Agroforestry for high value tree systems: Results of innovations

Project name	AGFORWARD (613520)
Work-package	3: Agroforestry for High Value Tree Farmers
Deliverable	Deliverable 3.8 (3.2) Agroforestry for high value tree systems: results of innovations
Date of report	30 January 2018
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AGFORWARD (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

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 Deliverable 3.8 (3.2) contributes to the second objective in that it provides a summary of ten reports which individually describe the results of the innovations studied across ten stakeholder groups in a participatory research and development network focused on agroforestry for high value trees. Similar reports have been produced for the networks focused on agroforestry of high nature and cultural value, agroforestry for arable farming and agroforestry with livestock farmers.

2 Overview

Table 1 provides an overview of the lessons learnt reports for innovation activities related to agroforestry for high value tree systems. The activities can be considered into four groups: those focused on the intercropping or grazing of i) high value timber trees, ii) olive and citrus groves, iii) apple orchards, and iv) hedgerow trees. Unfortunately, the stakeholder group focused on pollarding was unable to produce a lesson learnt report as the stakeholder group leader was ill during late 2017; hence the results are derived from the previous system report (Van Lerberghe and Malignier 2016) and the innovation leaflet (Colin et al. 2017).

Table 1. Titles and references for the lessons learnt reports related to agroforestry for high value trees

Group	Title of report	Reference
High value trees for timber	Lessons learnt: Silvopastoral management of Mediterranean timber plantations	López-Díaz et al. (2017)
	Lessons learnt: Chestnut agroforestry in Galicia, Spain	Mosquera-Losada et al. (2018)
Intercropping of olive groves and orange orchards	Lessons learnt - Wild asparagus and other crops in olive orchards in Italy	Rosati (2017)
	Lessons learnt: Olive agroforestry in Molos, Central Greece	Pantera et al. (2017a)
	Lessons learnt: Olive agroforestry in Kassandra, Chalkidiki, Greece	Mantzanas et al. (2017)
	Lessons learnt: intercropping of orange groves in Greece	Pantera et al. (2017b)
Grazed orchards	Lessons learnt: Grazed orchards in France	Corroyer (2017)
	Lessons learnt – Grazed orchards in England and Wales	Burgess et al. (2017)
	Lessons learnt: Grazed orchards in Northern Ireland	McAdam (2018)
Hedgerow trees	System Report: Traditional Pollard Agroforestry in South-West France	Van Lerberghe and Malignier (2016)

3 Results for grazing or intercropping of high value timber systems

Timber from species such as walnut, wild cherry and chestnut can produce high revenues, but some production systems involve substantial energy, water, and agrochemical inputs. One group from the University of Extremadura in Spain focused on the possibility of grazing and intercropping between walnut trees and wild cherry trees grown on plantations (Table 2). The group at the University of Santiago de Compostela in Galicia, Spain focused on the use of pigs and the integration of mushrooms with sweet chestnut. Although not specifically considered within work-package 3, the intercropping of wheat and barley (Arenas-Corraliza et al. 2017) between walnut and maize and medicinal plants trees between walnuts (Mosquera-Losada et al. 2017a; 2017b) (considered in work-package 4) could also be considered as agroforestry for high value timber systems.

Table 2. Focus of agroforestry innovation activities related to high value tree systems

Activity	Partner(s)	Type of work
Silvopastoral management of Mediterranean timber plantation	Universidad de Extremadura, Spain	Four experimental trials: 1. Two essays in hybrid walnut to test understory management & alternatives to fertilization, 2. Two essays to evaluate tree management: Tree thinning (walnut), and tree pollarding (wild cherry)
Chestnut agroforestry	University of Santiago de Compostela, Spain	Comparative study on chestnut tree protection from pig grazing
Chestnut varieties		Comparative study to investigate new approaches to producing selected varieties of chestnut

López-Díaz et al. (2017) reports the following lessons from their studies and analyses of four experimental plots in Extremadura, Spain, combining high value timber trees (hybrid walnuts and wild cherries).

