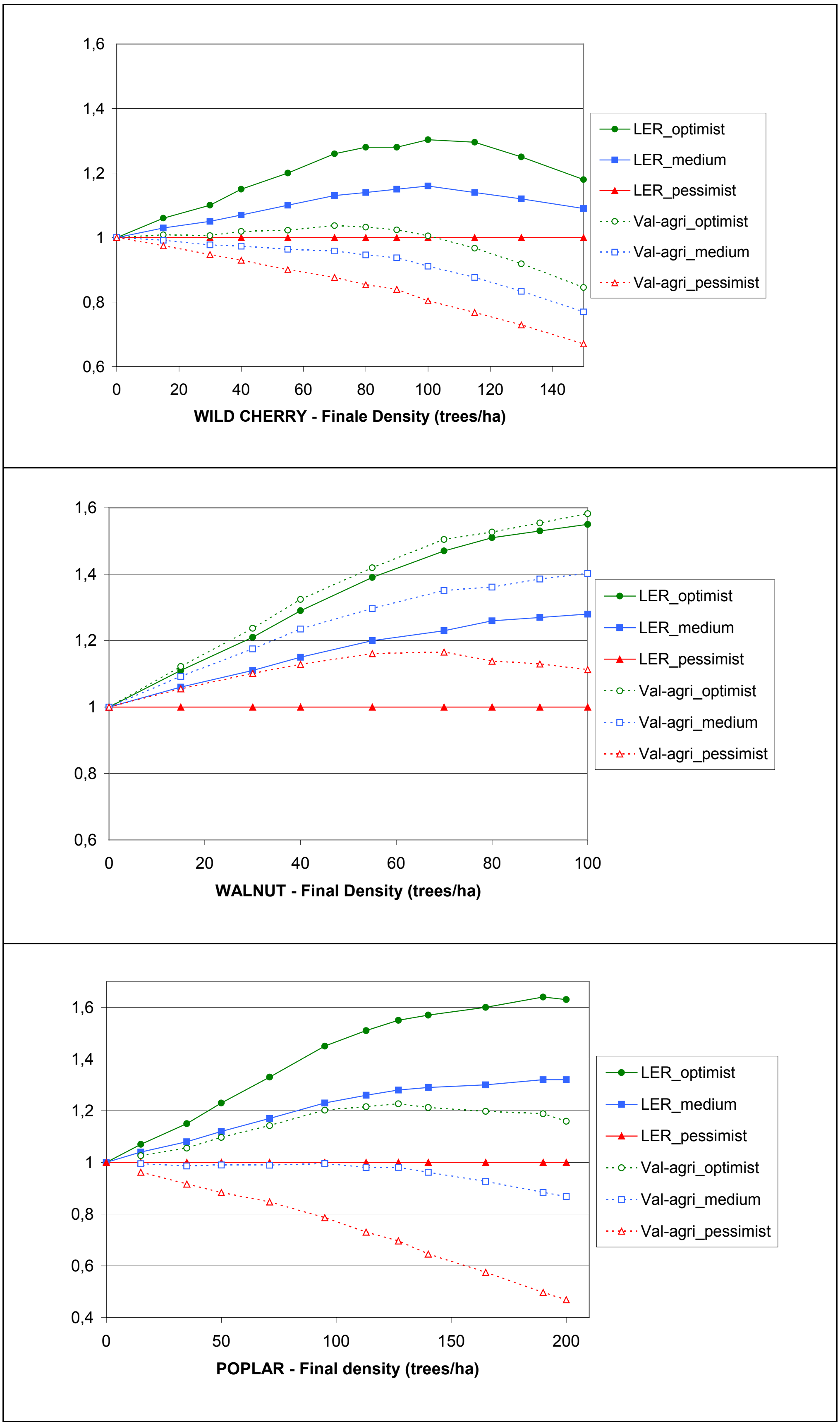


Figure 116: Influence of tree final density on the LER value and the Agricultural value for wild cherry, walnut and poplar silvoarable stands.

For all tree species, the density to maximize the LER is higher than the density to maximize the Agricultural Value. For the species with a poor Tree RA (Walnut and wild cherry), the range of density is similar (see Table 26). The best density would vary between 80 to 120 trees/ha to get the highest LER, while the farmer will get the best profitability with a density included between 60 and 90 trees/ha. Of course, with a higher TGA, this range would increase.

Result	Wild Cherry	Walnut	Poplar
LER	80 - 120	80 - 120	130 - 200
Agricultural Value	60 - 90	60 - 90	100 - 130

Table 31: Range of density to get the optimum LER and Agricultural Value results for each specie (trees/ha – final density), assuming a conservative TGA=1.2.

For the poplar, the optimum densities are higher than for the other 2 species. This result is due to the fact that the biomass produced by the silvoarable poplar is similar to the biomass produced by poplar in forestry (no thinning in both stands).

What could influence these results? The growth performance of silvoarable trees would. If the TGA were higher than 1.2, the optimum densities would be higher. The policy schedule and the price level of the crop and tree component will then be the most important parameters. In the case of the walnut, the choice of a density of 75 trees/ha is a wise option.

Comparing a silvoarable scenario with a forestry scenario

We assessed also the scenario where the farmer hesitates between a forestry investment and a silvoarable investment from a profitability point of view (Figure 117).

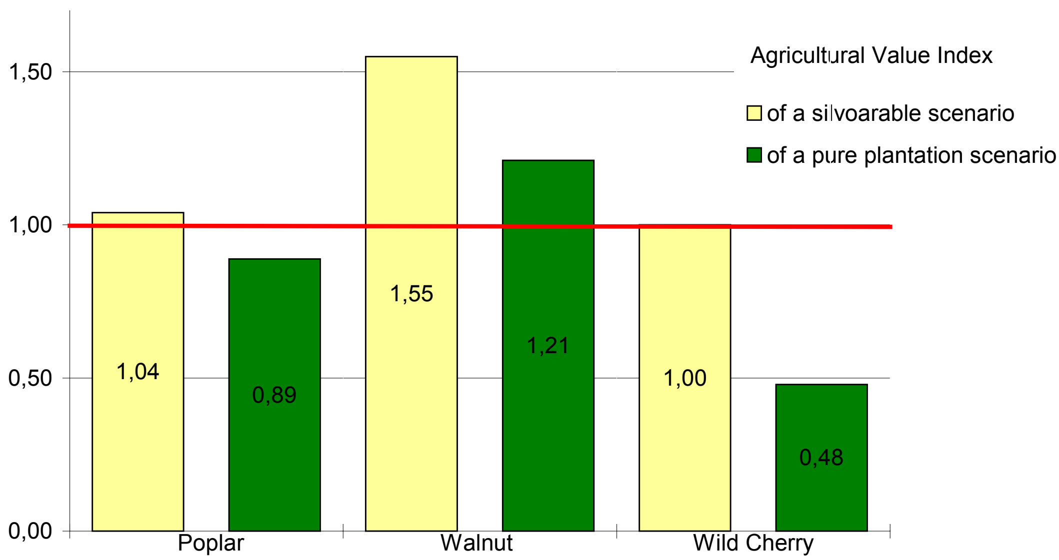


Figure 117: Comparison of the profitability of the silvoarable and afforestation scenario with the agricultural scenario. Silvoarable plantation of 120 wild cherry per ha with a LER of 1,15.

