



Synthesis of the Research and Development Protocols related to Agroforestry with High Value Trees

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1 Context

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

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

This report contributes to the second objective where innovations are being field tested within four agroforestry sectors; this report from work-package 3 focuses on agroforestry with high value trees, for example the intercropping and grazing of fruit orchards (e.g. olive, walnut, chestnut, apple, orange) and high value timber plantations (e.g. walnut and wild cherry). This report, [Milestone 10 \(3.3\)](#), contains a synthesis of 13 research and development protocols within that sector.

2 Synopsis of research and development protocols

Research and development protocols focused on agroforestry for high value trees have been produced by nine partners (Table 1). During 2014, each partner established a stakeholder group including farmers and other interested people, which highlighted key challenges for a range of agroforestry practices. Each group then identified potential innovations, and this report synthesizes the planned activities to test and develop these. Full details of the individual protocols are available on the AGFORWARD website as indicated in the reference list at the end of this report.

Table 1. Acronyms of partners used in this report

Acronym	Full name of partner
AFAF	Association Française d'AgroForesterie, France
AFBI	Agri Food and Biosciences Institute, UK
APCA	Assemblée Permanente des Chambres d'Agriculture, France
CRA	Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Italy
CRAN	Cranfield University, UK
IDF	Centre National de la Propriete Forestiere, France
TEI	TEI Stereas Elladas, Greece
UEX	Universidad de Extremadura, Spain
USC	University of Santiago de Compostela, Spain

This report describes the research and development being undertaken by each group in terms of system components, and the production, management, environmental, and socio-economic issues addressed (Table 2). This is followed by Table 3 which summarises the key treatments and measurements being undertaken.

Table 2. Summary of the components and issues addressed in the protocols related to agroforestry for high value tree systems

Partner and country	System and reference	Component			Issue			
		Tree	Animal	Plant	Environment	Production	Financial	Management
AFAF/ IDF France	Bordure trees (van Lerberghe and Maligier 2015)	Ash (<i>Fraxinus excelsior</i> L.)	Sheep	Grass		Branch & tree biomass	Better resource use and Increased income	Allometric equations to improve wood management
APCA, France	Grazed orchards in Normandie (Corroyer and Upson 2015)	Apple (organic), 550 and 790 trees/ha	Sheep	Grass	Less herbicides	Fruit quality & quantity, animal production	Financial & labour impact of grazing	
TEI, Greece	Intercropping of orange groves (Pantera et al 2015)	Orange		Chickpeas potatoes	Less fertiliser	Yield quality & quantity	Lower cost for chemicals and increase income	Species to intercrop
TEI, Greece	Intercropping of olive groves, Molos (Mantzanas et al 2015b)	Olives (60 years old), 2 ha, 120 trees/ha		Chickpea, oregano	Less fertilizer	Yield quality & quantity	Lower cost for chemicals	Species to intercrop
TEI, Greece	Intercropping of olive groves, Chakidiki (Mantzanas et al 2015a)	Olives (80 years old)		Barley, Common vetch	Less pesticides & fertilizers	Increased yield	Lower cost for chemicals and labour costs	Pruning time and companion plants
CRA, Italy	Intercropping and grazing of olive orchards (Rosati and Mantovani 2015)	Olives		Asparagus, Narcissus, tulip	Water conservation	Increased production	Better resource use and increased income	Assessment of technical feasibility
UEX, Spain	Grazing and intercropping of plantation trees (Moreno et al 2015)	Walnut (hybrid: <i>J. major x nigra</i>) 15 years, 333 trees/ha	Sheep	Grass	Lower chemical use; carbon sequestration	Increased production Quality timber	Lower cost (nitrogen fixation)	Best management for lower competition & increased production
UEX, Spain	Pollarding high value tree species (Bertomeu García et al 2015)	Pruned and unpruned wild cherry (11 years)			Environmental outcomes	More quality timber	Increased income	Best management practice for quality wood
USC, Spain	Chestnut agroforestry in Galicia (Fernández Lorenzo et al 2015)	Chestnut (> 50 years old)	Celta pigs		Habitat and landscape preservation	Increased chestnut production	Increased income to farmers	Best management options for chestnut production
USC, Spain	Chestnut agroforestry in Galicia (Fernández Lorenzo et al 2015)	Chestnut (> 50 years old)		Mushroom <i>Boletus edulis</i>	Habitat and landscape preservation	Improved mushroom production	Increased income to farmers	Best management options for chestnut production
USC, Spain	Chestnut agroforestry in Galicia (Fernández Lorenzo et al 2015)	Castanea species			Habitat and landscape preservation	Best variety selection	Increased income to farmers	Best management options for chestnut production
CRAN, UK	Grazed orchard in England and Wales (Upson et al 2015)	Apple (10 years old), 30 samples/plot	Sheep (5 ha ⁻¹)	Grass	Less herbicides	Fruit quality & quantity, animal production	Financial & labour impact of grazing	Grazing period, mowing or grazing, and tree damage
AFBI, UK	Grazed orchard in Northern Ireland (McAdam and Ward 2015)	Apple (dessert 1485/ha & cider 1485/ha)	Sheep (5 ha ⁻¹)	Grass	Less herbicides	Fruit quality & quantity, animal production	Financial & labour impact of grazing	Grazing period, mowing or grazing, and tree damage

