Elm Farm: integrating productive trees and hedges into a lowland livestock farm

Jo Smith and Sally Westaway, The Organic Research Centre

January 2020

Summary

Elm Farm is an 85-hectare organic livestock farm in West Berkshire situated within a wooded landscape in the North Wessex Downs Area of Outstanding Natural Beauty. Over the last ten years, a range of agroforestry approaches have been introduced to Elm Farm; 3800 new trees have been planted on the farm (1115 trees with Woodland Trust support) and new hedgerow management methods trialled to increase the overall productivity of the farm and provide environmental benefits. This review consolidates the research results and experiences of this agroforestry journey.

The review is divided into four sections

1. New tree and hedge planting
2. Managing hedges for bioenergy
3. Silvopasture trial
4. Tree fodder

1. New tree planting supported by the Woodland Trust.

In 2014, Elm Farm was one of the first schemes to be planted under the PUR/Accor Hotels funding stream. Three different schemes were designed and established with aims to improve the farm business and rural economy, benefit the environment and support the Organic Research Centre's research and knowledge exchange activities. Planting included new hedges for bioenergy; a multifunctional tree avenue; and in-field trees. This section documents the process and the lessons learnt, as well as bring together data on establishment rates and growth collected over the years, with new data collected in October 2019.

2. Managing hedgerows for bioenergy production.

Since 2014 we have been investigating the potential of coppice management of field boundary hedgerows to produce woodchip for bioenergy. We have conducted trials to assess the impacts of coppicing on the environmental and cultural value of hedges. These trials have demonstrated that woodchip of a marketable quality can be produced from coppice management of hedgerows, and that this woodchip is best suited to local or on-farm use. This section summarises the key findings from the machinery trials, practical information on the costs of different methods and the woodchip quality as well re-growth and productivity data from different hedge types and research on the wider impacts of coppicing.

3. Integrated bioenergy and livestock production.

An innovative alley cropping system integrating willow and alder short rotation coppice for bioenergy and livestock production was established in 2011. This section reports on the key results of the nine years of research from the early years of establishment through to current day, including tree:crop interactions, productivity of trees, pasture and whole crop barley, microclimate impacts, invertebrate and plant biodiversity and financial performance. Results suggest that introducing trees to pasture has negligible impact on sward productivity, alley crops, biodiversity, and the microclimate within the first six years. Net present value (NPV) calculations, while overall positive, showed the initial investment not repaid until five years after establishment which may prove a barrier to establishment.

4. Tree fodder

Trees on livestock farms can provide multiple benefits including access to shade and shelter. Another less understood benefit is the use of tree browse and fodder for nutritional and medicinal purposes. ORC research into the value of trees as feed for livestock has been underway since 2011 and includes both analyses of tree leaves for their feed value as well as browsing trials of livestock within the agroforestry trial at Elm Farm. This section summarises the key data and outcomes of this research.

The variability in feed value from trees is one of the biggest challenges to uptake; there are many different species as well as seasonal variation in quality and availability. The chemical composition of willow coppice at Wakelyns was found to change with age of growth and season. Research at Elm Farm have shown alder, English elm, goat willow and ash had levels of digestible organic matter that compared favourably with typical livestock forages. The greatest potential for tree fodder, however, may be as sources of minerals, and the pilot study on air-drying suggests there is scope to extend the value of minerals in tree fodder beyond the growing season.

Acknowledgements

Thanks to ORC colleagues over the years Lindsay Whistance, Meg Chambers, Mary Crossland, Katharine Leach, and the ORC interns involved in sampling and data collection (Sarah Waterfield, Caitlin Fuller, Jessica Bach, Valentin Deremetz, Lucie Lombard, Ellie Brown, Anais Rousseu, Seda Aydin, Will Peters, Daria Erik). A particular thank you to volunteers Bob Winfield, Bob Hotchkiss, Corinne Sreeves, Theo Stenning, Bob Sarney and the rest of the West Berkshire Conservation Volunteer team and dormouse volunteers, and also to Matthew Prince for his help over the years of research trials and data collection.

