Quality of Life and Management of Living Resources

Silvoarable Agroforestry For Europe (SAFE)

European Research contract QLK5-CT-2001-00560

SAFE PROJECT FINAL PROGRESS REPORT
(August 2004 - January 2005)

Volume 2: Work Packages Reports
Quality of Life and Management of Living Resources

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In a container experiment by INRA-System, the root system of a wild cherry tree was totally distorted by a local supply of water. This experiment allowed to parameterise the root module of the Hi-sAFe model (plasticity of root systems in heterogeneous conditions).

Scattered trees in cropped areas have environmental consequences that were often raised as benefits by interviewed farmers in 7 European countries.

The SAFE project did not cover all kinds of agroforestry technology. Agroforestry with vineyards, such as this vineyard-Pinus pinea experimental plot at INRA-System was not investigated in this project.

The final map of target areas in Europe for silvoarable technology produced by partner FAL of the SAFE consortium. Check WP8 report.

Member of the European Parliament Marie-Anne Isler-Beguin opened the final Conference of the SAFE project in Brussels on March 30 2005.

A key finding by the UEX partner of SAFE was that Dehesa oaks have an extended and deep rooting system that do not follow conventional assumptions on the shape of the rooting system of trees.

Measuring the transpiration of agroforestry trees was achieved using numerous sap flow gauges at this agroforestry experimental plot (Vézénobres, August 2004).

Captions for the cover pictures

SAFE PROJECT FINAL PROGRESS REPORT
(August 2004-January 2005)

Volume 2: Work Packages Reports
SAFE Consolidated Progress Report – Year 4

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**PROJECT COORDINATOR**

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<tr>
<th>Name</th>
<th>Title:</th>
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<tr>
<td>DUPRAZ Christian</td>
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<td>Telephone:</td>
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<tr>
<td>33 4 99 61 23 39</td>
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<td><a href="mailto:Dupraz@ensam.inra.fr">Dupraz@ensam.inra.fr</a></td>
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**Key words**: agroforestry, modelling, policy, Common Agriculture Policy, diversification

**World wide web address**: http://www.montpellier.inra.fr/safe/

**List of participants**: See project progress Summary (Volume 1)
SAFE Fourth Year Consolidated Progress Report

VOLUME 2

Work Packages Reports

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Due to the large size of the contractor contributions, the final progress report is organised in four volumes:

Volume 1: Progress summary; Objectives; Work plan; Management and Coordination; Exploitation and Dissemination

Volume 2: Work Packages Reports

Volume 3: Contractors Reports

Volume 4: Annexes (scientific papers)

This Volume 2 was built with material from the Contractors Reports. It is therefore on purpose that some materials (paragraphs, figures) appear both in the WP report and in the Contractor report. This was considered as the best solution for an easy reading of any part of the report.
WP 1: SILVOARABLE MODELLING STRATEGIES

Unchanged from previous reports

Work package number: 1 – Silvoarable modelling strategies
Start date: Month 06 (01 January 2003)
Completion date: Month 12 (30 July 2002)
Current status: Closed
Work Package leader: Isabelle Lecomte, INRA-UMR SYSTEM
Person months of WP1: 26.9

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WP1 is closed since month 6. The most important WP1 achievements were:

1. The SAFE consortium prepared two different biophysical models: a detailed process-based one called Hi-sAFe and a simple biophysical one called Yield-sAFe. Both work at the day time step. Hi-sAFe was designed for year runs, and Yield-sAFe for decades (tree life expectancy) runs.

2. The implementation of the Hi-sAFe model was done under the CAPSIS modelling platform developed by INRA-AMAP.

3. The SAFE consortium adopted the STICS crop model (C version) as the crop module of the Hi-sAFe model.

4. The Hi-sAFe model should include a Decision Making Module (DMM) as suggested by end users. This was not envisaged in the Technical Annex, and explained the expanded duration of the WP.

All deliverables are available on-line on the Web site.

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<td>Common modelling framework platform including documentation and technical report (month 6)</td>
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WP2: EUROPEAN SILVOARABLE KNOWLEDGE

Work package number:  2 – European silvoarable knowledge
Start date:    Month 01 (01 August 2001)
Completion date:   Month 42 (31 January 2005)
Current status:   Completed
Partner responsible:  Fabien Liagre, APCA
Person months of WP2:  65.0

Time finally allocated to Work-package 2.

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In compliance with the modified Technical Annex, the partners involved in WP2 fulfilled their commitments. Most teams met their objectives by the end of the SAFE project. We note that 4 teams exceeded their commitment: LEEDS, WU-FINIS, APCA and CNR.

A significant time was allocated to the coordination of this work package by APCA. This was essential to produce the last deliverables. The final number of countries involved in the farmer’s survey (D2.3) made the analysis more difficult to achieve, due to the heterogeneity of the regional samples (in number of data but also in farm features).

OBJECTIVES AND CURRENT TASKS

These are unchanged from the Technical Annex.
Objectives:

To collect and analyse available information on European silvoarable agroforestry with the following objectives:

O2.1: To collate the information gained in earlier studies including EU projects that would be relevant to silvoarable systems and could fill gaps in the research of SAFE. No previous EU project dealt with silvoarable systems, but projects on poplar and walnut cultivation, farm forestry and silvopastoral systems will be reviewed. The most prominent European silvoarable systems will be documented, including intercropped poplars in valleys, oak parks and intercropped fruit and nut tree orchards (walnut, chestnut, apple, pear and peach). Study programmes of implementation of timber trees within farmlands and traditional agroforestry systems for landscape conservation are available. Special attention will be given to temperate silvoarable systems that have been recently adopted widely in temperate non-European countries such as the Paulownia-wheat system in China (about 3 million hectares set up in 25 years) and the walnut-cereal system in North America.

O2.2: To collect historic data from existing systems required for validating the plot-scale yield model and economic evaluation. Special attention will be given to plots older than the experimental plots managed by the contractors. Innovative pioneer farmers or foresters installed such plots. Aged 10 to 80 years, they will provide a unique data resource.

Current tasks:

WP2 tasks include the collation of (historic) European silvoarable knowledge and its presentation in form of a database on a Web site for common use by the participant.

T2.1. Collate historic data from both traditional silvoarable practices and previous long-term silvoarable experiments, including experiments closed prematurely (due to the difficulty of maintaining long-term experiments). Synthesise data on the biological productivity and the financial return, and where possible, the soil and climatic conditions pertaining at these traditional sites, as required by the WP1 guidelines. Those data will be made ready for input

T2.2. Collate information on European databases of silvoarable constraint criteria for dissemination of silvoarable systems: soil type and structure, soil hydraulic characteristics, climate exposure, climate variability as deduced from algorithms that will predict daily climatic variables for target sites in Europe.

(Previous) T8.3: Investigate the financial and non-financial constraints on sample farmers’ (who currently grow arable or tree crops) awareness of agroforestry and their objectives and constraints (resource endowments). Collect data in test areas to constitute the necessary basic information for the prediction of the potential implications of different encouraging / deterring scenarios. Investigate the likely uptake of agroforestry given yields and revenue streams predicted from the silvoarable model. In the test regions, workshops will be conducted to discuss the feasibility of agroforestry, as resulting from task T8.2 with farmers, extension service workers and local politicians.

PROGRESS DURING THE LAST PERIOD

Most of the time input by WP2 partners was devoted to writing and improving the deliverables.
The agroforestry publication database
Achieved during the previous period. Available on the web site.

The extant silvoarable systems in Europe database
During the last period, the database has been completed. This task included:

- The accessibility and understanding of the data.
- The introduction of maps to locate easily the European agroforestry sites described by the database has been carried out. When maps are available, 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).

![High quality furniture timber trees with arable intercropping](image)

University of Leeds
Headley Hall Farm
Bramham, West Yorkshire

Figure 1: A map included in the agroforestry database to locate a demonstration site
• Photos of the sites (when photos were available) have been introduced to provide a more user-friendly presentation.

Survey of farmers' reaction to modern silvoarable systems

The deliverable 2.3 has been achieved with some delay. The interviews had been achieved in time, but the data analysis was more difficult than we had previously forecast. We must here underline that the technical annex included only 3 countries (The Netherlands, France and Spain) in this survey. But given the high value of this survey for the whole project, and the will of many SAFE contractors to participate, we extended the survey to 4 more countries (Greece, Germany, the Netherlands and the UK). This made the analysis of data more difficult to manage. The samples of farmers were quite different in terms of data (number and quality) in the different countries. Some national farmers samples included as few as 15 farmers all sampled in a very restricted area. It was therefore difficult to integrate them in a global statistical analysis. It made difficult the possibility to isolate some key parameters for the adoption of agroforestry or to determine which kind of farmer is more prone to invest in agroforestry or not... This heterogeneity imposed to analyse separately some issues.

Are farmers interested to carry out a silvoarable project?

After talking about virtual project, we asked to the surveyed farmers if they would be interested to set up some silvoarable plot in their own farm. The results were quite surprising: **48% of the interviewed farmers were willing 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 Northern countries such as France, England or The Netherlands, farmers are more reluctant. But, even in these countries, where farmers had previously almost excluded trees from their cropped area, 20 to 40% of the farmers considered this option. The idea of planting trees in a well-managed system attracted many farmers.
80% of the farmers interested in setting up a silvoarable project consider it for a near future (within the next 3 years). Of course, we must not consider that half of the farmers we interviewed will initiate next years a silvoarable project... Most farmers indicated that they would engage in agroforestry only if some conditions were met. At the end of the interview, more than half of the farmers doubted about the profitability of silvoarable systems. One third asked questions about the technical feasibility, and one quarter pointed out the subsidy availability. In general, they wanted to see some concrete experiments. As a farmer said: "We don't care about photos, we must see it!»

It is well known by interviewers that a role game often induces a temporary “euphoria” that leads to ignore real life constraints. This is well known from social investigators, and often used by door-to-door salesmen. This aspect could have had an effect on the results.

**Nonetheless, many farmers expressed an interest 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.

Less than 40% of the farmers declared to be definitely against any silvoarable project on their farm. The rest of the sample hesitated. The proportion of farmers interested is therefore higher than the farmers who are reluctant.

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**Figure 2:** Percentage of farmers interested in introducing a silvoarable project on their farm for the different regions surveyed.
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 on one hand to identify the motives for the decision to carry out a project and on the other hand the factors that influence the size of the planted area.

This statistical analysis identified 2 types of motivated farmers:

1. Old farmers constitute the most important group. They are usually between 45-55 year old. They would initiate a project mainly for environmental reasons. The presence of a successor on the farm does not influence their motivation, which means that the value of trees as a timber asset for inheritance is not a major point. The silvoarable project would cover a rather small area (less than 10 % of the farm size).

2. Young farmers constitute the second group. They are about 35-45 years old. The younger the farmer is, the most important the economical profitability of the project is. 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 cropped area of the farm…).

The statistical analysis permits describing the typical profile of the motivated farmers:

1. They have medium to small sized farms. The cropped area per worker is about 40 ha against 70 ha for the farmers who are not interested in a project. Farmers with small surfaces to manage have more time to invest in agroforestry. They also want to diversify the farm incomes without reducing the current productions.

2. The farmers who are well informed are more prone to initiate a project than the others. And the surface of the project would be larger. Some farmers showed the interviewer some journal articles they had filed about agroforestry.

3. 25 % of the motivated farmers would plant more than 25 % of their cropped area. Many farmers consider agroforestry as a real diversification of their cropping area. Some very motivated farmers declared that they were 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 private companies to work in their project.

4. The motivated farmer comes more often from the Mediterranean than from the temperate part of Europe. There is a strong disparity in the results according to the climatic zone. Spain and Italy are the countries of agroforestry (Mediterranean parts of France were not included in the survey). Farmers from the temperate zone demand more guaranties on the feasibility than the Mediterranean farmers.

5. 50% of the motivated farmers considered the possibility to intercrop in new parcels that they would rent and 40% approved to intercrop in a parcel that they
already rent to a landowner, in case the landowner would be interested to plant trees.

![Image](image.png)

**Figure 3: Farmers interested in a silvoarable project are more open to rent a parcel that is planted in agroforestry by its landlord.**

**Main technical options for the project**

Motivated farmers favour the following technical options for their virtual project:

1. They would plant larger areas
2. They would stagger the set up of several plots
3. They would choose good quality sites rather than poor quality sites (especially in the Mediterranean zone).
4. They would choose low tree densities compatible with intercropping up to the end of the tree rotation.
5. Cropping would be more intensive in the Mediterranean zone than in the temperate zone: Mediterranean farmers would intercrop very next to the tree row. On the opposite, Northern farmers would allow a wider distance between the tree row and the cropped area.

In France, the choice of the distance between the tree lines depended on the width of boom sprayers. The distance between the tree lines ranged from 1.1 to 1.4 of the width of the boom. Motivated farmers would plant larger areas, between 8 and 13 % of the total farm area. In Spain, the distance between tree rows and crops would be less than one meter, and this is partly explained by the small size of the tractors and machineries. A small machine is easy to drive and allow to crop near the trees. The use of wide booms demands a safe distance, to avoid any damage to the trees and the boom.
Two years after the survey, are farmers still interested in setting up some silvoarable plots?

In France, we phoned again each farmer, two years after the interviews, to sound their opinion again about the silvoarable project. Did they change their mind about agroforestry?

![Survey Results](image)

**Figure 4: Change as of 2005 of the interest in creating a silvoarable project by the farmers interviewed in 2003.**

After 2 years, the farmers interested in creating a project are less numerous than during the first survey. However, still 17% of the farmers are still enthusiastic without having got any more information in the meantime. Finally, half of the interviewed farmer rule out planting trees in their cropped area, but some of them still say that they don’t definitely leave out the idea... Significant subsidies would convince them, they said.

**Conclusions of deliverable D2.3**

Despite of set ideas, European farmers are open to introducing trees back in their cropped area. Trees disappeared from cropped areas mainly because of intensification and mechanical constraints, that resulted in land consolidation schemes and, more recently because farmers didn’t want to lose CAP payments for the areas covered by trees.

But if tree plantation is well designed and adapted to the present date mechanisation, trees are not any longer considered as a definite 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 in their own farm. With more recent agroforestry experience, Mediterranean farmers are more ready to this eventuality than the farmers of Northern countries. But even in some intensive agricultural region, where trees totally disappeared from the fields, one third of the farmers were interested. That was a surprise for the
SAFE consortium: we were not expecting such an interest from cereal farmers. And it was even less anticipated by agricultural extension services in the different countries: they remain very cautious and sometimes suspicious about our results.

The farmers have identified various advantages. The main advantages that farmers have pointed out are rather economical than environmental. The most important one is the possibility to diversify the farm production. Faced to poor agriculture prospects and to the possible decrease of the Single Farm Payment in the future by the modulation effect, farmers look for new opportunities. Agroforestry could be one of them. An other interest for agroforestry resulted from the possibility to comply with the cross-compliance rules of the new CAP (Good Agricultural Environmental Conditions). Besides these CAP aspects, agroforestry is seen as a possibility to improve the agro-environmental performance of the farm (nitrogen leaching, soil erosion, biodiversity), with a system that can make money for the future. Many farmers said that most of the Agri-Environmental Measures (AEM) are pushing for practices that are not profitable and therefore they will depend on subsidies that are not everlasting.

But as one French farmer said, “farmers don’t mind about photos, they need to visit some experiment”. Most of the farmers prudently identified clear conditions to the adoption of agroforestry. They wanted more information on the impact of trees on crop yields. They wanted advice on tree densities to plant. They wanted more information, and 80% asked to be contacted again.