Table 3. Summary of the treatments and measurements as reported in the protocols related to agroforestry for high value tree systems

Partner and country	System and reference	Components	Treatments	Measurement	Modeling	Design
AFAF/IDF France	Bordure trees (van Lerberghe and Maligier 2015)	Ash trees, sheep and grass		Tree characteristics (stump, log, branches)	No	Trial
APCA, France	Grazed orchards in Normandie (Corroyer and Upson 2015)	Apple trees, sheep and grass	Conventional mowing or grazing	Apple and grass yields; tree & grass mineral content, sawfly presence and damage; apple scab damage, floral diversity; labour and other costs	No	Trial: 2 treatments on 0.69 ha & 0.66 ha
TEI, Greece	Intercropping of orange groves (Pantera et al 2015)	Orange trees, and chickpeas or potatoes	Chickpeas and potatoes	Tree characteristics & nutrients, harvest data & characteristics; Crop yield, Soil characteristics, labour and other costs	No	Trial including orange trees, orange trees with chickpea, and orange trees with potatoes
TEI, Greece	Intercropping of olive groves, Molos (Mantzas et al 2015b)	Olive trees with chickpeas or oregano	Olives, olives + chickpea vs olives + oregano	Tree characteristics & nutrients, olive yield Crop yield, soil characteristics, LER, Labour and other costs	No	Simple experimental design
TEI, Greece	Intercropping of olive groves, Chakidiki (Mantzas et al 2015a)	Olive trees with barley or common vetch	Olives, olives + barley vs olives + vetch	Tree characteristics and olive yields Crop yield, LER, labour and other costs	Yes	Latin square design with 3 replicates
CRA, Italy	Intercropping and grazing of olive orchards (Rosati and Mantovani 2015)	Olive trees with asparagus, narcissi, or tulips	Traditional vs high density olives with different crops	Tree characteristics, asparagus and flower production, meteorological data and soil moisture	Yes	Trial: 2 treatments, asparagus between trees & flowers rows of trees Pot experiment: 12 asparagus pots shaded and 12 in full sunlight
UEX, Spain	Grazing and intercropping of plantation trees (Moreno et al 2015)	Walnut trees with sheep and grass	Walnuts either grazed or fertilized (three treatments each)	Tree characteristics, pasture production Soil characteristics & nutrients, pasture & trees roots, Carbon sequestration	No	Experiment with 3 fertilizer treatments (NPK v legumes + PK v control; 6 reps) and three grazing treatment (ploughed v clearing v grazing; 9 rep)
UEX, Spain	Pollarding high value trees (Bertomeu García et al 2015)	Wild cherry	Pollarded vs upollarded trees	Cavitation in pollarded v unpollarded trees Tree height and diameter, LAI	No	Replicated experiment with 5 pairs of plots (3 rows of treesX6 trees/row)
USC, Spain	Chestnut agroforestry in Galicia (Fernández Lorenzo et al 2015)	Chestnut trees with Celta pigs	Chestnut trees and pigs	Tree characteristics & damage	No	3 replicates of 10 protected & unprotected trees,
USC, Spain	Chestnut agroforestry in Galicia (Fernández Lorenzo et al 2015)	Chestnut trees with mushrooms	Chestnuts and mushrooms	Mushroom production in relation to tree diameter	No	Randomised block with 3 replicates of chestnuts and mushrooms
USC, Spain	Chestnut agroforestry in Galicia (Fernández Lorenzo et al 2015)	Chestnut tree species and cultivars	Grafted chestnuts	Laboratory (rooting, survival, max grafting cycle, μ scions/cycle) & field (graft compatibility, scion length and diameter at 6, 12 & 22 months)	No	20 grafted combinations variety/hybrid & 5 combinations variety/seedling & 5 self-rooted varieties, in 15 random blocks
CRAN, UK	Grazed orchard in England and Wales (Upson et al 2015)	Apple trees, sheep and grass	Mowing vs grazing	Tree characteristics & damage, grass yield, sheep weight, minerals, labour and other costs	Yes	Trial with two treatments
AFBI, UK	Grazed orchard in Northern Ireland (McAdam and Ward 2015)	Dessert and cider apple trees, sheep and grass	Mowing vs grazing	Tree characteristics & damage, apple yields and scab incidence; grass yield; soil (chemical & physical); labour and other costs	No	Replicated split plot with six treatments (dessert mown, cider mown, mown, dessert grazed, cider grazed, grazed) and 4 reps, 80 trees/plot, 3 sheep/plot

