Agroforestry for Arable Systems: Synthesis of System Descriptions

Project name	AGFORWARD (613520)
Work-package	4: Agroforestry for Arable Systems
Deliverable	Deliverable 4.10 (4.1): Synthesis of system descriptions
Date of report	13 May 2016
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Contents

AGFORWARD (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

1 Context

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

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

This report contributes to the second objective. It contains a synthesis of 13 system descriptions, Deliverable 4.10 for the participative research and development network focused on the use of agroforestry in arable systems. This report contains a summary of the components (tree and crop), structure, ecosystem services and economic value of the systems. Agroforestry in arable systems is the focus of work-package 4 in the project. Similar reports exist for agroforestry of high nature and cultural value, agroforestry with high value trees, and agroforestry for livestock systems. The data included in this report will also inform the modelling activities which help to address Objective 3. Further details of individual protocols can be obtained from the individual documents listed in the reference list.

2 Agroforestry for arable farmers

This Participative Research and Development Network (PRDN) focuses on agroforestry for arable farmers (Work-package 4). Arable agriculture provides large quantities of food, but it can be associated with reductions in soil and water quality, biodiversity, and the release of greenhouse gasses. The integration of trees within arable systems can provide a variety of ecosystem services, product diversification and improved resource efficiency.

This PRDN has the following objectives:

i. to identify examples of the best practices, key challenges and innovations to address challenges identified by the stakeholder groups within the PRDN,
ii. to describe and explain the key inputs, outputs and ecosystem services flows for case studies (association with work-package 6),
iii. to agree within the PRDN, the key innovations or improvements in knowledge needed in order to promote adoption of high value tree systems,
iv. to agree and implement within the PRDN an experimental protocol to develop and test proposed innovations at existing experimental plots and through on-farm experiments, and;
v. to provide and promote guidelines for farmers on how to establish economically viable agroforestry practice in high value tree systems.

Silvoarable agroforestry covers about 358,000 hectares corresponding to about 0.2% of the agricultural area in the EU. The largest areas of silvoarable agroforestry are found in Spain, Italy, Portugal and Greece (den Herder et al. 2016). Work-package 4 of the AGFORWARD project includes stakeholder groups in Italy, Greece and Spain, together with France, Germany, Hungary, Switzerland, and the UK. Typical crops cultivated in arable agroforestry systems and studied by these stakeholder groups include cereals, potatoes, sugar beet, fodder crops such as alfalfa, and pulses.

3 Systems description summaries

This section describes the silvoarable systems in work-package 4 of the AGFORWARD project. It firstly describes the components (tree and crop), then the ecosystem services and lastly the economic values of the systems. The results are synthesised from 13 system descriptions (Table 1).

Table 1. Thirteen system reports focused on agroforestry for arable systems provide the basis for this report

Gosme M and Meziere D (2016). System Report: Durum Wheat Production in Agroforestry Systems in France. 18 January 2016. 12 pp. Available online: http://agforward.eu/index.php/en/mediterranean-silvoarable-systems-in-france.html

Mantzanas K, Papanastasis V, Pantera A, Papadopoulos A (2016). Systems Description: Silvoarable Agroforestry in Greece. 10 February 2016. 7 pp. Available online: http://agforward.eu/index.php/en/trees-with-arable-crops-and-grassland-in-greece.html

Meziere D and Gosme M (2016). System Report: Weed survey in Mediterranean Silvoarable Group in France. 15 January 2016. 9 pp. Available online: http://agforward.eu/index.php/en/mediterranean-silvoarable-systems-in-france.html

Mirck J, Kanzler M, Quinckenstein A (2016). System Report: Alley Cropping in Germany. 30 October 2015. 11 pp. Available online: http://agforward.eu/index.php/en/alley-cropping-systems-in-germany.html

Moreno G, Arenas G, Lopez-Diaz ML, Bertomeu M, Caceres Y, and Juarez E (2016). System Report: Cereal Production beneath Walnut in Spain. 1 October 2015. 12 pp. Available online: http://www.agforward.eu/index.php/en/silvoarable-systems-in-spain.html