Before reaching a decision, most farmers needed more information on two key aspects:

1. They wanted to know more about the biophysical performances of such systems. They needed results from research programmes. They wished to visit existing experimental or demonstration plots and to see by themselves if wheat can grow between the trees (in quantity and quality)…They also wanted to know more about the economical results of silvoarable agroforestry (investment cost, cash flow, timber price).

2. They asked if CAP regulations would be adapted to agroforestry. All the farmers agreed to say that if agroforestry complies with the GAEC, it must not be penalized by a reduction in the CAP payments. They advocate for the tree area to be eligible to the SFP payment. A subsidy of 50% of the investment costs is considered by the farmers as a minimum aid to support an agroforestry project. Sometimes, farmers underlined 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 adoptions are set up, we can predict that a large number of farmers will adopt agroforestry (more than 100 projects in the last 4 years in France without any programme of extension). We were very surprised to record that in France, 12 % of the farmers we interviewed in 2003 have initiated a project on their farm in 2005, 2 years only after being interviewed, and without any substantial extension programme available.

If this interest from farmers is confirmed, large-scale adoption of agroforestry systems in Europe is plausible during the next decades, and this should be anticipated by political decisions such as:
- Taking into account agroforestry issues by National Agronomical and Forestry research institutes. So far, agroforestry is not addressed by any of the national European research institutes, and experimental plots are scarce and not maintained on the long term.

- Implementing extension programmes for agroforestry, and especially training extension officers to agroforestry issues.

Conclusions

Objectives of WP2 are now completed. During the last period of the project, we focussed on the survey of farmers’ attitudes, which was the final and most important Deliverable (D2.3) of WP2. A scientific paper is now in preparation that will detail the most important results of D2.3. A large number of articles have been published in extension journals (more than 25, mainly in France and Germany), and many of them relate the results of the interviews. The WP2 Deliverables have been extensively used in the final national Conferences of the project, and in the final project Conference in Brussels. The potential interest of European farmers for agroforestry is one of the major results of the SAFE project and induced interesting discussions with different national administration and extension services.

Deliverables and milestones

They are all available on line on the SAFE webs site (http://www.montpellier.inra.fr/safe/)

Deliverables

D 2.1: Database of current silvoarable systems in Europe. Available since month 12. This deliverable will be up-graded in the future, after the SAFE project, by some end-users and research team.

D 2.2: Identification of European target farming systems. Available since Month 36.

D 2.3 (formerly 8.3): Survey of farmers’ reaction to silvoarable systems. Available since Month 42.

Milestones


M 2.2: Maps of the potential target areas for silvoarable agroforestry in Europe. (Achieved in Month 35):

Publications and extension activities during the last period

- Scientific publications
Articles:


All the draft manuscripts are available on the SAFE web site.

Communications to Congresses:


- Extension activities

Oral presentations have been given at the national SAFE Conferences (Paris, Thessaloniki, Madrid, Wageningen) and at Brussels by Fabien Liagre and Christian Dupraz. In France, the results of the interviews have been also presented in each participating region during French regional Conferences (at Besançon, Niort, and Orleans). The slide-shows are available on the SAFE web site. A small booklet has been prepared to send to all the interviewed farmers.

In France, an important publication is expected in June 05, in the magazine of the French Chambers of Agriculture. 20 pages will be offered to document agroforestry and the achievements of the SAFE project. A previous article is expected in April 05.

Some extension articles were published during this period in France, presenting the farmer’s reaction study (they are all displayed on the SAFE website):
- L’agriculture intensive n’offre pas les meilleurs rendements! Science et vie n°1050 - Mars 2005
- Le retour des arbres - La terre de chez nous - 26 Fevrier 2005
- L’agroforesterie : une mobilisation des chambres d’agriculture et de l’INRA - Communiqué de presse APCA - 27 Janvier 2005
- Mètamorphose des campagnes françaises ? FUTURA Sciences - Janvier 2005
- Agroforesterie : des arbres parmi les cultures - Agri79 - 17 Decembre 2004
- Des cultures à l’ombre des arbres L’agroforesterie, une logique de la nature - La terre - Septembre 2004

In Spain, a national meeting for the forestation program (National and Regional Administrations in charge of the afforestation programs) has been held in Ciudad Real, 15th February. Gerardo Moreno participated as an invited speaker and presented the prospect of agroforestry in Europe (Perspectivas para la Silvoagricultura en Europa).

A workshop on Silvoagricultura, cultivo e inversión was organised in Soria, 28-29 October 2004. Organized by CESEFOR-Junta de Castilla y León. Gerardo Moreno and Fabien Liagre participated as invited speakers on the prospect of agroforestry in Spain and the behaviour of farmers faced to this new system (Funcionalidad, manejo y estado actual de la Silvoagricultura). The Spanish television Channel Antenna 3 has interviewed both.

In Italy, with the contribution of Anna Perali, Università di Perugia, Laurea Course in Agricoltura Scienze, a CD Rom in html format was prepared on the extant silvoarable commercial plots that were surveyed within the SAFE Project during the first year of the activity of the project. This CD Rom is part of the student’s final dissertation on the current status of agroforestry systems in Italy. The student will defend the dissertation in April 2005. The CD Rom is in Italian and will be published on the website of the C.N.R. I.B.A.F.
WP 3: SILVOARABLE EXPERIMENTAL NETWORK

Work package number: 3 – Silvoarable Experimental Network
Start date: Month 01 (August 2001)
Completion date: Delayed to Month 38 (30 November 2004)
Current status: Completed
Work Package leader: David Pilbeam, UNIVLEEDS

Objectives and Current Tasks

Objectives

O3.1. To provide field experimenters with a forum to exchange know-how and expertise.

O3.2. To manage field experiments in a sound and concerted way. Duplicated experiments will be identified if any. Emphasis will be given to complementary and well-documented experiences.

O3.3. To provide a unified protocol for basic field measurements accessible to the consortium so that comparable analyses can be done.

O3.4. To provide accurate and quality controlled data from field experiments for model parameterising and testing.

Current Tasks

T3.1. 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 below-ground tree-crop interactions; b) data on the productivity of trees and crops and c) management data for economic modelling. Three management areas can be distinguished: arable crop, trees and tree row under-storey. Important aspects to study are: labour costs and consumable costs under various design and management practices. Look-up tables of parameters and time series of data will be provided to modellers through the SAFE website.

T3.2. 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.

T3.3. Validate models with the field data in a dynamic interaction with modellers.
WORK CARRIED OUT IN THE LAST PERIOD

During the reporting period we:

- Finished to manage field experiments in a sound and concerted way with unified protocols for field measurements.
- Finished to collect data from the experimental sites
- Analysed the data and updated the database.

The methods for achieving this were established in the first year of the project (see first annual report).

The participants of WP3 have had regular contact and discussions on the running of their experiments, the measurement methods, the management practices, the data requirements of the modellers and other matters.

Managing field experiments in a sound and concerted way with unified protocols for field measurements

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 had previously carried out field experiments and had carried out measurements on them according to the experimental protocols agreed in the first two years of the project. Some of these experiments ended during the final period of the project, mostly in terms of analysis of data obtained during earlier growing seasons.
Figure 5: Poplar trees at two of the Experimental Sites. Left; Leeds, UK (Partner 4), intercropped with oilseed rape. Right; Vézénobres, France (Partner 1), intercropped with durum wheat. The Leeds trees were photographed in spring 2003, when they were 11 years old; the Vézénobres trees were photographed in spring 2004, when they were 7 years old. Note how much faster the Vézénobres trees have grown.

Working towards providing data from field experiments in a standardised format for model parameterisation and testing

The database of results from the consortium experimental sites had already been constructed in its final form, and an introductory section (Guidebook to the European Experimental Resource, Deliverable 3.1) had been written before this reporting period. This database represents the main activity of WP3, and is Deliverable 3.2 (Database of Consortium Experiments). It is posted on the SAFE website so that it is accessible by all consortium members.

The database is in use by the modellers in the SAFE consortium, and some of the data are used to verify the Yield-sAFe model in a paper that was finally submitted on May 11 2005 (W van der Werf, K Keesman, M Mayus, R Stappers, P Burgess, A Graves, L D Incoll, D J Pilbeam, C Dupraz and H van Keulen, Yield-sAFe, a parameter-sparse, process-based dynamic model for predicting resource capture, growth and yield in agroforestry systems). Data are also being used for the Hi-sAFe model.

Consortium members have still been collecting data from their experimental sites during the reporting period to add to the database to give longer time spans for datasets.
Collection of data from the experimental sites

Task 3.1 Collect data from existing experiments as required by the modelling activity

Partner 1 (INRA, France) Data were analysed for experiments carried out over the summer of 2004 by staff at INRA-SYSTEM, in particular experiments on tree-crop distance and tree line orientation on hybrid walnuts intercropped with durum wheat at Restinclières, and on tree-crop distance, tree line orientation and tree canopy pruning effects on poplars intercropped with durum wheat at Vézénobres. Details of the experimental results from Restinclières were given in the Third Annual Report, but the data from Vézénobres were only fully analysed in the current reporting period.

The agroforestry system in Vézénobres consists 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, or 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. This is short compared with the life cycles of the silvoarable poplar plantations in Leeds and Cranfield (Partners 4 and 5), which are expected to be at least 25 years. This has given the SAFE scientists access to data from poplars not only of different developmental ages, but also in different climate zones and different growth conditions.

At both sites, 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 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. The tree-crop interactions depend also on the degree of spatial and temporal complementarity. In this context, the trees have been intensively measured over the course of the SAFE project, in particular at Vézénobres. Here phenology, height, diameter, leaf area, sap flow, and root length densities at different depths and distances have been recorded. The above- and belowground studies are described in detail in the reports for WP4 and WP5 respectively.

One objective of the crop measurements is 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 (Report of WP6, part WP6a). Secondly, the field observations aimed to assess the influence of the trees on the growth and yield of durum wheat. This was achieved by measuring its development and grain yields along transects of the tree-crop interface and in the crop control, i.e. outside the influence of trees. All measures were done at 2 distances and 2 orientations from the tree lines. The experimental unit was a subplot (micro-plot) of 1 m², consisting of 7 to 8 one metre-long crop rows parallel to the tree line. The root-pruning treatment of the 2002/3 season was not repeated as it showed no effect on wheat production, and during the 2003/4 season a tree canopy pruning treatment was introduced. The overall treatments 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. Data from these experiments were analysed during the reporting period, and details are given in the Partner 1 Contractors Report.

At the UAM DYNAFOR sites measurements continued at Grazac (experiment on the management of wild cherry and hybrid walnut) and at Pamiers (experiment on wild cherry). At Grazac yield data were determined for an oilseed rape crop intercropped with the cherry and walnut trees that was harvested on days 166 and 167 of 2004. At Pamiers an intercropped maize crop was harvested and the yield components were determined during the reporting period. Details of the yields obtained can be found in the Partner 1 Contractors Report for the current reporting period. Data from these experiments were prepared for publication in two papers, one of which was accepted for publication and one was submitted during the reporting period.

Partner 4 (University of Leeds, UK). During the time of the SAFE project the Leeds site was managed with crops standard to a cereal rotation in the UK. In the 2003/4 cycle winter wheat was grown, following on from oilseed rape as a break crop in the 2002/3 cycle. Details of the cultivation were given in the 36-month report, but harvest of the crop did not occur until into the current reporting period, in August 2004. Details of this harvest are given in the Partner 4 Contractors Report for the current reporting period. Tree growth in 2004 was due to be measured in February 2005, but due to windy conditions this is now scheduled for March 2005. Details of tree growth over the course of the SAFE project, and before, are given in the Partner 4 Contractors Report for the current reporting period.

The Leeds site has formed part of the UK silvoarable network, and was originally funded from another source. That funding finished at the start of year 3 of the SAFE project, but the experiment has been kept operational during the SAFE project. 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. 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). No work on data collection during the reporting period. This site also formed part of the UK silvoarable network up to the middle of year 3 of the SAFE project, and as funding for that project came to an end at that time no further crop has been sown.
Partner 6 (CNR Istituto di Biologia Agro-ambientale e Forestale, Italy) During the reporting period measurements at the two experimental sites continued. At both sites the walnut trees were intercropped with clover (*Trifolium incarnatum* L.) during the 2003/4 season. Measurements included growth of the trees (diameter at breast height, bole height, crown diameter and phenology of leaf fall). Meteorological data were obtained from a local meteorological station.

The work was written up for publication, firstly in the Tesi di Laurea (final dissertation) of a student working on the experimental plots for defence at the University of Tuscia, Viterbo (Italy) in February 2005, and secondly for a paper in the journal ‘Agroforestry Systems’ (Paris P., Pisanelli, A., Todaro, L., Olimpieri, G, Cannata, F.). The Tesi di Laurea is summarised in the Partner 6 Contractors Report for the current reporting period. 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 season (2003 and 2004) in two experimental walnut plantations established in 1992 and 1994, respectively, in the hilly area of Monti Vulsini (Orvieto, Italy), an area of volcanic origin and with a meso-Mediterranean climate The paper for Agroforestry Systems has been accepted, and will be published shortly. Further details of the results are given in the Partner 6 Contractors Report.

Partner 7 (University of Extremadura, Spain) No further experimental data were obtained during the reporting period, although staff at UEX has prepared a synthesis of the most prominent results of the four experimental farms. This will form the basis of a paper to be published in a special issue of the journal ‘Agroforestry Systems’, which will include a selection of papers presented in the International Congress “Silvopastoralism and Sustainable Management”, carried out in Lugo – Spain, April 2004 (see the third year Contractors Report of Partner 7).

Partner 10 (University of Thessaloniki, Greece). No data were collected during the reporting period.

Figure 6: Walnut trees growing at the Restinclières site of Partner 1 (France) at harvest of durum wheat (left) and at the Biagio site of Partner 6 (Italy) in winter (right).
Task 3.2: At the SAFE experimental sites specific information needed to parameterise the biophysical model will be collected

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. INRA-SYSTEM therefore equipped the plots at Restinclières (in 2002) and Vézénobres (in 2003) with piezometers, and the data have been analysed and used for the Hi-sAFe model during the current reporting period.

Analysis of hemispherical photographs taken over the previous growing season 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, was carried out. In 2004 the photographs were taken in May and June. The results of the prior season illustrate that the available daily light is homogenous on the plot with a North-South orientated tree row and heterogeneous for the plot with a West-East tree row orientation. The data are being used to validate the Hi-sAFe model. This requires information of the available radiation around an average tree surrounded by average trees (torus symmetry), as can be obtained by hemispherical photographs. The method was explained in the Second Year Contractor report in the chapter of WP4. Phenological measurements continued, with leaf fall being observed at the end of November 2004.

At the Les Eduts site of Partner 1 work was carried out during the reporting period on characterising the root system of trees in silvoarable agroforestry. Four black walnut (*Juglans nigra* L.) trees were originally 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) have now been 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$^3$. Full details of the work and the results are given in the Partner 1 Contractors Report for this reporting period.

At the Partner 4 site (Leeds) phenological measurements of leaf fall were made. 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.

At the Partner 6 sites (CNR, Italy) phenological measurements of leaf fall of the walnut trees were made. This occurred between September to December 2004.
CONCLUSIONS

Deliverables and milestones

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<tr>
<td>D3.1 Guidebook to the European experimental resource</td>
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<td>M3.2 Report of field measurements and analysis of results of years one and two</td>
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<td>Completed month 28, but extra data (from year 3) have been made available by site managers</td>
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<tr>
<td>M3.3 Database of look-up tables for model parameters derived in years one and two</td>
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1.4 MODIFICATION TO TECHNICAL ANNEXE

In the original timetable, field experiments were due to start in month 4 and were due to finish in month 33. With a six month delay to the start of the project it was impossible to overcome the fixed times of the growing season, so field experimentation ran from month 10 to month 40 (actual start of project occurred on month 9 of the original timetable).