3 Experimental protocols: a short description

Each stakeholder group identified the key challenges to the selected agroforestry systems. In this section, the experimental protocols, developed to address identified challenges and potential innovations, are considered under the titles of grazed orchards, olive agroforestry systems, agroforestry with walnuts, chestnut agroforestry systems, and agroforestry with citrus trees.

3.1 Grazed orchards

The grazed orchards included the systems in England and Wales (CRAN), Northern Ireland (AFBI) and Seine Maritime in France (APCA).

3.1.1 Grazed orchards in England and Wales, UK

Initial idea: grazing sheep in orchards will reduce mowing costs and provide grazing for sheep.

Innovations to be tested: the group at Cranfield University has already started an unreplicated trial of a grazed and an ungrazed orchard and is collecting data to allow the development of new parameters for the Yield-SAFE model for orchards. Their questions include: 1) the use of Shropshire sheep for grazing orchards, as some authors consider that this breed are 'tree friendly', and can reduce mowing costs, less use of herbicides, whilst increasing farm income, 2) improved understanding on how grazing of lower leaves will affect apple production and quality and 3) developing parameters for the Yield-SAFE biophysical model for 'bush' orchard systems.

3.1.2 Grazed orchards in Northern Ireland, UK

Initial idea: an area of cider and dessert cultivars was established in 1998, and a heritage site was established in 2002. This could provide a basis for comparing apple and livestock performance under grazing. Other potential ideas included integration of sheep with conventional Bramley apple production; the involvement of local apple producer groups, and encouraging policy involvement.

Innovations to be tested: a replicated split-plot with six treatments of four replicates to provide information on: 1) grazing management guidelines, 2) fruit quality and quantity as well as animal production, 3) improved understanding of the environmental benefits from grazing, 4) an improved understanding of how sheep could improve income, and 5) the grazing of leaf litter to reduce apple scab infections.

3.1.3 Grazed orchards in Seine Maritime Department, France

Initial idea: 1) feasibility study of grass control due to grazing including a study of the competition between grass and trees, 2) study of the impact of the tree density on grass productivity, 3) a study of fruit production in two pruning options, 4) assessment of tree value, and 5) technical and economic management of sheep with apple trees.

Innovations to be tested: a trial of two treatments to provide information on: 1) grazing management guidelines, 2) fruit quality and quantity as well as animal production, 3) improved understanding of the environmental benefits from grazing, 4) an improved understanding of how sheep could improve income and reduce costs, 5) the grazing of leaf litter to reduce sawfly, and 6) mineral nutrition and floral diversity.

3.2 Intercropping and grazing of olive groves

This second group of systems is the intercropping and grazing of olive systems, including two stakeholder groups in Greece (TEI at Chakidiki and at Molos) and one stakeholder group in Italy (CRA). The Italian system was focusing on the use of asparagus, which was not a crop consumed widely in Greece. In Greece there was an initial focus on the use of aromatics.