In this example, we assumed a probable LER of 1.15 in the silvoarable option. In almost all our simulations, the silvoarable options are more profitable than the forestry option. The forestry option may be more profitable in the case where the crop margin is very poor, above all if it is possible to plant some valuable species, such as walnut for example.

It is also interesting to notice that for poplar, the silvoarable option could be a possibility to stimulate the poplar market. In France, the poplar area is currently decreasing because of the fall in price of the timber (now less than €45/m3). Agroforestry could therefore be a possible strategy to reduce the market risks.

Property holdings evaluation in agroforestry

According to his age, a landowner who plants trees will not necessarily benefit from the tree harvest. However, as a farmer told us, a farmer has three possibilities for income: the sale of his products, the stock variation and the possibility of making a capital gain. In this last option, a silvoarable plot is a capital, which could be realised if necessary (inheritance, expropriation, property sale). The land evaluation in agroforestry is the combination of the agricultural land evaluation and the future value of the trees (Figure 118).

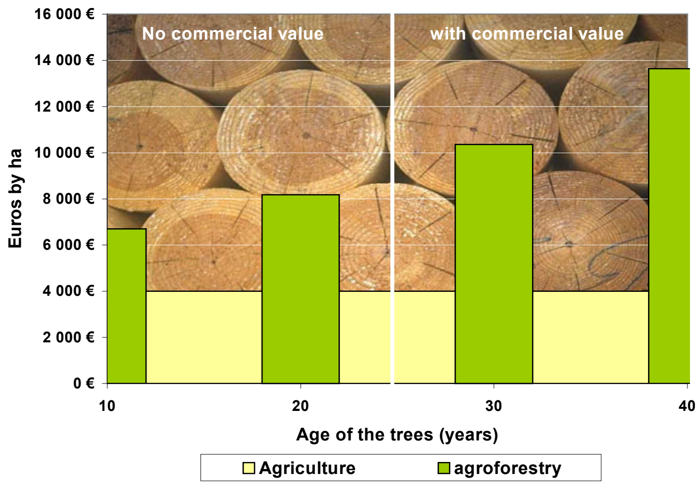


Figure 118: Evolution of the monetary value of the silvoarable land with the age of the trees. In agroforestry, this value is the sum of the agricultural value plus the timber future value. If the young trees could have a future value, for example when 10 year old, they don't necessary have a commercial value in the sense that the landowner cannot expect some income if he cut them.

In this example of a wild cherry plantation, the capital evaluation may represent between twice and four time the agricultural land value according to the age of the trees. In the case of a walnut plantation, it may represent up to 7 times this value 10 years before tree harvesting.

Figure 119: A silvoarable plot with 30-year-old wild cherry trees. The value of the standing volume is estimated to €4000/ha, which matches the value of the land. But the future value of this plantation is much higher and will exceed €10000/ha.

Main conclusions

To invest in agroforestry represents a light investment in money and labour compared with most new systems of farm diversification. In our simulations, the profitability increases by 10 to 50 % with walnut trees, and -5 to +15 % with wild cherry and poplar, as compared with the agricultural scenario.

A progressive calendar of tree plantation on small surfaces is a good option for the farmer (reduced impact on labour needs and cash flow). When 10 % of the farm is planted, the reduction in the farm gross margin never exceeds 3 % until the first tree harvest. The farm income will increase by more than 15% (with both walnut and wild cherry trees in this example). The gross margin of the farm could double in the long term if the farmer plants his whole cropping area progressively. But such a scheme has a strong impact on the cash flow until the first tree harvest and requires a high labour input.

If the best bio-physical option is to plant between 80 to 120 trees per hectare (130 to 200 for the poplars), the best economical option is to plant a lower density around 60 to 90 trees per hectare (100 to 130 for poplar). This means a distance between the trees lines varying between 24 to 36 m.

None of our simulations have taken into account the environmental benefits, such as carbon sequestration, the lowering of nitrogen pollution, increases in biodiversity. These aspects could be calculated and their economic equivalents could be added to the whole profitability of the silvoarable systems in line with current theory on ecosystem services.

WP8: Up-scaling to the farm and region scale

About target regions for silvoarable systems

Silvoarable Agroforestry (SAF) could mitigate negative environmental impacts of agricultural land use in Europe. In a geographic information system (GIS) data on soil, climate, topography, and land cover were integrated 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. The environmental benefits could justify the support of SAF by subsidies. Target regions for SAF systems were identified for Pinus pinea, Juglans ssp., Populus spp., Quercus ilex and Prunus avium. The investigation covers the entire European continent.

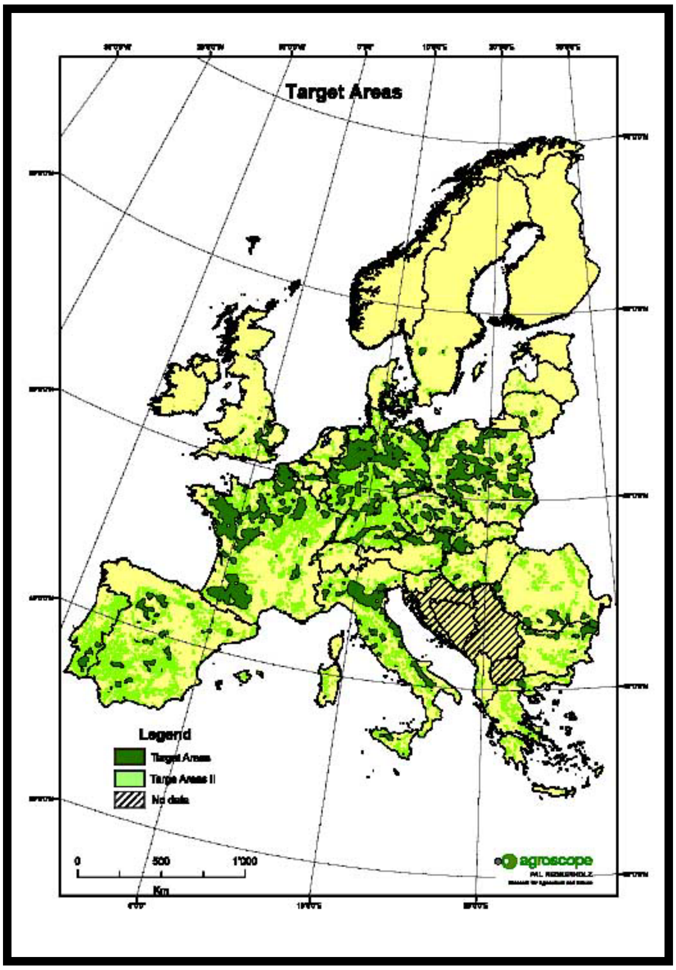


Figure 120: Target regions suitable for silvoarable agroforestry with agro-environmental problems that agroforestry could mitigate

Critical remarks

Both climate and soil conditions are important in determining the capability of these species to grow successfully at a specific site. Climatic factors are particularly useful for indicating broad regions where specific species can grow. Within these broad regions, soil characteristics constrain the suitability at a smaller scale. When interpreting the maps, it has to be kept in mind that they are based on coarse, European datasets with a resolution of 1 sq km. In reality, for specific sites, the local edaphic or microclimatic conditions can of course differ. The maps would probably look different if they were derived from national data of higher spatial and thematic resolution. Therefore we would recommend that national level analyses should be undertaken in order to increase the precision of the maps. Our analysis, however, has the merit of being applicable to the entire European continent.

