Agroforestry for arable farmers: Results of innovations

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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 4.11 (4.2) contributes to the second objective. It contains a summary of the 13 lessons learnt reports derived from the participative research and development network (PRDN) focused on the use of agroforestry in arable systems. The deliverable is connected with work-package 4 which focuses on agroforestry for arable systems. Similar reports exist for agroforestry of high nature and cultural value, agroforestry with high value tree systems, and agroforestry for livestock systems.

2 Overview of the lessons learnt reports

Originally there were eleven stakeholder groups in the agroforestry for arable systems participative research and development network. During the course of the project, the research of the silvoarable group in South-West was merged with the group in Western France. A synthesis of agroforestry innovations to be evaluated by each group was described in Milestone 15 by Mirck et al. (2014), the research and development protocols were summarised in Milestone 16 by Mirck and Burgess (2015), and the synthesis of the system description reports was provided in Deliverable 4.10 by Mirck (2016).

Unfortunately the facilitator of the Western France group was seriously ill at the time of report preparation and it has not been possible to compile a lesson learnt report for that group. The focus of the missing report was on the dimensions of walnut trees planted between 1973 and 1977 in the silvoarable system at Les Eduts in Western France. During a visit by the EIP-Agri Agroforestry Focus Group to the Les Eduts site in November 2016, it was interesting that although the system may superficially appear to be the integration of trees in an arable system; the trees were planted because the farmer was required to replant trees on an area of cleared woodland (Burgess, 2016).

The remaining nine stakeholder groups have produced 12 lessons learnt reports which are available on the individual web-pages of each stakeholder group (Table 1; Figure 1). Six stakeholder groups produced one report. The silvoarable agroforestry groups in the UK (Smith et al. 2017a, b), in Galicia in Spain (Mosquera Losada et al., 2017a, 2017b), and in Mediterranean France ((Gosme and Desclaux 2017; Mézière et al. 2017) produced two reports each (Table 1). An additional report was produced by Universidad de Extremadura in Spain (Arenas-Corraliza et al. 2017). Although the main research of this stakeholder group is considered within work-package 3, a particular focus of their work was on cereal responses, and hence it is reported in this report. Hence there are a total of 13 lesson learnt reports.

