AGFORWARD
Agroforestry for Europe

Agroforestry for arable farmers: guidelines

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Contents

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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 Deliverable 4.12 (4.3) contributes to the second and fourth objectives. It contains a summary and copies of twelve innovation leaflets focused on the use of agroforestry in arable systems. The deliverable also supports the dissemination activities to address the fourth objective. Whilst this report focuses on agroforestry for arable farmers, similar reports exist for agroforestry of high nature and cultural value, agroforestry with high value trees, and agroforestry for livestock farmers.

2 Leaflets overview

Twelve innovation leaflets derived from the "agroforestry for arable farmers" participative research and development network have been produced and presented with other innovation and best practice leaflets in a folder (Balaguer et al. 2017) (Figure 1).

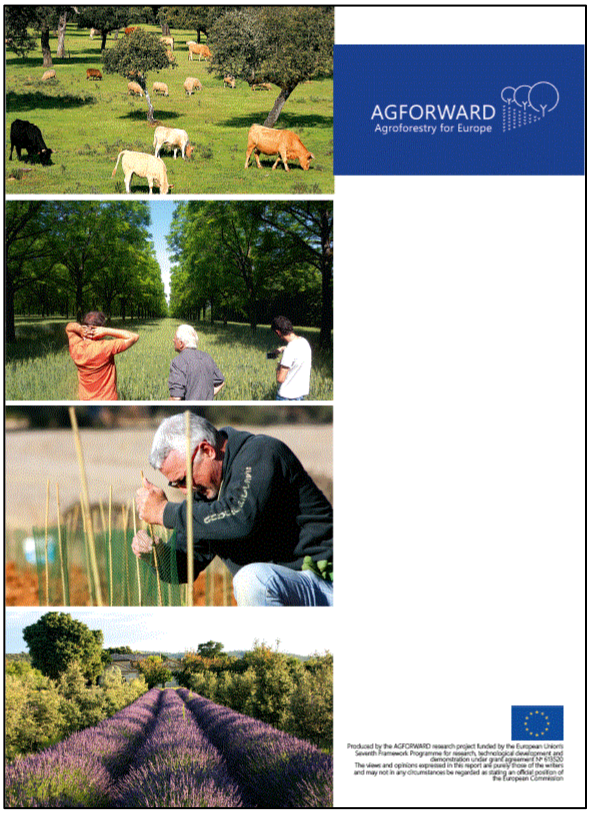

Figure 1. The 12 innovation leaflets focused on agroforestry for arable farmers were included in a folder with a total of 46 innovation leaflets and 10 best practice leaflets (Balaguer et al. 2017)

The work-package 4 stakeholder groups from Italy, Germany, Greece, Hungary and Switzerland produced one leaflet each, and the groups in Southern France, Spain and the UK produced two leaflets each (Table 1). A report focused on cereal production beneath walnut, initiated by a University of Extremadura stakeholder group in work-package 3, is also included in the work-package 4 innovation leaflets because of the focus on cereal production. Although no innovation reports were produced by the silvoarable stakeholder groups in Northern, Western, and South Western France, Philippe van Lerberghe from the French Institute of Forestry Development (IDF) produced a set of 10 Best Practice leaflets (Table 2).

Table 1. Overview of the innovation leaflets

Stakeholder group	Organisation	Number	Title of leaflet	Reference
Cereal production beneath walnut in Spain	Universidad de Extremadura (UEX), Spain	27	Cropping cereals among timber trees	Moreno and Arenas 2017
Silvoarable systems in Spain (SAS)	University of Santiago de Compostela (USC), Spain	28	Productivity and quality of maize under cherry trees	Feirreiro-Dominguez et al. 2017
		29	Intercropping medicinal plants under cherry timber trees	Mosquera Losada et al. 2017
Mediterranean Silvoarable systems in France	INRA, France	30	Organic crops in olive orchards	Panozzo and Desclaux 2017
		31	Understorey management in alley cropping systems in France	Mézière et al. 2017
Trees for timber with arable crops in Italy	Consiglio Nazionale delle Ricerche (CNR) and Agenzia Veneta per l'Innovazione nel Settore Primario (VEN), Italy	32	Hybrid poplar and oak along drainage ditches	Paris and Dalla Valle 2017
Silvoarable agroforestry in Greece	Aristotle University of Thessaloniki (TEI), Greece	33	Walnut and cherry trees with cereals in Greece	Mantzanas 2017
Silvoarable agroforestry in the UK	Organic Research Centre (ORC), UK	34	Agroforestry and decentralised food and energy production	Wolfe 2017
		35	Trees and crops: making the most of the space	Westaway and Smith 2017
Alley cropping systems in Germany	Brandenburg University of Technology Cottbus-Senftenberg (BTU), Germany	36	Yield and climate change adaptation using alley cropping	Mirck 2017
Silvoarable agroforestry in Switzerland	AGRIDEA and Agroscope, Switzerland	37	Agroforestry with standard fruit trees in Switzerland	Jäger and Herzog 2017
Alley cropping in Hungary	University of Sopron, Co-operational Research Centre Non profit Ltd, Hungary	38	Weed suppression in alley cropping in Hungary	Vityi et al. 2017

Table 2. Overview of the Best Practice leaflets which had a specific focus on alley cropping, but which are also relevant for agroforestry with high value trees and with livestock

Number	Title	Reference
1	Alley cropping systems: key objectives	Van Lerberghe (2017a)
2	Analysing the site and choosing tree species	Van Lerberghe (2017b)
3	Choosing quality-planting material	Van Lerberghe (2017c)
4	Planning an agroforestry project	Van Lerberghe (2017d)
5	Protecting trees against wildlife damage: assessing the options	Van Lerberghe (2017e)
6	Preparing the land	Van Lerberghe (2017f)
7	Planting the trees	Van Lerberghe (2017g)
8	Fitting tree protection to prevent deer damage	Van Lerberghe (2017h)
9	Mulching for healthy tree seedling	Van Lerberghe (2017i)
10	Shaping the trees	Van Lerberghe (2017j)

3 Brief description of the innovation leaflets

The studied cropping systems included cereals, legumes, maize, sugar beet, and vegetables (Table 3). The agroforestry innovations included the use of trees for timber and/or fruit production or as a woody biomass feedstock. Tree species for timber and fruit production included walnut, cherry, poplar, olive, apple, maple, alder, and oak. The trees for production of biomass feedstock included willow, hazel and poplar. Studies focused on the tree understory usage included medicinal plants, legumes and flowers.

Table 3. Types of crop and focus of study of the tree component in the 12 innovation leaflets

Leaflet No	Tree component			Arable crop				
	Timber and/or fruit production	Tree under-story	Woody biomass feedstock	Cereals	Legumes	Maize	Sugar beet	Vegetables
27	x			x				
28	x					x		
29	x	x						
30	x			x				
31	x	x		x				x
32	x			x	x			
33	x			x				
34			x	x				x
35	x	x						x
36			x	x			x	
37	x			x				
38	x				x			

3.1 Production of timber and/or fruit and crops

Many of the guidelines were derived from systems including cereal and/or maize production with timber or fruit trees.

The combination of barley and walnut trees for timber production in Spain is discussed in Leaflet 27 (Moreno and Arenas 2017). The authors suggest that the combination of short-cycle winter cereals (that flower and mature early in May) and late-sprouting deciduous trees (e.g. some hybrid walnuts and chestnut) was preferred to minimise competition for light and soil resources.

The productivity and quality of maize plants under cherry trees in Galicia (Northwest Spain) is discussed in Leaflet 28 (Feirreiro-Dominguez et al. 2017). They conclude that this agroforestry system can produce high quality timber, as well as enhance carbon sequestration and nutrient cycling. This may lead to decreased need for fertilisers and therefore a reduced carbon footprint of the farm.

An alley cropping system with hybrid poplar and oak combined with cereals, studied in north-east Italy, is presented in Leaflet 32 (Paris and Dalla Valle 2017). The potential benefits of this intercropping system were diversification of products, improved microclimate conditions and increased productivity per unit of land.

The yield performance of cereal and trees (walnut and cherry) in Greece is described in Leaflet 33 (Mantzanas 2017). The effect of trees on crop yield was minimal, most likely due to their young age of 14 years. It was suggested that intercropping fits well to the local soil and climatic conditions of northern Greece and can provide various goods and services.

Leaflet 30 by Panozzo and Desclaux (2017) describes the yields of cereal and olive trees in a trial evaluating the capacity of durum wheat cultivars to respond positively to olive trees in France. While the wheat maintained or even increased olive production, the yield of durum wheat in the olive orchard was generally lower. Nevertheless, the land equivalent ratio in the studied period ranged between 1.3 and 1.7, suggesting that intercropping produces 30% to 70% higher yield than separate areas of mono-cropping.

Lastly recommendations for standard fruit trees on arable land were given to farmers in Switzerland by Leaflet 37 (Jäger and Herzog 2017). In summary, fruit trees have a positive influence on biodiversity and soil quality. Moreover, the fruit produced can be processed into high-quality products contributing to farmers' income.

