



## Lessons learnt: agroforestry for ruminants in England

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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, as it focuses on the field-testing of an innovation within the “agroforestry for livestock systems” participatory research and development network. It contributes to Deliverable 5.14: Lessons learnt from innovations in agroforestry systems.

## 2 Background

New agroforestry systems integrating bioenergy crops (short rotation coppice: SRC) and livestock or arable production can help reconcile conflicting demands for land use, but are currently rare in the UK, and so there is a lack of information regarding the performance and potential of these systems. The stakeholder workshops held within work-package 5 identified that there is a need to get better estimates of the value of the woody vegetation for meeting the nutritional needs of the animals in relation to management of trees (e.g. impact of pollarding, cutting or grazing period on the quantity or quality of this woody forage resource) (Hermansen et al. 2015). Building on previous research of the establishment phase of a novel silvopastoral system integrating short rotation coppice with livestock production, this project aimed to investigate system productivity, impacts on biodiversity and fodder value (Smith 2015).

## 3 Description of system

A novel agroforestry system combining bioenergy production and livestock production was established on Elm Farm in Berkshire in the UK in 2011 (51°23'14.19"N; 1°24'08.34"W), with the aim of assessing the potential impacts of utilising agroforestry for low-input and organic dairy systems. A replicated plot trial incorporating short rotation coppice (SRC) and pasture was planted in April 2011 using an alley-cropping design with tree rows running north/south (Figures 1 and 2). Willow was chosen as a SRC species as it has a dual value as both a bioenergy source and a livestock fodder; a mixture of five bioenergy varieties of *Salix viminalis* was planted. Common alder (*Alnus glutinosa*) was chosen as a second species to test; its value as a fodder crop was unknown, and while it coppices well, it is not a common species for SRC bioenergy production. However, it is one of only a few temperate tree species that fixes nitrogen, and so is of interest in an organic system. A mixed species treatment combining both willow and alder was also trialled to test the hypothesis that combining the two species may result in higher productivity (N-fixation by alder enhancing growth of willow and pasture) and potentially decreasing pest and disease damage and increasing its value for biodiversity. Trees were planted in twin rows, 0.7 m between twin rows and 1.0 m between trees within rows. Tree rows are roughly 3 m wide, with 24 m between tree row centres (i.e. about 21 m of pasture alley). A silage cut was taken once or twice a year for the first four years, and cattle were introduced in August 2015 for two months (Figure 1).



Figure 1. Silvopastoral system combining short rotation coppice for energy production and cattle production

Pasture productivity and biodiversity were measured in June 2015, and tree height assessed in August 2015, prior to cattle being introduced into the system. Cattle behaviour was monitored in August 2015 and tree damage assessed once the cattle had been moved out of the field in September. A summary of these data was presented in Smith and Gerrard (2015). The pasture alleys were due to be ploughed and reseeded in spring 2016 with diverse sward mixtures. However, due to bad weather conditions in spring 2016, ploughing was not completed until October, and a break crop of oats for whole crop silage was sown on 10 October 2016 (at a rate of 185 kg seed per hectare).

This report summarises research carried out in the trial plots in 2016 and 2017:

- (1) tree growth and woodchip production;
- (2) the nutritional value of tree leaf samples from the SRC willow and hazel, and pollarded elm, goat willow and ash;
- (3) establishment and growth of oats for whole-crop silage and associated weeds in the alleys;
- (4) earthworm and beetle biodiversity, and
- (5) soil organic matter.

Finally, the results are summarised into key findings.



Figure 2. Alder short rotation coppice with oats in the 21 m wide alley (May 2017)

#### 4 Tree height

Trees were measured in August 2014 and July 2015 (prior to cattle being introduced) (Figure 3). After the browsing trials in 2015, those tree rows that cattle had access to in August 2015 were coppiced to 10 cm above ground in February 2016. Trees were measured again in November 2016 (Figures 4 and 5). The alder showed good re-growth with heights similar to what they were pre-coppicing (Figure 5a). The willow has also re-grown well after coppicing in February 2016 with trees in the coppiced plots taller than pre-coppicing measurements in July 2015 (Figure 5b).

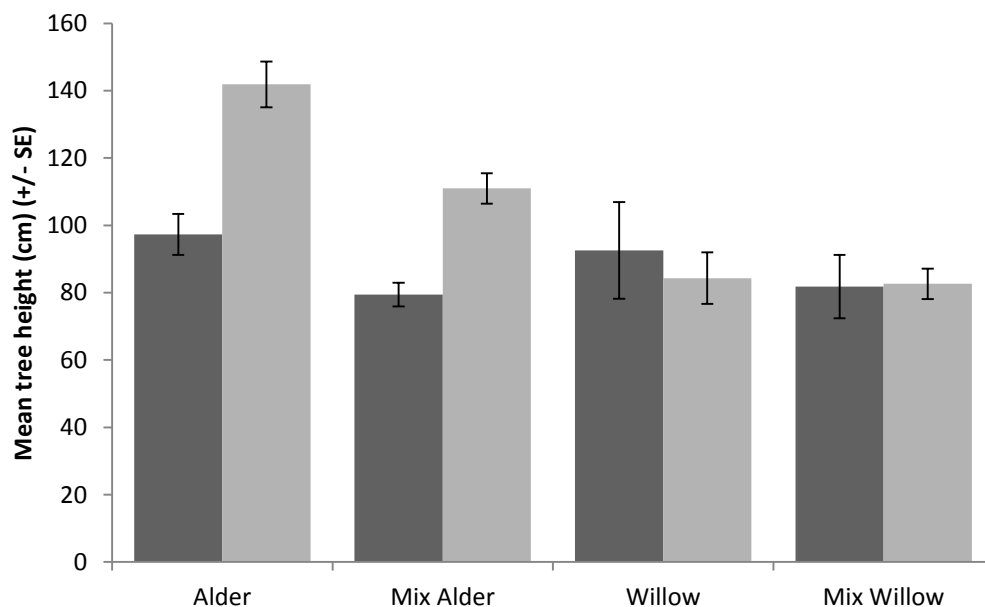


Figure 3. Tree height in 2014 (dark bars) and 2015 (light-coloured bars)