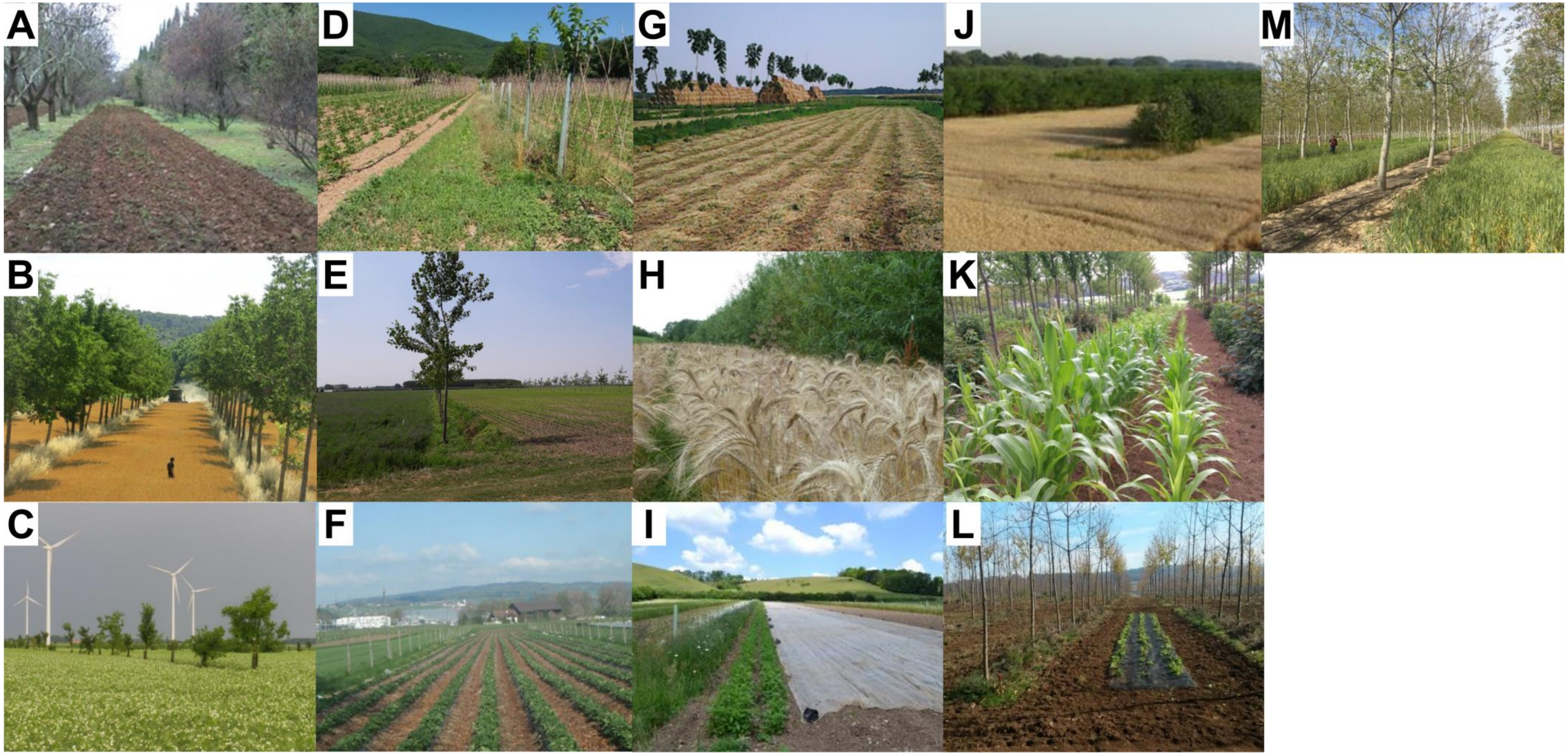

Figure 1. Agroforestry for arable systems across Europe were studied in France (A, B, and C), Greece (D), Italy (E), Switzerland (F); Hungary (G); the UK (H and I), Germany (J) and Spain (K, L and M).

Table 1. Name of stakeholder group (and lead organisation in italics), title of 13 lesson learnt reports and reference

Stakeholder group and lead organisation for lesson learnt report	Title of lesson learnt report	Reference	Acronym (report number)
Silvoarable agroforestry in the UK *Organic Research Centre, UK*	Lessons learnt: Silvoarable agroforestry in the UK	Smith et al. (2017a)	ORC (I)
	Lessons learnt: Silvoarable agroforestry in the UK (Part 2)	Smith et al. (2017b)	ORC (II)
Alley Cropping in Germany *Brandenburg University of Technology Cottbus-Senftenberg, Germany*	Lessons learnt: Alley cropping in Germany	Kanzler and Mirck (2017)	BTU
Mediterranean silvoarable agroforestry *INRA, Montpellier, France*	Lessons learnt: Mediterranean silvoarable agroforestry weed survey	Mézière et al. (2017)	INRA (I)
	Lessons learnt: Screening durum wheat cultivars for agroforestry	Gosme and Desclaux (2017)	INRA (II)
Northern silvoarable systems in France *Assemblée Permanente des Chambres d'Agriculture, France*	Lessons learnt: Weeds and silvoarable agroforestry in Northern France	Wartelle et al. (2017)	APCA
Silvoarable Agroforestry in Greece *Aristotle University of Thessaloniki, Greece*	Lessons learnt: Silvoarable agroforestry in Greece	Mantzanas et al. 2017	TEI
Alley cropping in Hungary *Sopron, Co-operational Research Centre Non profit Ltd, Hungary*	Lessons learnt: Alley cropping in Hungary	Vityi et al. (2017)	NYME
Trees for timber with arable crops in Italy *CNR and Agenzia Veneta per l'Innovazione nel Settore Primario (VEN), Italy*	Lessons learnt: Trees for timber and arable crops in Italy	Paris et al. 2017	CNR/VEN
Silvoarable Systems in Galicia, Spain *University of Santiago de Compostela, Spain*	Lessons learnt: Maize in silvoarable systems in Galicia, Spain	Mosquera Losada et al. (2017a)	USC (I)
	Lessons learnt: Medicinal plants in silvoarable systems in Galicia, Spain	Mosquera Losada et al. (2017b)	USC (II)
Intercropping Mediterranean hardwood plantations in Spain *Universidad de Extremadura, Spain*	Lessons learnt: Cereal crops within walnut plantations in Mediterranean Spain	Arenas-Corraliza et al. (2017)	UEX
Fruit Tree agroforestry in Switzerland *Développement de l'agriculture et de l'espace rural, Switzerland*	Lessons learnt: Agroforestry systems with fruit trees in Switzerland	Jäger (2017)	AGRIDEA

