



## Lessons learnt: Silvoarable agroforestry in the UK (Part 1)

Project name	AGFORWARD (613520)
Work-package	4: Agroforestry for Arable Farmers
Specific group	Silvoarable agroforestry in the UK
Deliverable	Contribution to Deliverable 4.11 Lessons learnt from innovations within agroforestry for arable farmers
Date of report	12 November 2017
Authors	Jo Smith <sup>1</sup> , Ambrogio Costanzo <sup>1</sup> , Nick Fradgley <sup>1</sup> , Samantha Mullender <sup>1</sup> , Martin Wolfe <sup>1</sup> , and João Palma <sup>2</sup> <sup>1</sup> Organic Research Centre, Elm Farm, Newbury RG20 0HR UK, and <sup>2</sup> FORCHANGE, Centro de Estudos Florestais, Instituto Superior de Agronomia, Tapada da Ajuda, Lisboa
Contact	<a href="mailto:jo.s@organicresearchcentre.com">jo.s@organicresearchcentre.com</a>
Approved	Michael Kanzler and Paul Burgess

### Contents

1	Context.....	2
2	Background .....	2
3	Description of system .....	3
4	The tree component .....	5
5	The cereal component .....	7
6	Yield-SAFE .....	11
7	Summary of lessons learnt.....	15
8	Acknowledgements.....	16
9	References .....	16



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 Objective 2. It contains results of the studied innovations from one of the systems being studied within work-package 4 which focuses on agroforestry for arable systems. Together with other reports, this document will contribute to Deliverable 4.11 on lessons learnt from agroforestry for arable farmers. Similar reports exist for agroforestry of high nature and cultural value, agroforestry with high value trees, and agroforestry for livestock systems.

## 2 Background



The initial stakeholder report (Smith et al. 2014) and the research and development protocol (Fradgley and Smith 2015; Smith 2015) provide background data on silvoarable systems in the UK. There is also a system description provided by Smith (2016). These systems are currently rare in the UK. The few systems that exist are usually based on an alley cropping design with arable crops in the alleys. The tree component consists either of top fruit trees (apples, pears and plums), timber trees, or short rotation coppice (SRC) for biomass feedstock production. The development of arable crops specifically adapted for agroforestry systems was identified as an innovation for further development at the workshop held on 18 November 2014 (Smith et al. 2014).

Evolutionary plant breeding can be used to develop varieties that are particularly well adapted to growing in close proximity to trees. The principle is to let natural selection act on these diverse crop populations to select the plants that are best suited to the prevailing conditions i.e. develop an 'alley-edge' population and an 'alley-centre' population. A spring wheat composite cross population (CCP) was grown in plots across a willow system agroforestry alley in 2014 at Wakelyns Agroforestry. Plots of bulk CCP were harvested separately from plots on either side of the alley. In 2015, this seed was used to sow 12 m<sup>2</sup> plots in a replicated cross-over trial to test the effect of the population adapting under natural selection to each environment. This was repeated in 2016. This "lessons learnt" report summarises these trials, as well as presenting yield data from the short rotation coppiced willow and hazel grown as the tree component of the system. The report also includes a summary of the modelling work carried out using Yield-SAFE to assess the overall productivity of the willow SRC silvoarable system.

### 3 Description of system

A description of the system is provided in Table 1.

Table 1. Description of the specific case study system

Specific description of site	
Area	Farm = 22.5 ha Willow SRC silvoarable system ~4 ha Hazel SRC silvoarable system ~2 ha
Co-ordinates	52.361489°N 1.3559639°E
Site contact	Jo Smith or Martin Wolfe
Site contact email	<a href="mailto:jo.s@organicresearchcentre.com">jo.s@organicresearchcentre.com</a> <a href="mailto:wolfe@wakelyns.co.uk">wolfe@wakelyns.co.uk</a>
Example photograph	 <p>Figure 1. Barley in SRC willow silvoarable system at Wakelyns Agroforestry</p>  <p>Figure 2. Potatoes in the SRC hazel silvoarable system, Wakelyns Agroforestry</p>
Climate characteristics	
Mean monthly temperature	6.1°C mean min temp and 14.4°C mean max temp (mean for 1981-2010)
Mean annual precipitation	620 mm
Details of weather station (and data)	Scole met office weather station, location 52.365, 1.160, 27 m amsl <a href="http://www.metoffice.gov.uk/public/weather/climate/u12cfksmy">http://www.metoffice.gov.uk/public/weather/climate/u12cfksmy</a>

Soil type							
Soil type	Beccles series (WRB Eutric Albic Luvic Stagnosols). Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils						
Soil depth	25cm						
Soil texture	Sandy clay to clay loams (sand 49%, silt 23%, clay 28%)						
Additional soil characteristics							
		P (mg/l)	K (mg/l)	Mg (mg/l)	Organic matter (LOI %)	pH	CO2 burst (mg/kg)
	Crop alley	14.7	134.75	55.5	4.825	8.1	25.625
	Tree row	20.4	165.5	67.075	6	8.175	149.3
	Soil analyses of four composite samples in centre of crop alley and centre of tree row carried out in September 2015						
Aspect	Flat						
Tree characteristics							
Species and variety	Hazel SRC system: <i>Corylus avellana</i> Willow SRC system: <i>Salix viminalis</i>						
Date of planting	February 1995						
Intra-row spacing	Hazel: 1.5 m between trees, 1.5 m between twin rows (i.e. 2 lines of trees in each tree row) Willow: 1.2 m between trees, 1.5 m between twin rows (i.e. 2 lines of trees in each tree row)						
Inter-row spacing	Cereal alley 10 m wide. Tree row ~3 m wide						
Tree protection	None; mypex weed control barrier						
Crop/understorey characteristics							
Species	Organic cereals and field vegetables						
Management	Six year organic rotation with three years of fertility building ley.						
Typical cereal yield	Yields per ha of crop (not per ha of agroforestry) Oats: 5-7 t/ha; Spring wheat 1-5 t/ha; Winter wheat 4-7 t/ha Barley: 3.5 t/ha; Triticale: 5.5 t/ha						
Fertiliser, pesticide, machinery and labour management							
Fertiliser	Diverse fertility-building ley grown 3 years out of 6 year rotation; cut regularly and then incorporated into soil before next crop. First cut usually composted and applied to other alleys						
Pesticides	None						
Machinery	Plough, power harrow, drill, combine, mower (for ley); tractor-mounted circular saw for SRC harvest						
Manure handling	None.						
Labour	Two part time contractors do the field operations, including SRC harvesting. Tree surgeon prunes the standard trees.						
Fencing	Fields have diverse boundary hedgerows						
Livestock management							
Species and breed	Small flock of organic laying hens (Rhode Island red, Light Sussex, Norfolk grey, Moran)						
Description of livestock system	Pen with 40-50 hens in alleys measuring 15 m x 75 m, centred on tree row.						



