AGFORWARD
Agroforestry for Europe

System Report: Silvoarable Agroforestry in the UK

Project name	AGFORWARD (613520)
Work-package	4: Agroforestry for arable farmers
Specific group	Silvoarable Agroforestry in the UK
Deliverable	Contribution to Deliverable 4.10 (4.1): Detailed system description of a case study system
Date of report	12 January 2016
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Approved	Jaconette Mirck (February 2016) Paul Burgess (April 2016)

Contents

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1 Context

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

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

This report contributes to Objective 2, Deliverable 4.10: “Detailed system description of case study agroforestry systems”. The detailed system description includes the key inputs, flows, and outputs of the key ecosystem services of the studied system. It covers the agroecology of the site (climate, soil), the components (tree species, crop system, livestock, management system) and key ecosystem services (provisioning, regulating and cultural) and the associated economic values. The data included in this report will also inform the modelling activities which help to address Objective 3.

2 Background

The initial stakeholder report (Smith et al. 2014) and the research and development protocol (Fradgley and Smith, 2015, and Smith, 2015) provide background data on silvoarable systems in the UK. 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 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^2 plots in a replicated cross-over trial to test the effect of the population adapting under natural selection to each environment.

3 Update on field measurements

Yield measurements (t/ha), hectolitre weight (g), and thousand grain weight (TGW) described in the research and development protocol (Fradgley and Smith, 2015) were carried out in 2015 when the plots were harvested. This report presents these data and provides a detailed description of the case study system, Wakelyns Agroforestry.

4 Description of system

Table 1 provides a general description of silvoarable agroforestry systems in the UK. A description of a specific case study system is provided in Table 2. Missing data will continue to be sourced during 2016.

Table 1. General description of the silvoarable system

General description of system	
Name of group	Silvoarable agroforestry in the UK
Contact	Jo Smith
Work-package	4: Agroforestry for arable farmers
Associated WP	3: High value trees
Geographical extent	Silvoarable systems are found throughout Europe, but rare in the UK,
Estimated area	Very small nationally – probably less than 1000 ha
Typical soil types	Varied
Description	In recent years, a small but growing number of adventurous farmers and growers have been planting new alley cropping systems. The tree component consists either of top fruit trees (apples, pears and plums), short rotation coppice, and/or timber trees, with arable or horticultural crops in the alleys. The drivers behind planting trees into arable systems vary from farmer to farmer, but are often related to improving the environmental conditions for the crops (reduced wind speeds providing shelter; improved functional biodiversity) as well as diversifying the business by introducing a new product. The systems are usually organised as alley cropping systems with alleys varying in width from 10 m to 24 m (workable alley).
Tree species	Varied: Fruit trees: *Malus domestica* (apple) SRC species such as willow (*Salix viminalis*) and hazel (*Corylus avellana*) Timber species such as small-leaved lime (*Tilia cordata*), hornbeam (*Carpinus betulus*), wild cherry (*Prunus avium*), Italian alder (*Alnus cordata*), ash (*Fraxinus excelsior*), oak (*Quercus petraea*), and sycamore (*Acer pseudoplatanus*)
Tree products	Top fruit (apples) Woodchip for bioenergy and/or mulch/compost Timber Craft materials (willow for sculptures/fencing and hazel for thatching/hedge laying)
Crop species	Wheat (spring and winter varieties plus composite cross population) (*Triticum spp*) Barley (*Hordeum vulgare*) Oats (*Avena sativa*) Oil seed rape (*Brassica napus*) Field vegetables
Crop products	Grain, rape oil, vegetables and fruit
Animal species	Usually none; occasionally pigs, poultry or ruminants as part of the rotation
Animal products	Not applicable
Other provisioning services	

Regulating services	The trees can provide shelter for the crops (reduced wind speeds, reduced soil erosion, reduce evapotranspiration in summer). Above-ground, the trees will increase carbon storage. Tree roots can reduce soil erosion and access nutrients below the crop roots, bringing nutrients to the upper soil horizons through leaf fall. The tree rows support functional biodiversity that regulate pollination, pest control and decomposition services.
Habitat services and biodiversity	The tree row represents a stable habitat in an otherwise highly disturbed agricultural landscape so can provide shelter and resources for plants and animals, as well as acting as corridors linking up other semi-natural habitat patches. These species may be beneficial, neutral or detrimental to provisioning services.
Cultural services	Introducing trees into an arable system may increase job opportunities and skills with regards tree management. The landscape also changes from an open arable landscape to a partly wooded environment depending on design of the system. This landscape change can be both an improvement and degradation depending on the context and individual preferences.