Deliverable D3.2 Database of consortium experiments (originally scheduled for month 26) was completed in month 28, although further data have been made available after the end of the year 3 growing season. This is the database of historical values of tree and crop growth and management practices at all of the field sites. Milestone M3.2 Report of field measurements and analysis of results of years one and two (scheduled for month 27) was slightly delayed as measurements were made over the winter season, and some were not available until month 33. This was completed by the end of month 36, in so far as the analyses of results were included in the reports of individual contractors in the third annual report of the SAFE project. Milestone M3.3 Database of
look-up tables for model parameters derived in years one and two (originally scheduled for month 31) is included in the database that has been completed (Deliverable D3.2). Milestone M3.4 Collation of data for all participating field experiments (originally scheduled for month 40) is now complete as the data are reported by the Partners in the individual Contractors Reports. Deliverable D3.1 Guidebook to the European Experimental Resource (scheduled for month 36) was delivered on time.

It should be noted that WP3 was due to finish in month 28. However, there was an anomaly in the original project description in so far as the timetable in the Technical Annexe shows WP3 being responsible for specific validation field experiments in the third growing season, always scheduled to be after the end of month 28. Data from these experiments have now been made available for modellers to use for validation of their models. The data have been used for WP4, WP5 and WP6.

1.5 **FUTURE WORK AFTER THE SAFE PROJECT**

The main activity of WP3 has been completed for some time. Now that the Site Managers and the modellers are familiar with the experiments in progress at the consortium Experimental Sites it is likely that collaborations between individuals and groups of SAFE consortium members will lead to new experiments being carried out in the future. All of the sites have several years until the trees are due to be felled, and it is anticipated that consortium members will continue to monitor tree and crop growth during that time on several of the sites. These data will give information on productivity of silvoarable agroforestry at the later stages of tree growth, including data on Land Equivalent Ratios. It is also possible that there will be collaborations between the managers of the Experimental Sites and the tree physiologists in the consortium on experiments designed to increase our understanding of tree and crop growth, and the interactions between trees and crops.

However, it must be recognised that two of the experimental sites (Pamiers and Grazac in France) will not be maintained, as the consequence of a decision by INRA that agroforestry was not a priority of research for the local Toulouse team. Similarly, both the Leeds and the Cranfield experiments in the UK have no funds for further monitoring of the plots. Monitoring long-term experiments is always a very difficult issue.

1.6 **SIGNIFICANT DELAYS**

None during reporting period.

1.7 **PUBLICATIONS**


WP 4: MODELLING ABOVE-GROUND TREE/CROP INTERACTIONS

Work package number: 4 – Above ground interactions
Start date: Month 04 (01 November 2001)
Completion date: Month 36 (31 August 2004)
Current status: Completed
Partner responsible: INRA
Work Package leader: Christian Dupraz (INRA-SYSTEM)
Person months of WP4: 84.0

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The total of person-month allocated to the WP is very close to the Technical annex. However, the INRA part was less than expected, but the UEX part was more than expected. The INRA shortage is mainly related to the failure of the development of a microclimate interaction module, and to the low commitment of the INRA APC team.

OBJECTIVES

These are unchanged from the Technical Annex.

Objectives

To design and validate sub models for aboveground tree-crop interactions that are relevant to both crop and tree growth. Emphasis will be given to light and transpiration partitioning between trees and crops. The light model will 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. The aboveground models will be derived from comparisons between existing models, where the most sophisticated one will serve as a reference to test assumptions and then to derive a simple model.
Current Tasks

T4.1. Characterisation of the above-ground space occupied by trees and crops, in 3 target experimental sites as identified by WP3, 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.

T4.2. Select and modify an appropriate model for describing, analysing and predicting partitioning of light and transpiration between trees and crop. The resulting transpiration model will take into account light microclimate as predicted by the light module and measured microclimate variables (air temperature, humidity and wind speed). Mechanistic models will be used to formulate and test the approximations of more ‘coarse grained’ (or simple) model. Water availability will be considered as non-limiting at this model level. Water status and related plant regulation aspects will be introduced in WP6.

T4.3. Improve or design a model for the effect of the tree-crop canopy on local microclimate, i.e. the ‘forest ambience’ (air temperature, humidity, wind speed). Collation of algorithms for generating daily climates from public domain synoptic weather records will be performed.

T4.4. Improve or 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 will 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.

PROGRESS DURING THE FINAL 6 MONTHS

WP4 had almost competed its activity during the third year of the project. During the last 6 months of the project, the main activities were limited to:

- Improving the Hi-sAFe light competition module
- Monitoring some additional data about above-ground competition such as tree fall phenology or tree transpiration measurements in some experimental fields
- Analysing previously recorded data about tree-crop competition for light
- Using the Hi-sAFe model to improve the simplified Yield-sAFe above-ground model by calibrating the $K_t$ parameter of Yield-sAFe

Improving the Hi-sAFe light competition module (INRA-System)

Field observations show that branches of mature deciduous (without leaves) trees produce significant shade in winter. This reduction of light can affect winter crop physiology. A simple way to account for the branch shade was to assume that a low leaf area density was still present in winter. This has been added to the Hi-sAFe phenology module. To simulate trunk and branches shade of trees before bud burst and after leaf fall, field measurements are necessary (hemispheric pictures) to get a value for the new parameter that is called $winterVirtualLad$ with a default value of 0.03 m$^2$ m$^{-3}$. However,
this modification implies that the light module is now executed even in winter season, which significantly slow the model runs.

Figure 7: Hi-sAFe outputs showing how a 8 meter high walnut tree significantly shades the crop at noon, on 21st December (2 months after leaves fall)

While testing, it appeared that the Hi-sAFe light module did not predict correctly the interception of direct light by the tree on the scene when both the cells are small and the scene is large compared to the canopy size. The problem is more serious when the tree canopies are high and narrow, such as for poplars. This was the consequence of direct beam interception being calculated only five times a day. In that case, some cells escaped the direct shade of the canopy, and this resulted in incorrect direct beam maps on the scene (Figure 8, top).

The solution consisted in running the direct interception routine more frequently each day. In the last version of Hi-sAFe, the number of calculations per day is a parameter that the user can tune in the range 5 to 11. A further improvement would be an automatic optimisation of this parameter by taking into account the size of the cells, the width of the canopy, the height of the canopy and the height of the pruned part of the tree.

However, it can be checked on Figure 8 (bottom) that even with 11 calculations per day, some anomalies still exist at a distance of the tree canopy larger than two diameters of the canopy. Projected shades of the canopy are still disjoined, resulting in direct shading being underestimated for some cells.
Figure 8: Hi-sAFe prediction of the daily integrated tree shade, the 15th of May, with different frequencies of direct beams interception: 5 times a day above and 11 below.

Note that the integrated daily radiation map exhibits a banana-shaped shade that is very close to the a priori shape that we used in the further steps of the design of the Hi-sAFe model.

Figure 9: Assumption of the integrated daily shade of an isolated tree as hypothesised during the WP1 work on the Hi-sAFe concept (The North is in the right top corner).
Monitoring some additional data about above-ground competition such as tree fall phenology or tree transpiration measurements in some experimental fields

This was done at INRA sites of Restinclières and Vézénobres for leaf fall, and at INRA site of Vézénobres for sap flow measurements. More details are available in the contractor report.

Analysing previously recorded data about tree-crop competition for light

This was performed by INRA-System and CNR

Durum wheat yields in a mature poplar silvoarable system (INRA-System)

Figure 10: Field layout with measurement points (micro-plots) at Vézénobres

The agroforestry system in Vézénobres consist 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 or, even, in
Europe. The poplar plantations showed a fast growth in height and diameter, and we expect that its life cycle will be not more than 10 - 12 years. This is short compared to the life cycles of the silvoarable poplar plantations in Leeds and Cranfield (both in UK), which are expected to be at least 25 years.

Hemispherical photographs were taken 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. In 2004, the photos were taken in May and June. The results of the prior season illustrate that the available daily light is homogenous on the plot with a North-South orientated tree row and heterogeneous for the plot with a West-East tree row orientation. The data will be used also to validate the model Hi-sAFe. This requires information of the available radiation around an average tree surrounded by average trees (torus symmetry), as can be obtained by hemispherical photographs. The method was explained in the Second Year Contractor report in the chapter of WP4.

In 2002-2003, a root pruning (= root trenching) treatment was set up in both plantations. Roots were cut at 2 and 3.5 m from the tree line. This treatment appeared to have no impact on the water competition between trees and crops and a limited effect on tree performance. Therefore, the root pruning treatment was not further investigated during the growing season 2003 – 2004. The forestry control plots are disked twice a year to limit weed proliferation.

In April 2004, a new treatment was included in the agroforestry systems, i.e. two different tree canopy pruning height (6 m is the standard, 10 m is the extra high pruning).

The poplar trees of both plots were measured for height and diameter at breast height (i.e. at 1.3 m) in January 2005. In November 2003, the poplars reached a height of about 20 m.

The major phenological dates, i.e. start, finish and date of 50% of a) bud break and b) leaf-fall in were observed. In 2003, bud break started at the beginning of April (around DOY 95) and leaf fall was monitored at the end of November (around DOY 327). In 2004, the dates were very similar.

### Tree management

<table>
<thead>
<tr>
<th>Day of year</th>
<th>Date</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>Extra high canopy pruning in blocks</td>
<td></td>
</tr>
<tr>
<td>Forestry plantation disked</td>
<td></td>
<td></td>
</tr>
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Table 1: Calendar of tree management at the Vézénobres farm in 2003-2004

Durum wheat management
<table>
<thead>
<tr>
<th>Day of year</th>
<th>Date</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>329</td>
<td>25.11.03</td>
<td>Sowing (150 kg ha(^{-1}))</td>
</tr>
<tr>
<td>5</td>
<td>1(^{st}) week Jan</td>
<td>Fertilisation (ammonium nitrate: 180 kg ha(^{-1}))</td>
</tr>
<tr>
<td>56</td>
<td>Last week Feb</td>
<td>Weeding (Hussard: 1 l ha(^{-1}))</td>
</tr>
<tr>
<td>62</td>
<td>1(^{st}) week March</td>
<td>Fertilisation (sulfamox: 250 kg ha(^{-1}))</td>
</tr>
<tr>
<td>108</td>
<td>15 - 20 April</td>
<td>Fertilisation (ammonium nitrate: 180 kg ha(^{-1}))</td>
</tr>
<tr>
<td>111</td>
<td>21 April</td>
<td>Fungicide application (OPONAN)</td>
</tr>
<tr>
<td>120 / 182</td>
<td>30.4 + 1.7</td>
<td>Hand weeding of the micro plots</td>
</tr>
<tr>
<td>200</td>
<td>19.07.04</td>
<td>Harvest</td>
</tr>
</tbody>
</table>

Table 2: Calendar of durum wheat management at the Vézénobres farm in 2003-2004

During the season 2003-2004, we concentrated the observations on plots with the poplar cultivar I214. The root-pruning treatment was not repeated, since it showed no effect on wheat production. A new treatment was included in the agroforestry systems, i.e. tree canopy pruning. The overall treatments were:

\[ 2 \text{tree row orientations} \times 2 \text{plot orientation} \times 2 \text{pruned/ unpruned} \times 2 \text{distances} \]

All measurements were done on all treatments (micro-plots).

The influence on crop growth was observed till maturity in a two-week interval. Measurements included: crop height, the phenological stage (Zadoks scale) and the number of organs (brown and green leaves, tillers). At each micro-plot, 5 plants representative for the location were randomly selected. The measurement of flowering (onset, 50%, 100%) and maturity (onset, 50%, 100%) were the most important stages.

In Mid-June, on DOY 200, the harvest took place about 229 days after sowing. The crop has achieved physical maturity, but the drying of the grains was not finished at all measurement locations. The number of difference in DOY when physical maturity was achieved was visually measured in all micro-plots. The micro-plots plots were harvested manually (hand clipper) after weeding. The plants were cut at ground level and the fresh weight of the sample was measured. Then the number of panicles were counted and cut from the stem and their fresh biomass was weighted too. For each micro-plot a sub-sample of 60 panicles was randomly selected for grain weight, fresh and dry (48 hours at 60 °C).

The weather of the growing season 2003-2004 was rather dry as usual for the region (Figure 11). However, during the early crop establishment the plots were heavily flooded. In particular in plot 1997 the water in the vicinity of several poplar rows was causing a delay in crop development and at some places even death of plants. Nevertheless, we could find reasonable sampling points.
In 2004, the grain yields of durum wheat in the poplar agroforestry stand were highly reduced compared to the monocropping control plots (Table 8). Overall the reduction was about 50%, with large differences between the treatments. At the first glance, two major effects can be distinguished: pruning and orientation of the plots, while the distance to trees appears to be less important (Figure 5).

<table>
<thead>
<tr>
<th>Agroforestry treatment</th>
<th>Yield in agroforestry (AF) T/ha</th>
<th>Yield in crop control T/ha</th>
<th>Ratio Yield AF/ Yield control</th>
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</thead>
<tbody>
<tr>
<td>All agroforestry plots</td>
<td>1.94</td>
<td>4.11</td>
<td>0.47</td>
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<tr>
<td>Plot 96: Tree row N-S</td>
<td>2.08</td>
<td>2.38</td>
<td>0.40</td>
</tr>
<tr>
<td>Plot 97: Tree row W-E</td>
<td>0.97</td>
<td>2.35</td>
<td>0.31</td>
</tr>
<tr>
<td>Plot 97: Tree row W-E*</td>
<td>0.97</td>
<td>2.35</td>
<td>0.24</td>
</tr>
<tr>
<td>Plot 97: Tree row W-E**</td>
<td>0.97</td>
<td>2.35</td>
<td>0.19</td>
</tr>
</tbody>
</table>

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

**Table 3: 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 (ratio yield plot96/ yield plot97 was 0.82 in 2003 and 0.61 in 2004) may also refers to the shade cause. 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 (Table 7). Soil analysis will show if also difference in soil fertility played a role.

The impact of the pruning regimes on wheat yield was impressive in the 1997 plot but less pronounced in the 1996 plot (Figure 12). 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 (Figure 7). The standard errors (not presented) are large, due to a combination of few repetitions and large spatial variability. In the East-West tree rows plot, it must be noticed that the best yields were observed NORTH of the poplars in 2004, which is the contrary to 2003. This can be explained by the simultaneous effect if tree height increase and high pruning. Tree height increase moved the sunshade further north, where it reached the next tree row, while high pruning allowed this light to reach the zone situated North of the trees. This total change in only one year illustrates the fast dynamics of a silvoarable system. The researchers advised the farmer not to seed the zone north of the trees, but the farmers did seed. He was right!

From these data, is it possible to conclude that shade is the limiting factor for the 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. What we observe is a non-symmetrical impact well correlated with the light availability that suggests that light is the limiting factor.
In plot 97, the higher yield on certain micro-plots can be explained by a higher number of grains and an elevated “1000 grain weight” (Figure 13). The higher number of grains is mainly the result of the grain number per panicle, while the number of panicles is only affected in the north of unpruned tree. The latter are the plots with the lowest light availability. In plot 96 with generally more light (Figure 14), there is almost no effect on panicle numbers and grain weight (not presented), and the small effect occurs only in the vicinity of the trees. Figure 15 presents the correlation between light availability and grain yield and yield components.