Mosquera Losada MR, Ferreiro-Domínguez N, Fernández Lorenzo JL, González-Hernández P, Rigueiro Rodríguez A (2016). System Report: Silvoarable Systems in Galicia, Spain. 13 January 2016. 11 pp. Available online: http://www.agforward.eu/index.php/en/silvoarable-systems-in-spain.html

Paris P, Laureti M, Ciolfi M and dalla Valle C (2016). System Report: Trees for timber with Arable Crops in Italy. 18 January 2016. 17 pp. Available online: http://agforward.eu/index.php/en/trees-for-timber-intercropped-with-cereals-445.html

Petrillo M and Herzog F (2016). System Report: Silvoarable Agroforestry in Switzerland. 12 February 2016. 12 pp. Available online: http://agforward.eu/index.php/en/integrating-trees-with-arable-crops-switzerland.html

Smith J (2016). System Report: Silvoarable Agroforestry in the UK I. 12 January 2016. 17 pp. Available online: http://agforward.eu/index.php/en/silvoarable-agroforestry-in-the-uk.html

Smith J and Venot C (2016). System Report: Silvoarable Agroforestry in the UK II. 27 October 2015. 13 pp. Available online: http://agforward.eu/index.php/en/silvoarable-agroforestry-in-the-uk.html

Van Lerberghe P, Malignier N, Hannachi Y (2016). System description: Walnut Trees on Arable Land in France. 18 January 2016. 10 pp. Available online: http://agforward.eu/index.php/en/agroforestry-for-arable-farmers-in-western-france.html

Vityi A, Marosvoeglyi B, Kiss A, Schettrer P (2016). System report: Alley Cropping in Hungary. 30 November 2015. 11 pp. Available online: http://agforward.eu/index.php/en/alley-cropping-systems-in-hungary.html

Wartelle R, Meziere D, Gosme M and La-Laurent L (2016). System report: Weed Survey in Northern Silvoarable Group in France. 15 January 2016. 8 pp. Available online: http://www.agforward.eu/index.php/en/mediterranean-silvoarable-systems-in-france.html

3.1 Tree and crop components of selected systems

Silvoarable agroforestry is the deliberate integration of trees and arable crops on a single parcel of land. Silvoarable systems have the potential to combine food, feed, fibre and renewable energy production (USDA 2011). The 13 systems descriptions were produced by the University of Santiago de Compostela (USC) and the University of Extremadura (UEX) in Spain, TEI in Greece, INRA, APCA and AFAF/IDF in France, the Organic Research Centre (ORC) in the UK, BTU in Germany, EVD in Switzerland, CNR and Veneto Agricultura in Italy and NYME in Hungary (Table 1).

The studied trees include both fast and slow growing species. Fast growing tree species include poplar, hazel, Italian alder, black locust, and paulownia. They are included in the studies by INRA (wheat shade and weed studies), ORC (wheat shade), BTU, EVD at Buus, and NYME. Short rotation coppice systems are also being studied at ORC and BTU. Slow growing species, which include high value timber trees and/or fruit and nut producing trees, are being studied by each group except BTU in Germany.

The most common arable crop is wheat and other cereals. Other crops include maize, beans, peas, sugar beet, potatoes, horticultural crops, oilseed rape, sunflower, alfalfa and medicinal and aromatic plants.

3.2 Structure of selected systems

Each system has an alley cropping design which means that the trees have been planted in straight rows with the arable crop planted in the alley between the trees. The alley widths vary between 6 m and 96 m (Table 2). Most hedgerows consist of single tree rows except for the two short rotation coppice (SRC) systems. Both young and old study site are being studied.