1. Cultivation increased water recharge of the soil in rainy season, but reduced the soil moisture in summer, when the competition of both strata of vegetation by water is high. Any treatment to improve pasture yield, either fertilization or sown of legume forage, decrease the water available for trees, but with no significant effects on the water status of trees.
2. Cultivation increased N and Ca short-term availability but reduced the P available in soil. The sowing of legume forage increased very significantly the soil mineral N and K^+ but reduced significantly the available P. Again consequences for trees were barely significant, although a slight but significant decrease of tree leaf content of P and Ca was detected.
3. Unmanaged pasture yield was around 3.5 Mg ha^{-1} y^{-1}, what could support around 0.6 LU ha^{-1} y^{-1}. Sowing rich-legume pasture in the alleys could roughly double the stocking rate without compromise the tree growth.
4. Mineral fertilization also double the pasture understory yield, but the rooting profile of the pasture was deeper, what could strengthen the competition with trees for soil resources, especially for soil water. Unexpectedly, mowing and even more grazing produced also a deepening of the pasture rooting profile, what could explain why tree growth was reduced slightly respect to the plots ploughed.

5. Silvopastoral management with high stocking rates seems compatible with timber production for high quality such as hybrid walnut and wild cherry. Improving pasture production and quality by sowing legume-rich forages did not reduce tree growth relative to the control unfertilized trees. Cultivation resulted in better tree growth than grazing, and grazing resulted in greater tree growth than mowing.
6. Carbon sequestration was specially favoured by mowing the grass understory and by the sown of legume forage (even stronger that the effect of mineral fertilization). Grazing also had a slight positive effect on carbon sequestration.
7. The rooting profile of trees seems unresponsive to the soil/understory management, and in all case cases was much deeper than the rooting profile of the pasture understory.
8. Nitrate leaching seems negligible in the walnuts plantations studied, presumably by the deep rooting profile. Only in few cases, when favourable conditions for organic matter mineralisation overlap with inactive trees, a slight risk of nitrate leaching was observed in ploughed (mid-autumn) and mowed (early-spring) plots. Unexpectedly, control unfertilized plots exhibited the higher risk for nitrate leaching (that come of the natural mineralisation of organic matter), presumably because the lower pasture cover.
9. Thinning had a slight but positive effect on walnut tree growth, but the effect seems to be cancelled after three years. Pollarding had neither positive nor negative effects on tree growth, but damage but cavitation was drastically reduce, what we expect will have positive effect for the plantation productivity at midterm.
10. Overall, managing of Mediterranean hybrid walnuts and wild cherry timber plantation under silvopastoral schemes seem a feasible way to reduce the high economical maintenance costs of these plantation and the ecological risks, without compromising their productivity.

The impact of pigs grazing on chestnut trees were investigated by Mosquera-Losada et al. (2018). The overall lessons learnt from this study were:

1. Chestnut stands are widely distributed in Galicia, Spain.
2. Celtic pigs could graze in chestnut stands without damaging the trees if adequately protected.
3. This system is productive and have many environmental and economic profits
4. Management guidelines are very important.
5. Adequate stocking rates and space-distribution of the pigs are important to limit the damage to the trees.
6. It is a successful combination that preserves biodiversity, increases nutrient cycling and enhances farmers' income.

Mosquera-Losada et al. (2018) also discusses the main lessons learnt from producing ink-disease resistant graft of chestnuts:

1. Chestnut systems are important from environmental, financial and social points of view.
2. The production of ink-resistant varieties is important for the preservation of such system,
3. The technology presented can detect early incompatibilities of specific combinations of hybrid clones and varieties;
4. It can also minimize infections from the grafting process, is quicker and can produce ink-resistant plants.
5. There is an undergoing research on the production of resistant varieties such as "Loura" and "Parede" which, however, has not been fully field-tested yet.

4 Results of agroforestry innovations for olive and orange systems

The work included agroforestry olive systems in Italy and Greece and an orange system in Greece with inclusion of different crops with the aim to increase revenue. The Italian group focused on the use of asparagus, whereas the Greek groups tested the use of cereals and leguminous species (Table 3).