Table 2. Description of the specific case study system

Specific description of site	
Area	Farm = 22.5 ha Willow short rotation coppice (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	jo.s@organicresearchcentre.com wolfe@wakelyns.co.uk
Example photograph	 Figure 1. Barley in the short rotation coppice willow silvoarable system at Wakelyns Agroforestry  Figure 2. Potatoes in the SRC hazel silvoarable system, Wakelyns Agroforestry

Map of system

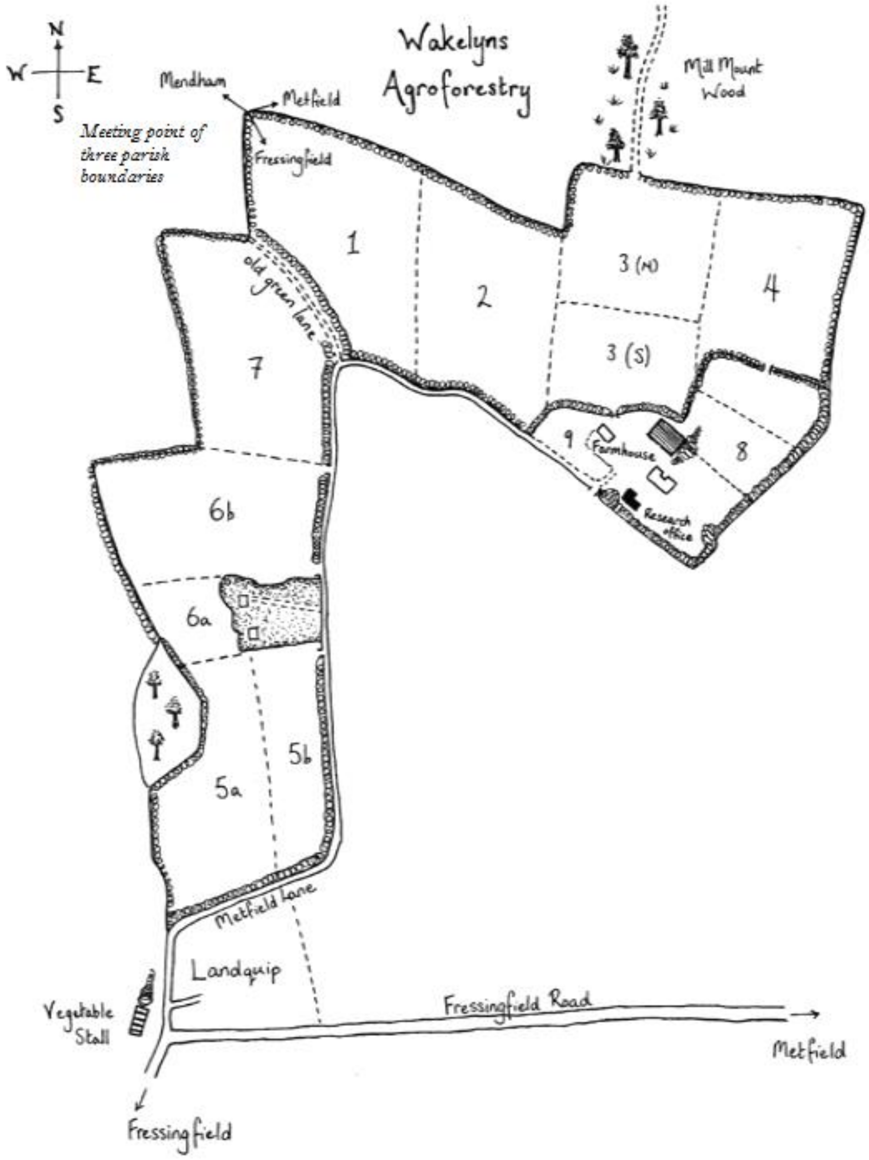

Figure 3. Map of Wakelyns Agroforestry (SRC systems are in Field 4 (Hazel) and Field 5 (Willow)

Fields and tree systems

1. Far Field • 2+ ha • tree rows planted Feb ’94 to 310 trees of 7 timber species (Ash, Wild Cherry, Italian Alder, Small-leaved Lime, Sycamore, Oak, Hornbeam)
2. Water Field • 2+ ha • tree rows as Far Field plus 42 apple trees of 21 old varieties
3. Home Field • 2+ ha • tree rows partially planted, starting in 2001, to fruit and nut trees (plum, cherry, apple, pear, quince, apricot, peach, hazel), each of multiple varieties
4. **Hazel Field • 2+ ha • tree rows planted Feb ’95 to 1200 hazel bushes, each individual genetically distinct; each row coppiced every 5-6 years**
5. **Willow Field • 4ha • tree rows planted Mar ’98 to a mixture of 5 fast-growing willow varieties; each row coppiced every 2-3 years**
6. Vineyard (6a) and Mid Field (6b) • 3+ ha • No trees yet
7. North Field • 3+ ha • tree rows planted in Feb ’01 to 20 walnut trees and in Jan ’02 interspersed with varieties of plum; other walnuts and plums have been added occasionally since then, and one row is not yet planted
8. Old Paddock (sometimes used for compost-making)
9. Kitchen Garden