Potential growth areas are locations where the tree species are worth considering for planting trees in an agroforestry setting on arable land. However, a tree species suited to a certain area may not be profitable due to other factors which were not included in this assessment, such as insects, diseases, weeds, limited availability of a suitable variety, and market access.

An important issue is the availability of data. The description of environmental requirements of the five tree species investigated is based on a range of factors. The factors used here have been widely applied around the world to assist species selection (CABI, 2003). They have the advantage that the climatic requirements are based on simple monthly mean temperature and rainfall data, which are available for the whole of Europe. However, long-term average data do not reflect year-to-year variations, so problems may be experienced if trees are established, for example, in low rainfall areas during a drought period.

The assessment model created for this study has some limitations. The model relies on relatively few climate and soil requirements to create target region maps. Requirements were selected because of their importance and availability. Additional requirements would strengthen the target region maps but the necessary data are so far not available at the European level.

About the up-scaling of the profitability assessment at the Land Test Sites across Europe

Using a geographical information system, a statistical analysis of climatic, topographic and land classification data was used to select 19 landscape test sites in Spain, France and the Netherlands. Within each site, land use, soil depth and texture, and elevation were digitised. Daily weather data were generated for each site using a weather generator. Proportional differences in solar radiation and soil water holding capacity were calculated and used in cluster analysis to divide the arable land at each site into between one and four land units. The biophysical model Yield-sAFe, developed as part of the SAFE project, was developed and calibrated for potential yields of a range of tree and crop species. Typical forestry and arable systems and associated management regimes were determined for each land unit and Yield-sAFe was calibrated for actual tree and crop yields at each site. The calibrated model was then used to calculate daily values of tree and crop yields for a forestry, arable and agroforestry system at each land unit according to changes in solar radiation, soil depth and texture. Financial data for forestry, arable, and silvoarable production at each site were collected and four grant scenarios were described (no grants, a pre-2005 scenario, and two possible post-2005 scenarios). The financial data were combined with the physical values in an economic model called “Farm-sAFe”, and the equivalent annual value (discount rate = 4%) at a plot-scale and the infinite net present value at a farm-scale were used to examine the profitability of different systems.

The Yield-sAFe biophysical model predicted lower timber yields and crop yields per hectare for silvoarable systems compared to the forestry and arable systems respectively (**Figure 73**). However, the total productivity of the silvoarable system, as determined by a land equivalent ratio, was predicted to be between 100 and 140% of that for the monoculture systems. High LERs were achieved with a tree stand density of 113 rather than 50 trees/ha,, suggesting that the high-density system made fuller use of the available light and water resources. The highest ratios were obtained by integrating deciduous trees and autumn-planted crops, which were complementary in terms of light use. The lowest ratios were obtained from evergreen tree species in Spain, where productivity appeared to be constrained by the slow growth of the trees and low soil water availability.

At a plot scale, the economic performance of the systems was compared in a zero grant scenario (**Figure 78**). In Spain, arable systems were marginally more profitable than silvoarable systems with oak or stone pine, which in turn were more profitable than forestry systems with the same species. By contrast in France, silvoarable systems with walnut in each of three regions, poplar in one region, and wild cherry in two regions were more profitable than arable and forestry systems. In the Netherlands, silvoarable systems with poplar, but not walnut, were predicted to be more profitable than the described arable system. However, both the poplar and walnut silvoarable systems were more profitable than forestry.

Under pre-2005 grants (**Figure 80**), support for silvoarable systems in Spain and the Netherlands was substantially lower than for arable and forestry systems. Hence, the profitability of silvoarable systems was always less than for arable or forestry systems. In France, support for silvoarable systems was marginally lower than for arable systems but significantly higher than for forestry systems. Hence it was predicted that silvoarable systems with poplar and walnut could be more profitable (at a 4% discount rate) than both forestry and arable systems. Silvoarable systems with cherry although more profitable than forestry were predicted to be less profitable than arable systems. In the Netherlands, silvoarable systems were more profitable than forestry, but less profitable than arable systems.

Under two possible post-2005 grant regime (**Figure 81**), the relative value of support for forestry in Spain was predicted to decrease, whilst for silvoarable and arable systems it was predicted to increase. In France and the Netherlands the relative value of support for silvoarable systems compared to arable and forestry systems remained similar to the pre-2005 regime for scenario 1, and increased marginally for scenario 2. Hence the profitability of silvoarable systems in Spain increased and frequently exceeded the profitability of forestry systems, but remained marginally less profitable than arable systems. In France and the Netherlands, little relative change in profitability between the systems was predicted.

At a farm-scale and under both pre-2005 and post-2005 grants in France, planting arable land with silvoarable systems of walnut and poplar increased farm profitability, while silvoarable systems with cherry reduced farm profitability. In Spain and the Netherlands, silvoarable systems consistently reduced farm profitability in comparison with the arable status quo. However, in both France and the Netherlands, silvoarable systems were a more cost-effective way of establishing trees on the farm than forestry. In Spain, under pre-2005 grants, silvoarable systems were a less cost-effective means of establishing trees than forestry. However, under post-2005 grants, silvoarable systems were predicted to be a most profitable means of establishing trees in half the examined cases.

A number of recommendations regarding further research can be made. Predictions are subject to uncertainty and this could be examined using sensitivity analysis or stochastic modelling. Certain baseline data could also be re-examined. The recorded value of walnut timber in the Netherlands and France differed greatly, even though both countries are part of a free-trade zone. This strongly influenced the relative profitability of walnut systems in these countries. The assumption regarding prohibition of slurry manure application in the Netherlands in forests also had an important effect. If this is a true opportunity cost, the establishment of productive forests on farms is unlikely to be attractive, unless the opportunity cost is removed or payment schemes can account for it. Assumptions regarding beating-up, tree management and the extent of payments could also be re-assessed for Spain. Tree mortality is likely to be high due to difficult conditions and should be accounted for; the assumptions regarding pruning and thinning costs in Spain may be valid for traditional management of widely spaced trees in open woodlands (Dehesas), but invalid for forestry and silvoarable systems, even if these are established within areas where Dehesas predominate. Finally, the assumptions and value of post-2005 grants should be re-assessed when the changes are implemented.

The process used to model plot- and farm-scale economics of arable, silvoarable and forestry systems in three European countries has been described. This integrated the use of geographical information systems with a biophysical model of tree, crop and integrated tree and crop growth, and an economic model developed during the SAFE project.

Under the economic conditions envisaged in the analysis, the most financially attractive silvoarable systems tended to have a land equivalent ratio that was substantially above one. Conditions that most favoured a high LER appeared to be the use of relatively high tree-densities to make full use of available resources, the use of deciduous trees and autumn-planted crops to make complementary use of light, and a high soil water availability to ensure that extra biomass production could be sustained. Conversely, it appeared that low ratios were associated with low tree density, evergreen trees, spring-planted crops, and low soil water availability.

Silvoarable agroforestry was most financially attractive where both components of the system were profitable as a monoculture since an unprofitable or relatively unprofitable component tended to reduce the profitability of the mixed system. In addition, the profitability of silvoarable agroforestry tended to be maximised if the profitability of the forestry and agricultural system were similar. Under the two proposed post-2005 grant regimes, it is predicted that silvoarable systems with walnut and poplar in France could provide a profitable alternative to arable or forestry systems. In Spain, it appeared that Holm oak and stone pine could be integrated into arable systems without significantly reducing arable production for many years. Since these trees are of ecological and landscape importance, rather than productive importance, additional support in the form of an agri-environment payment would be justified. A moderate annual amount would be sufficient to overcome income losses caused by yield reductions and encourage establishment for non-productive benefits. In the Netherlands, the low value of timber and an assumed opportunity cost of losing arable land for slurry manure application made silvoarable and forestry systems relatively unattractive compared with arable systems.