Table 3. Focus of agroforestry innovation activities related to olive and citrus systems

Activity	Partner(s)	Type of work
Wild asparagus and other crops inn olive orchards	CREA, Italy	Comparative study to test the intercropping of asparagus and flowers to olive groves
Olive agroforestry in Kassandra, Chalkidiki, Greece	TEI Stereas Elladas, Greece	Three years comparative studies on olive production when intercropped with cereals and legumes
Olive agroforestry in Molos, Central Greece		Three years comparative study on olive production when intercropped with cereals and legumes
Intercropping of orange groves in Greece		Two years experiment to evaluate the effect of a leguminous crop on orange production and soil characteristics

In the Italian study on the intercropping of asparagus and flowers in olive groves, Rosati (2017) draws the following lessons:

1. Both traditional and super-high-density olive orchards intercept no more than 50-55% of the incoming sunlight. The rest will fall on the ground and can encourage weeds. This light can be used by another crop which can increase the orchard productivity and revenue. The potential understory crop, which is adapted to shade, is wild asparagus (*Asparagus acutifolius*) which is a culinary specialty in the Mediterranean. The spears can be harvested and sold in local markets. Growing under the trees, the asparagus does not affect the olive yield.
2. Growing the wild asparagus in olive orchards appears technically possible.
3. Planting wild asparagus in the middle of the inter-row in super high density orchards needs to be evaluated based on the machinery available for weed control and olive harvest, otherwise the asparagus plants can be in the way. Planting them along the tree row is probably less productive, but poses fewer obstacles.
4. Yield of wild asparagus may be slightly reduced under the olive trees, particularly where there is more shade (e.g. under the tree row in super high density orchards), but the edible (i.e. tender) part of the spear increases, at least partly compensating for the reduction in spear yield.
5. Given the potentially high prices of wild asparagus spears, the income from their cultivation in the olive orchard can increase significantly the overall income from the orchard. However, the labour and the skills required to manage the intercropped orchard also increase.
6. Narcissus and tulips appear to be good alternative candidates for intercrops since their vegetative cycle begins after olives are harvested in the autumn, and terminates in spring when it is still possible to prune the trees, thus not interfering with most olive orchard management practices. However, farmers intending to exploit this possibility should carefully evaluate the market possibility of such intercrops.

Concerning intercropping olive trees with chickpeas, Pantera et al. (2017a) describe the following lessons learnt:

1. Chickpeas represented an additional income to the farmer.
2. The farmer also saved money because it was possible to achieve the same levels of olive production with applying nitrogen fertiliser. There were also lower chemical inputs to the system.
3. Planting in early spring is important to minimize the irrigation requirements for the chickpeas.
4. Oregano was planted in a small plot but it established well even if the production was low.
5. Intercropping with N-fixing plants represents an interesting option in olive orchards.

On a similar experiment in Greece but using cereals and legumes as intercrops, the overall lessons learnt were (Mantzanas et al. 2017):

1. The intercropping of olive trees with cereals (barley) and leguminous crops (common vetch) had positive effect on overall system productivity due to soil cultivation, nitrogen fixation and nutrient input by fertilization.
2. The production of the barley, in both the agroforestry and reference plots, was enhanced by early crop sowing (before the end of November).
3. The standard of farm management seems to be high because of the guidelines set by the agronomist of the farm (the specific farm belongs to the State Prison of Kassandra).
4. This trial provides an excellent demonstration for the whole area of Kassandra peninsula of the intercropping olive trees with cereals and legumes.
5. Intercropping needs experienced or well-trained farmers in order to achieve the best results.
6. Seminars for intercropping and modern agroforestry practices with olive trees should be organized not only in Chalkidiki area but also in the whole country.

The use of a leguminous species as an intercrop was investigated in orange trees, another Mediterranean tree species, and the lessons learnt are presented in the report prepared by Pantera (2017b):

1. Production of orange fruits and orange juice are the primary objectives of the system. During a period when the orange crop canopy was incomplete, intercropping with a nitrogen-fixing crop was possible.
2. Intercropping with chickpeas can contribute to soil nitrogen content and reduce the requirements for chemical fertilizers.
3. Other nitrogen fixing intercrops for orange groves could be beans and peas.
4. The establishment of an effect of nitrogen-fixing intercrop on soil properties was limited by the small number of replicates (three per treatment). Results from other trials suggest that nitrogen-fixing species can necessitate additional phosphorus
5. Shading from the tree reduced intercrop yields, relative to an unshaded area, however the farmer can still benefit from growing an intercrop.
6. Even though the establishment and yield of the chickpeas was good in 2016, the farmer decided to cultivate the field and incorporate the chickpeas to improve the soil, rather than harvest them.

5 Results of agroforestry innovations for apple orchards

The most commonly question investigated was the combination of apple trees for fruit or cider with sheep. The basic idea included the use of grazing sheep in orchards to reduce mowing cost, provide grazing for the livestock and reduce infections by natural enemies. The research highlighted the importance of the carefully considering the tree structure and spray programme before starting grazing (Table 4).