3 Summary of the main objectives

The main objectives addressed by the 13 lessons reports are briefly described below and are summarized in Table 2. They included investigations of agroforestry design for improved productivity, the effect of integrating trees on: arable crop yields, soil properties, the microclimate, weed populations, and the management of the tree understory.

In the UK, measurements undertaken at Wakelyns Agroforestry by the Organic Research Centre focused on the interactions between concurrent production of arable crops and short rotation coppice for bioenergy (Smith et al. 2017a). The fast growing tree species included hazel (*Corylus avellana) and* willow (*Salix viminalis)*. The crops included organic cereals and field vegetables. The main objectives revolved around assessing the productivity of the system including:

1) Biomass component
2) Cereal component
3) Modelling productivity using YIELD-SAFE

The second report by the Organic Research Centre in the UK provided a summary of the research carried out in cooperation with an organic grower, Iain Tolhurst of Tolhurst Organics CIC (Smith et al. 2017b). Tree species in this system included 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*) and the crops were organic vegetables. The aim was to compare the impact of different approaches to understory management on economics and biodiversity (plants (including weeds) and invertebrates). Field measurements started in June and July 2015 when all trees were measured and plant and invertebrate biodiversity assessed. Some assessments were repeated in 2016 and 2017. The activities involved:

1) Tree assessments
2) Plant biodiversity in tree understorey
3) Ground beetle biodiversity (2015 only)
4) Earthworm biodiversity (2016 and 2017)
5) Trees and the understorey: establishment costs and potential income

In Germany, the experimental plots were previously established by the Brandenburg University of Technology (BTU) within the research project "AgroForstEnergie - Economic and Ecological Evaluation of Agroforestry Systems in Farming Practice". The research which focused on soil and groundwater quality, microclimate conditions and yields of the agroforestry system relative to an adjacent area without trees, has been continued through the AGFORWARD project. Tree species included fast growing species poplar (*Poplar* spp.) and black locust (*Robinia pseudoacacia* L.) and the arable crops grown in the alleys included sugar beet (*Beta vulgaris*) and winter wheat (*Triticum durum*). The experimental work included the following objectives (Kanzler and Mirck, 2017):

1) To determine how tree hedgerows planted at three distances (24, 48 and 96 m) affect sugar beet and winter wheat yields
2) To monitor soil moisture content in the 15 cm topsoil layer, and sugar beet yields at different distances from the tree hedgerows
3) To assess the effects of drought stress on sugar beet yields and sugar content
4) To evaluate the impact of tree hedgerows on wind speed

In France, one focus of the "Mediterranean silvoarable agroforestry" stakeholder group was the effect of agroforestry on weed populations. Mézière et al. (2017), based at INRA, examined the effect of agroforestry systems on weed communities. The tree species included hybrid walnut (*Juglans x intermedia*), poplar (*Populus* spp.) and sorb (*Sorbus domestica*), while the crop species included winter barley (*Hordeum vulgare*), durum wheat (*Triticum durum*), and pea (*Pisum sativum*). The objective of the two-year trial was to assess the effect of the understory strip on weed community of the crop alleyways in alley cropping. Key questions included (Mézière et al. 2017):

1) Is the weed community of arable crops different (richness, abundance, composition) in silvoarable systems compared to conventional arable systems?
2) Is the understory vegetation responsible for increasing weed infestation in crops of the alleyways in a conventional alley cropping system?
3) Are the shading conditions responsible for changes in weed composition and abundance?
4) Does weed pressure for crops change in silvoarable systems compared to arable systems?