WP9: Developing European guidelines for policy implementation

Our work suggests that a positive approach towards agroforestry is needed in European regulations. This requires that agroforestry should be clearly defined, and accepted as a valid land use alongside agriculture and forestry. Our recommendations include:

- clarification that areas of scattered trees on farms are eligible for the Single Payment Scheme in both traditional and novel systems;
- clarification in the proposed new Rural Development Regulation to recognise the costs of initial agroforestry maintenance, and its role in environmental enhancement.

We consider that rural trees are part of productive agricultural systems, and contribute significantly to environmental services. Contradictions within the CAP first and second pillar payment need to be resolved. Rural trees work for both agriculture and the environment – and the regulations should reflect this.

Despite several mentions in the European Forestry Strategy, agroforestry has been largely ignored in national forestry strategies and in EU and national agricultural and rural development plans. Forestry and Agricultural Departments tend to concentrate on their own areas rather than on the value of interactions. This has endangered important traditional agroforestry systems, and currently prevents European farmers adopting modern agroforestry innovations.

Therefore, it is believed that a European regulation should clearly define what is agroforestry.

SAFE Proposal 1. The following definition of agroforestry is suggested by the SAFE consortium and could be included in the new RDR regulation.

Agroforestry systems refer to an agriculture land use systems in which high-stemmed trees are grown in combination with agricultural productions on the same plot. The tree component of agroforestry systems can be isolated trees, tree-hedges, and regularly spaced low-density tree stands. An agroforestry plot is defined by two characteristics:

- *at least 50% of the plot is in crop or pasture production,*
- *tree density is less than 200/ha (of stems greater than 15 cm diameter at 1.3 meters height), including boundary trees*[5]*.*

This definition is simple, and clearly distinguishes agroforestry from forests. It also encourages the conservation of boundary trees and hedges, since some countries make significant deductions (e.g. 10m in France) for crop area payments adjacent to tree-hedges. Furthermore, it recognises (following Article 5 of Regulation 2419/01) that agriculture is the predominant land use, since it can be conducted in a similar manner as on parcels without trees in the same area. The crop part of the parcel can also be classed as temporary set aside (which is currently recognized as an agricultural land use).

Grazed open-woodlands will usually qualify as agroforestry plots, unless their tree density is very high (greater than 200 stems (>15cm dbh/ha) OR their pasture cover is less than 50%.

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[5] Tree hedges fit into this definition. Tree density of mature tree-hedges are usually in the range 0.1 to 0.5 trees/m. The tree-hedges surrounding fully a 1 ha plot would have between 40 and 200 trees. This threshold is therefore adapted to most tree hedge systems of Europe. It avoids the difficulties of using a width criterion (2 or 4m) to define an eligible hedge. Given normal subsidiarity rules, countries would be free to suggest modifications of the thresholds suggested.

The only provisional EU guidance on what constitutes a 'forest/woodland' for the calculation of eligibility for SPS payments (Guidance Document AGRI/2254/2003) is not adapted to agroforestry systems (most tree-hedges systems, for example, would not fit within this threshold), gives a threshold based on tree numbers, without indicating the minimum size of a tree, and does not indicate whether edge trees are included. Our proposed definition of 'agroforestry' overcomes these difficulties, and leads to the second SAFE Proposal.

SAFE Proposal 2. The total area of the agroforestry parcel is eligible for the Single Payment Scheme.

This proposal is compatible with existing regulations (e.g. Article 5 of Regulation 2419/01 which indicates that: *'a parcel that both contains trees and is used for crop production (covered by Article 1 of Regulation 3508/92) shall be considered an agricultural parcel provided that the production envisaged can be carried out in a similar way as on parcels without trees in the same area'.*

We propose that scattered trees and hedges are considered part of the agricultural system, and need not to be excluded from the SPS eligible area.

The proposal also avoids a contradiction between two pillars of the CAP regarding rural trees, with the first pillar rewarding farmers who have removed trees from their fields, and the second pillar encouraging farmers to establish them!

It also simplifies controls, and avoids calculation of the 'forestry' and 'agricultural' areas in agroforestry systems, and inevitable changes in these over time. Costs of including the tree area of agroforestry plots in the SPS would be compensated by economies in monitoring and control visits, and by reductions in agri-environmental payments needed to protect scattered trees.

The solution, based as it is on the assumption that more than 50% of the land in an 'agroforest' is used for agricultural production, is similar to current rules allowing 'stacking' of full SPS payments for land planted with conventional forest plantations providing that at least 50% of the holding remains in agricultural use.

If the trees are nut trees, the farmer should opt for either the nut tree grant regime (Regulation 2237/03), or for the SPS regime. If he opts for the SPS system, the nut trees should be high-stemmed[6], the tree density should fit the 200 trees/ha criterion, and the crop component should fit the 50% area criterion.

If the SAFE Proposals 1 and 2 were implemented, many declaration and control operations would be simplified. Currently, to prove eligibility for crop area payments, tree cover (or some approximation of cover) must be subtracted from the eligible crop area within the IACS.

The Integrated Administration and Control System (IACS) was established at an EU level in 1992, but increasingly countries are implementing automated Geographical Information Systems to record parcels and their single land use. At the EU level this is coordinated through the Land Parcel Identification System (LPIS), and countries are using orthophotos to identify individual trees or tree-hedges and excluding the projected crown areas of these trees from the eligible crop areas.

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[6] High-stemmed trees should be defined by the regulation. Local uses vary in Europe for defining the minimum height of the branch-free stem. A 2 m height for novel systems seems adequate, and 1.5 m is better adapted to traditional existing systems (Streuobst, prés-vergers). In the case of grafted trees, the grafting point could be any place on the stem (some countries restrict that to grafts at the top of the stem, but this is not advisable from a biological point of view).

However, such projects usually ignore the parallax errors when tall trees are not located precisely at the centre of images. This results in significant over-reductions for the effect of trees, and increases the tendency for such trees to be removed. Already significant areas of Dehesa and Montado in Spain and Portugal are being removed following introduction of the SIGPAC system, and traditional hedgerows and orchards may be threatened in Eastern Europe[7]

Increasing use of Ikonos and Earlybird images will correct these errors, but until such time as the system can be implemented across Europe, following full implementation and testing of the INSPIRE Regulation (in 2013), it is best for agroforestry to be defined using Proposals 1 and 2 above.

Farmers should declare that a parcel's use is 'agroforestry' and record the number of trees (>15cm dbh). Re-measurement using sampling methods is possible at intervals decided by national authorities. Sub-categories of agroforestry may be introduced for an easy match with CAP regulations: arable agroforestry; pastoral agroforestry; orchard agroforestry; vineyard agroforestry.

SAFE <u>Proposal 3.</u> Planting and maintenance costs of new agroforestry plantings should be met within the new RDR, and improvement of existing agroforestry systems be supported by agri-environment payments.