## 4 The tree component

### 4.1 SRC production

Biomass production of the SRC willow has been measured since 2011 and the hazel since 2014. Willow is harvested on a two year rotation with every other row being harvested in a particular year (i.e. 50% of the rows are harvested each year). Hazel is harvested on a five year rotation, with only one side of the twin row being cut in any year. Before the main harvest, sample stools were cut by hand with a chainsaw and weighed using a spring balance mounted on a tractor (Figure 3).



Figure 3. Weighing willow sample with tractor-mounted spring balance

Stools were randomly selected every 12 m along the tree row. With the willow, the twin rows within each tree row are cut and so stools from alternate rows (east/west) were sampled. With the hazel, only one of the twin rows (east or west) is cut in any year and so all stools were from the same side (from 2-3 rows) with an average of 23 trees sampled per year. In addition to the 5-year regrowth samples, some additional samples were collected from different aged regrowth, but with fewer replications and from only single years (4 year regrowth in 2016, 6 year regrowth in 2014, 7 year regrowth in 2013 and 9 year regrowth in 2015). Sub-sampling and oven-drying of the willow and hazel in previous years have indicated a moisture content of on average 50% for willow and 32% for hazel and this is used to convert fresh weight to oven dry weight (ODW). Biomass production is first presented as ODW kg/tree and then converted to ODW per ha of agroforestry and annual ODW calculated for comparison (Table 2).

Table 2. Biomass production of hazel and willow short rotation coppice at Wakelyns Agroforestry

Species and age of regrowth	N*	Tree density per 100 m	Tree row area (m <sup>2</sup> )	Crop area (m <sup>2</sup> )	Trees density per hectare	Moisture content (%)	Oven dry weight		
							(kg/tree)	(t/ha)	(t/ha/yr)
Hazel 4 yr	8	133	300	1000	1023	32	24.92	25.49	6.37
Hazel 5 yr	92	133	300	1000	1023	32	23.65	24.19	4.84
Hazel 6 yr	10	133	300	1000	1023	32	25.69	26.28	4.38
Hazel 7 yr	10	133	300	1000	1023	32	32.91	33.67	4.81
Hazel 9 yr	10	133	300	1000	1023	32	37.74	38.61	4.29
Willow 2 yr	181	165	300	1000	1269	49	7.64	9.70	4.85

\*Number of trees sampled.

In 2015, the calorific content of woodchip was analysed (for the project TWECOM) as a measure of the energy content of the fuel. Woodchip samples were sent to the BioComposites Centre at Bangor University and their calorific content determined. Each one litre woodchip sample was milled to a fine powder using a Glen Creston mill. The powder was dried overnight and then combusted and analysed using a Parr 6100 bomb calorimeter. The results were reported in MJ/Kg and converted to GJ/t and annual energy production (Table 3).

Table 3 Energy production of hazel and willow short rotation coppice at Wakelyns Agroforestry

	Energy content (GJ/t)	Annual energy yield (GJ/ha)
Hazel 4 yr	19.35	123.32
Hazel 5 yr	19.35	93.63
Hazel 6 yr	19.35	84.76
Hazel 7 yr	19.35	93.08
Hazel 9 yr	19.35	83.02
Willow 2 yr	19.11	92.65

The two species of SRC produce very similar yields under current rotations (hazel 5 years and willow 2 years), when converted to annual biomass production. This gives farmers two options to produce a similar outcome; a willow system where the canopy is removed every other year so reducing the amount of shade on the alley crops, but requiring more frequent harvest (and potentially more competitive with crops for water and nutrients) versus a hazel system with slower growing trees, potentially casting more shade, but with fewer harvests to achieve the same yield. A detailed study of crop yields and microclimate conditions in the two systems would allow us to calculate and compare total productivity. It would also be good to include other ecosystem services such as biodiversity impacts (e.g. willow provides early season resources for bumblebees).

Yields of the four year regrowth hazel suggest that harvesting one year earlier than current practice may be more productive. However, these data were from only a single year and a limited number of trees, so further investigation would need to be carried out before changing the rotation. It may also be that harvesting on a four year rotation would impact future regrowth and yields.

#### **How much agroforestry is needed to heat a farmhouse?**

A typical farmhouse boiler (30-40 kW) uses 30-40 t of seasoned chip/year (at 30% moisture content). Converting the oven dry weight (ODW) yields to 30% moisture content, between 4.76 and 6.35 ha of agroforestry (3 m wide tree rows and 10 m wide alleys) is needed to heat a farmhouse each year.