Another weed survey was conducted by the specific group "Northern silvoarable systems in France" headed by APCA (Wartelle et al. 2017). The trees included between 6 and 12 species per field, represented by *Juglans regia*, *Acer platanoides*, *Prunus avium*, *Sorbus torminalis, Sorbus domestica, Malus sp.* and *Pyrus sp*p. The crops included cereals, mainly soft winter wheat, potatoes, sugar beet, oilseed rape, and faba bean. The weed assessment in this study began in the summer of 2015 and continued in 2016. Six fields were surveyed in 2015 and 2016. In 2016, the weed survey was carried out after budbreak when tree leaves were well developed and when crops were flowering (ca. May-beginning of June). The measurements focused on:

1) Assessing abundance of weeds at different distances from the tree hedgerows in crop strips
2) Comparison between abundance in conventionally and organically managed crop alley

The second report provided by INRA in France was based on the experiment conducted by the Specific group "Mediterranean silvoarable systems". The trees were almond tree (cultivar Ferraduel and Ferragnés) and the crops were durum wheat (*Triticum turgidum* L. subsp. durum (Desf.) Husn.). The objectives of this study were (Gosme and Desclaux 2017):

1) To determine if there is genetic variability in durum wheat regarding the suitability for cultivation in agroforestry systems
2) To perform a first screening of accessions from INRA collections in order to use them in a selection program of varieties adapted to agroforestry

During three years of experimentation, 45 accessions were compared by growing them in different shading conditions (obtained by using deciduous or evergreen trees, with different tree densities, tree heights or tree pruning strategies). Measurements were conducted regarding i) the growth and development of durum wheat: germination, winter survival, phenology, growth in height and ground cover, and ii) the yield components that determine yield. The decrease in light intensity under the trees was also measured. Comparison of these variables between the different shading conditions were used to classify the varieties regarding their shade tolerance.

Table 2. Summary of objectives

Objectives \ Acronym (report number)	ORC (I)	ORC (II)	BTU	INRA (I)	INRA (II)	APCA-PI	TEI	NYME	CNR/VEN	USC (I)	USC (II)	UEX	AGRIDEA
Design													
What is the effect of trees on crop yield?							x						
Measurement of crop yield at progressive distances from tree rows	x		x						x	x			
Assessing the effect of tree density on crop yield										x			
Assessment of tree growth in the establishment phase		x					x	x					
Testing crop varieties under different shading conditions/ Selection of adapted cultivars					x							x	
Management													
Assessing the production of biomass feedstock with different rotation	x												
Effect of the understory strip on weed community and dispersal in the crop alley				x		x							
How to control weeds effectively?								x					
To evaluate the effect of tree density and fertilisation on the yield and the concentration of active components of medicinal plants established under trees											x		
How to protect effectively trees from wild animals?								x					
Economic benefits													
Yield of tree and/or crop in agroforestry	x	x	x		x		x	x	x	x	x	x	
Assessing costs and labour time of weed control								x					
Tree and the understory: establishment costs and potential income		x											
Environmental benefits													
Effect on biodiversity		x		x		x							
Effect of trees on soil moisture			x					x	x				
Effect on soil carbon and nutrient							x	x	x				x
Wind protection and microclimate improvements			x		x			x					

In Greece, the "Silvoarable agroforestry in Greece" led by TEI investigated a research site comprised of two arable plots (Mantzanas et al. 2017). One site was planted with walnut trees (*Juglans regia*) at the end of March 2015 intercropped with common beans (Phaseolus vulgaris). The second site was planted with cherry trees (*Prunus avium*). The experimental work focused on the following questions:

1) How does agroforestry affect crop yield?
2) How does crop affect trees at the establishment phase?
3) What is the tree root distribution and how do tree roots interact with crop roots during the vegetation period?
4) How does agroforestry affect nutrient cycling?

The focus has been on the first two objectives, because it was considered that the root system of these young trees was still small with little effect on nutrient cycling.