This report was funded by the Woodland Trust.

Research funding for the projects included in this report came from a number of sources:

The Sustainable Organic and Low Input Dairying (SOLID) project (www.solidairy.eu) (Grant Agreement Nº 266367) was co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD. 1st April 2011 to 31st March 2016.

The Towards Eco-energetic Communities (TWECOM project) (www.twecom.eu/) was funded by the INTERREG 4b NWE Programme with co-funding in the UK provided by the Ashden Trust and additional funding by the Woodland Trust and the North Wessex Downs Area of Outstanding Natural Beauty Sustainable Development Fund. 1st January 2013 to 31st December 2015.

The AGroFORestry that Will Advance Rural Development (AGFORWARD) project (www.agforward.eu) (Grant Agreement N° 613520) was co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD, 1st January 2014 to 31st December 2017.

The Innovative and Sustainable Intensification of Integrated Food and Non-food systems to develop climate-resilient agro-ecosystems in Europe (SustainFARM) project (www.sustainfarm.eu) was funded in the UK by Defra as part of the European FACCE SURPLUS ERA-NET co-fund programme with funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement Nº 652615. 1st March 2016 to 31st March 2019.

Recommended citation:

Smith, J and Westaway, S (2020). Elm Farm: integrating productive trees and hedges into a lowland livestock farm. Organic Research Centre report for the Woodland Trust.

Contents

Introduction

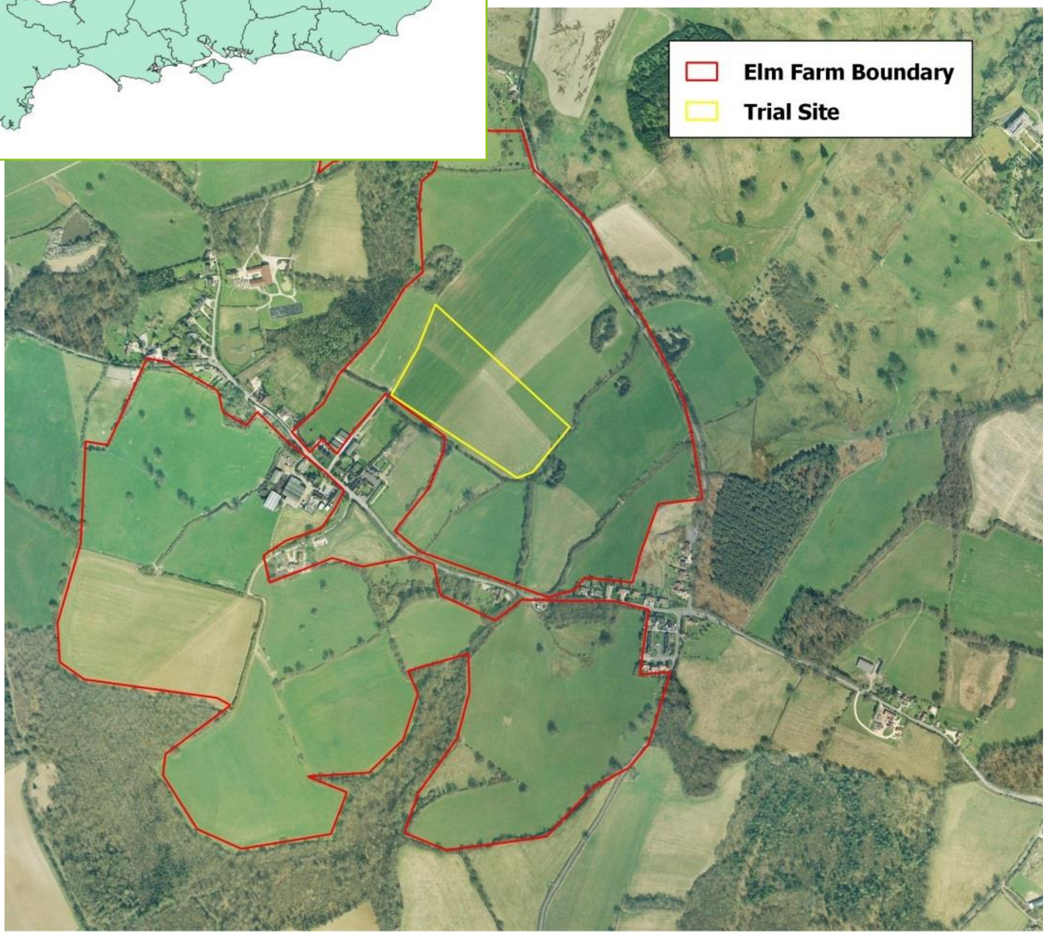
Over the last 10 years, Elm Farm, an 85 ha organic livestock farm in West Berkshire has planted 3800 trees (1115 trees with Woodland Trust support) and introduced new hedgerow management approaches to increase the overall productivity of the farm and provide environmental benefits. This review consolidates the research results and experiences of this journey into a more treed landscape. The review covers four main areas:

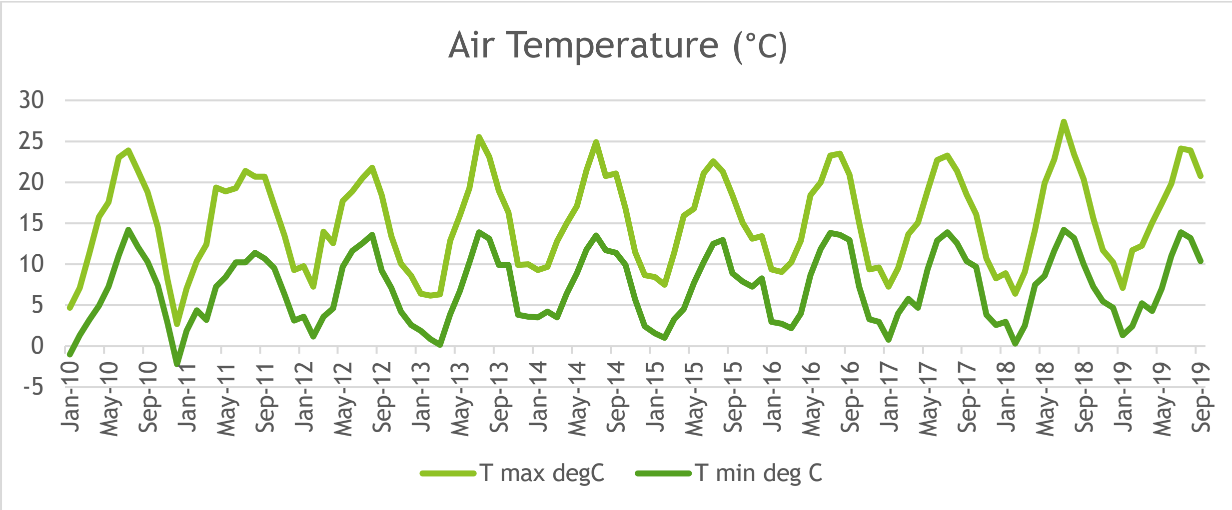
1) *New tree planting supported by the Woodland Trust*. In 2014, Elm Farm was one of the first schemes to be planted under the PUR/Accor Hotels funding stream. With Woodland Creation advisor, Hamish Thomson, three different schemes were designed and established: new hedges for bioenergy; a multifunctional tree avenue; and in-field trees. This section documents the process and the lessons learnt, as well as brings together data on establishment rates and growth collected over the years.
2) *Managing hedgerows for bioenergy production*. Since 2014 we have been investigating the potential of managing boundary hedgerows to produce woodchip for bioenergy, while maintaining their environmental and cultural values. This section summarises the key findings from the machinery trials, re-growth and productivity data, economic modelling, and biodiversity impacts.
3) *Integrated bioenergy and livestock production*. An innovative alley cropping system integrating short rotation coppice for bioenergy and livestock production was established in 2011. This section reports on the key results of the nine years of research from the early years of establishment through to current day, including tree:crop interactions, productivity of trees, pasture and whole crop barley, tree fodder analyses, microclimate impacts, invertebrate and plant biodiversity and financial performance.
4) *Tree fodder*. ORC research into the value of trees as feed for livestock has been underway since 2011 and includes both analyses of tree leaves for their feed value as well as browsing trials of livestock within the agroforestry trial at Elm Farm. This section summarises the key data and outcomes of this research.