Article 41 of the project of the new RDR introduces support for the establishment of new agroforestry systems. However there are a number of issues that require to be clarified:

1. Maintenance costs for agroforestry planting should be included in Article 41 in the same way as it is within Article 40 for forest plantations. This is justified because maintenance for tree-protection and pruning of low-density trees are particularly high, but are vital to guarantee the survival of the tree and the production of high-quality timber. Agroforestry would not be eligible for income compensation payments (provided that it is eligible for the SFS). Agroforestry is not a forestry practice, and to avoid it being considered by foresters as a "competitor" for European funds, it should be given a prominent place in the overarching EU Rural Development Strategy Document

2. To support the eligibility of existing agroforests for improvement and environmental payments
This is justified because of additional management costs of agroforestry stands involved in improving environmental and recreation values. There are several proposed agri-environmental and forest-environmental payments that would be relevant, and a French agroforestry environmental measure was approved by the STAR committee in 2001 and could serve a model.

SAFE <u>Proposal 4</u>. Ensure that the EU Action Plan for Sustainable Forest Management emphasises the need to very greatly increase the presence of scattered trees in farmed landscapes (agroforestry)

The 1998 Forest Strategy (COM(1998) 649, 03/11/1998) ran to 25 pages and mentioned agroforestry in several places: a) calling for the optimisation of agro-forestry systems, b) for research on multifunctional management of forests to include agro-silvo-pastoral systems; c) to recognise the biodiversity value of silvo-pastoral systems and b) to emphasise the importance of agroforestry for carbon sequestration[8]

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[7] http://reports.eea.eu.int/environmental_issue_report_2004_37/en/IssueNo37-Agriculture_for_web_all.pdf

[8] http://europa.eu.int/comm/agriculture/consultations/forestry/report_en.pdf

However agroforestry has little place in current national forestry strategies or in existing rural development plans, nor in the recently published Commission review of the success of the Forest Strategy[9], despite agroforestry's prominence in the public consultation[10].

[9] http://europa.eu.int/comm/agriculture/publi/reports/forestry/workdoc_en.pdf

[10] http://europa.eu.int/comm/agriculture/publi/reports/forestry/com84_en.pdf

Conclusions

The 9 most prominent outcomes of the SAFE project are the following:

1. The SAFE project **identified extant traditional and novel silvoarable systems across Europe**, and produced a database of these systems. Many traditional European agroforestry systems disappeared during the 20th century. Intensification, mechanisation and land consolidation were the most important incentives for tree removal from cultivated areas. Isolated trees, tree hedges, and low-density tree stands (such as traditional high-stemmed orchards) were largely destroyed. Those systems that still remain are now catalogued.

2. The SAFE project **demonstrated that the Common Agriculture Policy (CAP) has induced widespread destruction of rural trees in Europe** during the last 30 years. Trees are not considered as part of the cropping systems, and CAP payments for crops or pastures are usually reduced on parcels with scattered trees. This negative impact was not an objective of the CAP, but was the consequence of regulations that do not take into account the positive impact of rural trees. Reports of large-scale tree-removal are already emerging from new member states, in preparation for the introduction of CAP regulations. The destruction of many traditional agroforestry systems in Europe had unfortunate consequences: loss of know-how by farmers, simplification and standardization of landscapes, increased environmental problems such as soil erosion or water degradation, loss of a significant carbon stock, reduction of biodiversity, and the loss of a source of alternative income for the farmers.

3. **The SAFE project monitored experimental silvoarable plots** in France, England, Spain and Italy, and established pioneer plots in The Netherlands, Germany and Greece. In the experimental plots, the productivity of tree-crops systems was documented. The SAFE project demonstrated that modern agroforestry systems could be compatible with present-day agricultural techniques. Specific tree management schemes are necessary (such as tree alignment and stem formative pruning). In modern agroforestry systems, low tree densities (30-100 trees/ha) allow crop production to be maintained until tree harvest. The SAFE project demonstrated that the average productivity of silvoarable systems is higher than the productivity of separated trees and crops. Evidence for productivity increases up to 30% in biomass, and 50% in final products was obtained. The effect of ploughing and cultivation

between tree rows is generally to stimulate deeper growth of tree roots, providing year-round access to sources of water and nutrient, which may not be available to trees with normal superficial rooting.

4. **The SAFE project produced two biophysical models to simulate the dynamics of tree-crop systems** in various soil and climatic conditions. These models allow for predicting competition for light, water and nitrogen between trees and crops. They allow the operators to predict for how many years the crops will be profitable, and how fast the trees will grow. Finally, model outcomes illustrate favourable environmental impacts of tree-crop systems, such as a reduction in nitrogen leaching or an increase in carbon sequestration. Management practices for silvoarable systems can thus be evaluated through 'virtual experiments' on computers using these models. **A key result of the SAFE project is that tree-crop systems are able to capture more resources from the environment than pure crop or pure tree systems**. Competition induces adaptation, and temporal and spatial differences in resource use create complementarity. Using the SAFE models, optimum management schemes can be derived for tree stand densities, tree spacing, tree row orientation, tree species choice, intercrop rotation choice, and specific tree and crop management techniques, such as tree root pruning.

5. The economic calculations produced by the SAFE project, using plot- and farm-scale bio-economic models, show that **agroforestry plots can be as profitable as agricultural plots** in no-grant scenarios when they include high value timber trees such as walnut or Sorbus. Annual crops maintain the annual income for the farmer, while pruned low density tree stands provide capital for the future. Most European farmers could develop an agroforestry activity on part of their cropland, without a significant reduction in annual crop income. A farm that turned about 20% of its cropped land into agroforestry could increase significantly in value. With high-value timber, the timber income might double the farm profit in the long term (60 years).

6. However **the SAFE project provided evidence that current policies totally prevent European farmers from adopting silvoarable agroforestry**: in most cases farmers will lose the crop payments and are not eligible for any subsidy to plant the trees. This is why at the moment agroforestry is artificially unattractive for European farmers (with the exception of France, where the regulations have recently been adapted). Adoption of agroforestry requires that tax rules and cadastral land-status be implemented fairly for agroforestry plots. These issues should be addressed by national regulations in each European country.

7. A survey of more than 260 European farmers in seven European countries has shown that **European farmers are surprisingly perceptive with respect to agroforestry issues**. More than 40% would be willing to adopt agroforestry techniques on their farm. In France, 12% of the surveyed farmers were already engaged in agroforestry activities, 2 years only after having been interviewed. They devoted about 15% of the cropped land of the farm to this activity.

8. On a European scale, 90 million hectares are potentially suitable for silvoarable agroforestry and 65 million hectares would benefit from silvoarable plantations, which would help mitigate key environmental problems such as soil erosion and nitrate leaching. If 20% of the farmers in these areas were to adopt agroforestry on 20% of their farm, this would result in 2.6 million hectares of silvoarable agroforestry in Europe. A conservative yield estimate of 1 m3 of high-quality timber per hectare per year from silvoarable agroforestry on this area of land suggests that in the long term an annual production of about 2.6 million cubic metres of

high-quality timber could be possible in Europe. This is approximately 25% of the mean annual import of all tropical timber (logs, sawn wood, plywood, and veneer) into the EU between 1990 and 1999, and 100% of the mean annual import of tropical timber logs into the EU over the same period.