The "Alley cropping in Hungary" group, headed by NYME, undertook studies of a newly created silvoarable system with fast growing tree species (*Paulownia tomentosa var. Continental E*). The stated purpose of the trial was to produce quantitative information about the change in crop production and its vulnerability under rain-fed conditions (Vityi et al. 2017). Key questions included:

1) How does the alley cropping system affect
    a. local microclimate
    b. system resilience
    c. forage yields
    d. tree yields
    e. plant resistance
    f. soil water and nutrient content
    g. soil humus content
2) How to control weeds (cost) effectively, to reduce the amount of labour and mechanical or chemical treatment in tree rows
3) How to protect effectively trees from wild animals

In Italy, the alley-cropping system under study by the specific group "Trees for timber with arable crops in Italy" led by CNR/VEN was established by incorporating hybrid poplars (*Populus x euramericana (Dode) Guiner*) and pedunculate oak (*Quercus robur L.*) along the farm drainage ditches (Paris et al. 2017). This practice was expected to enhance both financial and environmental value of the farmland. The crop species included durum wheat (*Triticum durum*), sugar beet (*Beta vulgaris*), and soybean (*Glycine max*). The four main activities that were carried out in the silvoarable system in Italy during the AGFORWARD project included (Paris et al. 2017):

1) Measurement of tree growth rates, and stem forms, which were assessed by a fast and non-destructive index of stem straightness)
2) Measurement of yield and quality of intercrops at progressive distances from tree-rows
3) Trees shade assessment on intercrops by digital hemispherical photo
4) Eco-physiological measurements of the tree-crop interactions by stable isotopes analysis of soil and plant carbon, oxygen and nitrogen

In Spain, the specific group "Silvoarable Systems in Galicia, Spain" of the USC established two experiments to increase the understanding regarding the combined production of maize and high value trees such as wild cherry (*Prunus avium* L.). The experimental work included the objectives (Mosquera Losada et al. 2017a):

1) To evaluate the production of maize and the tree growth in a silvoarable system under *Prunus avium* L. established at three densities (333, 666 and 1333 trees ha^{-1}) in Galicia (NW Spain) compared with exclusively agronomic and forest systems
2) To evaluate the production of maize at different distances to the trees (1.5, 3 and 6 m) in a silvoarable system established with *Prunus avium* L. in Galicia (NW Spain) compared with an exclusively managed agronomic system

The second report provided by USC focused on establishing medicinal plants under *Prunus avium* L. in Galicia, NW Spain. The total number of treatments established was eight: two medicinal plants (*Melissa officinalis* L. and *Mentha x piperita* L.) established under *Prunus avium* L. at two densities (1333 and 666 trees ha^{-1}) without fertilisation and with fertilisation (5 t ha^{-1} of sheep manure and mineral fertiliser). The objective of the experimental work (Mosquera Losada et al. 2017b) was:

1) To evaluate the effect of the tree density and the fertilisation on the yield and the concentration of active components of *Melissa officinalis* L. and *Mentha x piperita* L. established under *Prunus avium* L.

The "Intercropping Mediterranean hardwood plantations in Spain" led by the University of Extremadura described an experiment within a hybrid walnut (*Mj209xRa;Juglans major* x *regia*) plantation. The high quality timber trees intercropped with annual crops of winter cereals (different cultivars of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.)). The objectives of this research were (Arenas-Corraliza et al. 2017):

1) To compare tree and crop productivity within the silvoarable system compared to trees without crops, and crops without trees under Mediterranean climate conditions (Experiment 1; Field experiment)
2) To start a research program for the selection of best adapted cereal cultivars for the silvoarable agroforestry under Mediterranean climate conditions in Spain (Experiment 2; Garden experiment)

In Switzerland, the stakeholder group "agroforestry for arable framers in Switzerland" led by AGRIDEA is part of the national network of agroforestry farmers, which was set up since 2014 within the framework of the national project "Agroforestry Network Switzerland" (Jäger 2017). This practice-on-farm network includes a total of 25 agroforestry farm sites, mainly with fruit trees. The specific group "Fruit Tree agroforestry in Switzerland" focused on an agroforestry plot with 545 apple trees of the varieties Boskoop and Spartan which occupied 22% of the plot area. The research questions addressed by the experiment were (Jäger 2017):

1) Can we monitor soil organic matter dynamics in agroforestry systems?
2) What is the variability of soil organic carbon and soil total nitrogen in the studied agroforestry system?