Table 4. Innovation activities of the three stakeholder groups focused on grazing of apple orchards

Activity	Partner(s)	Type of work
Grazed orchards in France	Chambre d'agriculture de Normandie, France	Comparative study of technical and economic analysis of grazing vs not grazing
Grazed orchards in England and Wales	Cranfield University, U.K.	Unreplicated trial of a grazed and an ungrazed orchard to collect economic data
Grazed orchards in N. Ireland	Agri Food and Biosciences Institute and Queens University of Belfast, N. Ireland	Comparative study on the effect of grazing in bush-like apple orchards

Corroyer (2017) reports that the lessons learnt from the French study in Normandy were:

1. A density of more than 4 ewes/ha is needed to maintain the low sward height required for apple harvest.
2. In the case study, the focus was on the maintenance of ewes. In other systems, the orchard may be stocked with fattening lambs which may provide additional income.
3. A lack of management, in 2016, led to sheep removing pieces of bark from 30% of the apple trees. It is important to regularly monitor grass height and sheep behaviour to minimise the sheep grazing the trees. The sheep should be removed immediately if there is evidence of significant tree damage.
4. In 2016, grazing by sheep was estimated to cause a 5% reduction on flowers and apple fruits.
5. Grazing in orchards could reduce apple scab infections, but the two-year study in Normandy needs to be continued to determine the response.
6. Grazing in orchards appears to reduce the number of voles' holes in the soil, but the long-term response still needs to be determined

Burgess et al. (2017) report that the main lessons learnt from the study in Herefordshire in the U.K. were:

1. A farmer who has an apple orchard and sheep can benefit financially from grazing the orchard with the key potential benefits being reduced mowing costs, reduced feed costs for sheep production, and the opportunity to use grassland elsewhere between April and July to produce, for example, a hay crop.
2. The critical issue is that the grazing does not result in a reduction in apple yields. Whilst it is evident that sheep can substantially reduce apple yields in bush orchards (McAdam and Ward 2015), the feedback from the stakeholder group was that there was minimal effect on the apple yield from half-standard and standard apple trees that are already pruned above the browsing height of the sheep.

3. Pruning the trees at this height can increase air movement through the orchard thereby reducing apple diseases and the inclusion of sheep can provide additional nitrogen to the apple crop.
4. It can be feasible to develop working agreements for orchard grazing between an apple orchard owner and a sheep farmer to the financial benefit of both. In such an agreement, the financial advantage for the orchard owner is particularly sensitive to there being minimal effect on the apple yield. The benefit for the sheep owner (who must have access to an additional area of grassland for at least 60 days before apple harvest) is dependent on making effective use of the grassland that is released whilst the sheep are in the orchard and the minimisation of transport costs. In the case study, the inclusion of a contractual cost of £100 between two parties effectively halved the financial benefit for each party and hence minimising this cost is also important.

The main lessons learnt from the study in Northern Ireland regarding grazing bush-like apple orchards were (McAdam 2018):

- The main lesson from this trial is whilst there can be benefits from sheep grazing high pruned orchards, sheep can also damage young bush orchards where the canopy starts below 1.2 m.
- Four of the components of a grazed orchard system are i) the apple trees, ii) the spray programme, iii) the sheep, and iv) the manager. A successful grazed orchard system with sheep requires each of these components to be correct.
    - Apple tree structure: the growth of apple trees can be managed so that the final tree can vary in the height of the tree and the height of trunk with no branches. As indicated above, sheep are likely to damage the canopy of young bush orchards where the canopy starts below 1.2 m.
    - Spray programme: a full season pesticide spray programme especially for the control of apple scab needs to be maintained with the Jonagold variety. This requires greater labour input to manage the sheep during spray operations. Considering the large levels of fruit scab and economics of sorting for the fresh market along with the low fruit size, all Jonagold produced in this trial would be likely to be sent to the juicing market resulting in a reduction in profit for the farmer
    - Sheep breed: the behaviour of sheep breeds can vary substantially. Some lowland breeds are relatively sedentary whereas some upland breeds can behave like goats and are able to get on their two hind legs to reach browse. Selecting the appropriate sheep breed and stocking rate can be important to minimise tree damage.
    - Manager: a successful grazed orchard system requires a manager or a management arrangement that pays attention to the health of the apple trees and the daily monitoring of the sheep and the availability of grass. Successful management of such complex integrated systems can be labour and knowledge intensive.