## 5 The cereal component

### 2014 cereal trials

The 2014 cereal trials of a spring oat variety (Canyen), a spring barley variety (Westminster), a spring triticale variety (Agrano), two spring milling wheat varieties (Paragon and Tybalt), an equal mixture of Paragon and Tybalt and a spring wheat Composite Cross Population (CCP) have been reported in Fradgley and Smith (2015). For information, Figures 4 and 5 show the yields of the various cereals in plots running from the east of the SRC willow row (Bed 1) to west of the SRC willow row (Bed 6). The beds are evenly distributed across the 10 m alley with each bed which is about 1.7 m wide.

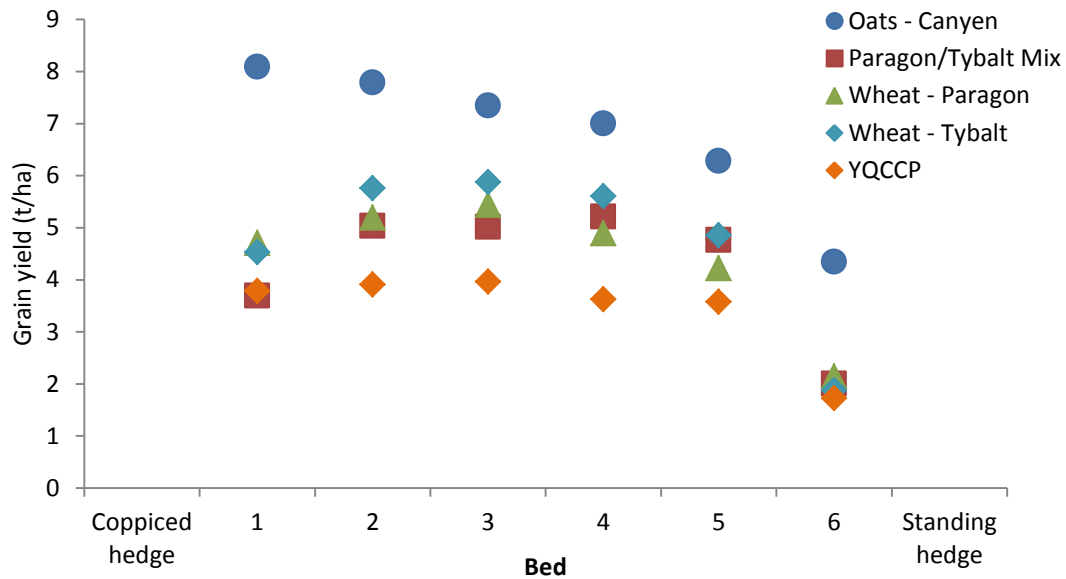


Figure 4. The mean grain yield ( $n = 2$ ) of a spring oat and wheat varieties, mixture and composite cross population (YQCCP) in six positions across a 10 m wide agroforestry cropping alley (Alley 4) between a coppiced and standing willow tree row in 2014

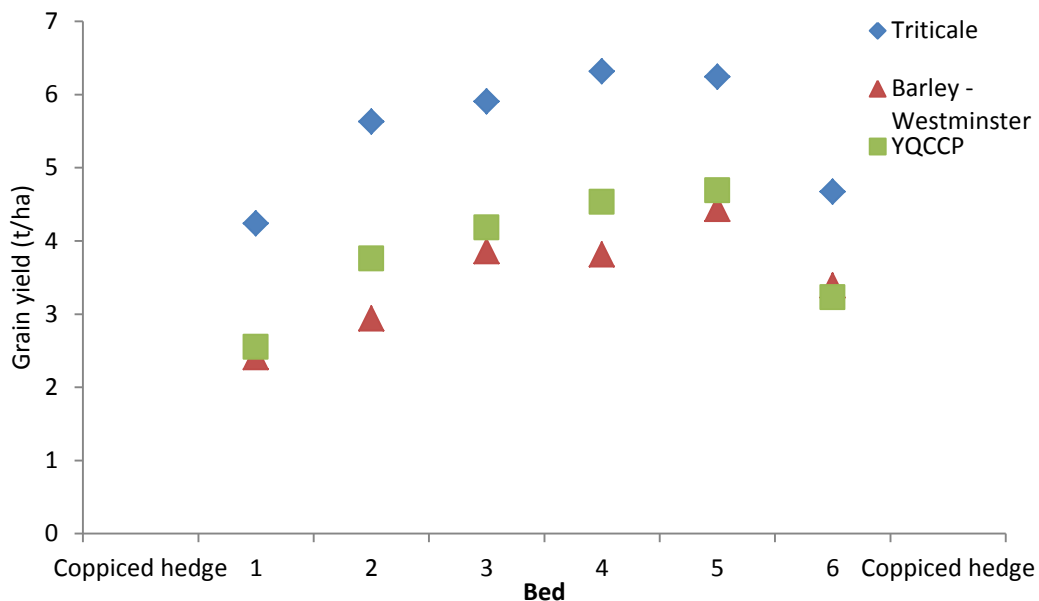


Figure 5. The mean grain yield ( $n = 2$ ) of spring triticale and barley varieties and a composite cross population (YQCCP) in six positions across a 10 m wide agroforestry cropping alley (Alley 2) between coppiced willow tree rows in 2014

The results of the 2015 trial were reported in a poster presented at the 3<sup>rd</sup> European Agroforestry conference in Montpellier in May 2016 by Smith et al. (2016). Some important parts of the poster are reproduced below.

### **Developing agroforestry-adapted cereals using an evolutionary plant breeding approach**

Smith J, Fradgley N and Wolfe MSW

In 2015, an experiment was established to test material selected in contrasting environments near to and away from the agroforestry tree rows. A replicated cross-over experiment aimed to compare performance of selected material in each environment based on the hypothesis that wheat lines will perform best in the environment from which they were selected (i.e. 'alley-edge' selected lines will perform better in the 'alley-edge' plots than 'alley-centre' lines). A spring wheat composite cross population (CCP) was grown in plots across a willow system agroforestry alley in 2014. Plots of bulk CCP were harvested separately from plots on either side of the alley, adjacent to the tree rows (East of Trees (EOT), West of Trees (WOT)) and the alley centre (Centre of Alley (COA)). In spring 2015, Plots measuring 1.2 m by 10.2 m were drilled in a replicated cross-over trial in a hazel SRC agroforestry system to test the effect of the population adapting under natural selection to each environment. Yield measurements (t/ha, hectolitre weight (g), and thousand grain weight (TGW)) were carried out in autumn 2015 when the plots were harvested.