3.2 Improved management of the tree understory

The importance of tree understory management in the rows of timber or fruit trees was discussed and guidelines were provided in four leaflets.

Leaflet 29 (Mosquera-Losada et al. 2017) describes the benefits of planting the medicinal plant lemon balm (*Melissa officinalis* L.) under cherry timber trees in Galicia. The combination of high value timber trees with medicinal crops can offer ecological advantages, improve landscape aesthetics and promote rural tourism.

The importance of the understorey vegetation in the tree rows in three French regions is demonstrated by Leaflet 31 (Mézière et al. 2017). At the time of tree establishment, the strips were sown with a mix of legumes (to enhance plant growth) or species that support honey production.

Best management practices for the understory beneath the trees from an agroforestry system in the UK are summarized in Leaflet 35 (Westaway and Smith 2017). The understory crops for horticultural agroforestry can include cut flowers, rhubarb, globe artichokes, and wild flowers. Growing rhubarb and daffodils in the tree strips requires minimal management and can help to control weed species and may boost farmers' income early in the season.

Leaflet 38 (Vityi et al. 2017) demonstrates the use of bio-mulch for weed suppression within a Paulownia and alfalfa agroforestry system in Hungary. The use of herbaceous biomass mulch to cover the tree rows has been shown to be both technically successful and economically viable.

3.3 Production of woody biomass feedstock and crops

The systems for production of woody biomass feedstock were the focus of the guidelines provided by Leaflet 34 for the UK and Leaflet 36 for Germany.

Leaflet 34 (Wolfe 2017) summarizes observations from alley cropping systems with willow and hazel in combination with cereals and vegetables in East Suffolk, England. Trees in coppice and pollard systems were managed in short rotations (not more than a 5 year harvesting cycle). In addition to generating renewable energy, benefits of this system included production of commercial crops, improving the microclimate and carbon storage as well as encouraging wildlife.

Leaflet 36 (Mirck 2017) discussed the tree and crop yields and climate change adaptation of alley cropping systems in Eastern Germany. In comparison to arable systems without trees, the tree hedgerows improve microclimate, provide shelter to the adjacent crops and soil from extreme weather events, facilitate product diversification, and increase land productivity.

4 Summary of the main advantages

The productivity of agroforestry for arable farmers is discussed by each leaflet. The combined production of annual crops and woody perennials increases diversification and can reduce financial risk (Leaflets 30, 32, 36). The annual revenues provided by the crop component can be used as a source of income until timber trees reach maturity, which improves the short-term profitability of the system (Leaflets 28 and 29).

Planting trees in agricultural land results in improved microclimate (Leaflets 32 and 36), reduced soil erosion (Leaflets 30 and 33), improved soil structure (Leaflets 30 and 37), reduced nitrogen leaching (Leaflet 27), improved nutrient cycling (Leaflets 28 and 29), and carbon sequestration (Leaflets 28, 29, 31, 33, 34). Trees can also be successfully used to shelter crops and soil from extreme weather events, induced by climate change (Leaflets 27, 32, 34, 36).

Furthermore, agroforestry can be used to enhance biodiversity, improve natural pest control and pollination (Leaflets 31 and 35), provide habitat to encourage wildlife, birds and insects (Leaflets 34 and 37). Chemical interventions can be reduced (Leaflet 34) and the use of bio-mulch can effectively suppress weeds (Leaflet 38). Moreover agroforestry can improve landscape aesthetics (Leaflets 29, 33, 34) which can encourage rural tourism (Leaflet 29).

5 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.

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Appendix A: The innovation leaflets

Agroforestry Innovation leaflet 27: Cropping cereals among timber trees (Moreno and Arenas 2017).

Agroforestry Innovation leaflet 28: Productivity and quality of maize under cherry trees (Feirreiro-Dominguez et al. 2017).

Agroforestry Innovation leaflet 29: Intercropping medical plants under cherry timber trees (Mosquera-Losada et al. 2017)

Agroforestry Innovation leaflet 30: Organic crops in olive orchards (Panozzo and Desclaux 2017).

Agroforestry Innovation leaflet 31: Understory management in alley cropping systems in France (Mézière et al. 2017).

Agroforestry Innovation leaflet 32: Hybrid poplar and oak along drainage ditches (Paris and Dalla Valle 2017).

Agroforestry Innovation leaflet 33: Walnut and cherry trees with cereals in Greece (Mantzanas 2017).

Agroforestry Innovation leaflet 34: Agroforestry and decentralised food and energy production (Wolfe 2017).

Agroforestry Innovation leaflet 35: Trees and crops: making the most of the space (Westaway and Smith 2017).

Agroforestry Innovation leaflet 36: Yield and climate change adaption using alley cropping (Mirck 2017).

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Cropping cereals among timber trees

Coping with climate warming in Mediterranean countries

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Trial with different cultivars of cereal in a walnut plantation for timber of the Bosques Naturales company, Carpio del Tajo, Toledo, Spain. *Ref : G Moreno*

Facing climate change

Global food production should at least double by the end of this century to meet the needs of the increasing human population. However, crop yield potential has stagnated (Ray et al. 2012), and some reduction in the crop yields is expected as consequence of climate change (Brisson et al. 2010).

The increasing number of early warm events in temperate regions are causing heat-stress during the grain filling phase, and drought during the period of stem elongation. This has strong negative consequences on crop yields. In the last few years, in several regions of Spain, cereal crops have not been harvested because of the lack of grain in the plants. Consequently, new cropping practices that mitigate the harmful effects of climate change, and crop species and cultivars better adapted to new climate conditions, are demanded by farmers.

View of the walnut trees in February (left) and May (right) with cereal cultivated in the alleys. *Ref : E Juarez*

Cropping among trees

Silvo-agriculture can be regarded as an adaptive cultivation system that can help to mitigate the negative effects of climate warming and help meet the challenges arising from the increased frequency of extreme weather events. Spaced trees can help to regulate the climate beneath them by reducing extremes of temperature, providing crops with shelter against wind and lowering evaporation from the soil surface. Indeed, it is already well documented that trees have a major role in Mediterranean wood-pastures in stabilizing grass production through the typically variable seasonal rainfall (Gea et al. 2009; Moreno et al. 2013).

However, most of currently available cultivars for cropping have been selected under full sunlight conditions, and, therefore, there is a need for cultivars which are able to photosynthesize at moderate radiance levels. Combining early maturing winter crops, especially cereal cultivars, with late sprouting deciduous trees seems a promising combination that may provide higher crop yields when compared to those grown in open fields.

View of the cereal (Triticale) in April when trees are sprouting. *Ref : G Arenas*

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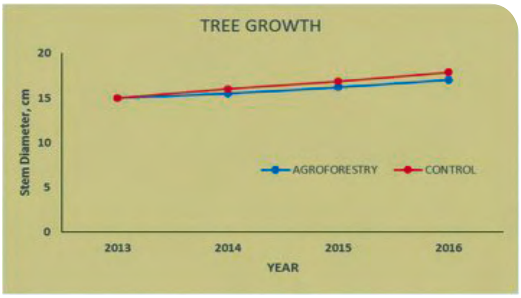
Advantages

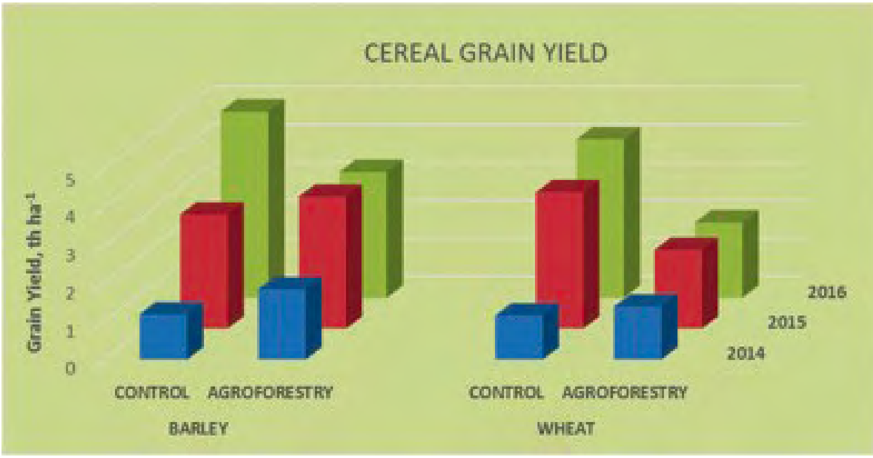
Partial shade, of up to 40%, can help reduce the damage to cereal crops caused by spring heat waves affecting Mediterranean countries with increasing frequency.

Trees, through their deep root systems, are able to capture some residual nitrogen leached below the root system of annual plants, which reduces the risk of nitrogen leaching.

Fine tree roots can be vertically and horizontally modified by the presence of the crop, thereby developing deeper rooting profiles than in pure plantations. This reduces the competition for soil nutrients and water.



Tree growth
Trees grow slower when combined with cereal crops, regardless of the cereal specie and cultivar. Spring rains seem to mitigate the detrimental effect of crops on trees.