4 Summary of the main lessons learnt

The main lessons learnt are considered in terms of the range of silvoarable systems, the effects of crop – tree row – tree interactions, the opportunities for revenue from the trees, the management of the system, and the environmental benefits.

4.1 Range of agroforestry systems for arable farmers

The focus of work-package 4 was on agroforestry for arable farmers. A common feature of most of the systems is that they are relatively new; with most of the trees being planted within the last 20 years in relatively straight lines to enable continued use of standard arable machinery to plant, managed and harvest the arable crops.

The width between the tree rows ranged from 6 m in the Spanish studies (Mosquera et al., 2017a, 2017b; Arenas-Corraliza et al. 2017), to 10 m at Wakelyns Agroforestry in the UK (Smith et al. 2017a) to 96 m in the alley cropping system near the town of Forst in East Brandenburg, Germany (Kanzler and Mirck 2017) (Figure 2). Although two stakeholder groups considered trees planted at 6 m, it may be more appropriate to consider these as intercropping of high value tree systems than agroforestry for arable systems. An alley width of 90 m was also reported at the new silvoarable agroforestry system established at Vallevecchia farm on the open wind-exposed flatland in the Veneto region of Italy (Burgess 2017). Understanding the range of alley widths is important in understanding the rationale for the systems and the responses of the crops in the system.

Many of the systems with relatively narrow alley widths have been developed on organic farms, often selling high value crops, and where farmers seek to derive high value products per unit area and have experience of using high labour inputs per unit area (Smith et al. 2017a, 2017b). The wider alley systems tend to occur on conventionally-managed farms who use mineral fertilizer and agrochemicals where required. Some of these systems occur on relatively flat land and an important consideration is the use of tree lines as wind-breaks to reduce wind speed and soil erosion and improve microclimate.

Figure 2. The alley width for the studied silvoarable systems ranged from 10 m for one system in the UK to 96 m on open wind-exposed land in eastern Germany.

4.2 Crop – tree row - tree interactions

4.2.1 Increased yields within alleys

At three sites there was some evidence that yields in the centre of the cropped alleys were greater than that achieved in more open areas without trees (Table 3). It should be noted that it is difficult to establish this statistically because of the problem in replicating pairs of control areas and areas of alley cropping. Two of these responses were obtained in Germany and Hungary where the alley cropping systems were established on relatively open land and where the trees provided wind protection. The other area where there was a positive response was under the relatively high temperatures found in Mediterranean Spain.

- At the site in Germany, BTU reported that at distances greater than 9 m away from the hedgerows within the alley cropping system, sugar beet and winter wheat yields were higher than at the open field site (Kanzler and Mirck 2017).
- In Hungary, NYME reported consistently higher crop yields in the agroforestry plot compared to the control plot suggesting that the change of soil moisture in the examined plots had a detectable effect on the yield of alfalfa (Vityi et al. 2017). The authors concluded that the use of trees in alley cropping can improve soil moisture for shallow-rooted crops (e.g. cereals and vegetables) and also reduce the extreme changes in soil temperature during periods of drought, associated with high temperatures or in extreme cold weather conditions.
- In Mediterranean Spain, a shading experiment demonstrated that barley and wheat yields could be increased with partial or 50% shade, compared to yields in full sunlight. Under some particularly dry and hot years, when the yield of the monoculture barley crop was particularly low, growing the barley within the trees increased barley yields (Arenas-Corraliza et al. 2017). However it was also noted that in cooler and wetter seasons, the highest barley and wheat yields were obtained from the monoculture crop.

4.2.2 Choice of arable crops and trees to complement resource capture and use

The research demonstrated that some combinations of trees and arable crop are more complementary in their use of solar radiation and water than others. The quality of some crops, e.g. plants grown for medicinal use, can also increase due to the lower temperatures associated with tree cover.