The statistical analysis was carried out using R version 2.10.0 (R Development Core Team, 2009). To identify the effect of alley location on the wheat populations, yields, hectolitre weight and thousand grain weights were analysed with a two-way ANOVA. Alley location (EOT, COA, WOT), wheat population (EOT, COA, WOT) and the interaction between the two were included as the fixed factors, and replicate block as the random effect.

Yields ranged between 0.90 and 3.99 t/ha (@15% moisture content); hectolitre weights between 367.83 g and 383.79 g (@15% m.c) and thousand grain weights between 42.90 and 50.48 g (@ 15% m.c.). There was a significant effect of location on yield ( $F_{2,17} = 48.89$ ,  $p < 0.001$ ) and hectolitre weight ( $F_{2,17} = 4.81$ ,  $p < 0.05$ ), but not on TGW. Yields and hectolitre weights were significantly higher in the centre of the alley than at either edge (Figure 6). There were no significant differences between the different populations for any of the yield parameters, and no significant interactions between the populations and their locations. This suggests that at this stage, there is no adaptation of populations to their selected locations (i.e. EOT populations do not perform any better in the EOT locations than in the other locations)



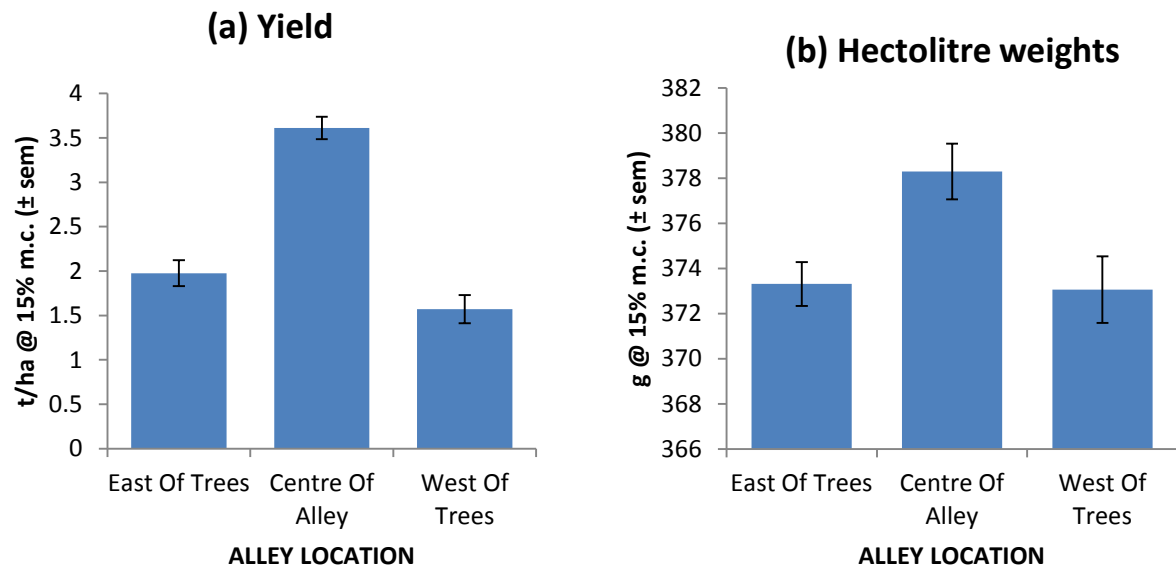


Figure 6. (a) The mean grain yield and (b) hectolitre weights of a composite cross population (YQCCP) in three positions across a ten meter wide alley

Crop yields at the edges of the alleys were roughly half what they were in the centre of the alley, but there were no significant interactions between populations and their locations. This suggests that, in this first year, there is no evidence of adaptation to alley location. It is perhaps unsurprising that there has been no obvious adaptation over such a short period; in a five year project investigating the level of adaptation that may occur when CCPs are grown continuously at the same specific sites for a number of years, molecular data and comprehensive field trials found no evidence of wheat populations adapting to the cropping conditions under which they were grown (Girling et al. 2014). The authors attributed this to the influence of yearly fluctuations in weather conditions that counteracted any adaptation to the site-specific factors associated with cropping management and soil conditions. It may be necessary to carry out more detailed selection of high performing individual plants by hand, which are then bulked up, to develop specific ‘alley edge’ populations for agroforestry.

### Experiment in 2016

The experiment has been repeated in the 2016 growing season with a similar experimental design in a North-South-oriented alley between two willow rows with differential management, as the west row was coppiced. Yield results were analysed through a two-ways RCB designs. Every factor was split into sets of two orthogonal linear contrasts to partition difference between:

- Centre of alley vs. Edges, and WOT (West -) vs. EOT (East-of-trees) positions as far as the position in the alley is concerned;
- Centre of alley vs. Edges, and WOT (West -) vs. EOT (East-of-trees) CCP selections as far as the populations position in the previous year is concerned.

The effect of the position in the alley (BED) is highly significant ( $p = 9.88e-08$  \*\*\*). The situation is completely different from the previous season. In fact, here, the western tree row has been coppiced prior to drilling (Figure 7). Therefore, yield was

- 51% more than field average East of the (coppiced) tree row (EOT),
- Intermediate (20% less than field average) in the centre (COA)
- Lowest (32% less than field average) West of the (non-coppiced) tree row (WOT).