Table 2. Components and structure of the agroforestry systems for arable farmers

Partner and country	Stakeholder group	Reference	Study	Tree component	Crop component	Other trees	Other crops	Tree Age (yr)	Control	Spacing (m)
USC, Spain	Silvoarable systems in Spain (SAS) (Mosquera Losada et al. 2016)	SAS	Maize	Walnut	Maize			8	No	5 x 6, 2.5 x 6, 1.25 x 6
			Medicinal plants	Wild cherry	Lemon balm and mint			8	No	2.5 x 6, 1.25 x 6
TEI, Greece	Silvoarable agroforestry in Greece (Mantzanas et al. 2016)	SAG	Field beans	Walnut	Common beans	Poplar	Grape, cereal, vegetables	2	Yes	5 x 15
			Aromatic plants	Cherry	Aromatic plants			2	Yes	5 x 15
INRA, France	Mediterranean silvoarable systems in France (Gosme and Meziere 2016)	MSAF	Wheat shade	Walnut	Wheat	Ash, pear, maple, hackberry,	Alfalfa, pulses	36	Yes	4 x 6
				Poplar	Wheat			16	Yes	6 x 13
				Sorbus domestica	Wheat			21	Yes	6 x 13
		MSAFW	Weed survey A	Walnut	Barley	Ash, pear, maple, hackberry	Alfalfa, oilseed rape	21	Yes	4-8 x 13
			Weed survey B	Poplar	Pulses			16	No	4-8 x 13
				Sorbus domestica	Pulses			21	No	4-12 x 13
ORC, UK	Silvoarable agroforestry in the UK (Smith 2016)	SAUKI	Wheat shade	Hazel, willow coppice	Cereals, potatoes		oilseed rape, field vegetables	5?	No	1.5 x 1.5 x 10-12
ORC, UK	Silvoarable agroforestry in the UK (Smith and Venot 2016)	SAUKII	Weed survey	Six broadleaf species[a]	Vegetables			7?	No	1.5 x 20
BTU, Germany	Alley cropping systems in Germany (Mirck et al. 2016)	ACG	Crop yield	Poplar, black locust (SRC)	Sugar beet, cereals	Alder	Potatoes, alfalfa, maize	7	Yes	0.9 x 0.75 x 1.8 x 24, 48, or 96

Table 2 continued. Components and structure of the agroforestry systems for arable farmers

Partner and country	Stakeholder group	Reference	Study	Tree component	Crop component	Other trees	Other crops	Tree Age (yr)	Control	Spacing (m)
UEX, Spain	Cereal production beneath walnut in Spain (Moreno et al. 2016)	CPWS	crop yield competition	Walnut	Cereals			9	Yes	5 x 6
EVD, Switzerland	Silvoarable agroforestry in Switzerland (Petrillo and Herzog 2016)	SACH	Sursee	Apple	Potatoes, strawberries, flowers			7	No	100 trees ha-1
			Möhlin	Sour cherry, apple, various wild berries	Organic horticultural crops			6-7	No	35 trees ha-1
			Buus	Poplar	Cereals, maize, green manure			2-5	No	?
CNR/VEN, Italy	Trees for timber with arable crops in Italy (Paris et al. 2016)	TTACI	Crop yield	Poplar, oak	Sugar beet, Cereals		Maize, soybean, sunflower, alfalfa, clover	3	Yes	5 x 35
NYME, Hungary	Alley cropping in Hungary (Vityi et al. 2016)	ACH	Crop growth and yield	*Paulownia tomentosa*	Alfalfa, maize			3	Yes	5 x 18
APCA, Picardy, France	Agroforestry for arable farmers in Northern France (Wartelle et al. (2016)	AAFNF	Weed survey	Six-12 broadleaf species[b]	Cereals, potatoes, sugar beet, oilseed rape, faba bean			2-8	No	26-50 m between rows
AFAF/IDF, France	Agroforestry for arable farmers in Western France (van Lerberghe et al.2016)	AAFWF	Tree and crop yield	Black walnut	Barley, pea			44	Yes	7 x 14m, 14 x 14

[An] Apple, maple, whitebeam, Italian alder, oak, black birch, hornbeam, cherry plum (*Prunus cerasifera*)

[B] Among others: Walnut, maple, wild cherry, *Sorbus torminalis, Sorbus domestica,* wild apple tree, and wild pear tree

4 Ecosystem services

Agroforestry provides a range of ecosystem services including cultural services as part of multifunctional landscapes. This multifunctional role of agroforestry has also been highlighted by the Millennium Ecosystem Assessment (2005) and the International Assessment of Agricultural Science and Technology for Development (2008). Environmental services can be divided into provisioning, regulating, habitat, and cultural services.

4.1 Provisioning services

The silvoarable systems provide products from the tree and crop components (Table 3). Using the categories in Table 3, the crop components provide at least 13 types of crop products. The tree components were also categorised into 14 types of tree products. These large numbers indicate that agroforestry systems have great potential for product diversification.