- In Spain, Arenas-Corraliza et al. (2017) reported that the effect of walnut trees on barley yields was more positive than that on wheat yields, because the barley crop can complete much of its development before significant leaf growth on the walnut trees.
- Mosquera Losada et al. (2017b) in a study on planting medicinal plants below *Prunus avium* L. shade in Galicia, Spain showed no negative effect on the yields of *Melissa officinalis* L. and *Mentha x piperita* L.. Moreover, the higher concentration of rosmarinic acid in *Melissa officinalis* L. associated to the high tree density compared with the low tree density, could be explained by the delay of the flowering period, due to the shade conditions, suggesting that the harvest period could be delayed without decreasing the concentration of active components in the medicinal plants improving farmer time organization.

Table 3. Summary of the positive (+), negative (-), or insignificant (=) attributes of integrating trees in arable systems

	ORC (I)	ORC (II)	BTU	INRA (I)	INRA (II)	APCA-PI	TEI	NYME	CNR/VEN	USC (maize)	USC (Medicinal)	UEX	AGRIDEA
Tree – tree row – crop interactions													
Positive effect of trees on crop yields			+					+					
Positive effect of trees on crop yields in dry years												+	
No effect of trees when trees are small									=				
Identification of complementary crop species											+	+	
Identification of shade-tolerant cultivars					+							+	
Reduced crop yields near trees	-		-	-						-			
Reduced crop yields near trees in wet years												-	
Reduced crop yields when trees are large									-				
Weed problems in conventional system						-							
Weed problems in organic system						=							
Use of herbaceous biomass for weed control								+					
Revenue from trees													
Revenue from fruit or short rotation coppice	+		+										+
Management													
Ease of management							-		=				
Capacity to put marketable crops in tree row		+											
Environmental													
Reduced wind speed – soil erosion control and microclimate improvement			+					+					
Increased biodiversity		+											
Increased soil moisture and nutrient retention			+					+	+				+
Increased below-ground carbon storage								+					+

4.2.3 Evidence that cultivars respond differently to the presence of trees

Two of the studies provide some evidence that it may be possible to select cultivars that perform relatively better than other cultivars under shaded rather than unshaded conditions.

- Arenas-Corraliza et al. (2017) in Spain report that the complementarity of resource capture and use between trees and crops varies with cereal cultivar. The cultivars which had a higher production and harvest index under intense shade (50% sunlight) were "Lagalia", "Carolina" and "Meseta" for barley and "Nudel", "Paledor" and "Solehio" for wheat.
- According to results of INRA in France, there was a large variability in the suitability of cultivars to cultivation in agroforestry conditions: yield differences in agroforestry compared to full sun conditions ranged from -62% to +77 % (Gosme and Desclaux 2017).

4.2.4 Competition from trees reducing crop yields

Although there were some cases where the overall arable crop yield was higher between the trees than in an open field, in many cases competition from the trees for solar radiation and water reduce arable crop yields (Table 3). Across six studies, declines in yields were reported for the arable crops planted in close proximity to the trees.

- For example in Germany, the sugar beet and winter wheat yields measured close to the tree hedgerows (3 m) on leeward and windward sites were usually lower than at the other locations within the alley cropping system and the open field reference site (Kanzler and Mirck 2017).
- According to results of INRA in France, the detrimental effect of tree competition against crops was almost always larger than the potential beneficial effects of agroforestry on crop growth (Gosme and Desclaux 2017).
- In Spain, results reported by UEX suggested that in very productive years, without climate constraints for cereal growth, cereal yields were reduced significantly by the presence of trees in the agroforestry system (Arenas-Corraliza et al. 2017). While trees seemed to favour the cereal growth in winter and early spring, after tree buds burst the growth of cereal plants slowed down and the last development stages could be negatively affected, evidencing that crop development was delayed and/or hampered by competition with trees for soil resources (Arenas-Corraliza et al. 2017).
- In the alley cropping system in Italy, intercrop yields showed some decline during the fourth year after tree planting, with soybean that, as warm season crop, might show some negative effect by tree shading in the near proximity of alley edges (Paris et al. 2017).
- In the system studied in Galicia, Spain, the maize production was lower in the agroforestry plots compared with tree-less agronomic plots probably due to the shade and the surface occupied by cherry trees and because maize varieties were selected for open sites (Mosquera Losada et al. 2017a). Therefore, testing other maize varieties was proposed in order to find the most appropriate variety for agroforestry.
- In the UK, although data for all studied cereal crops by the ORC indicated a decline in yield with greater proximity both to hedge (coppiced or standing) and tree rows, an exception of this trend was reported for oats, which even benefited from proximity to a coppiced hedge (Smith et al. 2017a).