Crop yield
Grain yield is usually lower under partial shade (up to 40%) when compared to that grown in open fields. However, in years that experienced heat waves in early spring, the growth of cereal plants in open fields was hampered and, consequently, the yields were higher under trees. The presence of trees was more positive for barley than for wheat.

Dendrometers used to monitor tree growth.
Ref : E Jaurez

State of different cultivars growing among trees (C: barley; T: wheat; TT: triticale). *Ref : G Arenas*

Recommendations

Short-cycle winter cereals that flower and mature quickly (early May) and late sprouting deciduous trees (e.g. some hybrid walnuts and chestnut for timber) are preferable, as this combination ensures that competition for light and soil resources is minimized. Tree lines should be oriented north-to-south to maximize and homogenize the light received by the crop.

Wide alleys (up to 20 m width) reduce crop-tree competition and also tree-tree completion. Timber plantation of low density (100-200 trees/ha) are appropriate for silvoarable combinations. The alley width should be adapted to accommodate farm machinery.

As irrigation is frequently needed for trees, watering by drip irrigation is recommended to begin immediately after crop harvesting.This will prevent uneven crop maturation across the alley.

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Further information

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Maize plants under cherry trees in Galicia (NW Spain)

Productivity and quality of maize under cherry trees

How to optimize maize growth under cherry trees

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Why combine maize with cherry trees?

Maize is in great demand all over Europe as livestock feed. However, intensive maize production requires large amounts of inputs, including fertilizer and water, which results in low returns and high environmental costs.

Currently, quality timber cherry trees have a high market value due to a shortage of supply.

The combination of high value timber trees with maize may be more profitable than maize and tree monocultures and result in enhanced ecosystem services.

Maize plants with cherry trees in Galicia (NW Spain)

How best to combine maize with cherry trees?

In areas with adequate water supply, light is the most limiting factor to growing maize. To reduce the amount of light captured by the trees it is advisable to:

a) plant trees widely spaced (at low density);
b) plant trees in a north-south orientation;
c) plant cherry trees with late bud break.

The combination of maize and cherry trees on the same unit land is an agroforestry system that can, with appropriate land management, enhance the profitability of both components. Due to lower tree densities, high value timber trees, such as cherry, may grow better on agricultural lands (with pH over 5.5) than on forest lands.

Maize plants can be grown in the alleys between the tree rows. The rows of the trees should have a north/south orientation, and there should be a 1.5 m buffer on both sides of the tree row. As maize is a C4 species, light is a limiting factor to growth. Cherry tree varieties should be selected based on timing of bud break; cherry varieties with late bud break should be used to allow maize establishment under less shady conditions.

Maize established with young cherry tree before harvest

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Advantages

- Producing high value timber is a profitable land management use. However, it is a very long-term investment. The combination of high value timber plantations with maize is advantageous because it provides an annual revenue.
- Cherry-maize agroforestry systems improve ecosystem services.

Harvest period of maize established under cherry trees

Establishment and management

Tree planting density and age are important factors when it comes to the combination of cherry trees and maize. The most shade tolerant maize varieties should be selected. Moreover, a low tree density with an adequate distribution of the trees along paddock borders is required to increase productivity of the system compared with monoculture systems. In general, in Galicia (NW Spain), due to the reduction of the surface available to crops, tree distances of 6 m reduce maize yields by 20% although, due to the tree value, productivity of the total system increases. High value cherry trees and maize can be established concurrently to force the trees to develop deeper roots. This improves anchoring of the trees and avoids tree growth reduction due to root damage.

Environment

Deeper tree roots can improve carbon sequestration which mitigates the effects of climate change. Better nutrient recycling is also obtained as trees will take up the excess of nitrogen and other nutrients. This type of agroforestry system, therefore, decreases the need for fertilisers, and reduces the carbon footprint of the farm as less external inputs are required.

Further information

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Intercropping medicinal plants under cherry timber trees

Understory planting to improve productivity of plantations.
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Why combine *Melissa officinalis* L. with cherry trees?

Melissa officinalis L. (commonly known as lemon balm in English) is used to supply rosmarinic acid to the pharmaceutical sector. *Melissa officinalis* L., like many medicinal plants, is well adapted to partial shading. Cherry trees are a high value timber tree with good economic return. They generate little shade compared with other trees.

Melissa officinalis L. **plants under cherry trees with plastic mulch.**

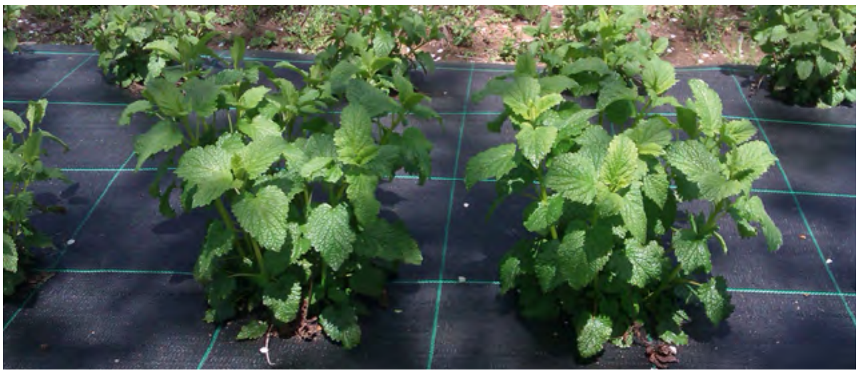
Melissaofficinalis L. **plants under cherry trees at the beginning of the spring.**

How to combine *Melissa officinalis* L. with cherry trees?

The combination of maize and cherry trees on the same unit land is an agroforestry system that can, with appropriate land management, enhance the profitability of both components. Due to lower tree densities, high value timber trees, such as cherry, may grow better on agricultural lands (with pH over 5.5) than on forest lands.

Melissa officinalis L. plants can be grown in the alleys between the tree rows. The rows of the trees should have a north/south orientation for light optimisation and there should be a 1.5 m buffer on both sides of the tree row. Adequate tree densities for high value timber cherry trees are usually between 666 and 1,333 trees/ha. In Galicia (NW Spain), trees are usually harvested when they are 25 years.

Melissa officinalis L. can be purchased as seeds (40-60% germination rate) and seeded. One crop lasts between 4 and 5 years and should be cultivated in alternate alleys to allow for tree pruning. *Melissa officinalis* L. should be established in the spring at a stocking rate of 30,000-40,000 plants/ha (40 and 70 cm spacing between rows) A nitrogen fertiliser should be applied (60 kg/ha for the first year and 80 and 60 kg/ha in the second year) at the beginning of the spring and after the first harvest, respectively. Weeds should be managed mechanically or through mulching (e.g. using plastic, bark or straw.)



Melissa officinalis L. **plants under cherry trees before the harvest.**

AGFORWARD Agroforestry for Europe

Produced by the AGFORWARD research project funded by the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 613520

Advantages

- Producing high value timber is a profitable land management use. However, it is a long-term economic investment. The combination of high value timber plantations with medicinal crops results in short, medium and long term returns.

- In addition, the combination of high value cherry trees and medicinal plants improves landscape aesthetics, which can encouarge rural tourism.

- Moreover, the system can also provide ecological benefits, such as increased rates of carbon sequestration and enhanced nutrient recycling.

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Leaves of *Melissa officinalis* L. before flowering

Establishment and management

Cropping *Melissa officinalis* L. within the alleys at the time of establishing the cherry plantation will force cherry tree roots to penetrate deeper. This allows trees to be better anchored, increasing system resilience against extreme weather events. Growing *Melissa officinalis* L. in the shade, improves the level of rosmarinic acid in the plant, as flowering is delayed

Farm work organization

The period of heavy labour demand is different for cherry trees and the *Melissa officinalis* L. Coping with this requires careful planning and good time management. Any extension of the harvesting period of *Melissa officinalis* L. will require additional labour inputs. Short value chains should be developed for both the tree and the crop component, to make this activity profitable. Labelling products as agroforestry will make it easier for consumers to identify outputs as being linked to sustainable land use practices, and thus command a premium price.

Environment

Melissa officinalis L. is used in organic farming to reduce aphid attacks, which reduces the needs for pesticides in forest plantations, and diminishes negative environment impacts. Deeper tree roots can improve carbon sequestration and mitigate the effects of climate change. Better nutrient recycling is obtained as trees will uptake excess nitrogen and other nutrients.

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Organic crops in olive orchards

Getting more income from your orchard, and enhancing biodiversity and soil fertility

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Evaluation of durum wheat varieties in an organic olive orchard (INRA Mauguio, France) to find the best adapted to agroforestry. *Ref : D.Desclaux*

Why an associated crop?

Olives and olive oil are central in the healthy Mediterranean diet, and there is an increase demand for olive products coming from sustainable and organic farming.

Olive orchards, both traditional and modern, have often large spaces between tree rows (5 m to 9 m) that must be managed, notably for weed removing. To face current challenges, including the increased need for (i) arable land, (ii) radiation use efficiency and (iii) fully covered-soil to avoid erosion, sowing an understorey crop appears a good solution.

Organic durum wheat, another significant component of the Mediterranean diet, is an interesting option to consider as an understorey crop.