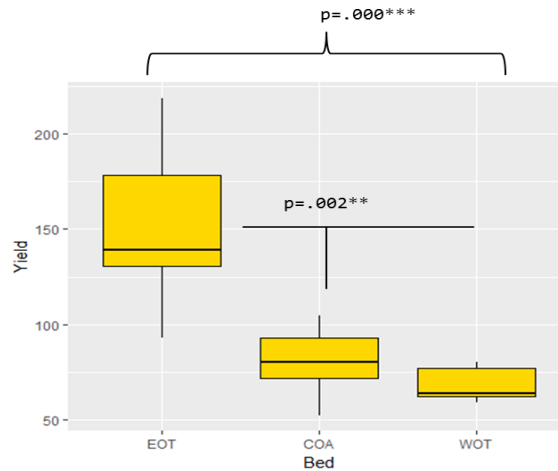


Figure 7. Wheat grain yield averaged by position in the alley in the 2016 growing season. P-values of orthogonal linear contrasts “Centre (COA) vs. edges of alley”, in the middle of the chart, and “East (EOT) vs. West of trees (WOT)”, above the chart, are indicated.

Unlike in 2015, in 2016 a significant effect of the variety, i.e. the selection of the CCP multiplied in EOT, COA or WOT position in the previous seasons, was detected ( $p = 0.012^*$ ). Although the COA-selected CCP did not differ from the average of the EOT and WOT-selected CCP, selection from the two field edges differed between each other, with the EOT selection yielding nearly 35% more than the WOT selection (Figure 8).

#### CCP WAF Alleys 2016

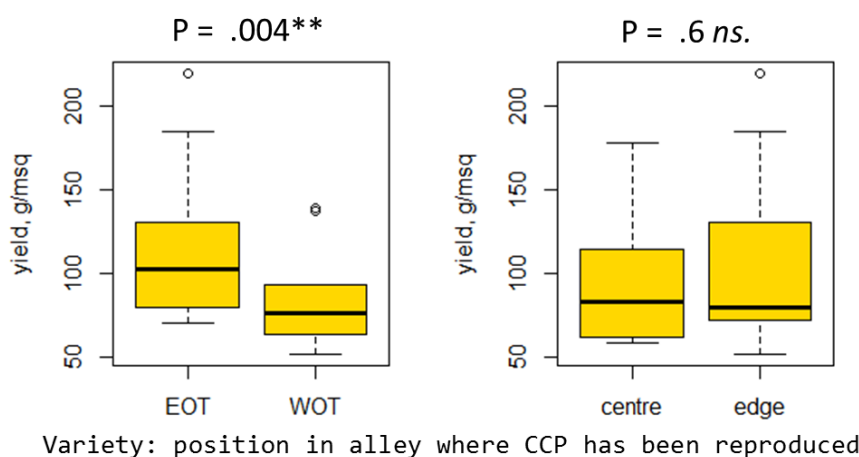


Figure 8. Wheat grain yield averaged by wheat CCP selection – reproduction position in the alley in the previous growing season. P-values of orthogonal linear contrasts ‘East (EOT) vs. West of trees (WOT)’ selection, and ‘centre vs. edge’ selection are indicated

This result seems to confirm the hypothesis that, in a North-South alley, conditions alongside a transect orthogonal to the tree rows are differentiated and able to exert a differential selection pressure over a wheat genetically diverse population. Whether the EOT selection is better adapted to a silvoarable context, or the WOT may instead accumulate seed-borne diseases due to higher persistence of humidity on the western side of the tree row, is not clear. However, this experiment brings the important conclusion that the yield potential of a wheat population can be influenced by the position in an alley between two North-south oriented tree rows where it has been multiplied.

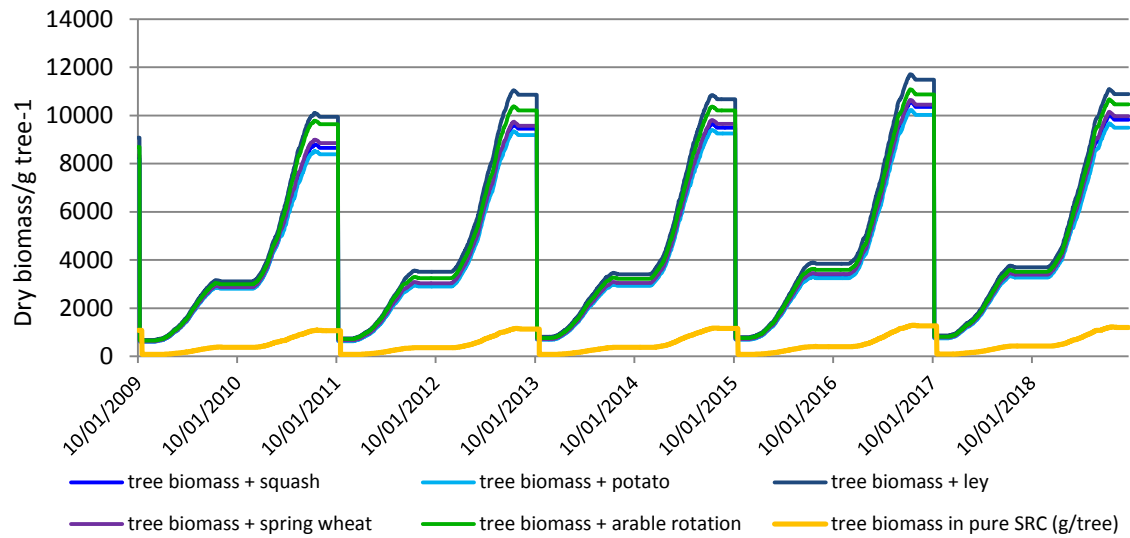
## 6 Yield-SAFE

The Yield-SAFE model, developed by Wageningen and Cranfield Universities in 2006 (van de Werf et al. 2007), permits the productivity of agroforestry systems over time to be modelled. It uses calibrated bio-parameters of tree and crop species to predict daily growth of the species in question given localised weather data and specified soil conditions and management practices.