9. Current CAP regulations give an inconsistent message regarding the value of trees on cultivated land. On the one hand, CAP first pillar payments (Single Payment Scheme) provide incentives to farmers to remove trees below the threshold necessary to ensure payment eligibility. On the other hand, CAP second pillar arrangements (Rural Development Regulation) encourage farmers to protect or introduce trees. **The SAFE project has produced guidelines for policy options in Europe that would permit European farmers to take advantage of agroforestry**.

Specific conclusions and recommendations from some Work-Packages are included below.

WP1 recommendations

Developing integrated models of tree-crop interactions was a challenge that was partially met by the SAFE consortium. The platform for modelling suggested by WP1 may need to be modified with the experience gained by the SAFE consortium. The STICS crop model included in the Hi-sAFe model appeared finally to be difficult to handle, because of its poor modularity. Considerable efforts were devoted to modifying and improving the code of this model, and this was not anticipated. It caused delays in the coding of the Hi-sAFe model, and this in turn prompted the need for a simpler model that would be more flexible and able to run on the long term.

Detailed biophysical models like the Hi-sAFe model should therefore be considered as a model for exploration of tree-crop interactions (toy-model). Simpler biophysical models like the Yield-sAFe model are more oriented towards the prediction of the outcomes of silvoarable systems.

WP2 recommendations

The future of the SAFE extant silvoarable systems in Europe database is a concern. It is hoped that some of the SAFE participants will keep monitoring the database.

Regarding the reaction of European farmers to silvoarable technology, published papers are now necessary. However, the difficulty to maintain a common standard across the different European countries on the methodology to interview farmers was a problem. Further studies should tackle this aspect as a priority.

WP3 recommendations

The future of many silvoarable experiments in Europe is a major concern. Granting long-term experiments is always a challenge. The Pamiers, Grazac, Silsoe and Leeds experiments may not be maintained any longer, if grants are not obtained in the near future. This is a concern for the whole community, as such long-term experiments are of the highest value. It pushes for on-farm experiments (such as the Vézénobres or Restinclières experiments) where the involvement of a farmer and/or landowner warrants the future of the experiments, irrespective of grant availability.

Future silvoarable experiments should make sure that control forestry and arable treatments are included, and will remained unaffected by border effects from neighbouring plots over the long term. Most of the silvoarable experiments available to the SAFE consortium suffered from mistakes in the initial design (before the project commenced).

The experiment database should be used during the next years by modellers for cross-validating the biophysical models. The maintenance of the database is again a concern, as the facility for on-line feeding with new data by experiment managers is not available.

WP4 recommendations

The microclimate interactions between trees and crops are the dark side of this WP. More efforts should be devoted to assessing if this aspect is crucial or not in silvoarable systems. Many scientific papers are expected and should address the applied aspects of silvoarable management.

WP5 recommendations

The novel approach for modelling of belowground tree-crop interactions needs more validation efforts. The theses of Rachmat Mulia and Elena Cubera should be completed by the end of 2005 and will provide key papers on these models.

WP6 recommendations

Validating the two biophysical models is a priority for the future. Checking how the two models can exchange information is also of high interest. The future of these two models is a concern for the whole SAFE consortium. Efforts should be devoted to identify partners and funds to develop further the two models. The SEAMLESS European project is a first opportunity that will be used.

WP7 recommendations

Arising out of work-package 7 a number of conclusions and recommendations can be made.

Use and improvement of the biophysical and economic model

1. The Yield-sAFe model provided a systematic method for predicting tree and crop yields in a range of forestry, arable and silvoarable systems. This to our knowledge is the first time that a daily-time-step biophysical model has been used to predict tree and crop yields for the full length of a tree rotation for forestry, arable and silvoarable agroforestry systems in different countries of Europe. Although the model appeared to produce reasonable results, there is still a need to validate the tree component of the model with total dry matter and timber volume measurements for trees at a range of wide spacing.

2. The plot-scale economic analysis was undertaken in a worksheet called Plot-sAFe that included the biophysical Yield-sAFe model. Because Plot-sAFe has been developed in Microsoft © Excel, the workings of the model are transparent to other researchers. However it is recommended that an improved user-interface be produced to improve the ease of use for other users such as advisors.

Plot-scale economic analysis

1. Assuming no grants, the silvoarable systems with poplar in France, England and the Netherlands, with walnut in France, and with cherry in Poitou Charentes and Franche Comté were more profitable at a discount rate of 4% than the described forestry and arable systems. For these systems, the equivalent annual value (at a discount rate of 4%) for a silvoarable system with 113 trees ha^{-1} was on average 74 (range: 3 to 107), 70, and 19 € ha^{-1} a^{-1} greater than for the competing forestry and arable system in France, the UK and the Netherlands respectively. This analysis shows that without grants, there can be a financial incentive for silvoarable agroforestry.

2. Without grants, four conditions that seem to favour silvoarable agroforestry, relative to competing arable and forestry systems, are:

- ♦ A high land equivalent ratio (LER) improves the relative profitability of silvoarable agroforestry. This could be the result of complementary tree and crop growth patterns or a poorly optimised forestry system. Hence, assuming 113 trees/ha, the systems with deciduous tree species in France (mean LER = 1.30) tended to be more profitable than the systems with oak and pine (mean LER = 1.15) in Spain.

- ♦ Forestry without grants should to be profitable. This requires a tree species with either high quality wood (e.g. walnut) or a short rotation (e.g. poplar). However the value of timber appears to be country dependent. For example, the assumed value of walnut timber in France was almost twenty-times that determined in the Netherlands. It is recommended that the reasons for such differences should be determined, in what should be a free-trade area.

- ♦ Arable agriculture without grants should also be profitable. For example arable agriculture is not particularly profitable in the Franche Comté region in France and hence without grants poplar production is more profitable in forestry than in an agroforestry system.

- ♦ The profitability of forestry and arable agriculture should ideally be similar. If one particular system is substantially more profitable than the other, the farmer would tend to plant monocultures of that system rather than an agroforestry system combining the two.

3. Assuming the 2004 grant regime of the Common Agricultural Policy and that arable area payments were only paid when the land was cropped, the length of the optimal crop rotation in the presence of grants tended to be longer than in the situation with no grants. This means that the optimal silvoarable management regime with grants tends to be different from that without. With the 2004 grant scenario, the only silvoarable systems that were more profitable (at a discount rate of 4%) than the agricultural and forestry system were the poplar and walnut systems in France. The systems with cherry in France, and with poplar in England and the Netherlands became less profitable than the arable or forestry systems. It is clear that the current separation of agriculture-related payments within the Common Agricultural Policy from tree-related payments within a rural development policy is hindering the uptake of silvoarable agroforestry. In addition it creates non-optimal silvoarable management regimes where the farmer may seek to maximise grant income rather than non-grant-related profitability.

4. The 2005 grant scenario, based on the new single farm payments, generally gave similar results to the 2004 grant scenario. This is because it was assumed that the single farm payment would not be received on uncultivated land. The distortions present in the 2004 grant regime in relation to agroforestry appear to remain in the predicted future grant scenarios.

5. The above analyses are based on an analysis of predicted benefits and costs. Additional considerations, such as potential damage to machinery against the trees, which may prevent the uptake of silvoarable systems, were not considered. Similarly possible environmental benefits from agroforestry such as soil erosion control (Palma et al. 2004) were not included.

General recommendation

The SAFE project was focussing on the production efficiency of silvoarable systems. It helped to answer the following questions:

- •What patterns of LERs with ecological region, soil fertility (water reserve), tree species, crop species?
- •Can we forecast any progress in production efficiency through improved techniques?