<table>
<tr><th colspan="2">Possible modelling scenarios</th></tr>
<tr><td>Comparison</td><td>Willow SRC (coppiced every 2-3 years) vs. hazel SRC (coppiced every 5 years)
Different cereals/varieties/mixtures in alleys
Wheat composite cross populations – development and performance of ‘edge’ populations vs. ‘alley centre’ populations</td></tr>
<tr><th colspan="2">Climate characteristics</th></tr>
<tr><td>Mean monthly temperature</td><td>6.1°C mean min temp and 14.4°C mean max temp (mean for 1981-2010)</td></tr>
<tr><td>Mean annual precipitation</td><td>620.2 mm</td></tr>
<tr><td>Details of weather station (and data)</td><td>Scole met office weather station, location 52.365, 1.160, 27 m amsl
http://www.metoffice.gov.uk/public/weather/climate/u12cfksmy</td></tr>
<tr><th colspan="2">Soil type</th></tr>
<tr><td>Soil type</td><td>Beccles series (WRB Eutric Albic Luvic Stagnosols). Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils</td></tr>
<tr><td>Soil depth</td><td>25cm</td></tr>
<tr><td>Soil texture</td><td>Sandy clay to clay loams (sand 49%, silt 23%, clay 28%)</td></tr>
<tr><td>Additional soil characteristics</td><td>
<table>
<tr><th></th><th>P (mg/l)</th><th>K (mg/l)</th><th>Mg (mg/l)</th><th>Organic Matter (LOI %)</th><th>pH</th><th>CO_2 burst (mg/kg)</th></tr>
<tr><td>Crop alley</td><td>14.7</td><td>134.75</td><td>55.5</td><td>4.825</td><td>8.1</td><td>25.625</td></tr>
<tr><td>Tree row</td><td>20.4</td><td>165.5</td><td>67.075</td><td>6</td><td>8.175</td><td>149.3</td></tr>
</table>
Soil analyses of four composite samples in centre of crop alley and centre of tree row carried out in September 2015</td></tr>
<tr><td>Aspect</td><td>Flat</td></tr>
<tr><th colspan="2">Tree characteristics</th></tr>
<tr><td>Species and variety</td><td>Hazel SRC system: Corylus avellana
Willow SRC system: Salix viminalis</td></tr>
<tr><td>Date of planting</td><td>February 1995</td></tr>
<tr><td>Intra-row spacing</td><td>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)</td></tr>
<tr><td>Inter-row spacing</td><td>Cereal alley 10 m wide. Tree row ~3 m wide</td></tr>
<tr><td>Tree protection</td><td>None; mypex weed control barrier</td></tr>
<tr><td>Typical SRC yield</td><td>Hazel: 25.56 kg/stool oven dry weight (ODW) (translates to annual production of 5.44 t/ha of agroforestry, based on harvesting every 5 years and 1064 stools/ha of agroforestry)
Willow: 7.25kg/stool ODW (translates to annual production of 4.79 t/ha of agroforestry, based on harvesting every 2 years and 1320 stools/ha of agroforestry)</td></tr>
<tr><td>Typical increase in tree biomass</td><td>Based on data above:
Hazel 25.56 kg/stool ODW after 5 years re-growth = 5.112 kg/stool ODW/year
Willow 7.25 kg/stool ODW after 2 years re-growth = 3.625 kg/stool ODW/year</td></tr>
<tr><th colspan="2">Crop/understorey characteristics</th></tr>
<tr><td>Species</td><td>Organic cereals and field vegetables</td></tr>
<tr><td>Management</td><td>Six year organic rotation with 3 years of fertility building ley.</td></tr>
<tr><td>Typical cereal yield</td><td>Yields per ha of crop (not per ha of agroforestry)</td></tr>
</table>

	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 15m x 75m, centred on tree row.
Financial and economic characteristics	
Costs	To be determined Costs of tree establishment, harvesting and processing Cereal production

5 The tree component

5.1 Short rotation coppice production

Biomass production of the SRC willow has been measured since 2011 and the hazel since 2014. Willow is harvested on a 2 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 5 year rotation, with only one side of the twin row being cut in any year. Before the main harvest, sample stools are cut by hand with a chainsaw and weighed using a spring balance mounted on a tractor (Figure 4). Stools are 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) are sampled. With the hazel, only one of the twin rows (east or west) is cut in any year and so all stools are from the same side. 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/stool (Table 3), and then converted to annual production/100m and per ha of agroforestry (Table 4).

Figure 4. Weighing willow sample with tractor-mounted spring balance

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.