Using the model as was, it was possible to model the yields that might be expected at Wakelyns Agroforestry in the case of a pure arable system, a pure willow SRC system and a willow-arable agroforestry system for the coppice rotation. It was assumed that trees would show consistent growth characteristics across rotation cycles, with the exception of the first cycle (initial planting to first full harvest), which would be modelled separately. Arable crops added to the model for this purpose were: spring wheat, winter squash, potatoes and a two-year mixed ley. The modelled rotation was spring wheat – ley – potato – ley – winter squash – ley (repeat).

Figure 9 shows the modelled biomass of SRC willow at Wakelyns Agroforestry for a ten year period 30 years into the coppice system. As the model does not pick up aging of the trees due to calibration limitations (there are no aged yields in coppicing systems), the model projection assumes that the coppice cycles have reached some sort of stability. The modelled period is 2009-2018, selected to minimise climate change impacts on the weather assumptions. Figure 9a shows the productivity of an individual tree within the system as compared to a pure SRC (density of 15 000 trees ha<sup>-1</sup>) whilst Figure 9b) takes account of the density of trees per hectare and therefore the absolute biomass production per unit area. The graphs clearly imply that whilst overall production of woody biomass is higher in a pure coppice system, tree performance improves dramatically at lower densities, reaching almost similar levels of stand biomass. With an 80% reduction in tree-covered area (equivalent to a 20% reduction in area for agricultural use), only 11% reduction in total tree biomass occurs (mean biomass difference at tree harvest under the described crop rotation). Crops have different impacts on tree growth, with the percentage effect on total tree biomass at tree harvest ranging from 5% with a grass ley to 19% when coupled with potatoes.

## a) SRC willow biomass on a per tree basis



## b) SRC willow biomass on a stand basis

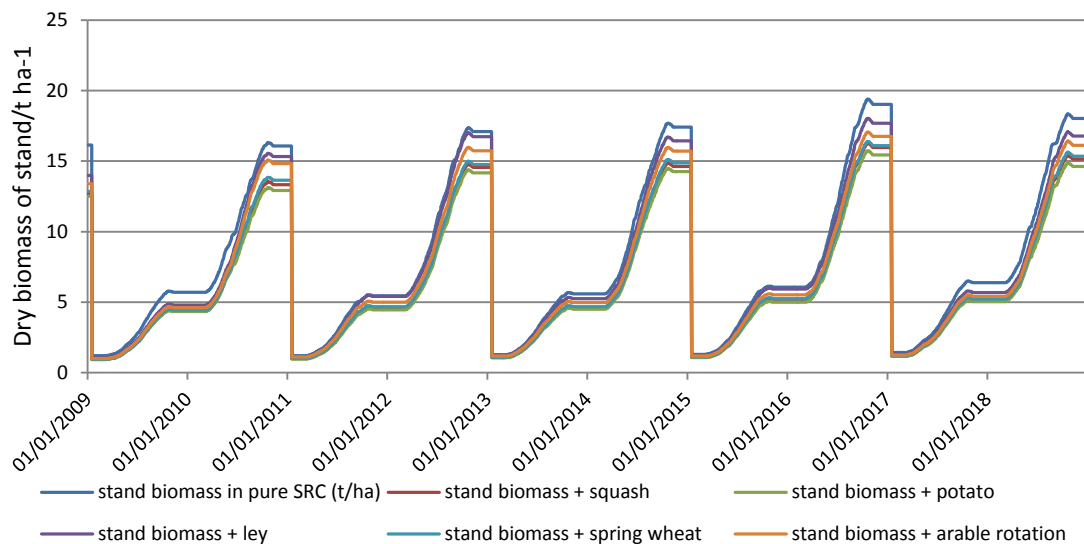


Figure 9. Modelled biomass of the SRC willow at Wakelyns Agroforestry from 1 January 2009 to 31 December 2018 on (a) a tree by tree basis and (b) for the stand as a whole. 'Rotation' refers to the modelled crops in the rotation specified above. 2009 harvest is winter squash. The stand density in 'pure SRC' is 15 000 trees ha<sup>-1</sup>.

Crops similarly show a modelled decline in biomass production when in an agroforestry system (Figure 10). As before, this was modelled taking into account the reduced area of crop cover and extrapolating the growth under agroforestry up as if the whole field was arable (equivalent to a plant by plant basis).