•What future research is needed on these aspects?But what about the environmental efficiency of silvoarable systems? This should be the focus of a new project in the future. It was only marginally addressed by the SAFE project. This is the priority for the future. Important aspects such as the efficiency of silvoarable systems on the control of nitrate leaching, the minimisation of soil erosion, the sequestration of carbon, the impact on biodiversity of cropped fields and on the control of pests through habitat management for predators are key issues to address.

Exploitation and dissemination of results

The outputs of the SAFE project will be used as follows:

1. The policy guidelines will be disseminated both at the European level and at the national levels, and suggestions made for implementation at national levels. Some Key European (e.g. Rural Development Regulation 2007-2013 Article 41) and national (French Regulations such as the Loi d'Orientation Agricole) policies have already taken SAFE project recommendations into account, but more effort is required by advocates of agroforestry to ensure that future national agricultural forestry and rural development policies implement the options for agroforestry now offered by the headline EU regulations. These policy guidelines have already been made available in the SAFE project final report, and they were presented at the final project symposium in Brussels on March 30th 2005. Some MEPs, staff of DG agriculture and Research of the European commission, and representatives of farmers' organizations across Europe attended this symposium.

2. The models produced by the SAFE consortium need further improvements and validation. The detailed biophysical model of tree-crop interaction will be improved by INRA, and its features expanded to allow its use in wider situations such as tropical agroforestry or temperate orchards and vineyards. A simplified version may be produced for extension officers dealing with agroforestry at a later stage, if financial support is obtained to contract a computer scientist for this task. The Yield-sAFe, Plot-sAFe and Farm-sAFe models proved to be useful research tools within this project for determining the long-term effects of trees and crops in terms of production, economic and the environment. However further refinement is proposed to make them more user-friendly for other users.

3. A European society for agroforestry is a further development that may be considered by some participants. National agroforestry societies, such as the Farm Woodland Forum in the UK, lobby their national parliamentarians, but there is a need to have an organization to inform MEPs about silvoarable agroforestry issues in the future, and to give a pan-European perspective.

4. The SAFE project web-site will be maintained after the SAFE project and transformed into an agroforestry dedicated site for the general public and for stakeholders

5. A plan for establishing 1 million hectares of silvoarable agroforestry across Europe could now be prepared by the European Commission, with the help of SAFE contractors such as INRA and APCA. Such a plan would have key impacts on the following aspects: quality of life (through improved landscapes), protection of the environment (protection of soils and water), reduction of the use of tropical timbers, increase of Carbon sequestration and employment in rural areas.

6. More research on biodiversity and carbon sequestration aspects of silvoarable agroforestry is needed, and some members of the SAFE consortium will prepare international collaborative proposals.

7. A special issue of the journal “Ecological engineering” will include 5 papers describing the main achievements of the SAFE project. The coordination team is currently considering a book on the SAFE project, and publishers have already expressed an interest in producing this.

8. With increasing demand of water resources in Europe, more research is needed on the relative effects of arable cropping, silvoarable agroforestry and forestry on groundwater recharge. The models developed provide a systematic approach for investigating this issue and future concept notes for research funding should be prepared.

9. Farmer’s organisations in several European countries have expressed their interest in using the SAFE project outputs to establish national or regional agroforestry schemes. The SAFE project resulted in a political pressure on the national ministries for agriculture and forestry to recognize the role of agroforestry systems in rural areas. Some pioneer projects have already been established (mainly in France, but more projects are now considered in Germany, Spain, Greece). Some SAFE scientists will be involved in training courses on agroforestry during the coming years.

Policy related benefits

The SAFE project made substantial proposals for improving current European policies related with trees on farms in Europe.

Contribution to EU policies

This section is adapted from the final part of the SAFE project Technological implementation Plan.

European dimension of the problem

Agroforestry systems are part of the history of the European Union rural landscapes. During the 20th Century, trees were progressively removed from the cultivated land of Europe as a result of mechanization and intensification, but also as a consequence of land consolidation schemes to increase the size of agricultural parcels. Many tree hedges and isolated trees were removed during these consolidation schemes. The removal of trees from cultivated and grazed areas has been very marked in all European countries. During the last 30 years, two opposing trends have been apparent. On the one hand, the role of trees has been progressively recognised, and schemes favouring the preservation of trees on farms have been implemented (plantations on agricultural land, plantation of new tree hedges, protection of isolated trees). <u>On the other hand, the main CAP crop and animal support regulations have clearly ignored the existence of trees outside the forest.</u> Payments were only available for treeless plots, or exaggerated estimates of the areas covered by trees were subtracted from grant-eligible cereal and forage areas. This had the very unfortunate (and probably unforeseen) consequence of widespread removal of trees from cultivated or grazing land to maximise levels of subsidy. There is today a risk that in the new member States from Eastern Europe, the same process is repeated. Reports already indicate that farmers are removing trees in many countries to get the full CAP Single Payment Scheme (SPS) payments.

In the meantime, modern and novel agroforestry systems have been designed, but are not very attractive to European farmers <u>because of current policy restrictions</u>. The advantage of these novel systems is that they were designed to be fully compatible with present day cultivation techniques and mechanization. They allow modern farming systems to take advantage of the benefits of rural trees.

Incorporating modern agroforestry as a new land use is therefore a relevant proposal for most of the 25 European Union countries, although forest grazing will be more important than silvoarable systems in Nordic countries. More than 90 millions hectares of cropland in Europe are suitable for silvoarable agroforestry. This could contribute to the achievement of a **sustainable agriculture and forestry**, which is a key EU policy. We identified a large area suitable for agroforestry in eastern Europe. It is worth mentioning that many of the new accession countries would benefit from agroforestry.

At the farm level, agroforestry systems would bring a security to farmers through the diversification of their income. Valuable trees on a farm are assets that may be used during difficult times. This was also a reason for the destruction of many valuable rural trees in Europe: providing income during difficult times. With the probable diminution of subsidies to European farmers in the long term, silvoarable systems may play a significant role in stabilizing farm incomes.

Contributing to policy design or implementation

The SAFE project made suggestions for policy implementation that cover a large number of European policies. The most important are highlighted in the SAFE Deliverable entitled "Options for Agroforestry policy in the European Union"

The European Forestry Strategy could be adapted

The 1998 Forest Strategy (COM(1998) 649, 03/11/1998) mentioned agroforestry in several places. However a recent consultation on the first 5-years of implementation of the Strategy concluded, *inter-alia,* that '***agroforestry and silvopastoralism*** *were seen as two potentially sustainable forms of land management and as land use forms that could be better used for rural development in the future, but that not enough emphasis had so far been given to raising the awareness of policy-makers, natural resource professionals and farmers, as regards the potential of* ***agroforestry and silvopastoralism***'

This comment seems justified by the fact that there is not a single mention of agroforestry in the 85-page commission staff paper reporting on implementation of the Forestry Strategy during the past 5 years, and we are unaware of many mentions of agroforestry in the Forest Strategies or Rural Development Plans of member states. Agroforestry plays a major role in several European landscapes and was much more important in the past. The forthcoming EU Action Plan for Sustainable Forest Management should recognise this. It **should give due emphasis to the need to massively increase the presence of scattered trees in farmed landscapes (agroforestry), and should not only focus on the sustainable management of 'forestry'.**

The new Rural Development Regulation should consider agroforestry

A draft Rural Development Regulation (2007-2013) was published in July 2004. It reflects results of internal reviews of the implementation of the current RDR. It will replace the current Rural Development Regulation (1257/99), which is a single legal instrument to ensure coherence between rural development and the prices and market policy of the common agricultural policy (CAP). **Article 41 of the draft RDR (COM(2004)490) contains for the first time a mechanism to support the establishment of agroforestry.** This is extremely welcome and should be supported by national governments.