3.2.1 Intercropping olives and cereals in Greece

Initial idea: the initial ideas of this group based at Chakidiki were: 1) to evaluate the current trends, constraints and opportunities for renovation of the system, 2) to test the viability and economical interest of certain innovative practices proposed in stakeholder workshops, and 3) to monitor a number of environmental services of the system at the plot scale.

Innovations to be tested: a Latin square experiment with 3 replicates and associated research and use of the Yield-SAFE model that will provide: 1) an inventory of the extant traditional olive tree systems intercropped with cereals and an evaluation of their economic viability, and 2) management guidelines.

3.2.2 Intercropping olives and vegetables in Greece (TEI, Molos)

Initial idea: 1) to evaluate the current trends, constraints and opportunities for renovation of the system, 2) to test the viability and economical interest of certain innovative practices proposed in stakeholder workshops, and 3) to monitor a number of environmental services of the system at the plot scale.

Innovations to be tested: a simple experiment that would focus on: 1) management guidelines for trees intercropped with aromatic/medicinal herbs, 2) the assessment of leguminous plants for soil amelioration, 3) higher quality products for human consumption or for feed and 4) calculation of a land equivalent ratio (LER).

3.2.3 Integration of olives with crops in Italy (CRA)

Initial idea: 1) improving income from olive orchards (which are tending to become increasingly unprofitable), 2) design, test and demonstrate new systems that combine low environmental impact with labour efficiency and profitability, 3) propose viable crops/animal species with good marketability to be intercropped, and 4) an assessment of the use of “bulb” flower crops.

Innovations to be tested: a simple experiment with two treatments that would answer the following questions: 1) develop best practices for growing wild asparagus and flowers in the olive orchard, 2) assess the technical feasibility and the economic profitability of this intercrop, and 3) evaluate production and water conservation.

3.3 Value timber systems

3.3.1 Grazing and intercropping of plantation trees in Spain

Initial idea: 1) evaluation of current trends, constraints and opportunities, 2) to test the viability and economic interest of certain innovative practices on a proposal from stakeholder workshops, and 3) to monitor carbons sequestration and biodiversity at a plot scale.

Innovations to be tested:

- a. *Walnut system:* a replicated experiment with 6 plots / fertilized and 9 plots per grazed treatment that would examine: 1) the productive and ecological consequences of managing

walnut plantations with grazing compared to intensive management (tillage and chemical inputs), and 2) the use of different fodder legume species and varieties to improve nitrogen nutrition of the trees.

- b. *Wild cherry system*: a replicated experiment with five pairs of plots to determine 1) best management guidelines, 2) provide data for an economic and environmental evaluation, and 3) examine the potential of pollarding to reduce stem cavitation during the summer drought.

3.3.2 *Bordure trees in South-West France*

This system comprises a silvopastoral system involving *Fraxinus excelsior L.* trees with grazing in a bocage landscape.

Initial idea: 1) to evaluate the constraints and opportunities to harvest aboveground biomass of a traditional *Bordure* trees system, and 2) to test the economic interest in trees pollarding (a little-known or a long-neglected practice proposed in stakeholder workshops).

Innovations to be tested: a trial that would 1) produce quantitative and qualitative information about branches biomass production of pollarded ashes, 2) determine the productive consequences and economic benefits of pollarding old trees, and 3) develop a simple mathematical model that could help increase farmers' income: an allometric equation to predict branches biomass.

3.4 Chestnut systems

An agroforestry system using chestnut was the focus of the stakeholder group in Galicia in north-west Spain that proceeded with three separate experiments.

Initial idea: the initial idea was to use the system for demonstration with a focus on both fruit (e.g. chestnut) production and animal production.

Innovations to be tested:

- a. *Chestnuts grazed by pigs*: a simple experiment with 3 replicates of 10 protected and 10 unprotected trees that would provide information on: 1) system productivity, 2) environmental and economic performance, and 3) management guidelines.
- b. *Chestnuts and mushroom production*: a randomized block experiment with three replicates that would 1) help develop techniques to increase mushroom production in old chestnut stands, and allow 2) evaluation of the productivity, and environmental and economic performance of the system, and provide 3) management guidelines.
- c. *Chestnuts varieties and grafts*: a trial that tests combination of hybrids and grafts focusing on: 1) the production of grafted plants of selected varieties of chestnut using the technique of micro-grafting, 2) the productivity, environmental, and economic evaluation of the system, and 3) management guidelines.