Table 3. Biomass production of willow and hazel SRC (ODW=oven dry weight, n=number of stools sampled, sem=standard error of the mean)

Year	ODW kg/stool	
Willow	**East tree row**	**West tree row**
2011/12	6.03 (n=9, sem=0.53)	6.72 (n=9, sem=0.59)
2012/13	10.39 (n=11, sem=1.62)	7.95 (n=11, sem=1.42)
2013/14	5.34 (n=16, sem=0.90)	4.53 (n=15, sem=0.78)
2014/15	8.79 (n=19, sem=1.33)	7.87 (n=19, sem=1.32)
2015/16	7.66 (n=19, sem=1.53)	7.25 (n=17, sem=1.35)
Hazel	**East tree row**	**West tree row**
2013/14	23.41 (n=20, sem=1.55)	22.17 (n=10, sem=2.36)
2014/15	25.33 (n=10, sem=3.05)	23.88 (n=33, sem=1.23)
2015/16	27.93 (n=9, sem=3.21)	37.74 (n=10, sem=2.15)

Table 4. Average biomass and energy production of willow and hazel SRC per ha of agroforestry

	Biomass production kg/stool (ODM)	Stools/ha agroforestry	ODW t/ha agroforestry	Annual biomass production (ODW t/ha agroforestry)	GJ/t	Annual energy production (GJ/ha agroforestry)
Willow 2 yr cycle	7.25	1320	9.57	4.79	19.11	91.44
Hazel 5 yr cycle	25.56	1064	27.20	5.44	19.35	105.25

6 The cereal component

2014 cereal trials

The 2014 cereal trials of a spring oat variety (Canyon), 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 5 and 6 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).

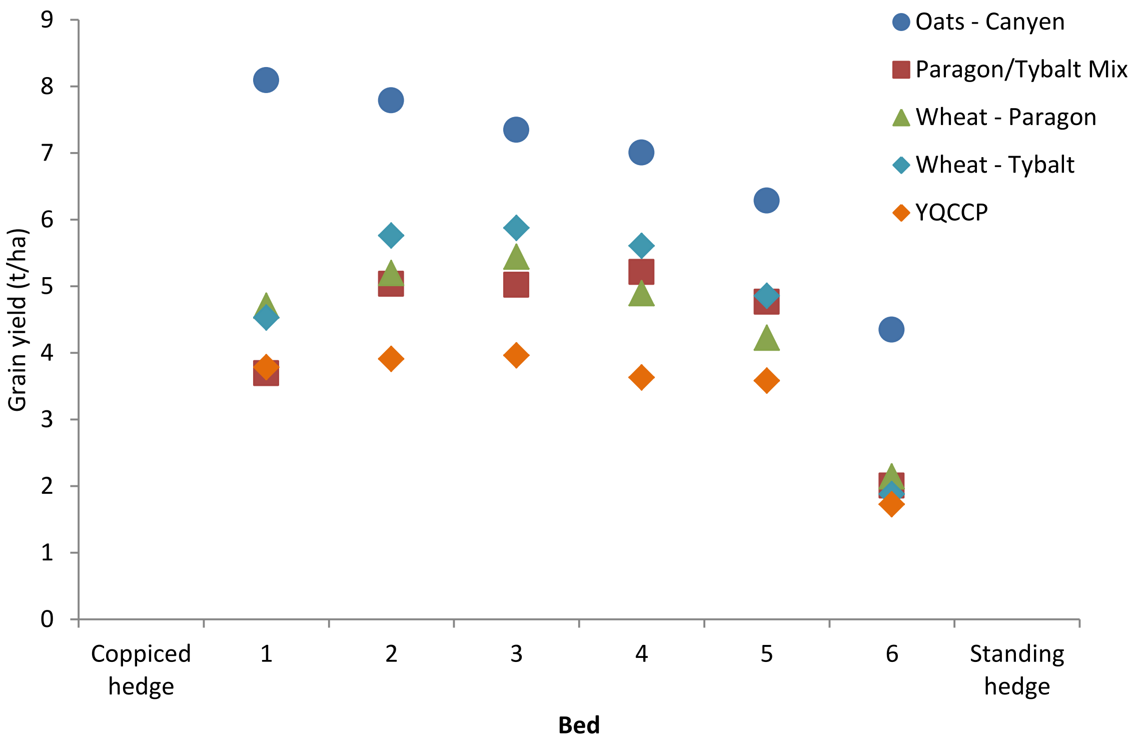

Figure 5. The mean grain yield (n = 2) of a spring oat and wheat varieties, mixture and composite cross population (YQCCP) in six positions across a ten m wide agroforestry cropping alley (Alley 4) between a coppiced and standing willow tree row in 2014