First pillar CAP regulation should be updated to consider agroforestry

The first pillar regulations should be improved to take into account agroforestry in the future. A short list follows, but is not exhaustive. Most regulations on the CAP first Pillar deserve to mention agroforestry systems.

1. Horizontal rules regulations

Regulations 1782/2003 and1783/2003 (horizontal rules) should be upgraded to take into account agroforestry systems (single farm payment, set-aside, modulation). The problem for traditional and modern agroforestry systems is that regulation 1782/2003 states that ‘woods’ (Article 43) and ‘forests’ (Article 44) shall be excluded from SPS eligibility. Regulation 1782/03 also defines 4 issues and 10 standards related to minimum levels of Good Agricultural and Environmental Condition (GAECs), which must be maintained by the farmer to qualify for the SPS. It should be stated that agroforestry does comply with the GAECs. Regulation 1783/2003 should define how the SPS scheme applies to agroforestry systems. Regulation 1782/2003 defines ‘woodland’ and ‘forest’. This definition should be clarified to ensure that scattered trees and hedges (‘agroforestry’) are distinguished, and to ensure that Pillar 1 and Pillar II payments are harmonised to protect and enhance these valuable farm landscapes.

2. Application rules regulations (795/2004 et 796/2004)

These regulations should provide practical guidelines for defining eligible areas of agroforestry plots to European payments.

- Articles 2 of both 795/2004 and 796/2004 could include a definition of an agroforestry plot and define the area that is eligible to the payments. This would modify the current Agri-2254-2003 document.

- Article 30 of the 796/2004 could be modified in the following way: scattered trees could be considered as part of the agricultural system, and their area should no longer be subtracted from the plot area to define the eligible area to the SPS. This would save a lot of time and money for field control, and would save a lot of … trees (check the SAFE D.9.3 deliverable for more details).

3. Other regulations

Regulation 2237/03 Chapter 5 sets levels and conditions for subsidies to nut plantations. It should be clarified regarding the eligibility of intercrops in nut orchards to the SPS payment. The farmer should decide if he applies for the SPS OR for the nut scheme, not both.

Article 5 of Regulation 2419/01 which indicates that: *'a parcel that both contains trees and is used for crop production (covered by Article 1 of Regulation 3508/92) shall be considered an agricultural parcel provided that the production envisaged can be carried out in a similar way as on parcels without trees in the same area'* is perfectly suited for agroforestry, and should be introduced in any further regulation about crop support in the CAP. This was done in regulation 796/04 (Article 8 replacing Article 5 of Regulation 2419/01): ‘*A parcel that contains trees shall be considered an agricultural parcel for the purposes of the area-related aid schemes provided that agricultural activities referred to in Article 51 of Regulation (EC) No 1782/2003 or, where applicable, the production envisaged can be carried out in a similar way as on parcels without trees in the same area.*’ **This Article justifies eligibility of agroforestry systems for the Single Payment Scheme, and also guarantees that such areas should be considered as agriculture for fiscal and cadastral purposes.**

Guidance Document AGRI-2254-2003, recommends that the threshold of 'woodland' be > 50 stems per ha, but does allow countries to define exceptions in the case of ‘mixed-cropping’. However mixed cropping is a confusing term in this context, as it is normally used for herbaceous mixtures – much better is the term ‘agroforestry’ – and this term is used in Article 44 of the draft Rural Development Regulation (2007-2013).

Finally, some current European directives (such as the Natura2000, Bird or Nitrate directives) could be updated and mention the key role that agroforestry systems may play for achieving their goals.

Defining control rules for ensuring fair-play with agroforestry systems

The rules of the IACS (Integrated Administration and Control System) or the more recent LPIS (Land Parcel Identification System) should be improved to remove the incentive for farmers to destroy rural trees. This work is supervised by the JRC-ISPRA MARS Unit, and SAFE participants are happy to work with this Unit to suggest options which minimize the overhead involved in remote sensing and spot-checks of farms containing isolated trees and hedges.

The Infrastructure for Spatial Information in Europe (INSPIRE) aims to establish an infrastructure for spatial information in Europe, and will help make spatial or geographical information more accessible and interoperable for a wide range of purposes supporting sustainable development. Support for INSPIRE is mandatory for member states, and will be fully implemented by 2013. Specific rules for monitoring agroforestry systems should be included in the INSPIRE approach.

Contribution to EU social objectives

Improving the quality of life in the Community:

Quality of life and the state of the environment are closely linked; the contribution of a pleasant, attractive, clean and safe environment is vital to a good quality of life. Society depends for its well being on the preservation of a viable natural environment. The SAFE project demonstrated or suggested that agroforestry can contribute to improving the quality of life in the European Union in many aspects:

- By improving the quality of rural landscapes, especially in monotonous intensive open-fields systems
- By protecting the environment, enhancing biodiversity in cultivated landscapes, improving the quality of waters, protecting European soils, reducing the need for the use of pesticides
- By producing food and timber in a productive, sustainable and environmental-friendly way
- By sequestering additional carbon (compared to agricultural systems) and helping to meet the Kyoto commitments
- By reducing the need to import high quality tropical wood, agroforestry will also contribute to protecting tropical forests.

The main result of the SAFE project is that all these benefits can be self-financed by the high productivity of silvoarable systems. This is a key aspect: subsidies for the establishment of silvoarable systems will be useful, but later silvoarable systems will no longer require high levels of subsidies to be maintained.

This efficiency of public money investment in agroforestry is therefore contributing to the quality of life in the EU.

Creating jobs in the Community

Producing a significant amount of high quality timber in new European agroforestry plots will boost the wood chain that is presently processing mainly tropical timbers. If 2 million hectares of agroforestry are established within the next 3 decades in Europe, more than 50 000 jobs could be created in different activities: e.g. nurseries, management of tree stands, tree harvesting, wood processing. Producing a significant amount of high quality timber in new European agroforestry plots will boost the part of the European wood chain that is presently processing mainly tropical timbers, and that may lose most of its activity during the next decades.

Managing agroforestry plots requires more labour than pure crop systems, and this will increase job opportunities on farms in rural landscapes. Pilot projects have already demonstrated the opportunity of agroforestry to providing additional work at periods of the year when agricultural tasks are limited.

Supporting sustainable development, preserving and/or enhancing the environment

Silvoarable systems preserve the environment by various mechanisms:

- By improving or maintaining soil fertility of agricultural soils (organic matter increase by tree-roots turn over, limitation of unwanted vegetation encroachment)
- By enhancing biodiversity in cultivated landscapes (trees and the tree zone host an extremely large variety of species, including birds, bats, insects, earthworms, etc.)
- By improving the quality of waters (trees help water infiltration, capture leached nitrates, block sprays of pesticides…)
- By protecting European soils (erosion control especially on cultivated slopes)
- By reducing the need for the use of pesticides (trees induce a biodiversity that helps control pests by natural enemies)
- By producing food and timber in a productive, sustainable and environmental-friendly way, and reducing the need for afforestation of good quality agricultural land.

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