3.4.1 *Orange trees intercropped with vegetables*

The only system involving citrus trees was an agroforestry system based on the intercropping of oranges on the Greek island of Crete.

Initial idea: as with the other Greek stakeholder groups, the initial ideas were quite broad including 1) an evaluation of current trends, constraints and opportunities, 2) testing the viability and economical interest of innovative practices, and 3) monitoring selected environmental services, at plot scale.

Innovations to be tested: a trial that would attempt to determine 1) the potential of using leguminous intercrops, such as legumes, to improve soil health, 2) the productivity, and environmental and economic effects of the system, 3) management guidelines, and 4) the potential to produce high quality products for human consumption or for feed.

4 Synthesis

During the next three years of AGFORWARD, the stakeholder groups will test selected technical innovations, involving replicated experiments with controls where possible. The research protocols can be synthesized into four categories (Table 4).

Table 4. Research and development plans categorized according to a focus on production, management, environmental or socio-economic issues

Category and description of research	Agroforestry component and partners
<p>Production</p> <p>Increased quantity and quality of products Productive consequences of managing plantations with grazing compared to mechanization Improve income through diversification with animals as an additional produce Techniques to increase intercrop production</p> <p>Interactions of Shropshire sheep and apple trees Parameterise Yield-SAFE biophysical model</p>	<p>All partners Walnuts: UEX, Grazed orchards: CRAN & AFBI Sheep: CRAN, ACTA-IDF & AFAF, AFBI, Apple orchards: UEX, pigs: USC Mushroom & chestnuts: USC, chickpeas: TEI, barley: TEI, asparagus & narcissus: CRA Grazed orchards: CRAN Apple orchards: CRAN; Olive groves: TEI & CRA</p>
<p>Management</p> <p>Plant species to be intercropped</p> <p>Animal breeds and effect on pests and diseases Grazing management guidelines and tests Techniques to increase mushroom and aboveground wood biomass production Graft production of selected varieties of chestnuts Best practices for growing wild asparagus</p>	<p>Olives: TEI in north and central Greece Walnuts: UEX; Orange groves: TEI Apple orchards: APCA Sheep: CRAN, AFBI, APCA Apple orchards: AFBI Mushrooms: USC; Ash: ACTA-IDF & AFAF Chestnuts: USC Olives: CRA</p>
<p>Environment</p> <p>Evaluation of ecosystem services Ecological consequences of managing walnut plantations with grazing Environmental and soil effects of grazing orchards</p>	<p>Olives: TEI in northern Greece Compared to intensive tillage and chemical inputs in a walnut plantation: UEX Apple orchards: APCA, AFBI</p>
<p>Socio-economic</p> <p>Economic assessment of the systems (all partners) Inventory of the extant traditional olive tree systems intercropped with cereals and evaluation of their economic viability Improve income through diversification with sheep as an additional produce (APCA & AFBI, apple orchards, UEX walnuts) Potential for high value marketable products</p>	<p>All partners Olives: TEI in northern Greece</p> <p>Apple orchards: APCA and AFBI Walnuts: UEX</p> <p>Olives: CRA, other products: USC</p>

Across the stakeholder groups, some of the research is focused on trials, and some on experiments.

- a) Trials are planned on bordure trees (ACTA-IDF & AFAF), grazed orchards (APCA and CRAN), intercropped orange trees (TEI), intercropped olives (CRA) and grafted chestnuts (USC).
- b) Replicated experiments (that include replicated treatments) include two experiments with grazed orchards (AFBI), intercropped olives (TEI), intercropped walnuts (UEX), pollarded cherry trees (UEX), chestnuts grazed by pigs (USC), and chestnuts and mushrooms (USC).

During late 2015, each partner will provide a detailed systems description and monitoring of the inputs, flows, and outputs of the key ecosystem services of at least one case study system within each stakeholder working group. The description will cover agroecology (climate, soil), components (tree species, crop system, livestock, management system), structure (planting arrangement, age, weed management policy), and key ecosystem services (provisioning, regulating and cultural), and associated economic values.

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