4.2 Regulating services

Agroforestry can regulate the microclimate, recycle nutrients or improve nutrient use efficiency, absorb greenhouse gasses, improve air and water quality, improve soil health, and regulate pests and diseases. Depending on temperature and levels of solar radiation and rainfall, agroforestry systems may either positively or negatively influence crop yields. To improve our knowledge regarding the interaction between crop and tree components, between 3 and 10 regulating services are being studied across the 13 systems (Table 4). The most commonly studied regulating services are carbon sequestration, temperature regulation and nutrient cycling.

4.3 Habitat services

Agroforestry can provide additional habitat opportunities and shelter for plants and animals in comparison to conventional agricultural or forestry systems (Table 5). The 13 silvoarable systems are studying between zero and six habitat services (Table 5).

4.4 Cultural values

Agroforestry may improve cultural values of agricultural landscapes through for example increased employment and educational opportunities, improved aesthetics and tourism (Table 6). The 13 silvoarable systems will carry out research on between zero and six cultural values (Table 6).

Table 3. Provisioning services studied in the agroforestry systems for arable farmers

Stakeholder group (see Table 2)	SAS	SAG	MSAF	MSAFW	SAUKI	SAUKII	ACG	CPWS	SACH	TTACI	ACH	AAFNF	AAFWF
Country	ES	G	F	F	UK	UK	D	ES	CH	I	H	F	F
Tree component													
High quality timber	x		x	x		x		x		x	x	x	x
Low quality timber		x	x										x
Nuts		x											
Fruits		x				x			x				
Wood chips					x	x	x		x	x			x
Mulch/compost						x			x				
Craft material					x	x							
Bioethanol										x			
Fire wood						x					x		
Prunings as fodder	x						x	x		x	x		
Prunings for fire wood	x							x					
Prunings as animal litter										x			x
Wood energy SRC				x	x					x			
Fence posts (black locust)							x						
Total tree	*3*	*3*	*2*	*2*	*3*	*6*	*3*	*3*	*3*	*6*	*3*	*1*	*4*
Crop component													
Fodder	x	x	x	x			x			x	x		x
Silage	x									x			x
Straw								x		x			
Medicinal plants	x												
Grain		x	x	x	x		x	x	x	x		x	x
Tubers					x	x	x			x		x	
Oil										x		x	
Pulses		x	x	x		x						x	
Vegetables		x			x	x	x		x	x			
Fruits						x			x				
Biogas										x			
Bioethanol										x			
Aromatic plants		x	x								x		
Total crop	*3*	*5*	*4*	*3*	*3*	*4*	*4*	*2*	*3*	*9*	*2*	*4*	*3*
Total provisioning services	**6**	**8**	**6**	**5**	**6**	**10**	**7**	**5**	**6**	**15**	**5**	**5**	**7**

Table 4. Regulating services studied in the agroforestry systems for arable farmers

Stakeholder group (See Table 2)	SAS	SAG	MSAF	MSAFW	SAUKI	SAUKII	ACG	CPWS	SACH	TTACI	ACH	AAFNF	AAFWF
Country	ES	G	F	F	UK	UK	D	ES	CH	I	H	F	F
Temperature regulation	x	x	x	x	x	x	x		x	x	x	x	x
Light regulation													x
Nutrient cycling/decomposition	x	x	x	x	x	x	x		x	x	x	x	x
Nutrient uptake above ground													
Nutrient uptake below ground										x			
Uptake GHG emissions and particulate emissions													
Phytoremediation										x			
Air quality													
Increased carbon sequestration	x	x	x	x	x	x	x	x	x	x	x	x	x
Soil improvement									x				
Reduced wind speed		x			x	x	x			x	x		
Reduced soil erosion due to wind		x			x	x	x	x	x	x			
Reduced soil erosion due to water		x			x	x		x	x				
Reduction of flooding													
Reduced evapotranspiration					x	x				x		x	
Weed management/suppression								x			x		
Reduced soil compaction					x			x					
Increased infiltration								x					
Water cycling									x	x	x		x
Water quality							x		x	x			
Reduced pests and diseases						x					x		
Poor drainage due to roots in tile drainage													
Total regulating services	**3**	**6**	**3**	**3**	**8**	**8**	**6**	**6**	**8**	**10**	**7**	**4**	**5**