Figure 13: Number of panicles and grains of durum wheat on micro-plots at different distances and orientations from a pruned and unpruned poplar row, Vézénobres in 2004

Figure 14: 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 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. At 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 the more shady the micro-plots. Data are currently analysed.

In general, the findings of the growing season 2003-2004 confirm the results of the prior season. As in 2003, the influence of 7 m tall walnut trees on the winter crop was negligible, while the reduction of durum wheat in the 20 m tall poplar plantation was remarkable.

The major conclusions that can be drawn are:

- In Restinclières, the walnut trees are still to small to affect significantly the crop yield. The late leafing date of the trees limit the shade impact, and their deep rooting pattern limit the water competition.

- At Vézénobres, the mature poplar trees are at a very high density for an agroforestry plot (156 trees/ha). Light competition is now strong, as a result of both early leafing and large tree sizes. The poplars have a deep rooting pattern that also limits water competition. Therefore, light competition seems to play a key role.

- Canopy pruning of poplars was very effective for maintaining crop yields, due mainly to shade reduction, but also possibly to a reduced water competition.

- In 2003, root pruning had no effect on wheat yields, because trees used the water at a deeper soil depth than the crop. Therefore the impact of root pruning on crop yield was not measured in 2004.
Figure 15: Relation between light availability and yield components: grain yield, number of grains per panicle, number of panicles per area, weight of 1000 grains

At Restinclières, by the time the walnut is developing its leaves (start and end of budburst was DOY 110 and 156, respectively), the crop was already flowering and suffered only few from shading. Similar competition for water and nitrogen are restricted to a short and less important phase in the crop life cycle. In addition, the root studies showed that an important part of tree roots are developed at much deeper soil depths than the zone occupied by durum wheat roots.

At Vézénobres, the crop yield in the alley of poplar trees was hardly affected during the first four years of the agroforestry system (i.e. 1997 –2000). Subsequently, with the increase of the poplar canopy size, the grain yield was progressively reduced. In 2001, the reduction was about 20% (3.7 t/ha AFS and 5 t/ha crop control), in 2003 and 2004 about 50%. In 2004, the grain yield of durum wheat outside the influence of trees (average of control plots 4.1 t ha$^{-1}$) was higher than in the growing season of 2003 (average 3.4 t ha$^{-1}$), partly due to better weed control. Without additional pruning, the yields keep dropping in 2004: 40% in the 1997 plot, 30% in the 1997 plot. But the additional pruning was very effective in increasing the crop yield to 50% in the 1996 and 70% in the 1997 plots.

In 2004, the distance to the poplar row had a minor role on crop production. In the last year the poplar trees were tall with large (partly each other touching) canopies, hence light was more homogenous distributed over the transect of an alley.
Water competition cannot be excluded, but the results suggest that in view of competition radiation was predominantly affecting the yield.

**Wheat and clover yields in a young but dense walnut system (CNR)**

During the reporting period CNR carried out activities in the experimental fields 1 and 2 of Biagio (see WP3 report), concerning in analysing data already recorded or measuring the leaf shedding of walnut trees in the period September-December 2004. Walnut leaf shedding data of the year 2004 were collected according to the common SAFE protocol for tree leaf phenology.

Formerly collected data were analysed and put in relation with the growth of intercrops (as plant height) during the years 2003 and 2004. An interesting aspect is that wheat and clover intercrops react differently to the walnut competition (Biagio 1). Wheat yield were negatively affected by increasing tree size (Figure 16) while clover yield was not affected by increasing tree size (Figure 17). The main explanation may be that clover is a cool season crop. It grows early before walnut full leaves emission.

![Decreasing wheat yield with increasing tree size](image)

**Figure 16. Biagio 1, Orvieto (Tr). Relationship between walnut stem basimmetrical area (G) and decreasing production of intercropped wheat in comparison with sole wheat.** * = significant for \( p \leq 0.05 \), ** = highly significant for \( p \leq 0.01 \).
Figure 17. Biagio 1, Orvieto (Tr). Relationship between walnut stem basal area (G) and intercropped clover yield in comparison with sole clover. G is function of tree stem diameter (DBH) and tree spacing; being tree spacing constant, as in most of our experimental plots, G varies with DBH or tree size. n.s = not significant.

However, it must be stressed that in Biagio 1 silvoarable plantation the tree spacing of 6 x 7m that is definitively too dense for a silvoarable plantations. With a lower tree density, the negative impact on the wheat yield would be observed at a much later age for the trees.

Using the Hi-sAFe model to improve the simplified Yield-sAFe above-ground model by calibrating the $k_t$ parameter of Yield-sAFe

$k_t$ is the radiation extinction coefficient of the tree leaf canopy and it appears in the Yield-sAFe equation that predicts the fraction of radiation intercepted by the trees in the agroforestry system: $f = 1 - e^{-k_tL_t}$, where $L_t$ is the leaf area index of the tree stand (m$^2$ tree leaf area per m$^2$ silvoarable stand. The Yield-sAFe model does not include an explicit desegregation of the tree canopies over the silvoarable plot, and assumes that the tree leaf area is spread over the whole agroforestry plot. The assumption made in Yield-sAFe was that the usual extinction coefficients of tree canopies could be applied to this equivalent leaf area over the whole silvoarable scene.

The $k_t$ parameter has a large relative effect on the predicted LER (cf. WP6b report). The nominal value assumed was 0.8. However, this resulted in a questionable pattern of tree-crop competition: it resulted in a long-term overestimation of tree growth. Reasoning from existing literature on light distribution in crops 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.

The Hi-sAFe model was therefore used to calculate the Yield-sAFe $k_t$ value for a range of tree densities (10 – 50 – 100 – 400 trees per hectare) and of tree sizes (1 – 10 – 100 – 300 m$^2$ of leaf area per tree). We used the Hi-sAFe model to calculate the average radiation available on the ground of the silvoarable plot at the day time step. Then a $k_t$ value was fitted to the Yield-sAFe equation so that the distance between the two estimates is minimized over the whole growing season of the trees. The winter period
with no tree leaves was not included in the fitting calculation. Hi-sAFe settings included a fixed leaf interception factor of 0.85, tree canopies were assumed to be ellipsoids with an homogeneous leaf area density, the diffuse radiation was modelled by a turtle with 48 directions and the Standard OverCast (SOC) distribution, and the direct radiation was recalculated when the tree leaf area had changed by 5% or the sun elevation has changed by 2 degrees.

100 trees/ha of 14 m² leaf area per tree resulted in a fitted $k_t = 0.54$

**Figure 18 : Fitting a $k_t$ value to match Plot-sAFe predictions and Hi-sAFe predictions of radiation availability at the ground level in a silvoarable plot**

Adequate Hi-sAFe settings were used to "see" small trees in a huge scene for low density / small trees scenes. There is a limit in Hi-sAFe for the LAI of trees, due to tree-tree competition: we could not get tree LAI values above 6.6. This means that the "1000 m²" trees are in fact smaller at density of 100 and above. The leaf area of a single tree is indicated in the last table.

Hi-sAFe is taking into account the 3D geometry of the system. A clear example of this is that when the leaf area of the tree is constant (after the end of the long shoots expansion until the beginning of the leaf fall), the leaf interception of the tree varies with the sun declination. Yield-sAFe cannot take this into account, and predicts a stable light interception when the leaf area is stable, irrespective of the sun elevation.

<table>
<thead>
<tr>
<th>Fitted $k_t$</th>
<th>Tree leaf area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tree density</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>(tree ha⁻¹)</strong></td>
<td>10</td>
</tr>
<tr>
<td>100</td>
<td>0.58</td>
</tr>
<tr>
<td>400</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Cells in red could not be simulated with Hi-sAFe due to the very small size of the trees; pink cells correspond to implausible tree stands (too high density for the size of individual trees)

**Table 4 : $k_t$ values for Yield-sAFe predicted for various silvoarable stands of walnut trees**
It finally appears that appropriate $k_t$ values for the Yield-sAFe model should not be constant with the age of the tree. The suitable range was from 0.85 for very small trees to about 0.2 for very large trees.

As a consequence, using Yield-sAFe with a fixed value of $k_t$ across the tree life induces an overestimation of the interception of the tree light by the tree component when the trees become large, and this was observed in the former Yield-sAFe calculations. Using the nominal and constant value of 0.8 resulted in large overestimations of the interception of light by the trees (Figure 18).

Similarly, using Yield-sAFe with a fixed value of $k_t$ across the growing season induces an underestimation of the tree light interception in spring and autumn (low sun elevation), and an overestimation in summer (high sun elevation). This may induce that Yield-sAFe unduly favours winter crops.

The impact of the tree density on the optimised value for $k_t$ was less noticeable. $k_t$ is slightly increasing with tree density for medium size trees.

If we ignore the seasonal (sun elevation) effect on $k_t$ and look for a stable annual value that would depend on the tree size and density, the following equation was produced:

$$k_t = -0.187 \log(\text{Tree Leaf Area}) + 0.000299 \text{ Tree density} + 0.717 \text{ with } r^2 = 0.97$$

This suggestion of a phased $k_t$ that decreases with time was finally included in Yield-sAFe.

![Figure 19: Fitted $k_t$ are well correlated with the leaf area of trees.](image)

Silvoarable Agroforestry For Europe Project – Fourth Year Report – Volume 2
CONCLUSIONS

Deliverables and milestones

WP4 had two deliverables. The first one is the description of the aboveground modules of the Hi-sAFe model, and is available since Month 26. It was however updated regularly to incorporate progresses on the modules.

The second one is the collation of scientific papers published on aboveground interactions. Only one scientific paper was accepted so far within this deliverable, which is not a good performance. Two were submitted, and three are in preparation.

<table>
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<tbody>
<tr>
<td>D4.1. Light partition and microclimate modules</td>
</tr>
<tr>
<td>(includes carbon acquisition and allocation)</td>
</tr>
<tr>
<td>Available on the SAFE web site and on paper on request</td>
</tr>
<tr>
<td>D4.2. Scientific papers on aboveground tree-crop interactions</td>
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<table>
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<tbody>
<tr>
<td>Delivered Month 26</td>
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<tr>
<td>Scientific papers are added on the SAFE web site when they are submitted (private section) or accepted (public section) for publication</td>
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The papers and posters available so far for deliverable 4.2 are the following:


### Milestones

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<th>Status</th>
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<tr>
<td>M4.1: Mock-ups of virtual trees for 4 key species available</td>
<td>Achieved month 34 for the three main tree species (Juglans, Prunus, Populus)</td>
</tr>
<tr>
<td>(following CMC2, 3 species expected : Poplar Wild Cherry and Walnut)</td>
<td></td>
</tr>
<tr>
<td>M4.2: Simplified model running at the day time step release</td>
<td>Achieved month 30 (look at Deliverable 6.2)</td>
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### Significant Difficulties or Delays Experienced during the Full Project

The major difficulty that we had to face during the whole project for the aboveground part of biophysical modelling was the integration of the transpiration interaction microclimate module into the Hi-sAFe model. We finally decide not to include such an interaction module. In fact, many participants feel that the interaction between tree and crop transpirations may be only marginal in the global water balance of the silvoarable system (may be except in some oasis types of silvoarable agroforestry). Note that what is not included in the model in the impact of one component of the mixture on the other through the modification of the local water vapour demand of the air as a consequence of its transpiration. This effect may be strong in some limited sets of conditions: low wind conditions, large leaf area index of the trees, significant difference in water stress between the crops and the trees. Such conditions are not common. This is why this failure to provide this module was not considered as a problem for the whole project.
WP 5: MODELLING BELOW-GROUND TREE/CROP INTERACTIONS

Work package number: 5 - Modelling belowground tree/crop interactions
Start date: Month 4 (November 2001)
Completion date: Month 36 (July 2004)
Current status: Completed
Work package Leader: Nick Jackson (NERC -CEH Wallingford)
Person months of WP5: 76.5

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<td>5.0</td>
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</table>

OBJECTIVES

Objectives

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.

No modifications have been made to the objectives in this final reporting period.
Current Tasks

WP5 comprises 4 specific tasks. Two modifications were made in the previous reporting period and are detailed in the second annual report:

T5.1a. Design and writing of simplified modules for water extraction and sharing, and nitrogen competition between a tree and a crop.

T5.1b. Design and writing of a separate module to simulate tree root growth in a dynamic fashion, in response to local soil conditions.

T5.2. Validation of the simplified modules by using more detailed models that are available but could not be used in the general model.

T5.3. Specific experimental protocols to be designed to be set up on existing silvoarable plots of target systems identified by WP3, using water flux characterisation (sap flow in roots and stems; soil water content monitoring; natural stable isotope tracing).

WORK CARRIED OUT IN THE LAST PERIOD

Task 5.1. Design and writing of a simplified model for water extraction and sharing between a tree and a crop.

The details of the belowground model were provided in previous annual reports. INRA and NERC staff undertook some final work during the final six months on refining the model. Although some of the more complicated aspects of belowground competition for nitrogen could not be included in the final model, it was judged to be a good attempt at simulating the behaviour of tree and crop roots in agroforestry systems as their roots compete for limiting water resources. It is hoped that work will go on with the model after the project has completed.

Modelling tree root growth and development continued in the final six months, and the model is able to simulate a tree root system that is asymmetrical in all directions in response to heterogeneous soil conditions found around the tree trunk.

In the last 6-month period ICRAF (as sub-contractor to INRA) contributed to this task and focused on producing an algorithm for water and N uptake. The final products that available are:

1. Water uptake algorithm: as a document and its instantaneous implementation in excel worksheet

2. N uptake algorithm: as a document and its instantaneous implementation in excel worksheet

3. Three draft manuscripts:
   i. A process-based algorithm for sharing nutrient and water uptake between plants rooted in the same volume of soil I. Water in static root systems
Field-based and controlled-conditions experiments continued (as described in the previous annual project report), designed to collect data needed to parameterise both the water competition module and the second module that deals with tree root growth and development.

Task 5.2. Validation of the simplified model by using more detailed models that are available but could not be used in the general model.

It had been intended to use a couple of PhD students to look at this task as the main of their theses. In the event, it was not possible to find students and the amount of time left to complete this task meant that the Hi-sAFe model could not be tested against more detailed models. It is possible that this might be accomplished after the project has ended.

Task 5.3. Specific experimental protocols will be designed to be set up on existing silvoarable plots of target systems identified by WP3, using water flux characterisation (sap flow in roots and stems; soil water content monitoring; natural stable isotope tracing).

Groups working with field experiments in France and Spain conducted most of the work on this task during the final reporting period.

**Partner: INRA-System, France**

**Objectives**

As described in previous reports, the root voxel automata is an important aspect of the Hi-sAFe model, including 6 parameters that describe the sensitivity of root systems to soil heterogeneity. To calibrate these parameters, container experiments were set up with hybrid walnut and wild cherry trees grown in containers, and final root densities were assessed in November and December 2004. Further work in continuing to determine how to use these data for calculating the parameters for Hi-sAFe, and will
form part of the Ph. D. thesis of Rachmat Mulia who is due to defend his thesis in May 2005. The details of these container experiments were presented in the previous SAFE reports (and are repeated in the INRA-System contractor report for this period). Excerpts with interesting results are shown below.