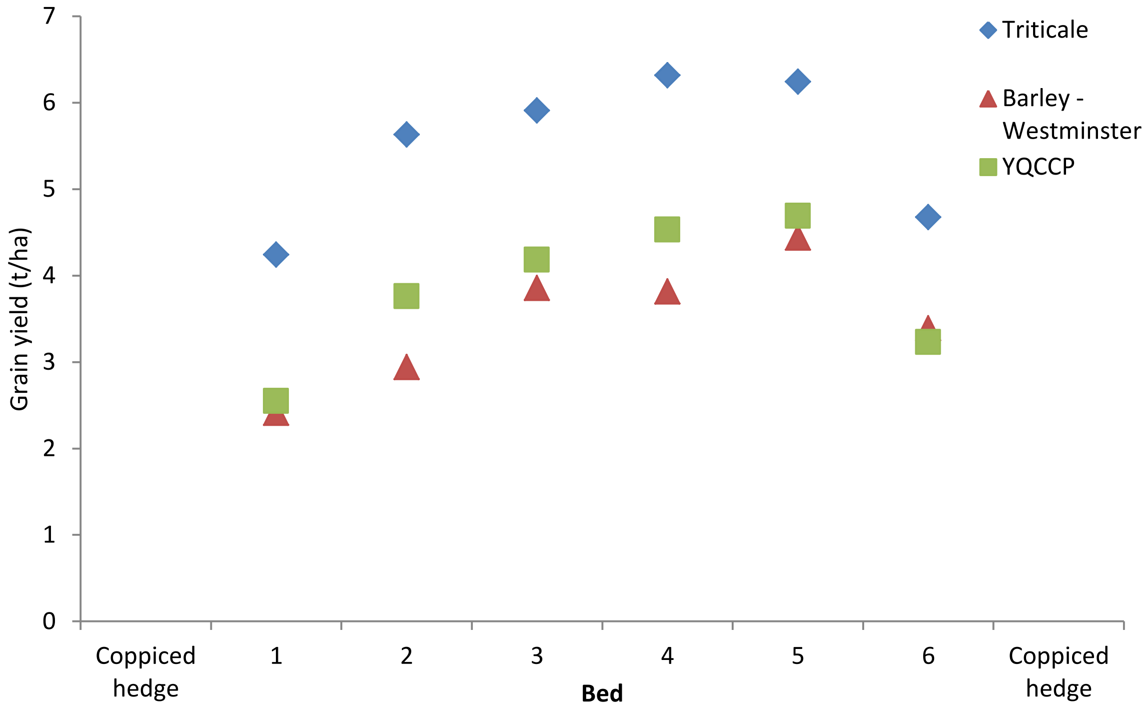

Figure 6. The mean grain yield (n = 2) of spring triticale and barley varieties and a composite cross population (YQCCP) in six positions across a ten meter wide agroforestry cropping alley (Alley 2) between coppiced willow tree rows in 2014.

Composite Cross Population trial

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 g and 50.48 g (@ 15% moisture content). 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 thousand grain weight. Yields and hectolitre weights were significantly higher in the centre of the alley than at either edge (Figure 7). 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).

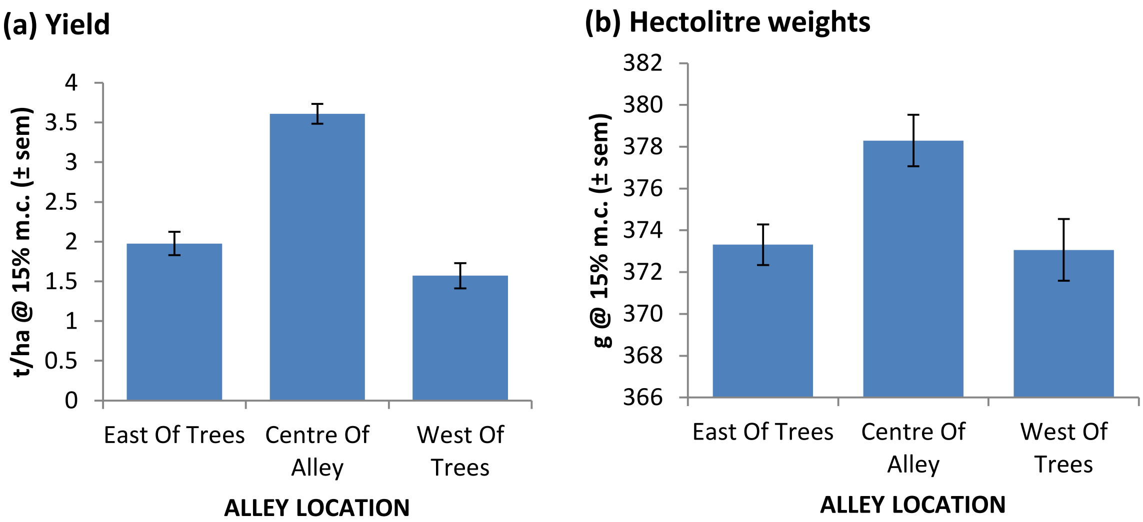

Figure 7. (a) The mean grain yield and (b) hectolitre weights of a composite cross population (YQCCP) in three positions across a ten meter wide alley. Error bars show the standard error of the mean.

7 Microclimate data

As part of two previous FP7 research projects (SOLID and Co-Free) and continuing within AGFORWARD, monthly point measurements of air temperature, wind speed, wind chill, relative humidity, soil moisture and soil temperature have been taken in the willow SRC silvoarable system and a neighbouring field that has no trees (but is part of the same arable rotation). Three transects have been established within each system (agroforestry and control), running east to west. Within the agroforestry system, transects run from alley centre to alley centre, with the willow tree row in the centre of the transect. This design allows spatial and temporal variation within the alleys to be studied as the willow goes through the two year rotation between harvests, with each transect centred on willow rows cut on the same rotation (January 2011, 2013, 2015). On each agroforestry transect, sample points are located at 4 m, 2 m and alley edge west, centre of tree row, and 4 m, 2 m and edge east of the tree row to give seven sample points per transect in the agroforestry system (Figure 8). Within the no-tree control, four sample points are spaced 4 m apart on each transect.