Figure 4. Measuring tree heights, November 2016

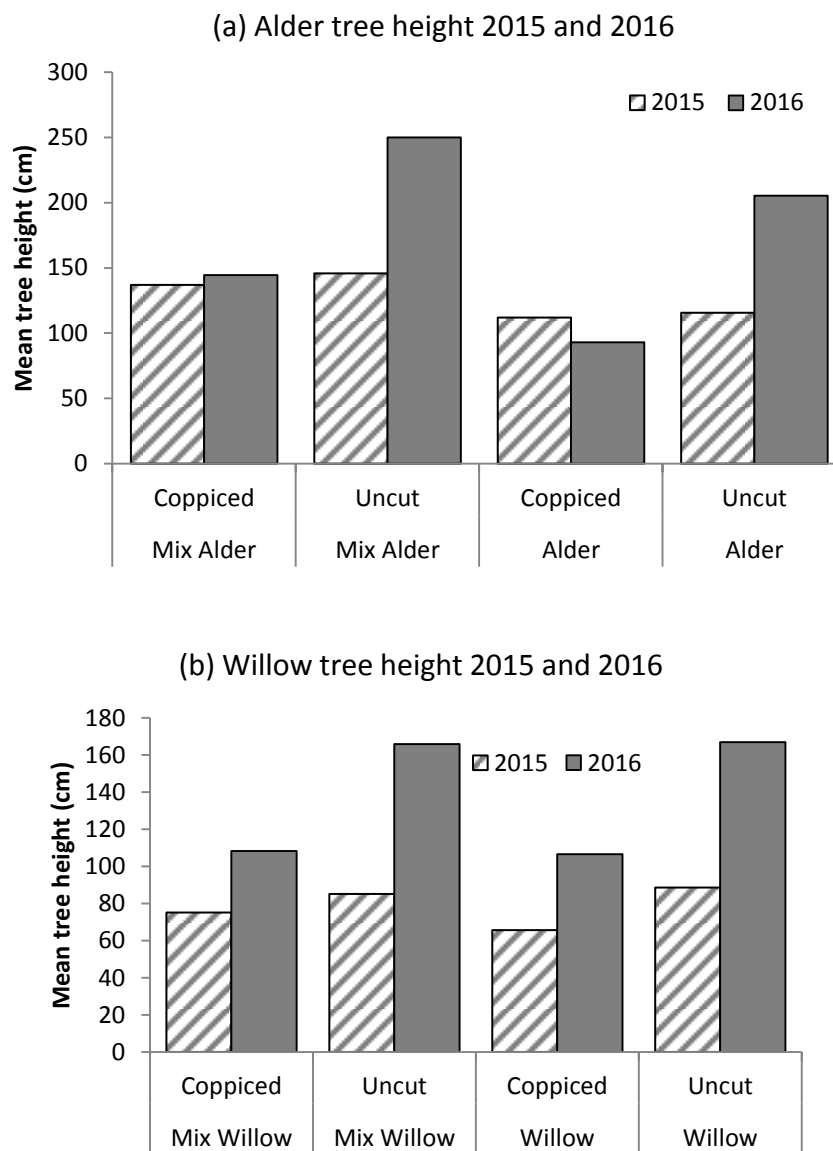


Figure 5. Tree height of (a) alder and (b) willow in 2015 (pre-coppicing) and 2016 (one third of tree rows coppiced)

## 5 Woodchip production

Trees from plots in three rows were coppiced by chainsaw in January 2017, and dried in the field until chipping in early March 2017 (Figure 6). This was the first harvest of these trees since they were planted in 2011. Woodchip volume per plot was recorded and sub-samples taken to calculate moisture content and weight conversion. Woodchip yields were calculated per tree and per hectare of agroforestry, based on a tree density of 833 trees per ha (Table 1).



Figure 6. (a) harvesting alder plots with chainsaw, January 2017; (b) chipping harvested material, March 2017; (c) harvested alder from one 50 m plot drying in field, March 2017.



Table 1. Woodchip yields from single species willow and alder, and mixed alder and willow short rotation coppice

Species	Plots (n)	Volume		Weight (oven dried)	
		cm <sup>3</sup> /tree (SE)	m <sup>3</sup> /ha	kg/tree (SE)	t/ha
Alder	3	3560 (960)	2.96	0.61 (0.17)	0.51
Willow	3	270 (70)	0.22	0.03 (0.01)	0.02
Mix	2	1250 (300)	1.04	0.20 (0.00)	0.17

The moisture content of the alder was 53%, willow was 49% and the mixed species, 50%. Yields between the alder plots varied, ranging between 0.39 and 0.94 oven dried (OD) kg/tree while yields in the willow plots were consistently low (between 0.02 and 0.04 OD kg/tree) (Figure 7). Standard figures for first harvest of SRC willow are between 10 and 20 OD t/ha (Nix, 2014) at a tree density of 15,000/ha; this works out as between 0.67 and 1.33 OD kg/tree. By comparison, the willow yields in the trial system are much lower than these standard figures, which may be due to a number of factors including high levels of deer damage to the willow, competition with grasses during the establishment phase, lower soil fertility (many SRC willow systems are fertilised), or unsuitable species/varieties. The *Salix viminalis* varieties used in the trial have been specifically developed for bioenergy production in SRC plantations and be better suited to other soil types or conditions. By contrast, white willow (*Salix alba*) was planted in new hedges on Elm Farm in 2014, and has established well, attaining 2-3 m height in the first two years. The alder compares more favourably with the standard figures (which may reflect the N-fixing ability of alder to compensate for the lack of additional fertiliser), but this first harvest was taken 6 years establishment, rather than three as with most willow SRC. Now the roots are well established, we expect that productivity will increase, and as can be seen from the re-growth measurements (Figure 5a), tree heights one year after coppicing are already higher than pre-coppicing.