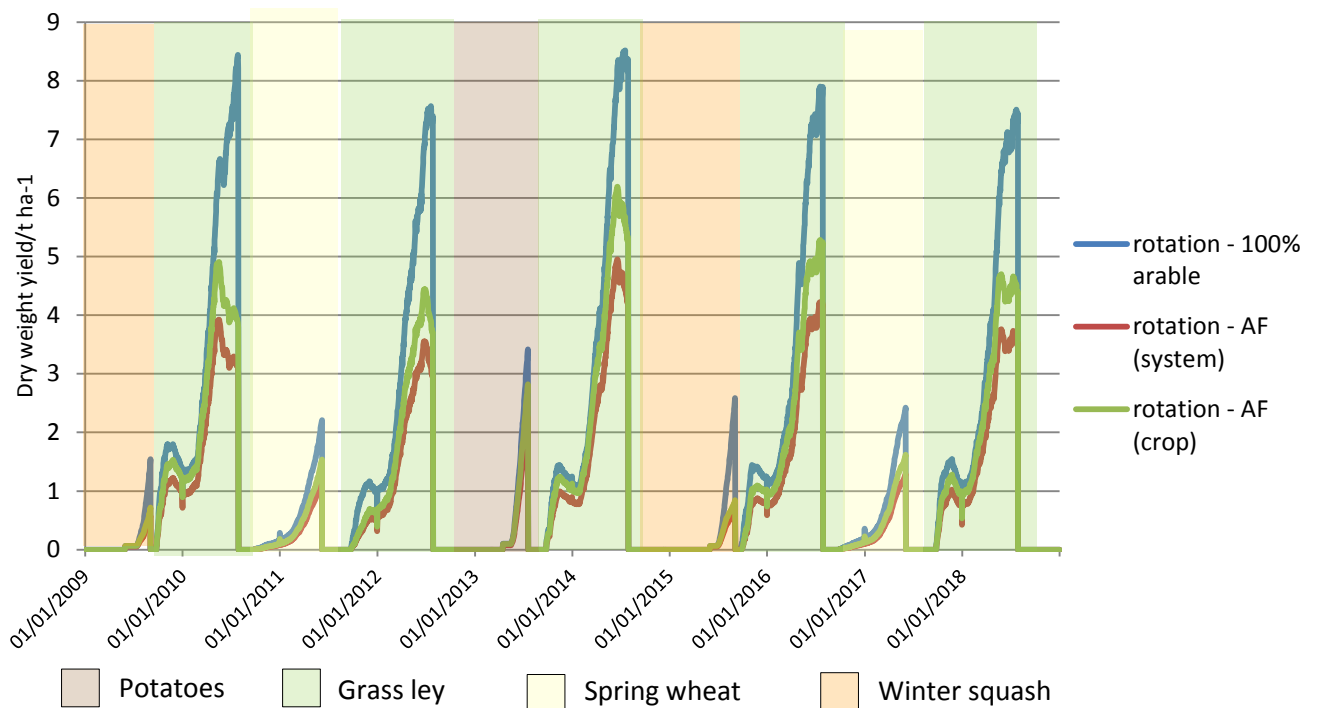


Figure 10. Modelled crop biomass at Wakelyns Agroforestry for the period 01/01/2009–31/12/2018 for a 100% arable system: rotation - 100% arable; the agroforestry system as is currently at Wakelyns: rotation - AF (system); and the cropped area of the agroforestry system taken in isolation: rotation – AF (crop).

The final thing that the models facilitate is comparison between a specialist arable or coppice system and an agroforestry system. Figure 11 below, for example, shows the comparison between the biomass production in the three scenarios 100% arable, 100% coppice and 20:80 willow: arable system (by area as if redistributed into two distinct blocks. This is the relative proportions found in the Wakelyns system).

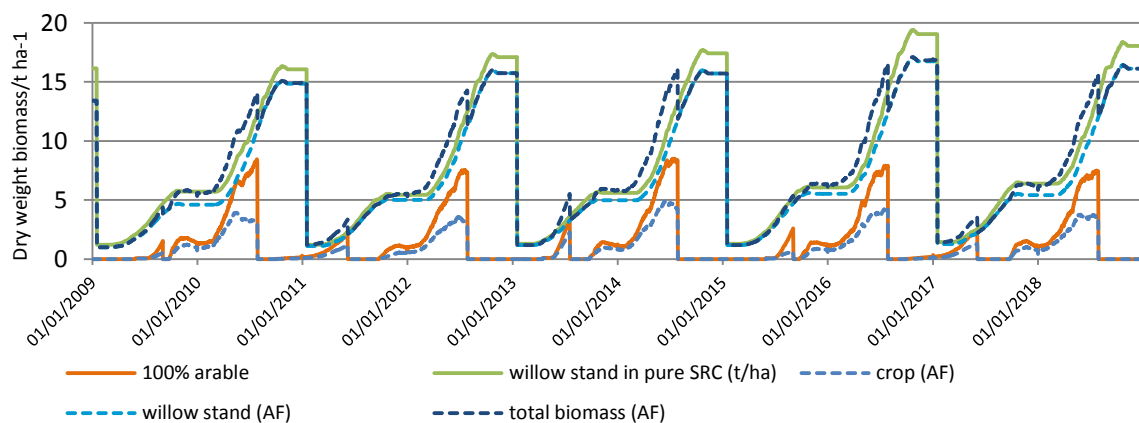


Figure 11. Modelled total biomass production at Wakelyns Agroforestry for the period 1 January 2009 to 31 December 2018 for an arable, a coppice and an agroforestry (AF) scenario. Pure SRC is modelled as 15 000 trees ha<sup>-1</sup>.

Figure 11 shows that there is more total biomass in the pure SRC than in the agroforestry systems. This does not, however, mean a lower harvested biomass, as the total harvested biomass – tree and crop – over the course of one full crop rotation (three coppice cycles) is modelled at 57 t ha<sup>-1</sup> under the described agroforestry system, compared to 47 t ha<sup>-1</sup> under pure SRC (15 000 trees ha<sup>-1</sup>) and 32 t ha<sup>-1</sup> under pure arable. These figures can be used to calculate a Land Equivalent Ratio (LER) – the ratio of productivity under agroforestry versus that in disparate systems. A ratio > 1 indicates that greater production is achieved under agroforestry than by an identical area of separate production systems – in other words, a greater area of land is needed to produce equivalent yields if arable and coppice are spatially separated than when they are combined in an agroforestry system. The LER is calculated as:

$$\frac{\text{harvested crop biomass (AF)}}{\text{harvested crop biomass (100\% arable)}} + \frac{\text{harvested tree biomass (AF)}}{\text{harvested tree biomass (pure SRC)'}}$$

where AF represents modelled yield ha<sup>-1</sup> from the agroforestry system. The LER was calculated across one full arable rotation (i.e. six years), starting from 2010 to allow the tree component of the model to settle.

Table 4. Modelled harvested yields (t ha<sup>-1</sup>) used for LER calculation within an agroforestry (AF), arable, or willow short rotation coppice (SRC) system.