Diversity of durum wheat varieties growing within an organic olive orchard (INRA Mauguio, France). *Ref : D.Desclaux*

How to manage durum wheat in organic olive orchards

Low nitrogen availability during reproductive stages is a significant problem for durum wheat in organic farming. Nitrogen deficiency results in a low protein content level and in a loss of vitreous aspect. This can lead to an income reduction for the farmer. Developing varieties adapted to organic conditions, to agroforestry, and to rotations or intercropping with legumes such as chickpea, lentil and fababean, are essential to improve nitrogen use efficiency and soil nutrient content. The design of traditional olive orchards in the South of France is based on 6 m x 6 m inter and intra rows, to ensure maximum sun light. The inter-row spaces are large enough to allow the passage of sowing and harvesting machines (up to 4 m wide) and, therefore, to hosting an understorey crop. The tillage should be minimal to limit olive tree root damage. Sowing of the cereal should take place immediately after olive harvesting in autumn. Some organic treatments can be applied on olive trees after the durum wheat harvest in June or July. Drip irrigation can also be used within the orchards.

The presence of trees leads to shade effects on crops and to modifications in microclimate, water availability and pest and disease patterns. Finding the best durum wheat varieties adapted to such conditions was the aim of a study evaluating a range of durum wheat genotypes (pure lines and populations) for their ability to respond and to interact positively with trees.

Durum wheat varieties grown between rows of unpruned olive trees (INRA Mauguio, France) to evaluate their shade tolerance. *Ref : D.Desclaux*

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Advantages

- Producing a second crop, such as durum wheat, under olive trees increases the productivity per unit of land, maximizes the radiation use efficiency, and helps to prevent erosion.
- Tillage between tree rows improves the soil structure and benefits the olive trees.
- Crop diversification can provide farmers with a more stable income, reduce financial risks due to the increased volatility of the olive oil market, and the susceptibility of olive species to alternate bearing.

Continuous microclimate measurements (air and soil temperatures, relative air and soil humidity, wind speed, and incident photosynthetic active radiation) are carried out in the agroforestry trial (INRA Mauguio, France.) *Ref : D.Desclaux*

Olive and wheat yield

Olive production was not reduced due to the presence of wheat and even showed an increase. However, further researech will be requred to confirm this trend. Wheat production under agroforestry was reduced compared to the control (open field without trees), but the level of reductionvaried largely among the evaluated varieties (from 5 to 80%). The reduction was due mainly to a lower number of tillers per plant. However, the number of spikes, the specific weight (+ 4 points) and the 1000-kernel weight increased (+25%) under agroforestry farming. The Land Equivalent Ratio was between 1.3 and 1.7 depending on the year, indicating that intercropping produces 30% to 70% more than mono-cropping.

Favourable environment for wheat and trees

Olive trees create favourable soil and air temperature conditions for wheat growth. The higher temperatures during seedling emergence are conducive to early vigour and a higher plant density both after winter and at maturity. In addition, during filling stages, the wheat suffers less from high temperatures as a result of the shade. Moreover, litter from olive trees provides a source of nitrate in the top soil. (In the agroforestry trials the value was 50% higher than in the open filed.. At the same time, the tillage carried out before wheat sowing improves the soil structure and benefits the trees.

Innovative breeding criteria for agroforestry adapted crop cultivars

When selecting cultivars adapted to agroforestry, it is important to consider response traits (i.e. how plants respond to environmental stimuli) and effect traits (i.e. how plants influence ecosystem functions). Often, crop breeding for agroforestry is focused on breeding for shade tolerance. However, this narrow way of thinking ignores the numerous potential benefits of interactions between crops and trees. It is important to consider the crop variety traits, not only in terms of adaptation and competition, but also in terms of contribution to the microclimate, the need for water and nutrients, and issues such as pests, weed and tree/crop management. Consequently, the most relevant core-traits concern radiation use efficiency, leaf structure, phenology, root morphology and rooting profile.

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Understory management in alley cropping systems in France

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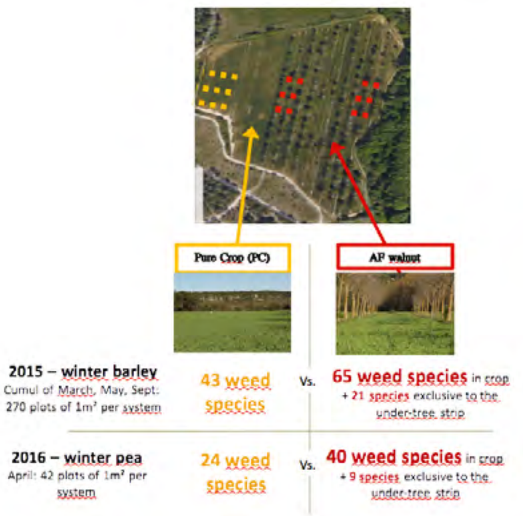
Non-crop vegetation strips under trees (before sowing the arable strips of the alley cropping system in Restinclières, Southern France, October 2014). *Ref : C. Dupraz*

Managing non-crop vegetation within the field

If trees and crops are the productive components of the agroforestry alley cropping systems, a third component must be considered: the non-crop vegetation at the tree strip.

This understory vegetation is the consequence of the difficulty of cultivating soil very close to the trunks without damaging trees. Even though this undisturbed habitat, analogous to a field margin, could be useful for enhancing beneficial biodiversity, it is commonly considered by farmers as a potential reservoir of weeds, which may disperse towards the crop alleys and, thereby, lessen crop production.

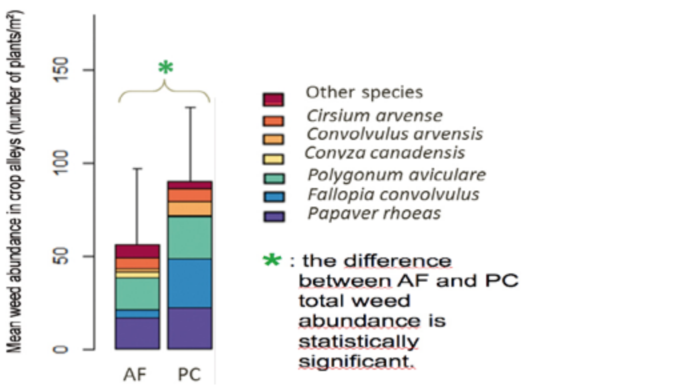


Comparison of plant richness found in the PC vs. the 20-year-old AF sections of the field

Does the weed community differ in agroforestry and pure crop fields?

To set the context for our investigation, we compared weeds in an agroforestry system (AF) vs. a pure crop system (PC), in the Restinclières Estate (southern France). Here, AF and PC crops have been managed according the same conventional cropping system (pea/winter wheat/winter barley rotation, chemical weeding), typical of the region, for 20 years. The only difference is the presence in the AF of hybrid walnut trees (13 m wide) and a spontaneous vegetation strip under the trees (last cultivated 7 years ago).

Our results show that weed species diversity was higher in the AF system for the two surveyed years. This is probably due to the heterogeneity of light and humidity conditions resulting from shading by trees (diversity of habitats), as well as the drift of some species from the tree strip (border effect) (Mézière et al. 2016). When accounting for the additional species we found within the understory strips, the plant diversity was even higher in the AF system. However, during the crop growing season of barley, in terms of abundance, weed infestation (i.e. all species together) was lower in the AF system than in the PC control. Results were similar in pea the following year (2016). When regarding the relative abundance for each species, we found that the most abundant species were similar in both systems, but always more abundant in pure crop (except for C. *canadensis*).



Weed abundance in barley (session of May 2015) in agroforestry (AF) and pure crop (PC) fields. Colours represent the relative abundance by species ("other species" include all the species with less than 3 individuals/m² on average).

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Advantages

The strips occupy a significant area of the field (3 to 10 %). This not only represents a direct loss of area for production, but strips can also host weed species that can spread to the crop. However, with planning, these strips can contribute to biodiversity conservation by providing habitats and resources for pollinators and pest predators, (Marshall and Moonen 2002) store high levels of carbon in soil (Cardinael et al. 2015) and, if planted with medicinal or fruit species, ensure an additional production service.


A


B


C


D

A: There are mainly common weeds on this tree strip [here: bindweeds (*Convolvulus arvensis*), poppies *(Papaver rhoeas)*, thistles (*Cirsium arvense*), wild oats (*Avena* spp.)] in organic cropping system with tillage without any strip sowing at the plantation. *Ref: D. Mézière, central France, August 2016.*
B: Good covering fescue (*Festuca rubra*) sown at the plantation 6 years ago. *Ref: D. Mézière, South-West France, May 2017.*
C: First trial by a farmer of cutting wild oats (*Avena fatua*) and bedstraws (*Galium aparine*) before seed production to avoid dispersal towards crop alleys. *Ref: D. Mézière, South-West France, May 2017.*
D: A 7-year-old old mix-species plantation. Most fields are very young plantations. Currently, the effect of tree shading on the weeds community is less than that provided by the vegetation strip. The effects will need to be studied over several years when tree growth is significant. *Ref: J. Ploumarc'h, March 2017, South West-France.*

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Does the understory strip affect weed infestation in crops?