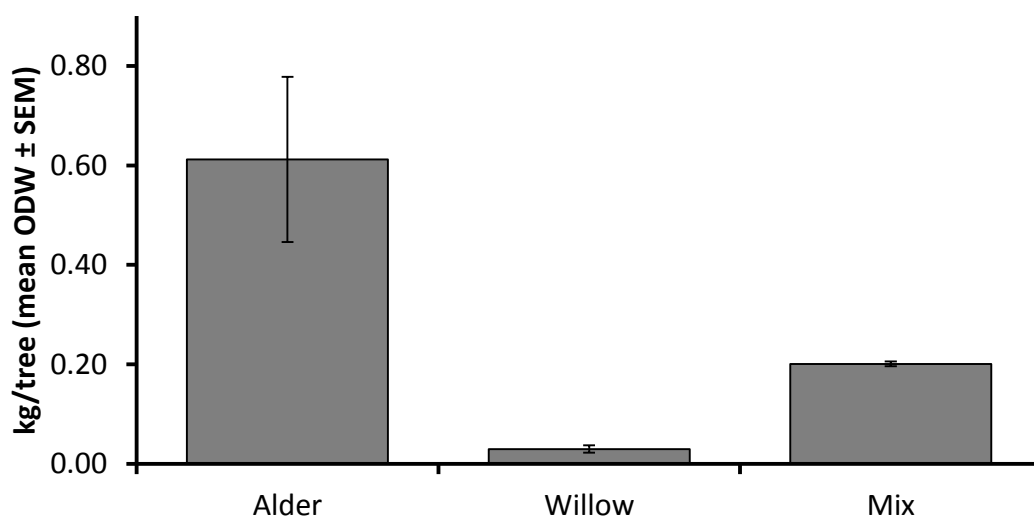


Figure 7. Woodchip yield per tree, 2016

## 6 Tree fodder

Leaf samples were collected from SRC alder and willow in August 2015, and from an ash (*Fraxinus excelsior*), goat willow (*Salix caprea*) and elm (*Ulmus minor*) tree on Elm Farm in June 2016. Leaf samples were taken from whole branches in both the SRC trees and standard trees; thus leaves were of varying ages. As part of a pilot study on the effect of air-drying tree fodder over winter and testing palatability, branches of the ash, goat willow and elm were bundled, tied and left to dry naturally in a covered barn from June to March (Figure 8). In March, leaf samples were taken from the air-dried bundles, before the bundles being fed to housed cattle and young stock (Figure 9 and see video at <https://vimeo.com/217077820>).



Figure 8. Harvesting tree fodder from an ash tree, June 2016



Figure 9. Feeding air-dried tree fodder to cattle and young stock, March 2017

Leaf samples were oven dried at 40°C until a stable weight was reached, and analysed for neutral detergent fibre (NDF), acid detergent fibre (ADF), lignin and digestible organic matter (DOM) by AGFORWARD partners INRA in France, and for Ca, P, N, Mg, S, K, Fe, Mn, Cu, Zn and B by NRM ([www.nrm.uk.com](http://www.nrm.uk.com)). Results contributed to the Tree Fodder on-line database managed by the Louis Bolk Institute (<http://www.voederbomen.nl/nutritionalvalues/>).



Digestible organic matter (DOM) varied between species, with lowest levels recorded for *Salix viminalis* samples collected in August (Table 2). Similarly low levels (42.1%) were recorded in *Salix viminalis* samples from a UK silvoarable SRC system (Smith *et al*, 2012). However, DOM of the other species were higher (Table 2) and compare favorably with typical livestock forages such as hay (47-67%), grass silage (52-67%) and grazed grass (64-75%) (Ministry of Agriculture Fisheries and Food, 1990). Lignin levels were higher in the *Salix viminalis* and *Alnus glutinosa* samples compared to the other three species; this may, however, be due to the samples being taken in August when leaves have matured and become lignified rather than reflecting any species differences.

Table 2. Chemical composition of tree leaves including neutral detergent fibre (NDF), acid detergent fibre (ADF), lignin and digestible organic matter (DOM)

Common name	Latin name	Date sampled	Dry matter (%)	NDF (% DM)	ADF (% DM)	Lignin (% DM)	DOM (%)
Willow	<i>Salix viminalis</i>	Aug-15	33	37.29	22.12	11.33	55.29
Common alder	<i>Alnus glutinosa</i>	Aug-15	38	37.61	24.76	13.51	76.19
Ash	<i>Fraxinus excelsior</i>	Jun-16	39	29.59	14.84	5.02	85.68
Goat willow	<i>Salix caprea</i>	Jun-16	35	32.15	20.57	8.77	73.51
English elm	<i>Ulmus minor</i>	Jun-16	37	43.06	12.15	3.31	77.72

The content of selected essential macro- and micro- minerals was tested for the five species of trees. Essential minerals elements are those which are known to have a metabolic function in animals or plants. All the tested elements increased in the air-dried leaves compared to fresh leaves although where levels were low in the fresh samples, this increase was minimal. For example, phosphorus in elm was 2.3 g/kg DM fresh and only 2.4 g/kg DM air-dried (Table 3). Levels of phosphorus (an essential element for bones) were highest in the dried goat willow (5.5 g/kg DM) but all trees compare favourably with grass at 2.8-3.5 g/kg DM, silage at 2.0-4.0 g/kg DM and hay at 1.5-3.5 g/kg DM (McDonald *et al*. 1995).