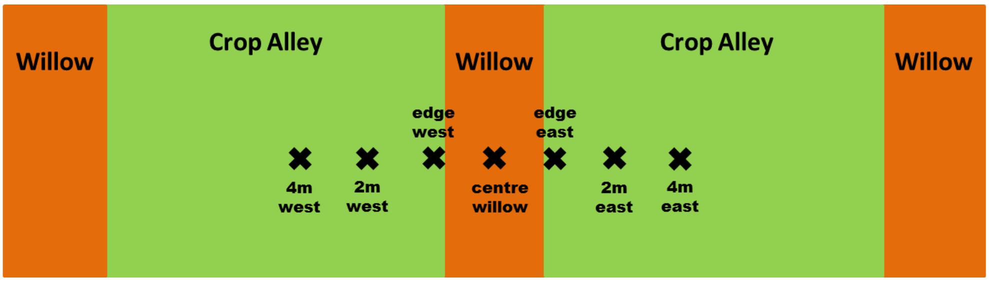

Figure 8. Microclimate sample points in the willow agroforestry system

Monthly measurements have been carried out at each of the sample points on transects in the agroforestry and control fields since February 2012. In this report we include data until March 2015. Air temperature (°C), average wind speed over 1 minute (m/s) and wind chill (°C) are measured at 1.5 m above ground using a Kestrel 3500 anemometer. Soil moisture is measured using a HH2 Moisture Meter with the SM300 soil moisture probe from Delta T (average of 3 readings per sample point), and soil temperature using a push-in soil thermometer.

In general, wind speeds were higher within the no-tree control field than in the agroforestry system (Figure 8a); combined with point measurements of air temperature at 1.5 m (Figure 8b), the resulting wind chill was colder in the control plots in most months (Figure 8c). Relative humidity appears to be higher in the control during the summer months (Figure 8d). There are no obvious differences in soil temperature (Figure 8e) but soil moisture was consistently lower in the agroforestry tree rows than the other locations (Figure 8f).