Weeds were surveyed in crop alleys of agroforestry systems at different distances from tree strips in the Restinclières site in southern France (10 fields), and in western France (10 fields). The results are reassuring, since it does not appear that the strip has a major affect on increasing weed infestation in either conventional-managed fields or in most of the organic-managed fields. One exception was spontaneous vegetation on the strips in some of the organic-managed fields. In these cases, weed infestation in crops was higher if pernicious weeds were present in the tree strips. Farmers should always keep a close eye on the species composition of the tree strip and be ready to act before problematic situations arise. Sowing the tree strips seems to be a very good approach to prevent the development of pernicious weeds.

Species typology according the risk of weed species dispersal from the strip towards crops and their harmfulness in crops for western France. (Donnet 2016)

Species only observed in the non-crop strip	Both in non-crop strip and in crop alley, but not very concerning (easy to manage and/or short-distance dispersal)	Both in non-crop strip and in crop alley. Pernicious weeds.* To survey and control to avoid wide development in the strip	Both in non-crop strip and crop alley. Very pernicious weeds*, difficult to manage. To destruct imperatively when they develop within the non-crop strip (by crushing for example)
Agrostis canina *Festuca arundinacea*	*Epilobium tetragonum* *Picris hieracioides* *Picris echioides* *Torilis arvensis* *Dactylis glomerata*	*Alopecurus myosuroides* *Lolium multiflorum* *Vulpia myuros* *Bromus sterilis* *Bromus erectus* *Avena fatua*	*Cirsium arvense* *Convolvulus arvensis* *Cynodon dactylon* *Rumex spp.* *Sonchus asper* *Sonchus oleraceus*

*Level of harmfulness defined according to expert knowledge for the surveyed regions of western France (Charente and Charente-Maritime).

Suggestions for sowing the strip at the time of tree establishment

Although further research is needed, there are some initial common-sense steps that can be followed. For instance:

- sowing of melliferous species and providing small shelters with pruned branches to support functional biodiversity,
- using tillage-sensitive and perennial species to avoid weed dispersal and reduce the time and financial costs of weed control,
- sowing a mix with legumes to enhance tree growth.

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Hybrid poplar and oak along drainage ditches

Enhancing the financial and environmental value of farmland
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Soybean and alfalfa within hybrid poplar in an alley cropping system. *Ref: Paris 2016*

Why plant poplars?

The Padana Plain in Italy is characterised by intensive agriculture. Cereals are the most common crop, and hybrid poplar (*Populus x euroamericana*) is the most common cultivated tree species for timber production. Intercropping poplar trees with arable crops is now recognized as a modern form of Smart Agriculture, due to the efficient use of site resources (light, nutrients and water) by canopies and root distribution.

The Common Agricultural Policy-Rural Development Plans 2014-2020 currently support the establishment of agroforestry systems in Europe, with direct grants encouraging tree inter-planting with arable crops. In Italy, the current CAP (2014-2020), measure 8.2, promotes these systems in Veneto, Umbria, Basilicata, Marche and Puglia regions.

With the objective of increasing the economic value of the farm through product diversification, linear tree systems, combining different woody species are encouraged by public administrations to enhance productivity and environmental benefits (carbon sequestration, biodiversity preservation, soil erosion control, soil and water quality). Farmers, as well as local people and tourists, appreciate their environmental and aesthetic value.

Where and how to plant poplar trees at low planting density for timber quality

Hybrid poplars are fast growing trees, best suited for cultivation on deep alluvial soils, with permanent groundwater (1-1.5 m below soil surface). Low-lying and flat alluvial soils, with frequent drainage ditches, (at a spacing of about 30-35 m) can be easily used for the establishment of alley cropping systems, by planting trees along one side of the drainage ditch, thereby optimizing the use of reclaimed lands. In each row, hybrid poplar trees are the principal woody species. They are planted for their fast growth at an intra-row spacing of 7-10 m. These may be alternated with other hardwood species, like pedunculate oak (*Quercus robur*). This is an endemic species in many areas of Europe. It is hygrophilous, produces a very high quality timber, and has a lower growth rate compared to hybrid poplars.

Hybrid poplars are planted using 3 m long rods, provided by specialized nurseries, with selected planting material. Rods are planted into deep holes, drilled using machinery or a manually operated motorized drilling device. Oak is planted using containerized seedlings. Care should be taken to use local germoplasm of pedunculate oak with appropriate certification. After tree establishment, localized weed control is required, along with occasional irrigation at times of prolonged drought. Formative pruning is necessary for good quality timber production.

Hybrid poplar and pedunculate oak in an alley cropping system. *Ref: Paris, 2016*

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Advantages

- Producing a second crop of wood (for plywood, packaging and chips) in between the arable crop facilitates product diversification and increases the productivity per unit of land.
- Improved microclimatic conditions within alley cropping systems benefit the arable crop at little additional cost.
- Tree hedgerows have the ability to shelter crops and soils from extreme weather events induced by climate change.
- Crop diversification can protect the farmer from complete crop failure.

Measuring solar radiation distribution across a 3 year-old tree alley with hemispherical photos. Crop shading by trees was almost nil. *Ref: Paris, 2016*

At tree maturity, the crown height does not hinder the use of machinery for crop cultivation. *Ref: Paris, 2017*

Tree yield

Hybrid poplars are fast growing trees reaching a harvestable diameter at breast height of 35 cm in 8-16 years, depending on site conditions. In 2017, poplars had a final value of between 40-50 € per tree. Simulations show that agroforestry trees, with low planting density, should have larger volumes than those grown in plantations.

Crop yield.

Crop yields are expected to be impacted, only slightly, if at all, by tree shading for the first years. Simulations show that crop yields should start significantly to decrease (approx. 70% of sole crop) approaching six years, which is half-way through the trees rotation (Graves et al. 2007).

Pests and diseases

Hybrid poplars, under intensive cultivation, are vulnerable to a range of pests and diseases, attacking leaves (e.g. *Melampsora, Marssonina*), root systems (*Armillaria, Rosellina*) and trunks (with wood borers e.g. *Saperda, Cossus, Crypthorhynchus*). For each specific site, it is important to refer to technical consultants. Canopy spraying should be avoided as this can lead to possible drift over intercrops. It is also recommended to use new resistant clones (Coaloa et al. 2016). Major trunk damage caused by wood borers, can be controlled by early spring spraying.

Labour, harvesting and marketing

Annual tree pruning is essential for producing high quality timber such as plywood). In agroforestry systems, with low planting density, the tree canopy should cover two thirds of the total height. Manual tools reaching high branches can be easily used. For intercrops, no additional labour is required due to tree rows. The maintenance of the ditches (mowing and modelling) is done from the open side. Wood of hybrid poplar is an important commodity, with many industrial uses.

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Walnut and cherry trees with maize. *Reference : Mantzanas, 2005*

Walnut and cherry trees with cereals in Greece

How to optimize maize growth under cherry trees

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Agroforestry is a traditional land use system in Voio, north-western Greece, in which farmers integrate agricultural production with high value tree species on the same area of land. This integrated approach ensures a steady economic return each year irrespective of weather conditions.

Walnut is a commonly cultivated tree species in the sub-Mediterranean and mountainous Mediterranean zones of the country. Walnut is combined with grapevines, cereals, alfalfa, vegetables or dry beans resulting in traditional silvoarable systems (Mantzanas et al. 2006). Although the trees in the experimental area were planted recently (2003), they are managed using traditional practices to produce fruits or nuts. Only recently has the potential of these trees to produce high quality timber similar, or better, to timber imported from tropical areas been recognized.

Walnut and cherry trees with winter wheat. *Reference : Mantzanas, 2017*

Experimental plots were established at the Municipality of Voio, a mountainous area in north-western Greece. Two plots covering an area of 2 ha were established in collaboration with local farmers. The tree species used were hybrid walnut, cherry tree and the local species known as the European nettle tree (*Celtis australis*). One of these plots was cultivated with cereals and the other with a rotation of maize and cereals. The distance between tree rows was 15 m and in the same row the tree distance was 5 m. The tree row width was fixed at 1.5 m. Measurements of height and diameter at breast height, were taken every March, before the onset of new tree growth.

13 year-old walnut and cherry trees in autumn period. *Mantzanas, 2016*

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Advantages

Walnut and cherry trees incorporated with local tree species such as *Celtis australis* intercropped with cereals or legumes constitute a modern agroforestry practice appropriate for northern Greece. They are valuable biological and economic systems as they fit very well to the local soil and climatic conditions and offer various goods (timber, fruits and nuts) and services (improvement of the landscape, erosion control, absorption of water and nutrients, shade, carbon sequestration).