Table 3. Macro-elements of tree leaves

Common name	Latin name	Date sampled	Ca (g/kg DM)	P (g/kg DM)	N (% w/w)	Mg (g/kg DM)	S (g/kg DM)	K (g/kg DM)
Willow	<i>Salix viminalis</i>	Aug-15	18.8	3	2.23	1.8	4.1	10.4
Common alder	<i>Alnus glutinosa</i>	Aug-15	13.3	2.2	3.16	2.5	1.9	9.1
Ash (fresh)	<i>Fraxinus excelsior</i>	Jun-16	12.8	3.1	1.78	2.2	1.8	14.1
Ash (air-dried)	<i>Fraxinus excelsior</i>	Jun-16	16	3.7	2.21	2.7	2.3	20
Goat willow (fresh)	<i>Salix caprea</i>	Jun-16	10.2	4.2	2.66	1.9	2.1	13.9
Goat willow (air-dried)	<i>Salix caprea</i>	Jun-16	14.5	5.5	2.16	2.7	2.6	19.0
English elm (fresh)	<i>Ulmus minor</i>	Jun-16	11	2.3	2.23	1.9	1.3	14.7
English elm (air-dried)	<i>Ulmus minor</i>	Jun-16	16.8	2.4	2.31	2.8	1.7	20.9

Zinc is present in all animal tissue, organs and bones, playing an important role in growth, cell repair, hormones, enzyme activation, the immune system, and skin integrity. Zinc also plays a role in the optimum utilisation of nutrients and a deficiency can impair protein and carbohydrate metabolism (Blair 2011). Willow is particularly high in zinc, with *Salix caprea* containing 144 mg/kg DM and *Salix viminalis* containing 245 mg/kg DM (Table 4) reflecting previous findings (e.g. Robinson et al. 2005). The level of zinc in willow is substantially higher than those found in grass at 5 mg/kg DM, in silage at 25-30 mg/kg DM and in hay at 17-21 mg/kg DM (McDonald et al., 1995). In New Zealand, the spores of the fungus *Pythomyces chartarum*, prevalent in pasture, cause facial eczema in cattle. Zinc supplements can prevent the eczema and browsing on willow has been shown to be more effective than drenching (Anderson et al., 2012).

Table 4. Micro-elements of tree leaves: iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and boron (B)

Common name	Latin name	Date sampled	Fe (mg/kg DM)	Mn (mg/kg DM)	Cu (mg/kg DM)	Zn (mg/kg DM)	B (mg/kg DM)
Willow	<i>Salix viminalis</i>	Aug-15	73	284	5.5	245	36.7
Common alder	<i>Alnus glutinosa</i>	Aug-15	92	129	11.2	53	28.9
Ash (fresh)	<i>Fraxinus excelsior</i>	Jun-16	91	25	7.4	18	15.7
Ash (air-dried)	<i>Fraxinus excelsior</i>	Jun-16	116	32	9.6	23	17.5
Goat willow (fresh)	<i>Salix caprea</i>	Jun-16	76	36	7.6	118	12.7
Goat willow (air-dried)	<i>Salix caprea</i>	Jun-16	142	46	10.9	144	18.2
English elm (fresh)	<i>Ulmus minor</i>	Jun-16	138	37	6.5	32	19.3
English elm (air-dried)	<i>Ulmus minor</i>	Jun-16	258	38	9.3	40	26.0

Levels of iron were notably high in the dried samples and in elm, in particular, at 258 mg/kg DM (Table 4). *Salix viminalis* and *Alnus glutinosa* contained substantially higher levels of manganese than did other tree species (Table 4). The differences in manganese content may reflect the time of harvest although comparisons with other tested minerals show that only boron content may support this. The role of boron is not as well understood as other minerals however, it is known to be essential for embryo development, for healthy bone metabolism and for immune function (Goldbach et al. 2007). Boron is also a component of polysaccharides which provide stability to the cell wall matrix of plants, playing a role in both crop yield and quality and in the successful establishment of clover in pasture (O'Neill et al. 2004; Sherrell 1983).

The results of mineral analysis in this study add to the existing body of knowledge which is being compiled in the database (<http://www.voederbomen.nl/nutritionalvalues/>). However, differences in mineral content between species, between fresh and dried samples and between seasons indicate that the value of tree fodder can be better understood with further analysis. The high levels of minerals in tree fodder suggest that trees can offer an alternative source of mineral supplementation. The higher levels in dried samples, compared to fresh, suggest that there is further scope to extend the value of minerals in tree fodder beyond the growing season.

## 7 Tree:crop interactions

The pasture alleys were ploughed in October 2016, and a break crop of oats (*Avena sativa*) for whole crop silage was sown on 10 October at a rate of 185 kg/ha (Figure 10). Due to the tree harvesting rotation, it was possible to study the effects of tree height on the oat crop in the alley. Three tree rows were coppiced in February 2016 (rows 3, 6 and 9), and three more in January 2017 (rows 1, 4 and 7), leaving the three remaining rows un-harvested (rows 2, 5 and 8).



Figure 10. Ploughing the pasture alleys (left) and drilling oats (right), October 2016

The impact of tree growth on the oats in the adjacent alleys was investigated by assessing growth stage, percentage cover and height of oats, and percentage cover of weeds and diseases. Cover of oats and weeds were assessed weekly between 11 April and 18 May 2017, and the other assessments, were assessed weekly between 11 April and 2 June 2017. Assessments were carried out at 4 m, 8 m and 12 m from the centre of the tree row, on two transects in each of the willow and alder plots (1<sup>st</sup> year regrowth; 2<sup>nd</sup> year regrowth; un-harvested). Full details are given in Deremetz (2017).

### 7.1 Growth stage, percentage cover, height and biomass of oats

The Zadoks growth scale (Zadoks et al. 1974) was used to determine growth stage and evolution of the oats. First, the number of tillers per plant was recorded for three plants per sample location. Then three main stems were collected and the growth stage determined as a function of the number of nodes. Subsequently, booting, ear emergence and flowering was recorded for each sample location. For each sample location, the percentage cover of oats was recorded in a 0.5 m<sup>2</sup> quadrat, and height of a representative main stem measured. A more detailed study of crop height was carried out in the alley with the oldest trees to identify any impact of the tallest trees on the crop. The height of a main stem was recorded at eight points spaced 4 m apart on transects parallel to the tree rows, at distances 2.5, 4, 8 and 12 m from the tree rows both east and west of the tree row.