**Results**

**Experiment with localised soil water supply**

The distributions of fine root biomass (g dm\(^{-3}\)) of walnut and wild cherry used in the experiment of localised soil water are shown in the figure below. The description was performed for each horizontal layer using SURFER software (Golden Software Inc, Colorado, USA). The heterogeneous soil water condition strongly affected the growth of the walnut root system (A, top row). Roots were more concentrated in the areas close to the irrigated soils and this situation can be regarded in the second, the third, and the last soil layer. However, the highest root concentration was found in the last layer and not the third soil layer. This fact likely indicates that water largely infiltrated to the bottom of the pot, which would make the soil area directly beneath the probe position very favourable for root growth.

**Figure 20 : Impact of a localised water supply on the root distribution pattern of walnut and wild cherry trees**
For wild cherry, there was no replication: the second tree did not survive, and the reliability of the water distribution is doubtful. In July 2004 we found that the plastic drip tube leaked and the pot was flooded. This accident might have contributed to absence of any effect of the localised soil water supply on the tree root distribution (B, bottom row).

**Experiment with localised nutrient supply**

The effect of localised nutrient supply (below) on the root system of walnut (A, top row) and wild cherry (B, bottom row) was impressive. In the third perlite layer, roots were clearly more concentrated inside the nutrient-enriched areas. It is worth noting that we watered the trees with 1 litre of nutrient solution every week, and therefore roots may grow well in other areas.

![Graph showing root distribution pattern](image)

**Figure 21 : Impact of a localised nitrogen supply on the root distribution pattern of walnut and wild cherry trees**

Intriguingly, we found that overall root distribution pattern of walnut and wild cherry was different. The bulk of wild cherry roots were found in the top 12.5 cm perlite layer and it was not the case with walnut root system. In the latter, the roots were more developed in the second layer with relatively higher concentration in deeper perlite layer. Related to the number of tree uprooted, we had two walnuts but only one wild cherry was available.
Experiment to verify the ability of roots going upwards

Walnut root density (g dm\(^{-3}\)) in pots with homogeneous and heterogeneous growing condition is shown below (A, top row) and (B, bottom row) respectively. In both situations, roots of walnut were able to grow upwards and were found in the first two layers. The fact that roots go upwards may be actually due to genetic rooting behaviour or nutrient supply in the first two upper layers. However, it is clear that if the upper layers are attractive in terms of nutrients then fewer roots would be found deeper and more would go upwards.

A) Perlite substrate in the whole container

B) Soil substrate in the two top layers and perlite in the two bottom layers

The letter ‘T’ indicates plant position. The black rectangle indicates position of root barrier.

Figure 22 : Experimental demonstration of the ability of walnut roots to grow upward (roots in the top two layers come from the deepest layers).

Conclusions

Analysis of the considerable amount of data from the above experiments (and others mentioned in the contractor report) could not be completely finished by the time of reporting. Nevertheless, the remaining data will be analysed, and the provisional conclusions for the Hi-sAFe model are as follows:

- Tree root systems react rapidly to soil heterogeneity: this was the central hypothesis for designing the root module of Hi-sAFe. It is confirmed.
- Both tree species react similarly to soil heterogeneity. This results in a distortion of the reference-rooting pattern that they exhibit in a homogeneous soil.
• We hypothesize that the same parameters will correctly describe the root sensitivity to soil heterogeneity for the two tree species.

• Global vertical and horizontal heterogeneity have very different impacts on tree root systems.

• Horizontal heterogeneity is more effective in distorting root growth. A favourable soil zone attracted tree roots (with about twice as many roots in the fertile soil as compared to the perlite zone for both tree species). This is very important for agroforestry, because agroforestry is the only system where horizontal heterogeneity is systematically occurring due to the patterns of extraction by the different neighbouring species.

• Vertical heterogeneity has less impact on the root distribution: unfavourable layers are less colonized, but the whole profile remains similar to the reference pattern. This is common in most soils and cropping systems.

It is difficult to compare the relative strength of the water and nutrient heterogeneity with our experiments. The most impressive distortion was obtained with the water heterogeneity for walnut and for the nutrient heterogeneity for wild cherry.

Finally, we must admit that for quantifying the reaction of tree root systems to soil heterogeneity, more intensive monitoring of soil variables would be necessary in 3D, and this was not within our possibilities during this project.

**Partner: INRA-Toulouse, France**

**Objectives**

During the 6 last months of the SAFE project, research activities of DYNAFOR team consisted of achieving root descriptions of two black walnut trees at Les Eduts (one in a silvo-arable field and one in a forest stand) as mentioned in the previous report.

Excerpts from these activities and some of the related results are presented below. Full details are provided in the contractor report. Root descriptions were made using two different techniques:

For the first tree, the root system was divided into elementary segments considered as homogeneous for direction. For each segment several parameters were registered:

- distance to the trunk centre of the beginning of the segment
- depth to ground surface of the two ends of the segment
- diameter of the two ends of the segment
- azimuth of the segment

Each root was removed after descriptions were made in order to avoid confusion between roots. Unfortunately, it has not yet been possible to describe all the roots.
because of the difficulty to clear them. With this operation, it was possible to describe 163 root segments of a total length of 70.70 m and a volume of 0.242 m$^3$. The average diameters of the segments were 46 mm (beginning, range: 180-9) and 35 mm (end, range: 126-2).

For the second tree root system a 3D digitiser connected to a computer was used. By clicking at the beginning and at the end of each elementary segment of the root system, it was possible to record the 3D position of the segment; at the same time, diameter at the two ends of the segment has been measured with a calliper and recorded on the computer. 270 roots (269 + stump and taproot) have been observed through the description of 1290 root segments of an average length of 14 cm. The main parameters of the root system (from F. Danjon calculations) are presented below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Total root length (m)</td>
<td>177</td>
</tr>
<tr>
<td>Total root volume (m$^3$)</td>
<td>0.129</td>
</tr>
<tr>
<td>Stump and taproot volume (m$^3$)</td>
<td>0.014</td>
</tr>
<tr>
<td>Total root volume without stump &amp; tap root (m$^3$)</td>
<td>0.105</td>
</tr>
<tr>
<td>Maximum radial distance from the trunk (m)</td>
<td>4.69</td>
</tr>
<tr>
<td>Maximum depth of roots (m)</td>
<td>1.08</td>
</tr>
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</table>

Table 5: Main characteristics of an uprooted and digitised black walnut tree at Les Eduts forestry site

From digitising, 3D views of the root system of F1 tree were obtained. The comparison between a photograph and the 3D view with the same orientation suggests that it is possible to get rather faithful representations with the digitising technique.
Figure 23: The excavated root system of a black walnut tree at Les Eduts and its digitised image (Picture F. Danjon)

It is also possible to analyse the root distribution according to depth and orientation. First observations suggest that the root distribution of trees in a forest stand such as F1 trees are not dependent on the row direction. It may depend whether distances between two next trees in the row and between the rows are the same (7m in our situation) or not.

Concerning the spatial distribution of tree roots, using the digitising technique in silvo-arable plots would give information on the effect of intercropping on the tree root development. Unfortunately, it is necessary to clear roots previously and this needs a lot of time especially if the soil is stony like at Les Eduts.

Partner: UEx, Spain

UEx continued with some of the experiments initiated in previous years and presented in previous reports. In brief, these activities are summarised in the following list:

- Continuing soil water dynamic measurements of Dehesa systems (study still ongoing).
- Following up the experiments to study the root dynamics of poplar and Holm oak, in order to parameterise the cellular root automata developed Rachmat Mulia and Christian Dupraz in the context of the SAFE project (work also ongoing).
- This year we have presented two communications to International Congresses (Annex 2.1 and 2.2) and we have written a paper (Annex 1.6):
Gerardo MORENO and José Jesús OBRADOR. 2004. *Consequences of Dehesa land use on nutritional status of vegetation in Central-Western Spain*. International Symposium “Forest soils under global and local change: from research to practice”, which was carried out in Bordeaux (France) in September 2004. (Annex 2.1).

Elena G and Obrador JJ. 2004. *Consequences of Dehesa land use on nutritional status of vegetation in Central-Western Spain*. International Symposium “Forest soils under global and local change: from research to practice”, which was carried out in Bordeaux (France) in September 2004. (Annex 2.2).


**CONCLUSIONS**

**Deliverables and milestones**

<table>
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<tr>
<td>N°7: Water partition and uptake module</td>
<td>Initial version delivered Month 22; Dual approach version for water competition currently being finalised</td>
</tr>
<tr>
<td>Separate modules have been developed for the two processes (water repartition and root growth + water uptake). Code for the former process has been developed and passed to the Hi-sAFe modelling team. Preliminary code for the root growth module will be delivered before the end of month 20.</td>
<td></td>
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| N°17: Scientific papers on below-ground interactions | Some papers already delivered as expected (Month 36). Work is progressing towards further papers by several authors working on WP5 |

<table>
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<th>Milestones</th>
<th>Status</th>
</tr>
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<tr>
<td>N°7: Water extraction modules for the SAFE biophysical model</td>
<td>Initial version delivered Month 22; Dual approach version for water competition currently being finalised</td>
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</table>
List of publications

Articles published or accepted for publication


Articles in preparation


Lusiana B., Noordwijk M V., Dupraz C. and de Willigen P.,2006. A process-based algorithm for sharing nutrient and water uptake between plants rooted in the same volume of soil II. Nutrients in static root systems

Mulia R., Dupraz C., 2005. The growth behaviour of plant root system, including negative-geotropism, in homogeneous and heterogeneous soil resource condition


Mulia R., Dupraz C., van Noordwijk M. 2005 A 3D model with voxel automata to simulate plant root growth in heterogeneous soil condition. I. Modelling concepts

Noordwijk M. v, Mulia R. Dupraz C., Lusiana B. 2006 A process-based algorithm for sharing nutrient and water uptake between plants rooted in the same volume of soil III. Growing root systems


WP 6A: THE DETAILED BIOPHYSICAL MODEL HI-SAFE

Work package number: 6A-
Detailed biophysical integrated plot modelling
Start date: Month 30 (01 January 2004)
Completion date: Month 42 (31 January 2005)
Current status: Completed
Work Package leader: Grégoire Vincent, ICRAF
Person months of WP6: 32.5

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For the sake of simplicity, the former WP6 was split in two at the 4th CMC in Porano. WP6a deals with the detailed biophysical integrated model Hi-sAFe that will be used for producing Land equivalent ratios of silvoarable systems at the year scale.

OBJECTIVES

This is adapted from the Technical Annex to suit the division of the WP in two.

Objectives of WP6a

The linkage of belowground and aboveground sub-models produced by WP4 and WP5 into one **detailed integrated biophysical modular silvoarable model** is a scientific challenge. It will include quantitative descriptions of the interactions and feedbacks between the two sub-models. A further challenge is 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 model will then be applied to analyse the effect of alternative management scenarios of silvoarable practices on long-term yield productivity and stability.

Tasks and methodology

The silvoarable model will be developed 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, will be identified and elaborated in cooperation with WP4 and WP5. Wherever possible, physically and physiologically realistic approaches will be used, but simplified relations may have to be incorporated to a) facilitate realistic parameterisations where warranted by the availability of data and or sensitivity analysis and b) to allow the final linkage to an economic model (WP6). The tasks will be:

T6.1. Defining the model concept.
T6.2. Linking the above and belowground module. Designing a C allocation module for the tree.
T6.3. Designing specific experiments for parameterisation and validation of the integrated model
T6.4. Evaluating the performance of the model using existing experimental plots.
PROGRESS DURING THE FINAL PERIOD OF THE PROJECT

INRA-SYSTEM was responsible for the implementation of the Hi-sAFe model under the CAPSIS 4 environment. I. Lecomte was in charge of this aspect, which was the main activity of INRA-SYSTEM for WP6.

During the final period of the project, we

- Improved many aspects of the model such as allowing to run it on several consecutive years
- Finalised the two water competition modules
- Explored the behaviour of the model
- Included a coarse root repartition module designed by Rachmat Mulia and C. Dupraz (INRA System). This module had to be translated in JAVA and integrated in Hi-sAFe.
- Upgraded the fine root cellular automata with a new version.
- Included a nitrogen competition module based on the WaNuLCAS approach.

Improving Hi-sAFe to allow runs on several consecutive years

This included some complicated issues about data buffers management. Soil initialisation is now correct and allows chaining years. Some concerns remain with the tree initialisation. This option was used for the following calculations of the water extraction modules

Implementing the two concurrent water extraction modules

During the last 6 months, the two water extraction modules (INRA and ICRAF versions) were implemented in the Hi-sAFe shell and evaluated. Both are now correctly operating. The full descriptions of the modules are already available in deliverable 5.1 for the INRA module, and in the ICRAF final report for the ICRAF module.

Exploring the behaviour of the integrated model

The water and root routines of the model were tested using the 2002 and 2003 weather data at the Restinclières experimental plot near Montpellier (Figure 24).
Figure 24: The rainfall pattern during the years 2002 and 2003 was similar with very heavy rains in autumn that caused floods in the area.

Both modules predict a strong water stress during the second year (Figure 25). The INRA module however indicates that the tree will not be able to extract water during 2 months (which means that the tree would die). Therefore, the module based on the water potential of the plants appears to be more efficient.
Using the ICRAF water competition module

Using the INRA competition module

Figure 25: The tree water demand and uptake of a 10 year old walnut tree predicted by the Hi-sAFe model at Restinclières in 2002 and 2003.

The pattern of prediction of soil evaporation, crop transpiration and tree transpiration was satisfactory (Figure 26). The comparison with field data is still in the making, and will be performed during the next year as part of the validation of the model, as explained in the Technological Implementation Plan.

Environmental indicators such as deep drainage of water and nitrogen under the tree stands can be calculated using the model (Figure 27). A preliminary assessment shows that the model predicts a significant decrease of water drainage under a plot of 10-year-old walnut trees at a density of 100 trees per hectare. Such trees are still small and their root system does not explore the whole area of the scene. Much higher impacts can be expected with larger trees. The consequence on nitrogen leaching was not yet quantified, but should be significant.
Figure 26: Soil evaporation, crop and tree transpiration of the agroforestry walnut plot at Restinclières as predicted by the Hi-sAFe model.

Figure 27: Deep drainage as predicted by Hi-sAFe during the very rainy 2002-2003 winter at Montpellier. The tree component of the agroforestry plot reduces the drainage by half in the tree-rooted cells, and by 16% on the whole agroforestry plot. No runoff was assumed for this calculation.
The model appears to simulate correctly the soil moisture heterogeneity (Figure 28). Soil moistures dynamics are quite similar in the topsoil in the cropped area and the tree row, and are dominated by soil evaporation. However, the crop water extraction is limited to the first meter of soil, while the tree extraction is much more deeper. The root voxel automaton correctly predicts the distortion of the tree root system that is expanding faster in deeper and moist soil horizons (Figure 29). For these simulations, the fine root density threshold for colonisation of neighbouring voxels was fixed at 500 m m$^{-3}$. This value needs further adjustment using field data. We initialised the rooting pattern of the
tree with a uniform density in the rooted zone, and the model predicts a reshaping of the root system that is close to the measured profiles in the experimental fields.

The tree fine roots were initialised with a uniform fine root density in a spherical rooted volume. The root colonisation threshold was 500 m m\(^{-3}\) in these runs. The distortion of the rooted profiles is clear.

**Figure 29 : Tree fine roots dynamics in the agroforestry plot at Restinclières**
As a conclusion, the belowground modules of Hi-sAFe for root growth and water extraction appear to behave correctly, but need further validation by comparison with the field data. This is the priority for the INRA team after the SAFE project.