Fig. 8(a) Average wind speed

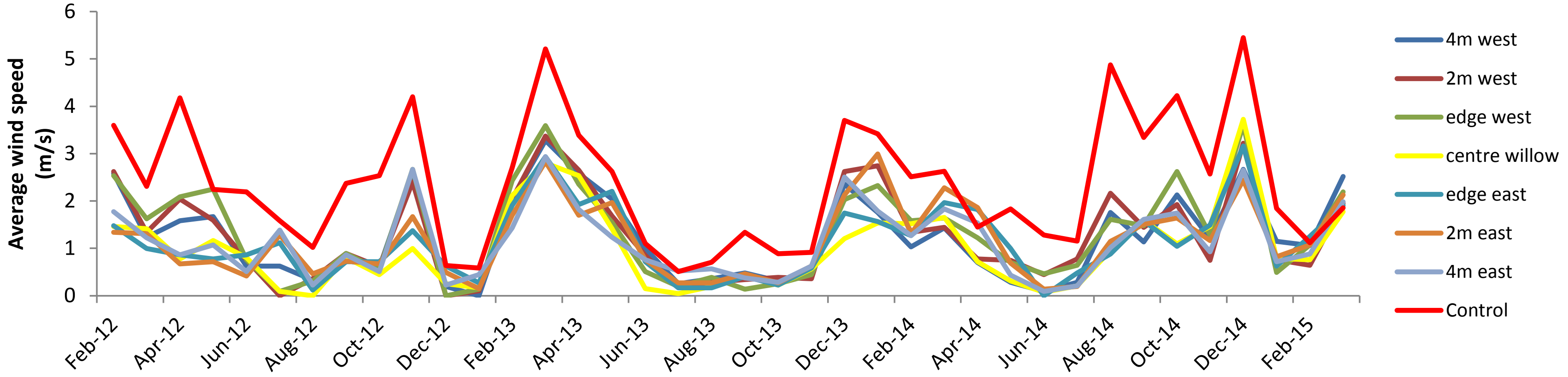

Fig. 8(b) Air temperature

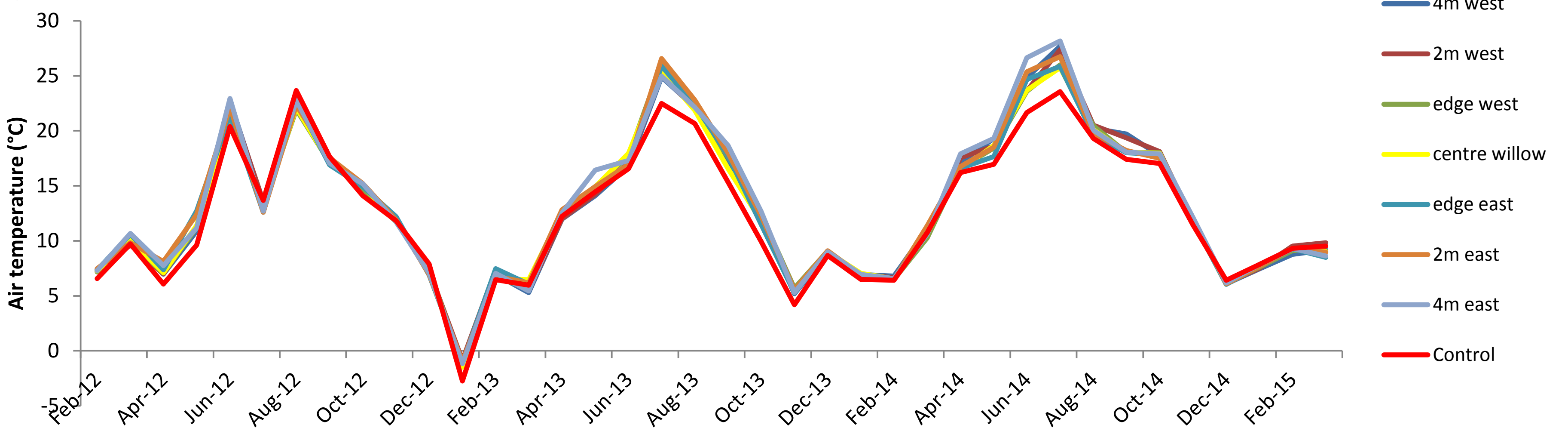

Fig. 8(c) Wind chill

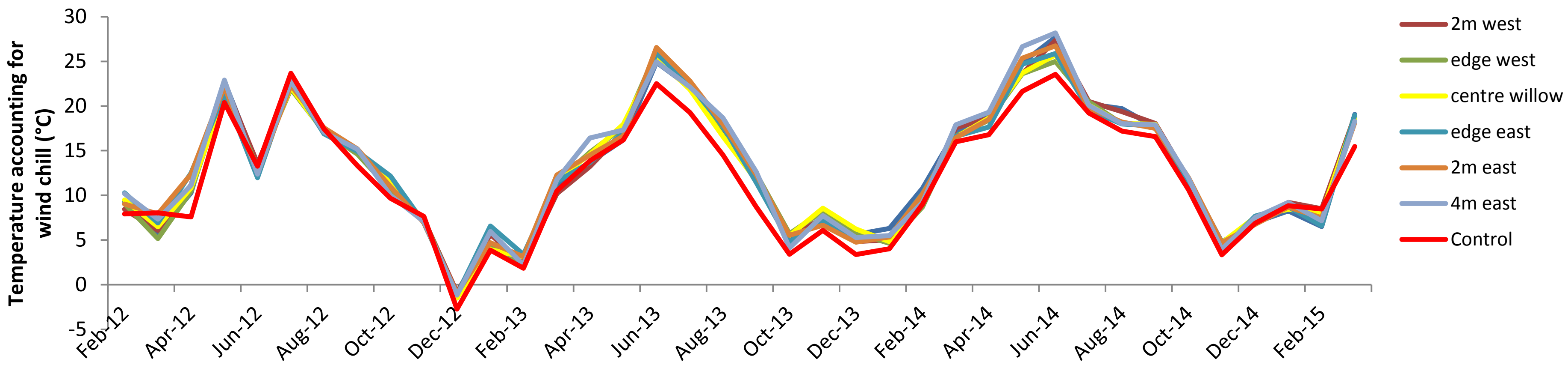

Figure 8(d) Relative humidity

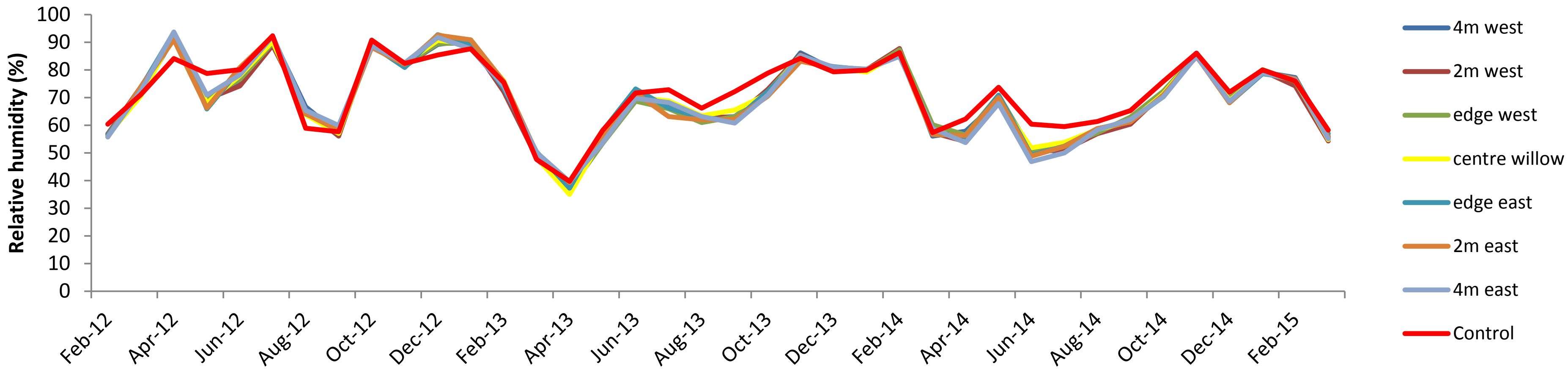

Fig. 8(e) Soil temperature

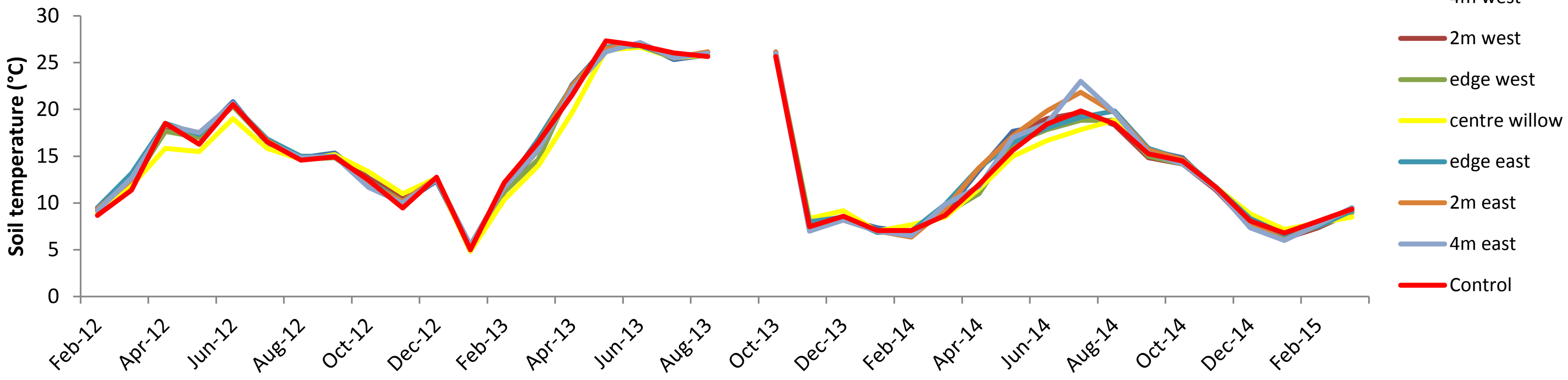

Fig 8(f) Soil moisture

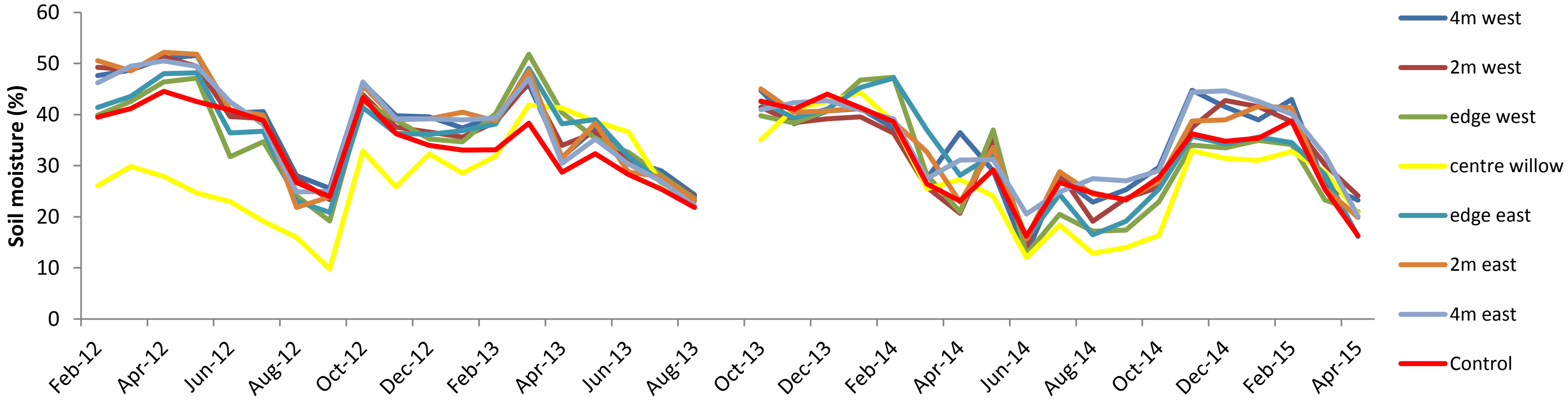

Figure 8. Monthly microclimate data measured on transects running across SRC willow silvoarable alleys and in no-tree control field, Wakelyns Agroforestry

8 Plans for 2016

The plans for 2016 are still to be fully determined but measurements of Leaf Area Index and Radiation will follow the common protocol developed by Mirck et al (2015).

9 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.

10 References

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