System	2010	2011	2012	2013	2014	2015	Totals
Squash (AF) <sub>a</sub>	-	-	-	-	-	0.67	
Squash (arable) <sub>b</sub>	-	-	-	-	-	2.59	
Grass ley (AF) <sub>c</sub>	3.03	-	2.92	-	4.23	-	
Grass ley (arable) <sub>d</sub>	8.21	-	7.28	-	8.36	-	
Spring wheat (AF) <sub>e</sub>	-	1.23	-	-	-	-	
Spring wheat (arable) <sub>f</sub>	-	2.21	-	-	-	-	
Potatoes (AF) <sub>g</sub>	-	-	-	2.26	-	-	
Potatoes (arable) <sub>h</sub>	-	-	-	3.42	-	-	
Total crops (AF) <sub>a+c+e+g</sub>							<b>14.34</b>
Total crops (arable) <sub>b+d+f+h</sub>							<b>32.07</b>
Willow (AF) <sub>i</sub>	-	13.72	-	14.55	-	14.54	42.81
Willow (pure SRC) <sub>j</sub>	-	14.87	-	15.81	-	16.11	46.79

$$LER = \frac{14.34}{32.07} + \frac{42.81}{46.79} = 0.45 + 0.91 = 1.36$$

This sort of modelling provides the basis for development to compare systems in terms of, for example, harvested yields, total profits, and optimal coppice:arable ratios. One could even set targets (based, for example, on the amount of woodchip required to meet the farm's own energy needs) and calculate the system design required to meet them. These are some of the questions now being explored as part of the ongoing FACCE Surplus project 'SustainFARM'.



## 7 Summary of lessons learnt

The principal lessons learnt from the measurements and observations in the Wakelyns silvoarable system include:

- Willow and hazel offer farmers two alternative system options but with similar returns.  
Trees have an influence on neighbouring land that varies between growth stage and species. Willow and hazel, given their different management requirements, differ in their effects. Both species, however, provide similar net yields. There is therefore flexibility for farmers to choose the tree species best suited to their wider farm system without suffering any consequences in returns regarding tree biomass. The decision of species on the basis of the wider agricultural system – as opposed to the fastest growth and shortest harvest cycle – should thus be encouraged. It is possible that this also extends to other tree species; this would offer an even greater range of choices and options to suit any system.
- The heating needs of a typical farmhouse can be met by a relatively small area of agroforestry.  
Given a farmhouse boiler of 30–40 kW and a system design the same as Wakelyns (3 m wide twin tree rows and 10m wide alleys), 4.76–6.35 ha of agroforestry is needed to fully meet the annual heating needs of a typical farmhouse.
- Cereal yields are negatively impacted by proximity to tree rows.  
Data for all studied cereal crops indicate a decline in yield with greater proximity both to hedge (coppiced or standing) and tree rows. The exception is for oats, which seems, in fact, to benefit from proximity to a coppiced hedge. Further trials are however needed to confirm this as an interaction with the hedge as opposed to a field-scale effect.
- One year is insufficient for composite cross population to show any adaptation to environmental conditions.  
In accordance with previous studies, seed selection from a composite cross population for different distances from tree rows does not result in any noticeable change in crop characteristics over the course of a single growing season. Some differences do seem to become apparent after two years, however. More targeted selection and breeding may be needed for the development of ‘alley edge’ populations.
- Modelling can be used in partnership with field trials and to assist with management decisions and system design.  
Biological based models such as Yield-SAFE allow for the modelling of specific locations and systems. This offers a number of potential contributions: modelling possible effects of future climatic changes and consequent changes in management needs (introduction of irrigation, for example); designing systems to produce sufficient quantities of specific products; and calculating land equivalence ratios for agroforestry versus specialised production represent just a few of the possibilities.

## 8 Acknowledgements

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

## 9 References

- Fradgley N, Smith J (2015). Research and Development Protocol for Silvoarable Agroforestry in the UK (part 1). 9 April 2015. 8 pp. Available online: <http://www.agforward.eu/index.php/en/silvoarable-agroforestry-in-the-uk.html>
- Girling RD et al. (2014) Adaptive winter wheat populations: development, genetic characterisation and application. Project report RD-2007-3378. AHDB Cereals and Oilseeds.
- Smith J, Wolfe M, Crossland M, Howlett S (2014). Initial Stakeholder Meeting Report: Silvoarable Agroforestry in the UK. 21 November 2014. 8 pp. Available online: <http://www.agforward.eu/index.php/en/silvoarable-agroforestry-in-the-uk.html>
- Smith J (2015). Research and Development Protocol for Silvoarable Agroforestry in the UK (part 2). 23 March 2015. 6 pp. Available online: <http://www.agforward.eu/index.php/en/silvoarable-agroforestry-in-the-uk.html>
- Smith J (2016). System Report. Silvoarable Agroforestry in the UK (part 1). 12 January 2016. 17 pp. Available online: <http://www.agforward.eu/index.php/en/silvoarable-agroforestry-in-the-uk.html>
- Smith J, Fradgley N and Wolfe MSW (2016). Developing agroforestry-adapted cereals using an evolutionary plant breeding approach. Poster present at 3rd European Agroforestry Conference 23-25 May 2016, Montpellier, France [https://euraf.isa.utl.pt/files/pub/docs/treecrop\\_40\\_smith.pdf](https://euraf.isa.utl.pt/files/pub/docs/treecrop_40_smith.pdf)
- van der Werf W, Keesman K, Burgess P, Graves A, Pilbeam D, Incoll L D, Metselaar K, Mayus M, Stappers R, van Keulen H and Palma J (2007). Yield-SAFE: A parameter-sparse, process-based dynamic model for predicting resource capture, growth, and production in agroforestry systems. *Ecological Engineering*, 29(4), 419-433.