Table 5. Habitat services and biodiversity studied in the agroforestry systems for arable farmers

Stakeholder group (See Table 2)	SAS	SAG	MSAF	MSAFW	SAUKI	SAUKII	ACG	CPWS	SACH	TTACI	ACH	AAFNF	AAFWF
Country	ES	G	F	F	UK	UK	D	ES	CH	I	H	F	F
Weed suppression										x	x		
Shelter/Stable habitat for animals		x	x	x	x	x	x	x	x			x	
Biodiversity for pollination regulation					x	x				x	x		
Biodiversity (general)					x	x	x			x	x		
Corridor linking					x	x				x			
Habitat diversification					x	x				x		x	
Predatory insects						x							
Total habitat and biodiversity services	**0**	**1**	**1**	**1**	**5**	**6**	**2**	**1**	**1**	**5**	**3**	**2**	**0**

Table 6. Cultural values studied in the agroforestry systems for arable farmers within the AGFORWARD project

Stakeholder group (See Table 2)	SAS	SAG	MSAF	MSAFW	SAUKI	SAUKII	ACG	CPWS	SACH	TTACI	ACH	AAFNF	AAFWF
Country	ES	G	F	F	UK	UK	D	ES	CH	I	H	F	F
Increased rural employment	x				x	x	x	x	x	x	x		x
Educational opportunities											x		
Tree management skills					x	x			x	x			
Improved crop quality		x											
Space orientation trees, farming challenges					x	x							
Reduced crop management costs		x											
Changes to aesthetics		x	x	x	x	x	x		x	x	x		
Increased tourism										x	x		
Health and well-being										x			
Leisure and recreation										x			
Total cultural value	**1**	**3**	**1**	**1**	**4**	**4**	**2**	**1**	**3**	**6**	**4**	**0**	**1**

5 Economic values

There is a great interest in land-use practices that provide financial benefits to landowners and farmers for environmental services (FAO 2007). These financial benefits for environmental services need to be weighed again possible extra labour, mechanisation and economic inputs.

5.1 Labour requirements

It can be expected that the extra tree component will require additional labour in comparison to conventional agricultural systems. However little is known about whether these requirements are low, medium or high. For three of the systems the additional labour requirements are considered to be low, for two they are considered to be medium. For the remaining 8 systems this information is not known (Table 7).

Table 7. Labour requirements studied in the agroforestry systems for arable farmers

Stakeholder group (See Table 2)	SAS	SAG	MSAF	MSAFW	SAUKI	SAUKII	ACG	CPWS	SACH	TTACI	ACH	AAFNF	AAFWF
Country	ES	G	F	F	UK	UK	D	ES	CH	I	H	F	F
Additional labour to conventional system (Y/N)	Y	Y			Y	Y	Y						
Additional labour level (L: low, M: medium, H: high)	L	L			M	L	M						
Soil preparation crops		x	x		x	x	x			x			
Soil preparation trees		x			x	x	x			x			
Seeding		x			x	x	x			x			
Initial tree planting		x			x	x	x			x			
Tree pruning	x					x				x	x		
Tree replacement		x			x	x	x						
Fertilizing crop							x			x			
Fertilizing tree													
Spraying (herbicide)		x					x			x	x		
Spraying (pesticide)		x									x		
Other weed management tasks (including organic, cover crop)		x			x	x							x
Crop harvesting		x			x	x	x			x			
Tree harvesting					x		x			x			
Conversion to organic										x			

5.2 Mechanisation requirements

Silvoarable systems are more complex than conventional arable systems and may therefore require additional or adjusted machines. Modern silvoarable systems can be designed to suit conventional agricultural machines, but they may constrain the choice of machinery for example the choice of sprayer width. Only one of the systems studied is considered to have low additional mechanisation requirements, two identified medium additional requirements and two high (Table 8). The two systems with high additional requirements were organic systems. For the remainder the additional requirements are not known.