Figure 11. Height measurements of the oat crop

There were significant differences in terms of growth stages, in response to age of the tree regrowth, and the interaction between tree age and distance from the tree row: timing of second nodes (Tree age:  $X^2 = 10.671$ ,  $p=0.005$  and interactions:  $X^2 = 19.174$ ,  $p = 0.014$ ) and timing of ear emergence (Age:  $X^2 = 7.360$ ,  $p = 0.025$ ). The timing of these growth stages was later in the second year of regrowth, compared to both the first year regrowth and the unharvested tree plots, so the delay can't be directly attributed to the effects of shading by the trees. There was a higher observed mean number of tillers per plant in the unharvested alleys (4.185 tillers) than in the two years old and the one year old alleys (3.815 tillers for the two years old alleys and 3.407 tillers for the one year old alleys), but the differences weren't significant ( $F = 2.846$ ,  $p = 0.069$ ). There were no significant differences in timing of growth stages in response to the interactions between tree regrowth age and distance from the tree row. It may be that the trees are too small, even the oldest, to significantly influence the timing of growth stages.

There were significant differences in percentage cover of the oats in response to the age of tree regrowth in all weeks except on 28 April (21 April:  $F = 4.285$ ,  $p = 0.020$ ; 5 May:  $F = 6.404$ ,  $p = 0.004$ ; 12 May:  $F = 4.565$ ,  $p = 0.017$ ). The cover of oats or cereals is directly linked by the establishment of plant after the drilling and this establishment is influenced by the size of the aggregates, the temperature of the soil, soil texture, the depth of seeding, the rainfall, the date of seeding (Blake et al. 2003). Trees may indirectly influence many of these factors by the enrichment of soil organic matter, as well as affecting the temperature and soil moisture directly. However, similar to the effects on growth stages, percentage cover of oats in the second year regrowth plots were significantly lower from the first year regrowth and unharvested plots (38% compared to 51% and 47% respectively), suggesting that shading from the trees alone was not the driving factor. There were no significant influences of the distance from the tree row and the interaction of distance and age of the trees on the cover of oats.

Focusing in more detail on the tree row alleys with the unharvested trees, there were significant differences between the distance ( $F = 64.521$ ,  $p < 0.001$ ) and orientation of the alley (West and East of the tree row;  $F = 21.251$ ,  $p < 0.001$ ) and their interaction ( $F = 3.300$ ,  $p = 0.022$ ) (Figure 12). Crops were tallest adjacent to the tree rows with a decrease with increasing distance from the tree row;

this effect was more noticeable on the east side of the tree rows (Figure 12). This may reflect the shading effect causing greater stem elongation in those plants closes to the tree rows. The impact of trees on the microclimate, enrichment of nitrogen by the fine tree roots, leaf litter and biological nitrogen fixation by the alders could also explain this observation.

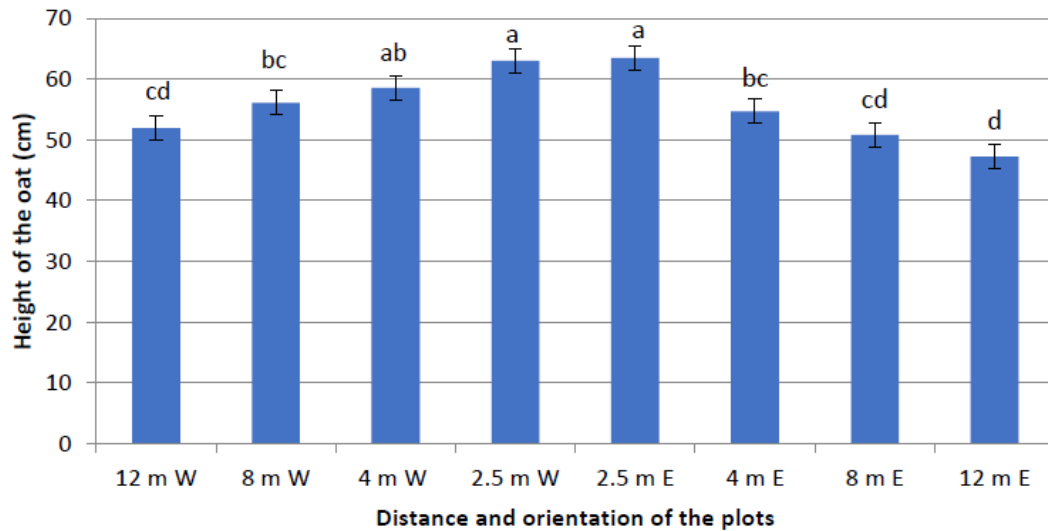


Figure 12. Crop height at 2.5 m, 4 m, 8 m and 12 m east (E) and west (W) from the tree rows (different letters signify significant differences)

Total above-ground biomass was sampled using 0.5m<sup>2</sup> quadrats prior to crop harvest for silage, when oats were at a milk-dough ripening stage (BBCH growth stage 77-83) in two transects across the unharvested alder alleys (20 June 2017). Sampling positions were identified along a transect orthogonal to the tree rows, at 2 m, 6 m and 10 m distance from the edge of cultivated area both East and West of the tree row. Crop and weed biomass were separately weighed after being oven-dried at 80°C until constant weight. With so few samples, it is not possible to detect a reliable pattern of biomass impacts of the trees although there seems to be no obvious reduction in biomass adjacent to the trees where competition would be greatest (Figure 13).