Tree presence improves the landscape of the area. *Reference : Mantzanas, 2015*

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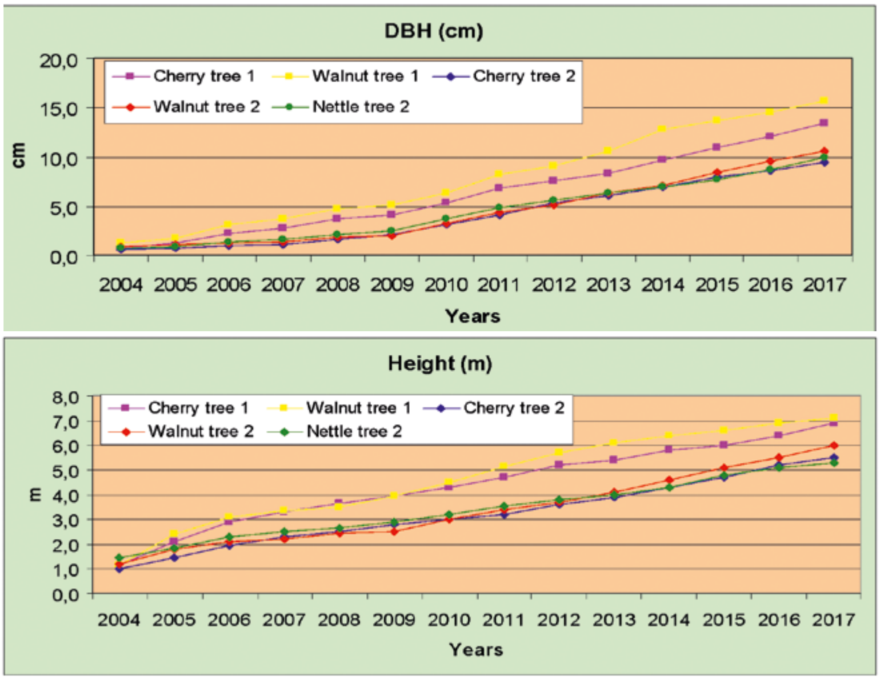

Diameter at the breast height (cm) and tree height (m) in the two plots (1 with crop rotation and 2 with winter wheat) for the 13 years of the experiment. *Reference : Mantzanas,*

Tree yield

Trees in the first plot (crop rotation starting with maize) showed strong growth during the first two years due to summer irrigation. After that period the farmer chhanged the crop and cultivated legumes without irrigation, resulting in a constant growth rate for a period of 4 years. During the last 7 years, continued increase in height and diameter at breast height was observed.

Crop yield

The trees had minimal effect on crop yield in either plot, due to their relatively young age (14 years old). Studies in the same area of hybrid poplars with an age of 15 years, have shown that there was no difference in the crop yield of cereals (durum wheat) at various distances from the trees (Mantzanas et al. 2005).

Labour and marketing

Cultivation is similar to that required for other monocrop cereal plots. Farmers are accustomed to cultivating between the tree rows and take care to avoid damage to branches and the rooting system. The marketing of the timber wood should be researched before the establishment of trees. The value of the timber is directly related with the size. Trees with more than 3 m clear stem and greater than 0.6 m in diameter are suitable for furniture industry.

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Aerial view of Wakelyns Agroforestry hazel system

Agroforestry and decentralised food and energy production

The role of coppicing and pollarding

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The tree problem

From the emergence of Homo sapiens until the last 200-300 years, trees have been the major source of energy (and other materials and food). Even 20,000 years ago, the ratio of trees to humans was about 1.5 million to one, but it has now fallen drastically to about 400 to one (and is still falling). To save the planet, and humanity, we need food and energy systems that are efficient in terms of supplying both of those outputs while improving the quality and sustainability of the biosphere. This could best be done by reversing this declining ratio of trees to humans.

Ideally, to minimise transmission losses, renewable energy needed to replace all fossil fuels should be produced close to where the energy will be used. The system should also deliver other benefits and be fully sustainable. All agroforestry systems are potentially able to do this, but systems that integrate food and energy production will be the most effective and sustainable.

Willow coppice harvested with circular saw

Fuel production: coppicing and pollarding

The systems being developed at Wakelyns Agroforestry, a 23 ha holding in East Suffolk, England were planned during the early 1990's. The first timber trees were planted in early 1994, the hazel coppice system was planted in 1995 and the willow in 1998. The cropping areas in both the coppice and timber tree systems are occupied by the same crops in a single organic crop rotation, including cereals and vegetables.

The hazel and willow trees were planted as double rows and coppiced with a circular saw, the hazel every 5 years, and the willow every two years. The cut stems are air-dried in the field during the summer and then chipped on demand. Into the winter, the willow stems are best covered to protect them against rain and early decomposition; the hazel stems are much more resilient.

Hazel coppice: there is a high rate of regrowth six months after coppicing

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Advantages

The main advantage of both systems, coppice and pollard, is that, in addition to the renewable energy being generated, commercial crops are being produced, carbon is being sequestered, climate extremes are being reduced, the trees provide a number of different habitats to encourage wildlife, and chemical interventions are eliminated.

In this way, an environment is produced which is agreeable to humans, from the points-of-view of aesthetics, physical and economic health, and the sustainability of the planetary biosphere.

Original sycamore with pollarded neighbour (3.5 yrs growth)

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For the next phase of development, Wakelyns are establishing a 5-yr rotational pollarding management system with 2.5 ha of timber trees (ash, hornbeam, Italian alder, oak, small-leaved lime, sycamore), which have been growing since 1994 also in a 12 m alley-cropping arrangement. The 5-yr rotation should maintain all of the trees in the active growth phase when they are at their most productive. This is starting to generate a large increase in available dried timber, which it is planned to use in a small-scale combined heat and power (CHP) unit to generate electricity as well as heat. The main option to be explored for the electricity produced is to store it in electrical vehicle batteries.

Energy yields

Although willow and hazel yields are variable, both species generate 4-5 t dry matter per ha of agroforestry (i.e. trees and crops) per year. The hedges and their understories occupy about 20% of the land area. The total mass is sufficient to provide ample central heating and hot water via a 20 kw boiler for the farmhouse for the year. These yield figures are higher than the expected short rotation coppice yields (of the order of 40 – 50% increase for both species). This is, probably, largely due to the reduced competition on the trees, with no shading and reduced water competition on the east and west sides of the tree rows, plus the fertility-building phase of the organic crop rotation contributing to increasing short rotation coppice biomass.

Disadvantages

The main disadvantages of both systems are first, the timing and integration of field operations for the trees and crops, and second, availability of space and access to the annuals and perennials for those operations. There is also a need for a wider range of combined heat and power units particularly suited to small-scale, on-farm energy production. These difficulties are not insuperable and an increase in experience and scale should lead to specialised management and machinery.

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Trees and crops: making the most of the space

Managing the tree understorey for increased food production and biodiversity

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Silvoarable system at Tolhurst Organics, June 2015 *Ref : Organic Research Centre*

Why manage the understorey?

In many agroforestry systems, the area between the trees and under the tree canopy is an overlooked and underutilised space. Unmanaged, this can create problems with weed control. This space can be put to productive use through planting crops that are adapted to shady conditions. In addition, when managed correctly, the tree understorey can be a resource for biodiversity, providing a habitat for beneficial insects and a food resource for crop pollinators.

Understorey crop and management options for horticultural agroforestry systems can include cut flowers, rhubarb and globe artichokes. These are all crops which thrive in the shade and can be sold alongside other produce. The understorey can also be sown with wild flowers, with species chosen to attract pollinators and provide habitat for beneficial predators.

Daffodils in flower, April 2016 *Ref : Organic Research Centre*

Understorey crop options: what works?

Different approaches to understorey management have been trialled at an organic farm in southern England. The farmer, Iain Tolhurst, has planted a mixture of trees for fruit, timber and coppice products in single rows Tree species are: apples (18 varieties); field maple (*Acer campestre*); whitebeam (*Sorbus aria*); Italian alder (*Alnus cordata*); oak (*Quercus robur*); black birch (*Betula lenta*); hornbeam (*Carpinus betulus*); wild cherry (*Prunus avium*). There are 20 m cropping alleys between where vegetables are grown as part of an organic rotation. The alley width was chosen to fit with the farm irrigation system, and tree rows oriented north/south. The system is still young. Trees were planted into existing ground vegetation in March 2015, and woodchip mulch was applied around each tree to reduce weed competition.

In December 2015, the understoreys of two tree rows were planted with daffodil bulbs (*Narcissus sp.*) with groups of 70 bulbs between each tree. In March 2016, rhubarb crowns were planted into another row; 90 crowns in total over the 150m row. The first saleable harvest of a small number of daffodils was in spring 2016, with the first main crop in spring 2017. Full production of rhubarb is expected in 2019. Ten species of cut flowers were sown in modules in spring 2016 and planted out in summer 2016. Globe artichokes grown from seed were planted in another tree row in late summer 2016, with the first crop likely to be in 2018.

The daffodils and the globe artichokes have been planted into rows sown with a diverse legume and herb mix for pollinators. In one tree row, the understorey has been left as a long-term beetle bank with perennial grasses and tall herbs to provide overwinter habitats for pest predators. Other options for understorey crops are shade-tolerant culinary herb species or species with pharmaceutical properties, such as Melissa.