Table 8. Additional mechanisation requirements (relative to a conventional crop system) of 13 agroforestry systems for arable farmers

Stakeholder group (See Table 2)	SAS	SAG	MSAF	MSAFW	SAUKI	SAUKII	ACG	CPWS	SACH	TTACI	ACH	AAFNF	AAFWF
Country	ES	G	F	F	UK	UK	D	ES	CH	I	H	F	F
Additional mechanisation to conventional system (Y/N)	Y				Y	Y	Y		Y				
Additional mechanisation level (L: low, M: medium, H: high)	M				M	H	L		H				
Soil preparation crops	x	x	x		x		x	x	x	x	x	x	x
Soil preparation trees					x		x			x			
Seeding		x			x		x						
Tree marking													
Initial tree planting							x			x			
Tree pruning	x									x	x		
Tree replacement							x						
Fertilizing crop							x			x			
Fertilizing tree										x			
Spraying (herbicide)	x						x			x		x	x
Spraying (pesticide)							x						
Other weed management tasks (including organic, cover crop)					x								
Crop harvesting					x		x			x	x		
Tree harvesting										x			
Tree harvesting (Circular saw for SRC)					x		x						
Other conventional agricultural machines	x	x	x			x	x	x	x	x	x	x	x
Phytosanitary treatment			x										

5.3 Economic inputs and outputs

Due to the complexity, it can be challenging to carry out a cost benefit analysis of agroforestry. Most of the systems studied cover only a few hectares except for the system in Germany. Nevertheless it is possible to establish the anticipated yields (Table 9) and economic costs of the systems (Table 10). In some countries the farmer may receive an area payment (ecological focus area) as well (Table 9).

Table 9. Known and studied economic outputs in the agroforestry systems for arable farmers within the AGFORWARD project

Stakeholder group (See Table 2)	SAS	SAG	MSAF	MSAFW	SAUKI	SAUKII	ACG	CPWS	SACH	TTACI	ACH	AAFNF	AAFWF
Country	ES	G	F	F	UK	UK	D	ES	CH	I	H	F	F
Additional outputs to conventional system (Y/N)					Y	Y	Y				x		
Additional output level (L: low, M: medium, H: high)					M	L	M						
Wood (m^3/ha/year)	20									x			
Wood (odt/ha/year)		8			5.4		8						
Maize (t/ha)	13-14												
Pulses (t/ha)		1-1.5											
Winter wheat (t/ha)			4.5				5-9[a]						
Spring wheat (t/ha)					1-5								
Barley (t/ha)				5-6.5									
Oats (t/ha)					5-7								
Sugar beets (t/ha)							16-20[a]			27.5			
Alfalfa											x		
Area payment (€/ha)					400		160			450			

[a]: Yields expressed on an over-dried basis

Table 10. Known and studied economic inputs in the agroforestry systems for arable farmers within the AGFORWARD project

Stakeholder group (See Table 2)	SAS	SAG	MSAF	MSAFW	SAUKI	SAUKII	ACG	CPWS	SACH	TTACI	ACH	AAFNF	AAFWF
Country	ES	G	F	F	UK	UK	D	ES	CH	I	H	F	F
Additional inputs to system (Y/N)					N	N	Y	Y					
Additional inputs (L: low, M: medium, H: high)							L	H					
Labour costs farm operation (€/hr)					30	10	40			20			
Labour costs expert (€/hr)					100	100	100				x		
Seeding cost (€/ha)					0-390		85-225			450	x		
Initial tree cost (€/ha)		500			260		1200-1650			1055	x		
Tree replacement cost (€/ha)		100					1200-1580				x		
Fertiliser N (kg N/ha)	x	x	x	x			67.5-114	x	103	up to 300	68	x	x
Fertiliser (kg P_2O_5/ha)							65-80		72		x		
Fertiliser (kg K_2O/ha)							115-160		72		x		
Fertlizer (t manure/ha)	5								x		x		
Fertilizer (green manure/ley)					x	x							
Fertilizer (compost)						x							
Limestone (kg/ha)							400-700						
Spray cost tree (herbicide) (€/ha)	x		x	x			50		x	x	x	x	x
Spray cost tree (pesticide) (€/ha)	x						11.6			x	x	x	
Spray cost tree (fungicide) (€/ha)				x							x		
Mechanical weeding trees (€/ha)							30				x		
Other tree management costs (€/ha)	x										x		
Fuel and repair costs (€/ha)							30				x		
Machinery cost (€/ha)							163-430				x		
Irrigation cost (€/ha)								x		1054			

6 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.

7 References

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