4.2.5 Dispersal of weeds and weed control

A recognized constraint of creating tree rows within an arable crop is that the tree row can act as a source for weed species.

- Field measurements by APCA-PI in Northern France showed that conventionally-managed crops had higher numbers of weed species near the tree row than in the centre of the alley (Wartelle et al. 2017). However they also noted that for the organically-managed crops, where the levels of weeds were higher, there was not a spatial effect of the tree row on weed distribution.
- In Hungary, the use of herbaceous biomass for weed control was shown to be both technically successful and economically viable (Vityi et al. 2017).

4.3 Revenue from trees

It can be argued that it may be possible to offset the negative effects of the trees on crop yields by the revenue generated by the trees. Many of the systems focused on trees being grown for timber and although it is possible to model the potential returns, the actual return can be difficult to quantify. However there are systems where the trees provide short to medium-term revenue. At Wakelyns in the UK, some of the tree rows were being harvested for short rotation coppice (Smith et al. 2017a). In addition in Switzerland, apple trees were being grown for fruit (Jäger 2017). One of the commercial silvoarable systems in the UK, which was not a specific focus of the study, also comprises rows of apple trees (Burgess 2017b).

4.4 Management, complexity, and required skills

Various initial stakeholder meetings highlighted the increased management associated with agroforestry as a concern.

4.4.1 Farmers' experience; management complexity

- In the alley cropping in Greece, the necessity of farmers experience and training was stressed, since intercropping needs time and labor for optimum results (Mantzanas et al. 2017). It was also deemed important that fields where modern agroforestry system is established were fenced or well protected in order to avoid any damages from wild and domestic animals.
- In Italy, the intercrops management, in terms of machinery movement along the alleys and distribution of fertilizers and herbicides was not negatively affected by tree rows planted along the drainage ditches (Paris et al. 2017).

4.4.2 Obtaining an additional crop from the tree understory

Management of the tree story can be time-consuming, and hence there is interest in ways of making tree row management cost-effective.

- In UK, it was demonstrated that the use of tree understory can improve the profitability of agroforestry. Results suggested that understory crops can help repay establishment costs within two to three years, if a market can be found for the new crops (Smith et al. 2017b).

4.5 Environmental benefits from integrating trees

One of the clearest lessons learnt is that the environmental impact of integrating trees in arable systems is almost always positive in terms of soil erosion control, increased biodiversity, nutrient retention and carbon storage (Table 3).

4.5.1 Reduced wind speed for erosion control and microclimate improvement

- In Germany, introduction of tree hedgerows within the agricultural landscape was suggested to reduce wind velocity, and thereby diminish wind erosion (Kanzler and Mirck 2017). The soil moisture content on the leeward side close to the tree hedgerows tended to be higher than under unsheltered conditions.

4.5.2 Increased biodiversity

- In the system studied by the ORC in the UK, plant biodiversity and evenness underneath the trees increased over time (Smith et al. 2017b). The stable habitat within the tree row also supported higher abundances of earthworms compared to the crop alley.

4.5.3 Improved water and nutrient retention

- In Hungary, results of NYME suggested that agroforestry led to a positive change in soil phosphorus and potassium compared to the control plot (Vityi et al. 2017).

- The agroforestry system studied in Central Switzerland accumulated substantial amounts of N under the tree rows in both topsoil and subsoil up to a depth of 60 cm after only 7 years (Jäger 2017).
- In Italy, results of the stable isotopes studies by CNR/VEN showed early positive synergic interactions between intercrops and trees concerning soil water and nutrients, with poplar trees using soil moisture in deeper soil layers than intercrops, and likely reducing N leaching (Paris et al. 2017).

4.5.4 Carbon storage

- In Switzerland, Jäger (2017) reports that after seven years, the soil carbon levels within the uncultivated tree rows were greater than within the cultivated alleys. On the basis of some stated assumptions, the silvoarable system (22% of area allocated to trees) was estimated to result in an addition 0.51 tonnes of organic soil carbon per hectare per year in the top 25 cm of soil.

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