Rhubarb establishing in the understorey, Sept 2016 *Ref : Organic Research Centre*

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Advantages

Growing additional crops in the tree understorey makes more efficient use of all available land and should increase the overall productivity of the farm. Fifteen percent of total vegetable cropping land was lost to plant the new agroforestry system trees at Iain's farm. Cropping the understorey helps to lessen the impact of taking land out of direct vegetable production.

Perennial crops, such as rhubarb and daffodils, require minimal management following establishment. In addition, active management of the understorey will help to control weed species, which may otherwise cause a problem in the vegetable cropping alleys. Understorey management can also improve resources for biodiversity on farm, helping control pests naturally and increase the presence of pollinators. Daffodils flower early in the spring, therefore supporting pollinators early in the season.

Crop irrigation between the tree rows.
Ref : Organic Research Centre

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Wild flowers in the tree understorey. *Ref : Organic Research Centre*

Yields, establishment and management

Economic data for the different understorey options are being collected. This includes data on the establishment and management costs of the trees and understorey crops, as well as data on vegetable production within the alleys. It is still too early in the trial to have accurate yield data for the understorey crops. Both rhubarb and daffodil crops provide a harvest early in the season, therefore providing an income boost at a time of year when it is most needed. Ongoing management is minimal with a woodchip mulch for to weed control applied around the trees in years one and two. As the plants age, yields will decline and both the daffodils and rhubarb will eventually need replacing. Most rhubarb plants will produce good yields of high quality rhubarb for at least four years, while daffodils can last much longer, although it is likely that some varieties will need replacing as shade increases. Good crop management and control of perennial weeds can extend the life of the plants.

There is the possibility that the understorey crops will compete for water and nutrients, to the detriment of the trees. Tree growth measurements across all rows will allow this to be monitored as the understorey crops establish. There may also be some competition with vegetable crops in the alleys, although it will be difficult to separate out the effects of the trees and understory crops.

Biodiversity: pest and weed control

The diversity of plant species and ground dwelling invertebrates in the different tree rows is being monitored as the different understorey crops establish and grow through to cropping. In 2015, prior to planting the understorey crops, the long-term beetle bank showed the highest plant species diversity and the three rows sown with a legume and herb mix showed the highest invertebrate abundance.

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Yield and climate change adaptation using alley cropping

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Winter wheat within poplar and black locust alley cropping system. *Ref : Freese 2014*

How can trees maintain crop yields?

Climate change scenarios predict fewer but more intense rain events. Dry spring and summer weather reduces crop yields. Water loss from the crop is controlled by solar radiation, air temperature, wind speed and humidity.

Alley cropping systems can modify the crop microclimate by reducing wind speeds and temperature extremes. Lower wind speeds increase humidity levels around the plant surface, thereby slowing water loss.

Many crops that are protected by hedgerows of fast growing trees, managed as short rotation coppice, demonstrate increased photosynthetic rates and water use efficiency.

Close-up of poplar hedgerow with winter wheat.
Ref : Mirck, 2016

How can alley cropping be arranged?

For the establishment of alley cropping systems, seven fast growing tree species (willow, poplar, black locust, beech, alder, ash, and oak) are currently allowed in Germany. Soil pH should range between 5.5 and 8.5, soil depth should be at least 50 cm, and for growing willow and poplar there should be a minimum precipitation rate of 600 mm.

Effective site preparation and weed control are essential for the successful establishment of fast growing woody crop hedgerows. The trees should be planted in winter or spring. Planting material is available through commercial nurseries. The material will be either seedlings or, in the case of willow and poplar, cuttings produced from the previous year's growth are also available. Planting may be done by hand or with mechanized planters. During the first growing year, weed control using chemicals should be carried out. During the second year, after root establishment, further mechanical weeding may be required.

Tree hedgerows can vary in width between 2 and 10 rows (2-15 m wide). Both single and double row designs can be used. Spacing for a single row design could be 2.55 m between rows and 0.4 m within the row. For a double row design, there should be 1.75 m between double rows, 0.75 m within the double row and 0.9 m within the row. The crop alley spacing can vary between 24 and 96 m.

Sugar beet within poplar and black locust alley cropping system. *Ref : Mirck, 2015*

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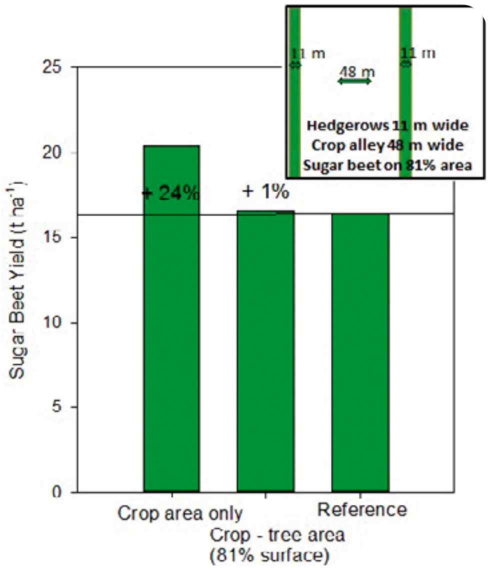
Advantages

- Improved microclimatic conditions within alley cropping systems benefit the arable crop at little additional cost.
- Tree hedgerows help to shelter crops and soils from climate change induced by extreme weather events and crop diversification can protect the farmer from complete crop failure.
- Producing a second crop of wood chips, in between the arable crop, facilitates product diversification and increases the productivity per unit of land.



Sugar beet crop yield before and after subtraction tree area in comparison with reference site. Measured in eastern Germany close to Forst (Lausitz).

Crop yield
Crop yields are expected to be impacted slightly or not at all. Studies in Germany have shown that, after subtraction of the hedgerow area, crop yields within the alley cropping system were similar to the reference area (+24% before hedgerow subtraction).

Tree yield
The above ground biomass can be harvested on a 3 to 5-year rotational basis. A hedgerow with 4 double rows and a 48-m alley width is expected to produce 1.045 – 1.300 t/ha/yr for the first rotation. Subsequen rotations are expected to produce up to 90% more biomass (Labrecque and Teodorescu 2003).

Pests and diseases
Both willow and poplar are vulnerable to a range of diseases, notably *Melampsora* fungi and poplar leaf beetle (*Chrysomela tremulae*). Septoria canker is of concern in North and South America, but it has not yet reached Europe. Fusarium canker, mildew and leaf-spot have been recorded on black locust in Germany. However, overall threats are much lower in Europe than in its native North America.


Mechanical harvest of tree hedgerows of the alley cropping system. *Ref : Kanzler, 2015*

Labour, harvesting and marketing
When grown in straight lines, the cultivation of fast growing trees is not expected to interfere with conventional crop production. Labour levels are expected to increase slightly. However, when practiced on a large scale, mechanical equipment can be used for planting, weed control and harvesting of the biomass feedstock. The marketing of the wood chips should be researched before the establishment of the fast growing trees. For the marketing of the wood products from fast growing trees, the transport distance and water content are important factors to consider. This distance should be kept as low as possible, and the woody crop should be dried before transport.

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High stem apple trees in combination with winter wheat. *Ref : Felder 2015*

Agroforestry with standard fruit trees in Swizerland

Improving production and enhancing biodiversity

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Why plant fruit trees?

There are various reasons why farmers in Switzerland have increasingly combined fruit trees with crops in recent years. One important motivation is to reduce soil erosion, and other benefits include the reduction of nitrate leaching, and increased carbon sequestration and biodiversity.

Through intercropping, farmers are benefitting from increased productivity and product diversification since, in addition to arable crops, they gain the profits of a fruit harvest. Farmers also receive direct payments for their ecosystem service. The Swiss agricultural policy, which is independent from the EU Common Agricultural Policy, promotes the planting of standard fruit trees on agricultural land. Tree contributions are paid irrespective of whether they are traditionally combined with grassland, pasture or in combination with crops.

Mulching of the tree strip in an agroforestry system with chestnut and spelt. *Ref: Jäger, 2016.*

How to plant

Agroforestry systems with cultivated or wild fruit varieties, offer many possible combinations. Depending on soil type and rainfall distribution, all stone and pip fruit trees can be planted.

When combined with wild fruit species (e.g. mulberry, *Sorbus* species, wild pear, wild apple), a lower labour demand for tree care can be expected. However, it will take longer for the trees to produce a substantial yield of harvestable fruit. If the harvest and processing of wild fruits are of interest, large fruiting varieties should be chosen.

Planting in a north-south direction is recommended to reduce shading of the crops. Within the rows, the tree distance should be 10-12 m for apple and pear trees and 10 m for wild fruit varieties. Between rows, spacing should be 18 - 26 meters to facilitate access by agricultural machinery.

The trees are planted in a 2 m wide tree strip, which is sown with grass. The grass must be regularly mulched or mown in order to limit the population of mice. Especially in the case of walnut trees, the grass around the trunk has to be kept very short or even suppressed in the first few years, to minimize grassland competition with the trees. It is recommended that trees are planted starting from the middle of November in order to make use of winter humidity for the growth of the young trees.