### Implementing a Nitrogen competition module in Hi-sAFe

A nitrogen module, linked to the ICRAF water competition module, has been delivered in January 2005 by the ICRAF sub-contractor. A word document describes the module algorithm and an excel sheet provides the equations. The full documentation on the Nitrogen module is available on line of the SAFE web site.

#### Basic principles

From single root to root system

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 co-ordinate system. If plant demand for nutrients is high most plants can exhibit a physiological uptake efficiency that is so high that we can describe roots as ‘zero sinks’, maintaining a concentration of virtually zero at the root surface. The amount of nutrients that can reach the root surface then depends on the effective diffusion rate (influences by soil water content), the average concentration in soil solution (that is related to the ‘available’ amount via a sorption constant) and the geometry of the system with the root surface area as inner diameter and the midpoint between roots as the outer boundary. An explicit equation describes the potential uptake supply as a linear factorial of diffusion and concentration and a non-linear function of root length density (Fig. 1). The basic equation has been used in a number of models describing the dynamics of nutrient and water uptake by monocultures (De Willigen and van Noordwijk 1987, 1994, 1995; Heinen, 2001).

![Figure 30: Relationship between potential uptake during a 1-day time step from a volume of soil and root length density; A. for two values of root diameter; B. for three levels of soil water content](image)

A related equation describes the potential supply to a root system by a combination of mass flow and diffusion – because the two processes show strong interaction and the...
combined result differs substantially from the sum of both processes. Quantitatively mass flow is more important for nutrients with relatively high concentrations in soil solution (such as nitrate) than it is for nutrients with low concentrations (such as phosphate). But a comparison of the total supply with or without mass flow shows, by contrast, that mass flow has a larger positive effect on possible uptake rates by the root for phosphate than it has for nitrate. The error made by ignoring the process of mass flow is probably of the same order of magnitude, but opposite sign of the error made by describing roots as zero sinks, rather than in need of maintaining a finite minimum concentration at the root surface area.

Figure 31: Relative error in the calculated potential uptake rate by a root system of given root length density from a unit volume of soil if the contribution of mass flow (dependent on actual water uptake) is ignored, on the basis of the equations developed by D

The switch (back and forth..) between supply and demand-limited situations can be made easily once a quantitative method exists for estimating daily demand given the current biomass, growth rate and nutrient content. By applying the lowest of the supply and the possible supply, the nutrient contents of the crop and plant can be updated for the next time step. Where total possible supply exceeds the current demand, actual uptake from any voxel of soil can be taken as a proportional share of the total – thus approaching a ‘minimum energy extended’ concept. The strong role for ‘plant demand’ in down-regulating uptake is in line with the plant physiological literature of the past decades, that has superseded the earlier focus on concentration-dependent uptake (and the related modelling approaches of the Barber school).

In the case of nitrogen most plants deal with two inorganic forms: ammonium and nitrate. The ratio at which they contribute to the ‘soil mineral N’ pool depends on the pH, activity of nitrates and recent fertiliser history. On most soils under agronomic use nitrification is rapid and nitrate will dominate. As there is good evidence that the plant regulates the combined uptake of the two N forms rather than ammonium and nitrate uptake separately, we can sum the potential uptake from both sources – acknowledging a substantial difference in adsorption behaviour. As the equation for the potential supply to a zero sink is linear in the concentration term, we can add the potential ammonium and
nitrate supply to a ‘mineral N’ heading by adjusting the apparent sorption constant (that relates concentration in soil solution to the available stock).

From mono-specific to mixed species vegetation

The basic equations can be applied to root systems in a volume of soil by first adding up the roots of all species present to a total root length density with its ensuing potential zero-sink nutrient supply, and then sharing out the potential uptake over the various species proportional to their contributions to total root length density. In doing so a number of additional considerations are:

- differences in root diameter between the plant species: this can be done by introducing the concept of ‘weighted mean root diameter’

- differences in current demand that may make the ‘zero sink’ assumption an overestimate for some of the plants: by using the current demand per unit root length at plant level as additional weighing factor roots of plants with no current demand don’t influence the possible uptake by roots of plants with a strong demand

- the possible uptake by any plant in a mixture can not be more than what it could get in a monoculture for the same root length density and soil concentration; a series of constraints on the uptake sharing rules ensure that adding roots of a non-demanding plant to the total root length density will not increase the possible uptake by the others…

With these additional rules, an efficient algorithm can be constructed. In the translation from the WaNuLCAS routines to Hi-sAFe, a number of minor changes were made.

References


CONCLUSIONS

WP6a had no specific deliverables or milestones. However, the major deliverable of this work package will be the manual and tutorial of the Hi-sAFe model that is still not completed. This will be detailed in the Technological Implementation Plan of the project.

List of publications

Most articles are still in preparation at the time of writing this report.


Lusiana B., Noordwijk M V., Dupraz C. and de Willigen P.,2006. A process-based algorithm for sharing nutrient and water uptake between plants rooted in the same volume of soil II. Nutrients in static root systems

Mulia R., Dupraz C., 2005. The growth behaviour of plant root system, including negative-geotropism, in homogeneous and heterogeneous soil resource condition


Mulia R., Dupraz C., van Noordwijk M. 2005 A 3D model with voxel automata to simulate plant root growth in heterogeneous soil condition. I. Modelling concepts


Noordwijk M. v, Mulia R. Dupraz C., Lusiana B. 2006 A process-based algorithm for sharing nutrient and water uptake between plants rooted in the same volume of soil III. Growing root systems

WP 6B: THE MINIMAL BIOPHYSICAL INTEGRATED MODEL YIELD-SAFE

For the sake of clarity, the former WP6 was split in two at the 4th CMC in Porano in October 2003. WP6b deals with the simple biophysical integrated model that was used for generating time-series of tree and crop productivity for various areas of Europe.

Work package number: 6B- Minimal biophysical integrated plot modelling
Start date: Month 30 (01 January 2004)
Completion date: Month 42 (31 January 2005)
Current status: Completed
Work Package leaders: Wopke van der Werf and Karel Keesman, WU
Person months of WP6 (Technical Annex): 48.5
Person months of WP6 (Allocated): 53.5

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1.1 OBJECTIVES AND CURRENT TASKS

The objectives and tasks have been slightly changed as compared to those specified in Workpackage 6A in order to provide a dynamic integrated biophysical silvoarable model suited for long term predictions in economic analysis and landscape evaluation.

Objectives

The linkage of belowground and aboveground model concepts into a minimal integrated biophysical silvoarable model is a scientific challenge. It will include quantitative descriptions of the interactions and feedbacks between the two sub-models. A further challenge is the year-to-year carry-over effect on tree growth as a result of the competitive) effects of the crop component during previous years. The application of dynamic system theory and uncertainty analysis will help to achieve more realistic model predictions. The integrated biophysical model will be carefully validated and evaluated. The model will then be applied to analyse the effect of alternative management scenarios of silvoarable practices on long-term yield productivity and stability.
Current Tasks

T6.1 (modified task) To conceptualise and evaluate the minimal model for linking to an economic model, identify and quantify interactions and feedback between components.

T6.2 Not relevant – task of WP6.A

T6.3 Not relevant – task of WP6.A

T6.4 To evaluate the performance of the model on the basis of available information from existing experimental plots, and apply the model for analysis of the effect of different management scenarios on long-term yield stability and indicators of soil fertility.

T6.5 Not relevant - task of WP6.A

T6.6 (modified task) To calibrate and validate the minimal silvoarable model, using appropriate time-series of experimental data provided by WP3. To validate the integrated model in the range of soils, climates and management regimes represented by available target experiments.

T6.7 To parameterise the model for a range of tree and crop mixtures, suitable for different parts of Europe.

1.2 Work carried out in the reporting period

During the final period of the project, the major achievements of WP6b were (i) evaluation Yield-sAFe calibration results, (ii) recalibration and minor model adjustments of Yield-sAFe (iii) final implementation of Yield-sAFe for long-term predictions, economic analyses and up-scaling in a Microsoft Excel environment.

The major work was related to calibration, application and evaluation 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.

The evaluation, recalibration and prediction of Yield-sAFe are described below in some more detail. Most of this work has been done by other partners in the SAFE consortium, in particular Cranfield University (Silsoe) and FAL (Zurich), with support from the groups at INRA (Montpellier) and Wageningen University. The contribution of Cranfield and FAL partners was not included in the technical annex of the project. This effort was decided at the Zurich final meeting of the consortium to meet our objectives.

(i) Evaluation Yield-sAFe calibration results

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-sAF2 predictions for the poplar-wheat site at Vézénobres when using the parameter set for Mediterranean region. The results suggested that the parameter value of $k_t$ has to change with time.

Following initial evaluation of the use of the model on selected Landscape Test Sites, three changes were proposed to the model and its parameterisation. These included the use of value of the light extinction coefficient, which was dependent on tree leaf area, the choice of the critical pF value for tree and crop growth, and limits placed on the water use efficiency values (gamma_t and gamma_c).

**(ii) recalibration and minor model adjustments of Yield-sAF2**

As a result of reviewing the original calibrations, four changes were proposed. See for details Burgess et al. (2005).

1. The use of phased $k_t$ for the tree component reduces the relative size of the tree at low densities and increases relative crop yield. The function of phased $k_t$ to be used for the trees comprise 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.

In a first step Yield-sAF2 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 1), that produce a yield from Yield-sAF2 that coincides with the realistic (measured) yield, will be found.
If, however, we fix \( \varepsilon \) such that \( \varepsilon = \varepsilon_0 \), 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 1). 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 1)! In general, constrained search algorithms will find estimates on some of the bounds (circle at intersection of curved line and box).

![Figure 32: Constrained estimation procedure.](image)

In conclusion, the following procedure has been proposed:

1. Initially, select \( \varepsilon \) and \( \gamma \) for the estimation step.

2. If the estimated combination \( \varepsilon - \gamma \) is not a vertex of the box (in Figure 1: estimated \( \gamma \) (see circle right) is not at its boundary, where estimate \( \varepsilon \) 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)

3. If the estimated combination is a vertex of the box, an additional parameter should be added, e.g. HI (harvest index), \( pF_{crit} \) (critical \( pF \) value related to the water uptake factor) or the box should be enlarged till step 2 can be fulfilled.

(iii) final implementation of Yield-sAFe for long-term predictions

Table 1 summarizes the conditions for predicting the tree and crop yields for each of the Landscape Test Sites.

Table 1 Description of the 44 different land units and the respective assumed tree species and crop rotation.
<table>
<thead>
<tr>
<th>Site</th>
<th>Unit</th>
<th>Rad (%)</th>
<th>Soil type</th>
<th>Soil depth (cm)</th>
<th>Tree species</th>
<th>Crop rotation</th>
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The detailed outputs for each of the Landscape Test Sites 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.

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/dp 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.
- If RY are relative yields (LER=RYtree + RYcrop) in the Silsoe experiment the ratio RYtree/RY 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_crig_tree and pF_crig_crop are dominant, where pF_crig_tree is most dominant.

• for AF = 50, the normalized main effects show that especially Kt_0, Tsumharvest, pF_crig_tree and pF_crig_crop are dominant, where again pF_crig_tree is most dominant.

• for AF = 16, the normalized main effects show that Kt_0, pF_crig_tree and pF_crig_crop are dominant, where again pF_crig_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. The analyses refer to a poplar - winter wheat system under optimum growth conditions, i.e. no water competition between trees and crop. 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.

1.3 CONCLUSIONS

Deliverables and milestones:
### Deliverables

<table>
<thead>
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<th>Deliverable</th>
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<tr>
<td>D6.1 Data sets (Time-series predictions) of tree and crop yields under documented site conditions, for incorporation in the economic module</td>
<td>Done month 35 with modifications in month 42 (see D6.4).</td>
</tr>
<tr>
<td>D6.2 Integrated silvoarable model (scientific papers, documentation and technical report)</td>
<td>Done month 33.</td>
</tr>
<tr>
<td>D6.3 Methodology and uncertainty appraisal report (documentation and technical report)</td>
<td>Done month 36.</td>
</tr>
<tr>
<td>D6.4 Report on the data obtained with model simulations</td>
<td>Done month 42.</td>
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### Milestones

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<th>Status</th>
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<tr>
<td>Certified data sets as input for the economic model (month 32)</td>
<td>Done month 35.</td>
</tr>
<tr>
<td>Land Equivalent Ratios of Silvoarable Systems (measure of their efficiency)</td>
<td>Done month 36.</td>
</tr>
<tr>
<td>M6.3. Quantification of the reliability of the integrated biophysical model</td>
<td>Done month 40 (via sensitivity analysis of Yield-sAFe).</td>
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### References:

Burgess, P., A. Graves, J. Palma, F. Herzog, K.J. Keesman and W. van der Werf. Deliverable 6.4: Parameterisation of the Yield-sAFe model and its use to determine yields at the Landscape Test Sites. February 2005


WP 7: ECONOMIC MODELLING AT THE PLOT SCALE

Work-package 7 - Economic modelling at the plot scale
Start date   Month 1 (1 August 2001)
Completion date  Month 42 (31 January 2005)
Current status  Completed
Work Package leader  Paul Burgess, CRAN
Total Person-months  74.0

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<td>11.2</td>
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</table>

OBJECTIVES

These are unchanged from the Technical Annex.

Objectives

O7.1. To achieve a literature analysis on the optimisation of dual systems with short (crop) and long (tree) term components linked by a mechanistic relationship.

O7.2. To develop an economic model and financial templates that can be integrated with the biophysical model.

O7.3. To use the bio-economic model to determine the long-term financial benefits and costs of optimal silvoarable systems at (a) the network sites and (b) selected high potential sites.

These are unchanged from the Technical Annex.

Description of tasks

T7.1. To review existing financial models of agroforestry, cropping and farm woodland systems.

T7.2. To select and develop an economic model and templates which can be linked with the biophysical model described in WP6. Where necessary, we will improve the bio-economic model to address problems raised by the validation.

T7.3. 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.

T7.4. To 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.

T7.5. To 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.
WORK CARRIED OUT FROM AUGUST 2004 TO JANUARY 2005

The work carried out for the period August 2004 to January 2005 on work-package 7 is described in relation to the five tasks in the work-package. For this period, the focus of the work has been on tasks 7.4 and 7.5. Task 7.4 relates to the plot-scale analysis for five network sites and task 7.5 relates 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.

Task 7.1 Review of existing financial models

Task 7.1 had largely been completed before the final six-months of the project. The review of existing economic models of agroforestry systems has been written up as two papers.

A paper entitled “Development and use of a framework for characterising computer models of silvoarable economics” has now been accepted and 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 6).

The second paper is entitled “Evaluating agroforestry investments” (Table 6). 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>
<thead>
<tr>
<th>Title of presentation</th>
<th>Comment</th>
</tr>
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</table>

Task 7.2 Selection and development of an economic model

Task 7.2 had largely been completed before the final six months of the project. However for clarity the main parts are summarised below. The criteria for the economic model were reported as milestone 7.1 in September 2002 (Table 7). This included agreement that economic models were 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 on 24 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 September and October 2003, it also became apparent that it would be useful to develop two models: a plot-scale model with an integrated biophysical model (Plot-sAFe), and a farm-scale model (Farm-sAFe). These models were described in the third annual report. In September 2004, an updated description of the Plot-sAFe model version 0.3 (Burgess et al., 2004a), which integrates the biophysical Yield-sAFe model, was made available to consortium members. The development of the Farm-sAFe model has also been described in draft paper (Graves et al. 2003b) and in a poster presented at the World Agroforestry Congress in June 2004.