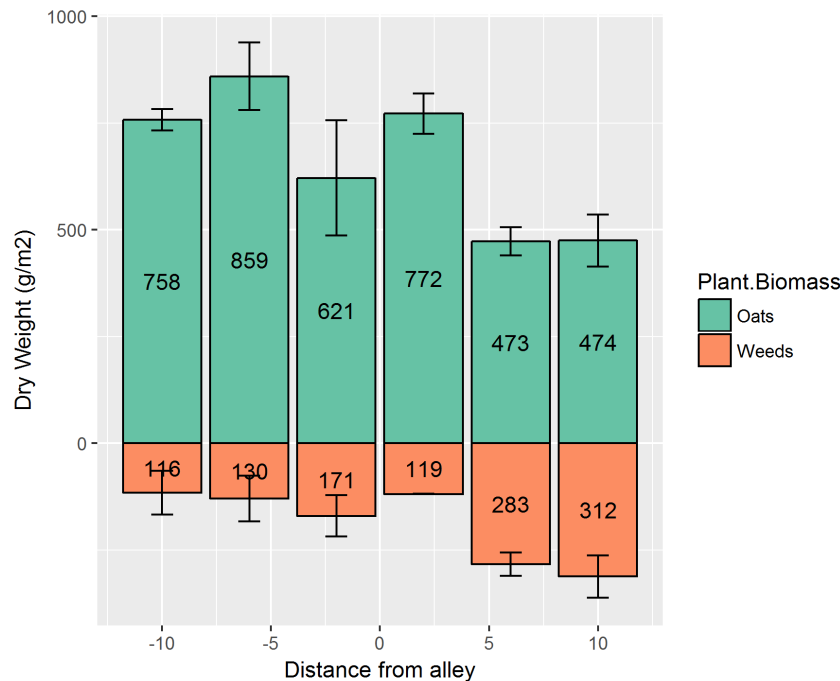


Figure 13. Biomass of oats and weeds at different distances from the tree row (0 = edge of tree row; samples taken at 2 m, 6 m and 10 m west (minus bars) and east (positive bars) of the tree row). Error bars are standard error,  $n = 2$ .

## 7.2 Percentage cover of weeds and diseases

To assess levels of crop diseases, leaves were collected from the first leaf unwrapped from the stem, to the top of the main stem, and all diseases identified and percentage cover recorded. After the flag leaf emerged, three flag leaves from three different main stems for each location were assessed. Percentage cover of weeds was assessed in  $0.5\text{m}^2$  quadrats at the same time and location as the crop samples. Species diversity was assessed in each sample location and twice in each of the tree rows. Total percentage cover, proportional cover of each species, diversity (inverse Simpson's Index), number of species, their value for wildlife and their life cycle (perennial or annual) were recorded, using the encyclopaedia of arable weeds (Clarke et al. 2015). In order to evaluate the wildlife value of the weed community, species were attributed 1 if they had a value for wildlife and 0 for no value for wildlife, and this number was multiplied by the species cover at each location and all species summed. For the life-cycle, the ratio of cover of perennials weeds to the total cover for each sample was calculated.

Concerning the cover of diseases, only leaf spot (*Pyrenophora avenae*) was found, and at low pressure (mean 1.19% on the third leaf). There were no significant influences of age of the tree regrowth and location on the cover of diseases on the third leaf, except for one week only; on 28 April, a significantly higher cover of disease was recorded in the second year re-growth plots (1.44%) compared to the first year regrowth (0.56%) and unharvested plots (0.72%). There were no diseases found on the flag leaves.

With regards weeds, there were no significant influences of the age of tree regrowth, distance from the tree row and the interaction distance-age during the weekly crop assessments. But there were



significant differences between the cover of weeds in the tree row in comparison to the alleys ( $F = 7.542$ ,  $p < 0.001$ ), with higher cover of weeds in the tree row (Figure 14).

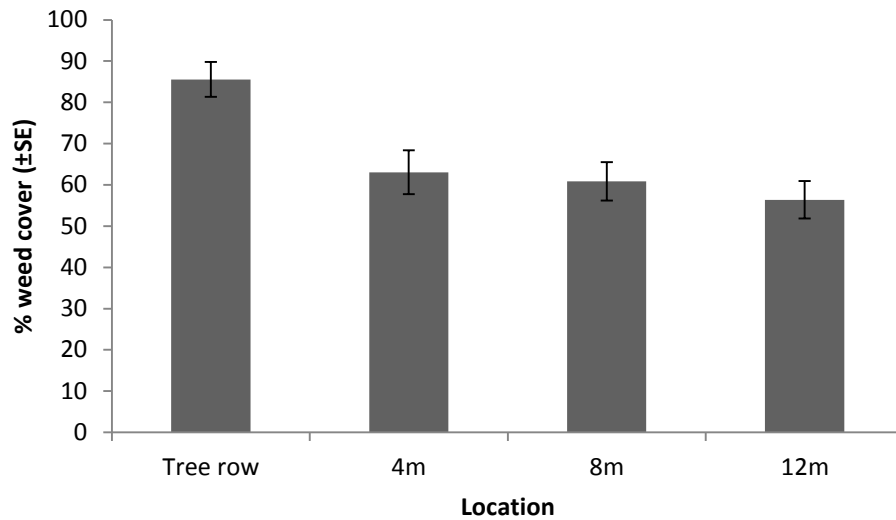


Figure 14. Percentage cover of weeds in the tree rows and at 4 m, 8 m and 12 m into the crop alleys.

Concerning species richness, there was a mean of 3.39 species in the trees row, 4.89 species at 4m, 4.78 species at 8 m and 5.06 species at 12 m. There was a significant effect of age of tree regrowth ( $F = 3.510$ ,  $p = 0.036$ ) and location ( $F = 5.247$ ,  $p = 0.003$ ), but no significant interaction. The difference between species richness in the alley and the trees row is explained by more species of annual weeds, as a response to the cultivation of the pasture before seeding. The Simpson Index showed a similar response with a value of 0.031 in the tree row, 0.078 at 4 m, 0.067 at 8 m and 0.072 at 12 m, with a significant effect of distance ( $F = 6.653$ ,  $p < 0.001$ ), with lower biodiversity in the tree rows again reflecting higher diversity of annual weeds in the crop alley.