Optimal plant protection in a newly planted agroforestry system with fruit trees: stable support post on the windward side, protection against browsing and fraying on the stem base. *Ref: Jäger, 2016*

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Advantages

- Fruit trees have a positive influence on the surrounding biodiversity - they offer an additional habitat for birds and insects.
- Through the leaf fall of the trees and the developing root system, soil humus can be enriched, thus improving soil structure and water holding capacity.
- The fruit produced can also contribute additional income and be processed into high-quality products. Therefore, great attention should be given to the selection of varieties and a clear marketing goal should be developed.

During harvesting time, the fruit has to be collected with tarpaulins or special catchers in order to avoid damage. *Ref : Jäger, 2015*

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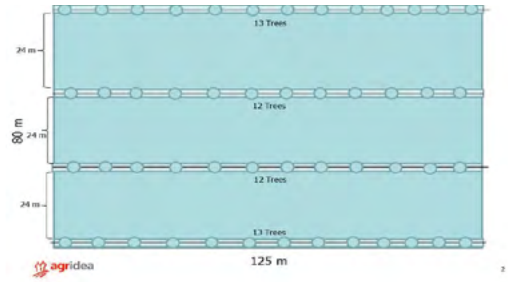

Typical planting scheme in an agroforestry system with fruit trees and arable crops. *Reference: Jäger, 2016*

Tree yield

Standard fruit trees can yield approximately 100 kg of fruit per tree 10 years after planting. Swiss agroforestry systems have an average of 50 trees per hectare (see planting scheme). The tree component (i.e the tree strip) is approximately 10% of the area. Therefore, under optimum conditions, a fruit yield of 5 t/ha can be expected, in addition to the crop yield from the remaining 90% land area, starting 10 years after planting.

However, the high maintenance cost of fruit trees is not to be underestimated. On average, maintenance and harvesting require about 120 working hours per hectare. For comparison, one hectare of arable crops (organic crop production) requires about 50.5 working hours. The economic viability of the system is therefore dependent on: the fruit yield and the income from sales, the costs for tree maintenance and any direct payments for ecosystem services (e.g. biodiversity and resource protection).

Crop yield

Agroforestry systems with fruit trees are still relatively new in Switzerland. So far, no loss of yield has been observed due to shading by the trees. As the age of the trees increases, the yield of the arable crop is expected to decrease due to shading by the tree crowns.

Pests and diseases

Depending on weather conditions, standard fruit trees can be attacked by fungal, bacterial and viral diseases common to these species. It is important to select healthy and robust varieties. Plant protection management is very demanding. Under no circumstances should trees be treated with plant protection products while arable crops are underneath, because there may be a conflict with the consumer safety regulations that restrict the application of pesticides for certain crops and during a certain period before harvest.

Harvesting and marketing

There is only a narrow time window available for the mechanized fruit harvest. For this reason, varieties should be chosen that can be harvested in the period between the crop harvest and the sowing of the following crop. High revenues for fruit products can be achieved through direct marketing. Possible marketing outlets should be evaluated before planting.

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Weed suppression in alley cropping in Hungary

The benefits of mulching with herbaceous biomass

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Biomass mulch in tree rows. *Ref : Péter Schettrer and Andrea Vity*

Why use mulch?

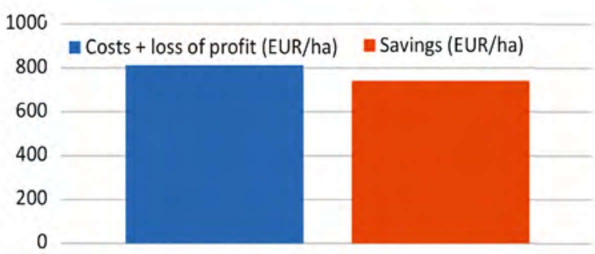
Mechanical weed management can be problematic because of eg. space availability and risk of tree damage. The costs of weed control per area is, therefore, higher than in large scale monocultures. Use of herbicides is not recommended, due to potential damage to the trees. Straw cover is a possible method of weed control, but its effectiveness depends on local circumstances (e.g. it is not effective in windy areas). Further, its removal is required during winter as it attracts rodents.

The use of herbaceous biomass has been shown to be both technically successful and economically viable. Furthermore, improved water use efficiency can be attained due to a reduction in soil evaporation within the tree rows.

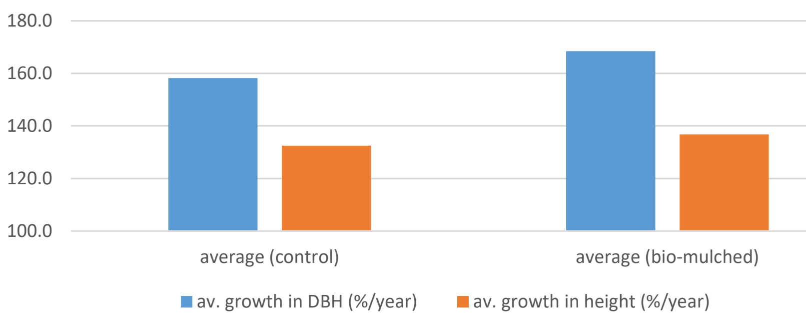
A comparison of treatments

Herbaceous flora of the tree rows and a part of the first harvest of the alfalfa crop were used to mulch the tree rows. It is important to harvest weeds before flowering, otherwise mulching will lead to the spread of weeds within the tree rows.

The innovation was tested in three of the six tree rows planted in an experimental agroforestry system. In three other tree rows manual weed control was performed to compare the results with. The herbaceous cover was made in early May in order to assess effectiveness during the most intensive growing period of the year. Weeds were cut using a motor-manual method, while alfalfa was harvested mechanically and spread by hand in the tree rows. The percentage cover of weed, as well as the labour time and costs of covering the surface for weed control were recorded.



Costs, loss of profit and savings of the tested innovation compared to control method (without external costs and benefits)



Effect of bio-mulching on tree growth rate

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Advantages

The benefits of the bio-mulch are that it:

- is wind-proof
- lowers overall cost
- is environmentally-friendly (replaces chemical and mechanical treatment)
- improves soil fertility in tree rows
- decreases erosion
- reduces manpower needs and mechanical working time and costs
- improves soil microclimate and water management
- accelerates tree growth

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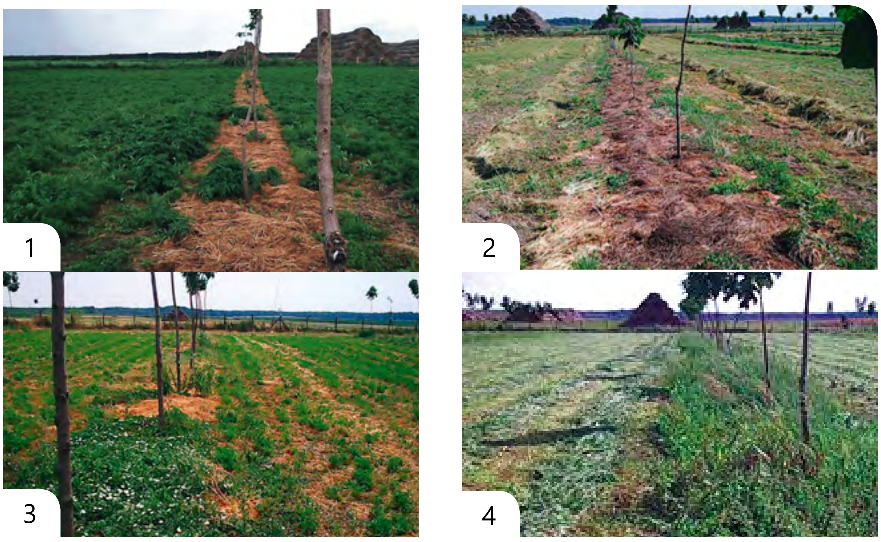

Change of weed pattern in tree rows in relation to time (1-2-3) and control rows without bio-mulching (4). *Ref : Péter Schettrer & Andrea Vityi*

Effectiveness

The weed control ability of the mulch was shown to be very effective:

- the bio-mulch effectively suppressed weeds for approximately 60 days and resulted in a reduction of two weed-cutting periods during the growing season,
- the percentage of weed cover in treated rows was 25% less than the non-covered rows by the end of the second month,
- the number of weed species and their density decreased significantly.

The thickness of the bio-mulch layer is crucial. It is recommended that it is 10 cm at a minimum. Using material harvested close to tree rows is the most economical approach.

Impact on tree development

The annual growth of trees was measured in the mulched and control (without bio-mulch) rows. The results showed a significant difference in tree growth for rows covered with bio-mulch (alfalfa and weed), when compared to non-covered rows.

Economic assessment

There is no significant difference between the overall balance – costs and savings – of the different methods (chemical treatment and mechanical treatment vs bio-mulching). However, taking the additional benefits provided by bio-mulching (e.g. improved microclimate and soil fertility; better tree development; reduced chemical stress and soil erosion) and the lower external costs of chemical or mechanical treatment (eg. contaminated soil, soil water and feed material, air pollution, external costs of herbicide production), the overall economic benefits of bio-mulching is more favourable.

Based on the results, mulching with locally available fresh biomass can be effective in organic production systems as well.

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