Table 7 Key outputs relating to the selection and development of the economic models (Task 7.2)

<table>
<thead>
<tr>
<th>Name of presentation or file</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criteria for the model (Milestone 7.1)</strong></td>
<td></td>
</tr>
</tbody>
</table>

| **Initial model development (Deliverable 7.1)** | |

| **Development of Plot-sAFe** | |

| **Development of Farm-sAFe** | |
| Silvoarable Agroforestry For Europe Project – Fourth Year Report – Volume 2 | Page 79 |
Task 7.3 To use templates to identify and quantify input, outputs, costs and revenues for the silvoarable system network systems, and existing arable and forestry enterprises for different parts of Europe

Task 7.3 was largely completed before the final six months of the project. 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. 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).

Table 8 Reports describing the output from task 7.3

<table>
<thead>
<tr>
<th>Authors, year of production, title and origin of reports</th>
<th>Dec 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network site reports</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Landscape test site workshop reports</th>
<th></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Final reports</th>
<th></th>
</tr>
</thead>
</table>
Task 7.4 To use 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 (Vézénobre) and in eastern England (Silsoe) (Figure 33). 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).
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 are presented in Table 9. The mean temperature ranged from 16.4°C at the Spanish sites to 9.7°C at Silsoe in Eastern England. The annual total short-wave radiation also decreased from 5830 MJ m⁻² at the Spanish sites, to 5120 MJ m⁻² and 3620 MJ m⁻² at Vézénobres and Silsoe respectively. At the Spanish sites, the annual rainfall was 510 mm of which 70% fell in the winter months between November and April. The mean annual rainfall of about 1000 mm at Vézénobres and the modelled value of 800 mm at Silsoe were relatively evenly distributed throughout the year. The soil types were classified as medium or fine (Wösthen et al. 1999).
Table 9 Description of the network sites

<table>
<thead>
<tr>
<th>Site name</th>
<th>Mean temp. (°C)</th>
<th>Annual solar radiation (MJ m⁻²)</th>
<th>Annual rainfall (mm)</th>
<th>Soil type</th>
<th>Modelled soil depth (mm)</th>
<th>Tree species</th>
<th>Crop species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sotillo</td>
<td>16.4</td>
<td>5830</td>
<td>510</td>
<td>Medium</td>
<td>700</td>
<td>Oak</td>
<td>Oats &amp; grass</td>
</tr>
<tr>
<td>Cerro Lobato</td>
<td>16.4</td>
<td>5830</td>
<td>510</td>
<td>Fine</td>
<td>1200</td>
<td>Oak</td>
<td>Oats &amp; grass</td>
</tr>
<tr>
<td>Dehesa Boyal</td>
<td>16.4</td>
<td>5830</td>
<td>510</td>
<td>Fine</td>
<td>1200</td>
<td>Oak</td>
<td>Wheat, oats &amp; grass</td>
</tr>
<tr>
<td>Vézénobres</td>
<td>14.7</td>
<td>5120</td>
<td>1000</td>
<td>Medium</td>
<td>4000</td>
<td>Poplar</td>
<td>Durum wheat</td>
</tr>
<tr>
<td>Silsoe</td>
<td>9.7</td>
<td>3620</td>
<td>790</td>
<td>Fine</td>
<td>1500</td>
<td>Poplar</td>
<td>Wheat, barley &amp; oilseed</td>
</tr>
</tbody>
</table>

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 34). 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 34 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 spacings. 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 35). 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 36). 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 37).
Figure 35 Comparison of the relative crop yields and the predicted tree size as estimated by Yield-sAFe with measured values at Dehesa Boyal

Figure 36 (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
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-sSAFE 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 45).

### Using Yield-sSAFE to predict network site yields

Following the initial validation, the Yield-sSAFE 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 spacings. 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 10). 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 10).
Table 10 Summary of tree densities and proposed orientation and cropped area

<table>
<thead>
<tr>
<th>Tree density</th>
<th>Original calibration</th>
<th>Land equivalent ratio calculations</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Tree spacing (m)</td>
<td>Crop width (m)</td>
</tr>
<tr>
<td>50 trees ha(^{-1})</td>
<td>40 x 5</td>
<td>38</td>
</tr>
<tr>
<td>113 trees ha(^{-1})</td>
<td>22 x 6.3</td>
<td>20</td>
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</tbody>
</table>

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 38). At Vézénobres, the timber volume per poplar was relatively insensitive to tree densities below 200 trees ha\(^{-1}\) (Figure 39). 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 39). In the silvoarable system with 133 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)

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

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

Figure 38 Predicted relative crop yield and timber volume using Yield-sAFe for arable, forestry and two silvoarable systems (50 and 113 trees ha\(^{-1}\)) at a) Sotillo, b) Cerro Lobato and c) Dehesa Boyal
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:

\[
LER = \frac{\text{Tree silvoarable yield}}{\text{Tree monoculture yield}} + \frac{\text{Crop silvoarable yield}}{\text{Crop monoculture yield}}
\]

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.

![Graph](image)

**Figure 40** Effect of site and tree density on the predicted tree and crop relative yields and the land equivalent ratio at each network site

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 40). 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 41).
- a relatively low tree density in the forestry treatment
- 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):

\[
\text{Gross margin} = R - V
\]

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).

\[
\text{Net margin} = R - V - A \quad \text{Equation 3}
\]

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):

\[
NPV = \sum_{t=0}^{\infty} \frac{(R_t - V_t - A_t)}{(1+i)^t} \quad \text{Equation 4}
\]

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:

\[
\text{Infinite } NPV = NPV \times \frac{(1+i)^n}{(1+i)^n - 1} \quad \text{Equation 5}
\]

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:

\[
EAV = \text{infinite } NPV \times i \quad \text{Equation 6}
\]

Use of Plot-sAFe and costs and prices

A financial model called Plot-sAFe was specifically developed for the analysis (Task 7.2). The model works with Microsoft© Excel and comprises separate worksheets for arable finances, tree-related values and tree-related costs (Figure 42).
Financial data

The revenues, costs and grants associated with tree and the arable component at each network site was 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, because grass for livestock production provides an important component of the “arable” and potential “silvoarable” systems, 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 on profitability, six scenarios were considered (Graves, 2004). 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 13) and for an optimised duration with no grants (Table 11).
Table 11 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

<table>
<thead>
<tr>
<th></th>
<th>Forestry</th>
<th>Arable*</th>
<th>Silvoarable* (113 trees ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tree period (a)</td>
<td>NPV (€ ha⁻¹)</td>
<td>EAV (€ ha⁻¹)</td>
</tr>
<tr>
<td>Sotillo</td>
<td>60</td>
<td>1180</td>
<td>-37</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>1370</td>
<td>-37</td>
</tr>
<tr>
<td>Cerro Lobato</td>
<td>60</td>
<td>1300</td>
<td>-37</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>1540</td>
<td>-37</td>
</tr>
<tr>
<td>Dehesa Boyal</td>
<td>15</td>
<td>5410</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>

*: Arable and silvoarable systems in Spain include grass for potential livestock production

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 11). This indicates that, assuming stated prices and costs, crops with livestock, forestry, or an integrated system of the two would not be undertaken commercially without governmental support. By contrast at Dehesa Boyal, where crop yields were higher, an integrated system of crop and livestock production had an EAV (at a 4% discount rate) of 116 € ha⁻¹ a⁻¹ without grants. This profitability was totally due to the crop component 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 11). 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 12). 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 11). 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 12 Actual value of the 2004 grants for the forestry, arable and silvoarable (113 trees ha⁻¹) system at each network site

<table>
<thead>
<tr>
<th>Network site</th>
<th>Time period (a)</th>
<th>Forest (€ ha⁻¹)</th>
<th>Arable (€ ha⁻¹)</th>
<th>Silvoarable (€ ha⁻¹) (113 trees ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sotillo</td>
<td>60</td>
<td>9380</td>
<td>8050</td>
<td>6360</td>
</tr>
<tr>
<td>Cerro Lobato</td>
<td>60</td>
<td>9380</td>
<td>13500</td>
<td>11510</td>
</tr>
<tr>
<td>Dehesa Boyal</td>
<td>60</td>
<td>9380</td>
<td>16970</td>
<td>13790</td>
</tr>
<tr>
<td>Vézénobres</td>
<td>15</td>
<td>3470</td>
<td>8960</td>
<td>8660</td>
</tr>
<tr>
<td>Silsoe</td>
<td>30</td>
<td>6320</td>
<td>11390</td>
<td>6560</td>
</tr>
</tbody>
</table>

*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 13). 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 13 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

<table>
<thead>
<tr>
<th>Network site</th>
<th>Tree NPV (€ ha⁻¹)</th>
<th>EAV (€ ha⁻¹ a⁻¹)</th>
<th>Crop period (a)</th>
<th>Arable NPV (€ ha⁻¹)</th>
<th>EAV (€ ha⁻¹ a⁻¹)</th>
<th>Stock period (a)</th>
<th>Silvoarable (113 trees ha⁻¹) NPV (€ ha⁻¹)</th>
<th>EAV (€ ha⁻¹ a⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sotillo</td>
<td>60</td>
<td>289</td>
<td>5560</td>
<td>101</td>
<td>60</td>
<td>11700</td>
<td>12350</td>
<td>378</td>
</tr>
<tr>
<td>Cerro Lobato</td>
<td>60</td>
<td>290</td>
<td>11960</td>
<td>221</td>
<td>60</td>
<td>20430</td>
<td>15840</td>
<td>392</td>
</tr>
<tr>
<td>Dehesa Boyal</td>
<td>60</td>
<td>289</td>
<td>23070</td>
<td>428</td>
<td>60</td>
<td>20430</td>
<td>15840</td>
<td>392</td>
</tr>
<tr>
<td>Vézénobres</td>
<td>15</td>
<td>477</td>
<td>9870</td>
<td>680</td>
<td>15</td>
<td>12350</td>
<td>15940</td>
<td>392</td>
</tr>
<tr>
<td>Silsoe</td>
<td>30</td>
<td>417</td>
<td>14540</td>
<td>504</td>
<td>18</td>
<td>15940</td>
<td>15940</td>
<td>392</td>
</tr>
</tbody>
</table>

*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 14).

<table>
<thead>
<tr>
<th>Grant scenario</th>
<th>Description</th>
<th>Arable payment</th>
<th>Tree payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>% arable; 0 tree</td>
<td>Cropped area</td>
<td>None</td>
</tr>
<tr>
<td>1.2</td>
<td>full arable; 0 tree</td>
<td>Total area</td>
<td>None</td>
</tr>
<tr>
<td>2.1</td>
<td>% arable; full tree</td>
<td>Cropped area</td>
<td>Specified level</td>
</tr>
<tr>
<td>2.2</td>
<td>full arable; full tree</td>
<td>Total area</td>
<td>Specified level</td>
</tr>
</tbody>
</table>

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 43) as in the 2004 grant scenario. By contrast, the $EAV$ of forestry, arable and silvoarable systems became similar at Dehesa Boyal.
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 43). 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 single 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\(^{-1}\).

### Sensitivity analysis

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 44).

![Figure 44 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](image)

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 45 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 45 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% in tree revenue was predicted to increase the NPV (at a 4% discount rate) by 5310 € ha⁻¹ or 60% (Figure 45a). 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 45a). 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.
Figure 45 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\(^{-1}\).

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.

**TASK 7.5 USE OF THE 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 46). The choice of the landscape test sites is described in work-package 8. During the last six months of the project, Anil Graves and Paul Burgess (Cranfield University) and João Palma (FAL) spent a substantial amount of time calibrating the Yield-sAFe model for each site in order to provide the biophysical data to allow a plot-scale economic analysis.
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 15; Figure 47).

Figure 46 Location of the landscape test sites in Spain, France and the Netherlands
Table 15 Summary of the annual rainfall, solar radiation and mean temperature at each site

<table>
<thead>
<tr>
<th>Country and region</th>
<th>Site name</th>
<th>Latitude</th>
<th>Long.</th>
<th>Altitude (m)</th>
<th>Mean temp (°C)</th>
<th>Solar radiation (MJ m(^{-2}))</th>
<th>Annual rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>Alcala la real</td>
<td>37.36N</td>
<td>3.88W</td>
<td>1000</td>
<td>15.3</td>
<td>5490</td>
<td>355</td>
</tr>
<tr>
<td></td>
<td>Castilla La Mancha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Torrijos</td>
<td>39.89N</td>
<td>4.39W</td>
<td>500</td>
<td>15.5</td>
<td>5560</td>
<td>348</td>
</tr>
<tr>
<td></td>
<td>Ocaña</td>
<td>39.94N</td>
<td>3.44W</td>
<td>700</td>
<td>14.7</td>
<td>5780</td>
<td>316</td>
</tr>
<tr>
<td></td>
<td>Almonacid de Zorita</td>
<td>40.23N</td>
<td>2.61W</td>
<td>900</td>
<td>12.6</td>
<td>6610</td>
<td>404</td>
</tr>
<tr>
<td></td>
<td>Castille-Leon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cardenosa El Espinar</td>
<td>40.78N</td>
<td>4.53W</td>
<td>1000</td>
<td>12.0</td>
<td>5700</td>
<td>404</td>
</tr>
<tr>
<td></td>
<td>Fontiveros</td>
<td>40.86N</td>
<td>5.00W</td>
<td>900</td>
<td>12.0</td>
<td>6170</td>
<td>393</td>
</tr>
<tr>
<td></td>
<td>Olmedo</td>
<td>41.28N</td>
<td>4.80W</td>
<td>750</td>
<td>12.5</td>
<td>5480</td>
<td>410</td>
</tr>
<tr>
<td></td>
<td>St Maria del Campo</td>
<td>42.11N</td>
<td>3.91W</td>
<td>800</td>
<td>na</td>
<td>5630</td>
<td>530</td>
</tr>
<tr>
<td></td>
<td>St Maria del Paramo</td>
<td>42.44N</td>
<td>5.69W</td>
<td>800</td>
<td>10.2</td>
<td>6600</td>
<td>519</td>
</tr>
<tr>
<td>France</td>
<td>Poitou Charentes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Champdeniers</td>
<td>46.41N</td>
<td>0.02E</td>
<td>200</td>
<td>11.0</td>
<td>4740</td>
<td>648</td>
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<td></td>
<td>Chateauroux</td>
<td>46.92N</td>
<td>1.65E</td>
<td>150</td>
<td>11.0</td>
<td>4750</td>
<td>587</td>
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<td></td>
<td>Fussy</td>
<td>47.18N</td>
<td>2.47E</td>
<td>200</td>
<td>10.6</td>
<td>4800</td>
<td>626</td>
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<tr>
<td></td>
<td>Sancerre</td>
<td>47.30N</td>
<td>2.72E</td>
<td>400</td>
<td>10.7</td>
<td>4590</td>
<td>724</td>
</tr>
<tr>
<td>France Comté</td>
<td>Champlilte</td>
<td>47.64N</td>
<td>5.58E</td>
<td>300</td>
<td>8.5</td>
<td>4940</td>
<td>773</td>
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<tr>
<td></td>
<td>Dampierre</td>
<td>47.61N</td>
<td>5.82E</td>
<td>300</td>
<td>10.0</td>
<td>5090</td>
<td>1072</td>
</tr>
<tr>
<td></td>
<td>Vitrey</td>
<td>47.81N</td>
<td>5.78E</td>
<td>400</td>
<td>9.5</td>
<td>4900</td>
<td>1084</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>Balkbrugg</td>
<td>52.57N</td>
<td>6.34E</td>
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<td>9.0</td>
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<td>801</td>
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</table>
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 Resiner, 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 48).
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 be 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>
<thead>
<tr>
<th>Country and region</th>
<th>Site</th>
<th>Code</th>
<th>Radiation (%)</th>
<th>Soil type</th>
<th>Soil depth (cm)</th>
<th>Tree species</th>
<th>Crop rotation</th>
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<td>Medium</td>
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<td>Medium</td>
<td>140</td>
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</tr>
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</tr>
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<td>FON2</td>
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<td>140</td>
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<td>Medium</td>
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<td>w/s/f</td>
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<td>w/s/f</td>
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<td>CAM2</td>
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<td>140</td>
<td>Oak</td>
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<td>140</td>
<td>Oak</td>
<td>w/w/s/f</td>
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<td>Fine</td>
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<td>W. cherry</td>
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<td>w/o</td>
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<td>FUS2</td>
<td>103</td>
<td>Medium</td>
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<td>o/w/s/w/w/w/o</td>
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<td>SAN2</td>
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<td>V fine</td>
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<td>w/w/gm</td>
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<td>140</td>
<td>Poplar</td>
<td>fm</td>
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</tbody>
</table>

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 16). 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 49). 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 49).