When comparing the proportion of perennial weeds of the total weed cover, there was a lower proportion of perennial weeds in the alley ( $X^2 = 22.464$ ,  $p < 0.001$ ; tree row = 0.97, 4 m = 0.81, 8 m = 0.75 and 12 m = 0.75). Finally, there was a difference in values for wildlife (natural enemies) with a significantly higher value of weeds associated with the tree rows than in the alleys ( $X^2 = 19.57$ ,  $p < 0.001$ ; tree row = 0.83, 4 m = 0.57, 8 m = 0.54 and 12 m = 0.48). This can be attributed to the mostly perennial weeds found in the tree rows, including the grass *Dactylis glomerata* (cocksfoot), *Cirsium arvense* (creeping thistle) and *Rumex* spp. (dock), a legacy from the pasture that the trees were planted into. Despite their value for wildlife, these weeds could become problematic and difficult to manage. To keep the value for wildlife without creating an unacceptable weed problem, it may be better to control weeds on the trees row by the seeding of grass, legumes and other plants with a high interest for wildlife. However, there was no observed contamination of the alleys from weed species found in the tree rows, and where there was dense tree cover in some of the unharvested tree rows, shading had caused the cover of perennial weeds to decline.

## 8 Biodiversity

### 8.1 Earthworm biodiversity

Samples were taken in April 2017 in the tree row and at 4 m and 9 m from the tree row. We took two at each distance to give a total of six soil cores per plot, in three alder plots and two willow plots. This work consisted of collecting a soil core (13 cm x 13 cm x 22 cm deep; volume of 0.0037 m<sup>3</sup> and surface area of 0.0182 m<sup>2</sup>) at each location and sorting through the soil core by hand, collecting all earthworms and calculating total abundance per m<sup>2</sup>. Adult earthworms were identified to species. There were significant differences in mean populations from the different locations ( $\chi^2 = 15.9$ ,  $p = 0.007$ ); earthworm populations were significantly higher in the alder tree rows than in the adjacent alleys, but there were no significant differences between the willow tree rows and adjacent alleys (Figure 15). The number of species varied between 0 (no adult earthworms) and 5; there were no significant differences between number of species at the different locations although some species were found only in the tree rows (*Lumbricus terrestris*, *Aporrectodea longa*). These are anecic species that make permanent burrows in the soil; therefore they require stable habitats and are less frequently found in disturbed arable soils. The higher abundance within the tree rows is likely to be due to the more stable habitat and higher levels of surface organic matter in the form of leaf litter, compared to the alleys which were ploughed the previous October.

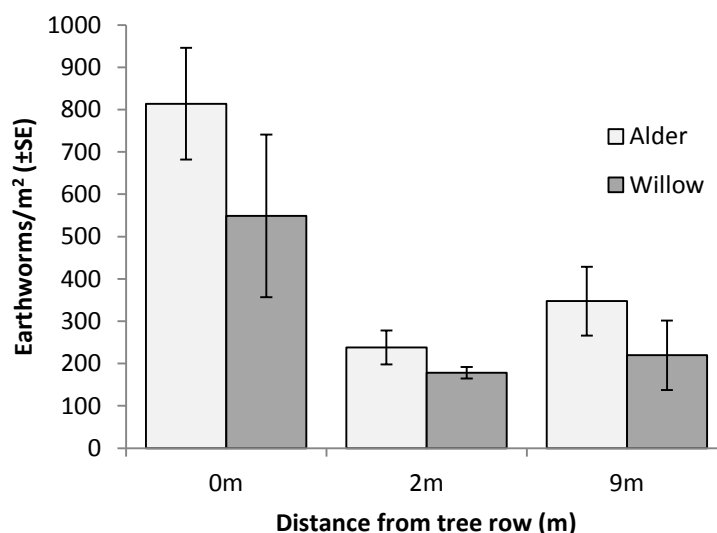


Figure 15. Earthworm abundance at different distances from the tree row in alder and willow agroforestry plots.

### 8.2 Ground beetle biodiversity

Pitfall traps were used to assess biodiversity of ground beetles (Carabidae), which are important ground-dwelling predators. Traps were buried into the soil with the top of the trap at the same height of soil surface. The traps were positioned under the trees and at different distances west from the centre of the tree row (4, 8, 12 m) in the un-harvested alder tree plots only, with a control plot set up in an area with no trees. Trapping took place at the end of April 2017 for six days and traps were emptied every two days. Ground beetles were identified to species using Luff (2007) and diversity (using the inverse Simpson's index), species richness and abundance between the different factors (age of tree growth and distance from the tree row) analysed.

There were significant differences in beetle abundance at the different locations, with lower abundances found in the tree rows compared with the alleys and control ( $X^2 = 24.897$ ,  $p < 0.001$ ; Figure 16).