6 Results of agroforestry innovations for hedgerow trees

The final grouping focused on agroforestry innovation for hedgerow trees. In work-package 2, Thenail et al. (2017) describes the lessons learnt for bocage agroforestry in the Brittany region of France. Van Lerberghe and Malignier (2016) describe their work on bordure trees in South-West France (Table 5).

Table 5. Focus of agroforestry innovation activities related to hedgerow trees

Activity	Partner(s)	Type of work
Bordure trees in South-West France	French Agroforestry Association (AFAF) and Institute for Forestry Development (IDF)	Study to produce quantitative and qualitative information about branches biomass production of pollarded ashes and economic benefits of pollarding old trees

Given the growing demand for firewood in the French Pyrenees, measurements were taken to quantify the wood production of the branches of pollarded ash trees. Although a lesson learnt report has not yet been produced, the following results are reported by Philippe Van Lerberghe, personal communication 2018:

1. The average crown height was greater than three times the trunk height.
2. The fresh biomass of the crown is higher than the trunk biomass (average ratio of 1.6: 1).
3. The biomass growth of the crown is closely related to the circumference of the trunk.
4. The crown biomass was not related to the number of branches. The trees with the largest trunk had the biggest branches.
5. Crown pruning is relevant for farmers looking for bigger branches which can be used as woodfuel.
6. Farmer should encourage open-grown pollarded trees to stimulate trunk diameter growth and crown wood production.

7 Conclusions

Work-package 3 specifically focused on agroforestry systems where, in most cases, the farmer or landowner is starting with a high value horticultural crop (e.g. olives, oranges, apples) or high value timber plantations (e.g. walnut and wild cherry).

1. In the southern sites in Spain and Greece, the focus was often on growing an intercrop. Light levels in these regions is relatively high and widely-spaced tree crops such as olives or walnut trees still allow substantial solar radiation to reach the understorey which can be captured by an understorey crop.
2. Successful understorey crops appear to legumes such as chickpeas (Pantera et al. 2017a; 2017b) *Trifolium michelanium* and *Ornithopus compressus* (Arenas-Corraliza et al. 2017) or a mixture barley with vetch (Mantzanas et al. 2017) which can fix nitrogen (which reduces nitrogen fertiliser needs for the tree crop and can maintain or increase tree yields). However it is noted that additional phosphorus may be required.
3. In Italy wild asparagus and wild flowers are reported as potential understorey crops (Rosati 2017). In Galicia, medicinal plants like *Melissa officinalis* L. and *Mentha* x *piperita* L., although producing low yields, produced similar yields to those obtained in open sites (Mosquera-Losada

et al. 2017b). Maize, as a C4 crop, was not the best choice of intercrop (Mosquera-Losada et al. 2017a).

4. The grazing of a walnut plantation was studied in Spain (Arenas-Corraliza et al. 2017). Grazing increased the density of pasture roots to a soil depth of 50 cm, compared to cultivation and mowing and there was some evidence that this increased the recovery of nutrients at depth and reduced the leaching of nitrate. Although grazing did not favour the tree growth as much as cultivation, it gave better results than mowing.
5. In the northern sites in the UK and Northern France, the focus was on the grazing of pasture below the trees, rather than establishing an intercrop. This is because the yield of grass, as a vegetative crop, can be less sensitive to shading than crops grown for grain or pulses. The three grazed orchard trials demonstrated that the pasture below apple trees can be sufficient to support significant numbers of sheep.
6. Sheep grazing in high stem orchards can be environmentally and financially beneficial (Burgess et al. 2017), however grazing in bush orchards is not recommended as the sheep remove all shoots below a height of about 1.2 m with potentially large short-term, negative effects on apple yields. The research in France suggests that grazing can reduce vole damage. McAdam (2018) outlines that the tree structure, the spray programme, the sheep breed and management expertise all need to considered before starting orchard grazing.
7. The final group focused on the pollarding of hedgerow trees. This is a traditional practice that can provide significant quantities of firewood. In Spain, pollarding was reported as a way of reducing the level of drought stress experienced by the trees (Arenas-Corraliza et al. 2017).

8 Acknowledgements

The AGFORWARD project (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD, Theme 2 - Biotechnologies, Agriculture & Food. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission. This research was co-financed by the Hellenic Ministry of Education, General Secretariat of Research and Technology.

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