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 10). 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.

![Figure 49](image-url) 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

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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 52).

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 50). 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.

![Graph showing relative yield of cherry, poplar, and walnut](image)

**Figure 50** Predicted effects of tree species in a silvoarable system (113 trees ha⁻¹) on the yield of the tree and the crop components relative to a monoculture

In Spain, the relative yield of autumn-planted wheat tended to be greater than that for spring-planted sunflower (Figure 51a). 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 51b). 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.
Figure 51  Effect of crop species on the partial crop land equivalent ratio below (a) oak in Spain and (b) cherry trees in France at 113 trees ha⁻¹
Figure 52  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 53). The land equivalent ratio for cherry, poplar and walnut also tended to higher than those for the oak and pine (Figure 54).

a) 113 trees per hectare  

![Graph showing land equivalent ratio for different countries at 113 trees per hectare.](image)

b) 50 trees per hectare  

![Graph showing land equivalent ratio for different countries at 50 trees per hectare.](image)

**Figure 53** 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\(^{-1}\)
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 17).
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 17).

### 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 55). 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 Alcalá, 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.

### Table 17 a) Forestry and b) agroforestry grants in the 2004 grant scenario

<table>
<thead>
<tr>
<th>Country Region</th>
<th>System</th>
<th>Planting Grant Year (€ ha(^{-1}))</th>
<th>Compensation Grant Year (€ ha(^{-1}))</th>
<th>Maintenance Grant Year (€ ha(^{-1}))</th>
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<tbody>
<tr>
<td>a) Forestry grants</td>
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<td></td>
<td></td>
<td></td>
</tr>
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<td>Spain Andalucia</td>
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<td>1 1149 1-20 225 1-5 240</td>
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<tr>
<td>Castilla La Mancha</td>
<td>Oak (600 ha(^{-1}))</td>
<td>1 1593 1-20 325 1-5 258</td>
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<tr>
<td>Pine (800 ha(^{-1}))</td>
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<td>Oak (800 ha(^{-1}))</td>
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<td>Pine (800 ha(^{-1}))</td>
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<td>France Poitou Charentes</td>
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<td>1-4 50% costs 1-10(^{th}) 300 0 0</td>
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<tr>
<td>Centre</td>
<td>Broadleaf</td>
<td>1-4 50% costs 1-10(^{th}) 240 0 0</td>
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<tr>
<td>Franche Comté</td>
<td>Broadleaf</td>
<td>0 0 0</td>
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</table>
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.

a) Spain

b) France

c) the Netherlands

Figure 55 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 56). 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 56). 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.
Figure 56 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 57).

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

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<td>Silvoarable</td>
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b) France

c) the Netherlands

Figure 57  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 58). 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 14) on the predicted EAV was relatively small.
**CONCLUSIONS AND 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 spacings.

2. The plot-scale economic analysis was undertaken in a worksheet called Plot-sAFe, which 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⁻¹, 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 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
be tend to plant monocultures of that system 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.

**DELIVERABLES AND MILESTONES**

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<td>Delivered month 16</td>
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<td>D8.4. Synthesis report on socio-economic studies (month 40).</td>
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The references for the deliverables are:

Deliverable 7.1

Deliverable 7.1 updated

Deliverable 7.2

Deliverable 7.3

Deliverable 7.4

Milestones and expected results

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<td>Financial templates modified and circulated (month 20)</td>
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<td>Initial investment appraisal for experimental sites completed (month 32)</td>
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<td>Use the model so that a) existing systems are optimised and b) systems for high potential areas are identified and optimised (month 36)</td>
<td>Delivered month 42</td>
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REFERENCES

http://www.pinetum.org/sp/PNpinea.htm


WP 8: UPSCALING TO THE FARM AND REGION SCALE

Work-package number: 8 – Upscaling to the farm and the region scales
Start date: Month 1 (01 August 2002)
Completion date Month 42 (31 January 2005)
Current status Completed
Work Package leader Felix Herzog, FAL
Total Person-months WP8 77.0

Person months per partner and total:

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WP8 involved mainly two partners: FAL (Zurich) and the University of Cranfield. The high input by the University of Cranfield was not foreseen. But difficulties encountered in the delivery of the economic models induced a large delay in the WP outputs, and the support by the University of Cranfield during the last year of the project was essential, and is gratefully acknowledged.

OBJECTIVES

(Unchanged from the Technical Annex)

The objective is 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 will be linked using a geographic information system (GIS). The spatial up-scaling will be made at two scales. At the farm scale, yield predictions and economic assessments will be investigated for characteristic experimental sites (prototype farms representative for the region under investigation) of three European countries and different management scenarios. The economic analyses will be done from the farmers' perspective. At the region (European) scale, a 'coarse-grained' assessment of the potential extension of agroforestry across Europe will be made, based on spatial analysis and additionally on policy analysis. Improved computer and software packages, providing techniques to represent decision criteria and multiple constraints, which influence different stakeholders like landowners and policy-makers, will be applied.

No modifications for the objectives.
METHODOLOGY AND STUDY MATERIALS

T8.1. Establishment of a 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.

T8.2. Extrapolate plot-scale predictions to farm and regional scales using existing national farm survey information and physical spatial databases of soils, topography and climate. The model developed in WP6 will predict crop and timber yields at the plot scale. It will be validated for a range of environmental conditions (soil, climate). Those conditions will be identified from spatial databases build in T8.1.

T8.3. Was moved to WP2 (European silvoarable knowledge)

WORK CARRIED OUT IN THE REPORTING PERIOD (MONTHS 36-42)

Task 8.1: Establishment of a spatial database for the farm scale (and landscape test sites LTS) and the regional scale (European level)

The spatial database for all LTS and for the European scale is finished.

Detailed information on the status and handling of the data are available in Deliverable 8.2 Spatial database for GIS for scaling up (farm scale, and regional scale)

Acquisition of biophysical data for LTS (landscape test site)

The acquisition of the biophysical data for all 19 LTS is finished.

Acquisition of economic data for LTS (landscape test site)

The acquisition of the economic data for all 19 LTS is finished.

Data acquisition and spatial database for Europe

The acquisition of the information at European level and the acquisition of spatial databases in Europe are finished.

Task 8.2: Extrapolate plot-scale predictions. Assessment at landscape and European level

Up-Scaling to the landscape: Assessment of the profitability of silvoarable agroforestry in the LTS (landscape test site)
Processing LTS data for model implementation
This work is finished for all 19 LTS.

Model development
The simplified model (Yield-sAFe) is parameterised for the SAFE LTS. See WP6 for more information.

The economic model (Farm-sAFe) is available in EXCEL, see WP7 for more information.

During the third year and also during the last six months, a lot of time was spent to parameterise and calibrate these two models. After calibration, the calculations of scenarios (for NPV) started, but are not finished yet.

Environmental assessment
The aim is to assess the environmental consequences of the implementing of silvoarable agroforestry in different landscapes.

The methodology for the assessment of soil erosion, nitrate leaching and carbon sequestration is well defined. For the assessment of landscape diversity still some issues are not solved.

For the assessment of soil erosion an AML (Arc Macro Language) was done using AML and ArcObjects Programming in ArcGIS 9. The results are ready for all 19 LTS for the potential soil erosion. Preliminary results for 3 of the 19 LTS will be summarised in the final report.

**Down-Scaling: defining target regions for modern silvoarable agroforestry in Europe**

The modelling of target regions in Europe for silvo-arable agroforestry is finished. A scientific paper was submitted in December 2004 to the Journal “Ecological Engineering”. The results were summarised in the previous report. The final map is included below.
Figure 59: Target areas for silvoarable agroforestry in Europe. Target areas II are areas where silvoarable agroforestry fits areas that cannot be shown in detail on a map at the European scale.
A survey on the existing extent of silvoarable agroforestry was made in randomly selected squares in France and in Spain. The outcome is reported in the attached document by Bob Bunce.

**DELIVERABLES**

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<td>D8.3. Report on farmers view on silvoarable issue (month 38) has moved to WP2 : check D2.3</td>
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**MILESTONES AND EXPECTED RESULTS**

WP8 had two specific milestones.

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<td>M9</td>
<td>Coupling GIS and SAFE for spatial data analysis (Scheduled month 30, met Month 38).</td>
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<tr>
<td>M14</td>
<td>Spatial and policy analysis at the European scale (Scheduled month 38, met Month 42).</td>
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All the Deliverables reports and Milestone details are available on line on the SAFE web site.
WP 9: EUROPEAN GUIDELINES FOR POLICY

INTRODUCTION

Work-package 9: European Guidelines for Policy
Start date: 1/8/2001
Completion date: 31/01/2005
Current status: Completed
Work Package Leader: GJ Lawson (CEH, Natural Environment Research Council)

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OBJECTIVES

Initial objectives were: "WP9 will 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. It will describe the effect of subsidiarity on farm-forestry practices, and use the socio-economic model to investigate the potential effects on agroforestry uptake of different legal structures, financial incentives and market price levels. National forestry and agricultural policies will be 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."

METHODOLOGY AND STUDY MATERIALS

- Task 9.1 Document problems encountered by farmers in setting up new silvoarable plots in 5 different European countries. This will be achieved by USERS partners that will monitor social experiments consisting in creating silvoarable plots within the framework of the present day agricultural and forestry policies.
• Task 9.2 Collate national government policies on silvoarable agroforestry. Scrutinise the national policies for bottlenecks on agroforestry (silvoarable and silvopastoral) implementation, and possible conflicting rules between forestry and agricultural policy.

• Task 9.3 Comment on current and proposed changes in EU forestry and agricultural policy based on regional scenario testing using the models. Design a policy framework for the implementation of a European agroforestry scheme based on the data from the models.

• Task 9.4 User participants in three different countries (NL, D, GR) where modern silvoarable technology is unknown will set up silvoarable plots as a social experiment. This will help identify practical and juridical obstacles when preparing the Policy Guideline document. This task will be launched from the beginning of the SAFE programme (month 6).

PROGRESS DURING THE FINAL YEAR

Task 9.1 – Document the problems of farmers establishing new silvoarable plots in at least 5 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 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.

Task 9.2 – Compare 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 Workpackage 9 report, and are summarised in Table 9.1.

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 9.1 Eligibility of Agroforestry Systems for Agricultural and Forestry Grants under current Pillar I and Pillar II rules

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<th>Country</th>
<th>Agricultural Payments (First Pillar)</th>
<th>Forestry Grants for Agroforestry Spacings (Second Pillar)</th>
<th>Agri-environmental (Second Pillar)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Arable Area Payment</td>
<td>Livestock payments in silvopastoral systems (if declared as ‘foreage areas’).</td>
<td>Planting</td>
</tr>
<tr>
<td>France</td>
<td>Yes on cropped area. (with young trees) or area reduced for crown area (mature trees)</td>
<td>Yes in grazed woodlands if forage area &gt;50%</td>
<td>Yes, proportion of total cost. But strong restrictions in practice (such as follow up of the plantation by a research institute)</td>
</tr>
<tr>
<td>Germany</td>
<td>Yes on cropped areas, but so far no references with mature trees</td>
<td>Yes in grazed woodlands if forage area &gt;50%</td>
<td>No</td>
</tr>
<tr>
<td>Greece</td>
<td>Yes on cropped area reduced by crown area</td>
<td>Yes in grazed woodlands if forage area &gt;50%</td>
<td>No</td>
</tr>
<tr>
<td>Italy</td>
<td>Yes usually reduced by crown area but can vary</td>
<td>Yes in grazed woodlands if forage area &gt;50%</td>
<td>No</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Yes on cropped areas, but so far no references with mature trees</td>
<td>Yes in grazed woodlands if forage area &gt;50%</td>
<td>No</td>
</tr>
<tr>
<td>Spain</td>
<td>Arable payments usually reduced by more than crown area.</td>
<td>Yes in grazed woodlands (e.g. Dehesas) if forage area&gt;50%</td>
<td>Proportion of total cost (density as low as 278t/ha for some species)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>?</td>
<td>Yes in grazed woodlands</td>
<td>No</td>
</tr>
<tr>
<td>UK</td>
<td>Yes on cropped area, provided connected to larger field.</td>
<td>Yes in grazed woodlands (the area is reduced to account for trees &amp; grazing should be possible for 7 months per year)</td>
<td>Pro-rata reduction from 1200t/ha for poplar (only). No income support</td>
</tr>
</tbody>
</table>

¹ 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);
Task 9.3 – Comment on proposed changes in forestry and agroforestry policy based on scenario testing using models.

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 spacings. 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 (nonwood 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)
TASK 9.4 – CO-ORDINATE THE ESTABLISHMENT BY USER PARTICIPANTS IN 3 COUNTRIES OF SILVOARABLE PLOTS AS A ‘SOCIAL EXPERIMENT’.

Replanting of dead trees and maintenance of crops has continued in the ‘social agroforestry plantings’ in Netherlands, Germany and Greece. These are described in the WP9 report of year 3, and were presented at the final SAFE workshop in Zurich in November 2004.

SIGNIFICANT DIFFICULTIES DURING THE REPORTING PERIOD.

Synthesis of recent changes in grants and subsidies and their impact on agroforestry (Deliverable 9.2) were produced later than expected. This is partially because many countries are still defining their interpretation of rules for the Single Payment Scheme. It is hoped that these synthesis can be continued beyond the end of the SAFE project, partially through the activities of end-user-groups in each of the member countries.

Results of the SAFE project will be presented at the annual meeting of the Farm Woodland Forum (with which all UK members SAFE project are associated) on 29/6-1/7 at the University of Wales Conference Centre at Gregynog, Powys, Wales. The theme of this workshop is ‘Ecosystem Services of Farm Trees’, and the SAFE presentation will focus on EU agri-environmental payments.

DELIVERABLES

Most of the work during the final period was devoted to preparing Deliverable D9.3 ‘Agroforestry Policy Options’ document. This document was released at the final Conference of the SAFE project at Brussels on March 30.

Figure 60. Dr. Gerry Lawson presenting the final deliverable of WP9 at Brussels on March 30 2005
MILESTONES

- M3. Set up of social experiments (silvoarable plots) in countries where the technology is unknown (month 12) **completed by month 20 but was maintained continuously during the project**.

- M5. Collation of existing national and sub-national agroforestry policies and attitudes (month 24) – **completed including many recent changes**

- M15 Agroforestry Policy Options report and ‘Agroforestry Policy Scenarios’ software distributed in paper, CD-ROM and web format (month 42) – **Released on march 30 2005 at Month 42, as expected**