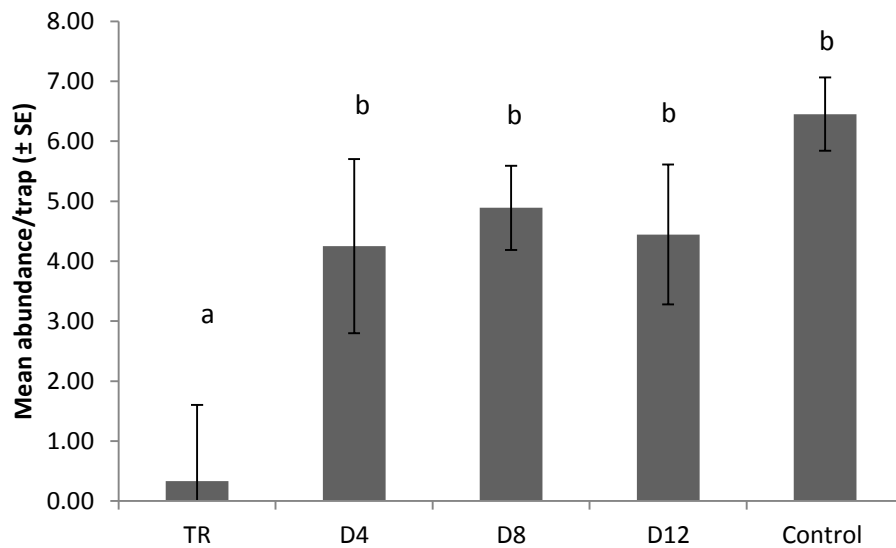


Figure 16. Ground beetle abundance at different distances from the tree row in non-harvested alder agroforestry plots and a control plot. TR = Tree row; D4 = 4 m from tree row; D8 = 8 m from tree row; D12 = 12 m from tree row. Letters indicate significant differences.

Species richness (i.e. number of species) showed a similar pattern, with fewer species in the tree row (0.33 species per trap in the tree row, 2.13 species at 4 m, 1.67 species at 8 m and 12 m and 1.87 species per trap in the control). The differences between the tree row, the alley and the control were significant ( $X^2 = 20.306$ ,  $p < 0.001$ ). The Simpson's Index showed no effect of SRC trees on the diversity of ground beetles in the alley compared to the control but a higher biodiversity in the alley and in the control than in the tree row ( $X^2 = 1.873$ ,  $p = 0.018$ ).

The most common species recorded in the pitfall traps were *Poecilus cupreus* and *Nebria brevicollis*, both common species found in agricultural fields (Luff, 2007). Our results showed that during the late Spring, the crop alleys supported higher abundance and diversity of beetles than the tree rows; this may reflect higher levels of prey within the crop, or a preferable microclimate in the crop than in the tree rows. However, many species of carabids commonly associated with crops require undisturbed or extensively managed vegetation for overwintering or reproduction sites (Pfiffner and Luka 2000). It would be useful to repeat the sampling during the winter to identify the role of the tree rows for providing an overwintering habitat.



## 9 Soil organic matter

Soil cores were taken on transects running perpendicular from the tree rows into the crop alleys, in the un-harvested alder plots only. Samples were located at in the tree row, and at 4 m, 8 m and 12 m from the tree row. Soil cores were collected with an auger to a depth of 20 cm. For each plot, two soil cores were taken and mixed to obtain a composite sample, along two transects per plot for the three blocks (total of 24 samples). Samples were sent to the NRM laboratory for analyses of total soil organic matter.

We found a soil organic matter level of 4.05% in the tree rows, 3.77% at 4 m into the alley, 3.53% at 8 m and 3.73% at 12 m. There were no significant differences between these levels of SOM ( $F = 0.484$ ,  $p = 0.697$ ). This lack of a difference between locations may reflect the time needed for trees to cause a significant increase in soil organic matter, or may be due to the incorporation of the grass sward in the alleys into the top soil during ploughing carried out in the previous autumn increasing soil organic matter.

## 10 Key conclusions

The research described in this report contributes to the evidence base on the performance and impacts of a novel agroforestry system in the early years following establishment. Low yields of woodchip from the SRC willow and alder reflect earlier problems during the establishment phase, and the *Salix viminalis* in particular has not established well, suggesting that this species (or varieties) is not well suited to the site. However, good regrowth of the alder trees following coppicing indicates that the root systems are now established and it is expected that yields of woodchip will increase significantly by the next harvest (3-5 years' time).

The value of tree leaves as livestock fodder is of increasing interest to farmers, as a buffer climate impacts on forage yields and quality. In this study, alder, English elm, goat willow and ash had levels of digestible organic matter that compared favorably with typical livestock forages. The greatest potential for tree fodder, however, may be as sources of minerals, particularly to address deficiencies in feed or forage, and the pilot study on air-drying suggests that there is further scope to extend the value of minerals in tree fodder beyond the growing season.

Although this agroforestry system is described as a silvopastoral agroforestry system, a crop of oats for whole-crop silage was grown in the alleys during 2016/17, as a break crop before establishing a new grass sward. This allowed us to study the potential impacts and interactions of combining trees and crops, by comparing the growth of oats in the alleys adjacent to trees at different stages of regrowth following coppicing as well as un-harvested trees. There was little observed impact of the trees on the oats, except a potential effect of shading immediately adjacent to the tree row resulting in taller crops, and as a competitive species, oats are well suited to being grown in an agroforestry system. A similar lack of effect was found in the study system in an earlier project that investigated sward productivity (Smith et al. 2016), although the trees at that stage were also younger and smaller. This suggests, however, that there is no significant impact of trees on the alley crops in this system at least during the first six years. As the system will be coppiced on a 3-5 year rotation, it is expected that this will help manage the competition for light by keeping the level of shading lower than in a standard tree system. It may be possible, also, to time the harvesting of the trees to coincide with re-seeding of the pasture in the alleys, to ensure highest levels of establishment of the

sward. Weed cover was higher in the tree row, with more perennial weeds in particular, compared to the crop alley. The perennial weeds offered greater resources for biodiversity but this may conflict with the potential for causing weed problems in the crop alleys.

Regarding impacts on biodiversity, the two taxa studied here support two important ecosystem services; earthworms are important drivers of organic matter decomposition and maintenance of soil structure, while ground beetles contribute to pest control. They showed different patterns of biodiversity in the agroforestry system, reflecting their different habitat and resource requirements. Earthworm abundances were higher in the tree rows, which represent an undisturbed stable habitat, buffered from extremes of temperature, while the more active ground beetles were in greater abundances in the crop alleys. The role of the tree rows in providing a refuge for ground beetles throughout the winter or during periods of cultivation in the alleys should be investigated further.

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