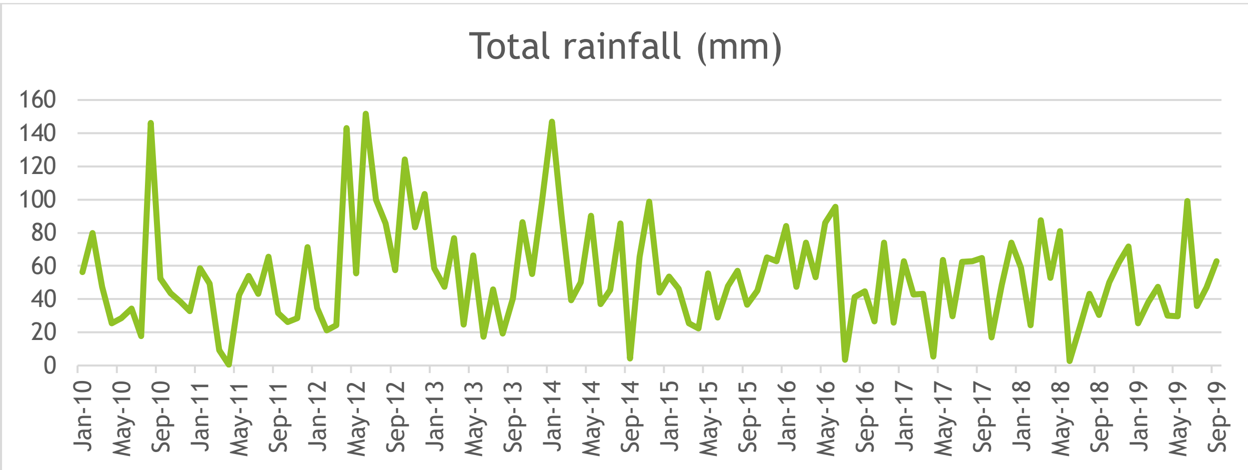
Farm description

Elm Farm is an 85 hectare organic livestock farm in West Berkshire (51°23'14.19" N; 1°24'08.34"W Figure 1). Now privately owned, Elm Farm was the base for the Organic Research Centre for 40 years from 1980 until 2020. Originally a dairy farm, it was the site of various crop trials until the mid 1990's. For the last 15 years it was managed by a local tenant farmer primarily for raising dairy youngstock and beef cattle. In November 2018, a new arrangement with a share farmer was developed, and sheep were brought onto the farm. Average annual rainfall for the area is 672 mm, average annual sunshine is 1584 hours, average annual minimum temperature is 6.9 °C and average annual maximum temperature is 14.6 °C (Met Office Oxford 1971-2000 averages). Minimum and maximum air temperature, sunshine hours and rainfall are shown in Figure 2 (data for 2010-2019 from nearest Met Office weather station in Oxford: https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data). The soil type is mainly Wickham Series clay (Eutric Luvic Planosols in the WRB classification), poorly drained clay loams susceptible to structural damage. The farm sits within a wooded landscape in the North Wessex Downs Area of Outstanding Natural Beauty, bordered by three small woodlands and a neighbouring estate with beautiful parkland.

FIGURE 1. AERIAL VIEW OF ELM FARM SHOWING FARM BOUNDARY AND LOCATION OF SILVOPASTORAL TRIAL SITE







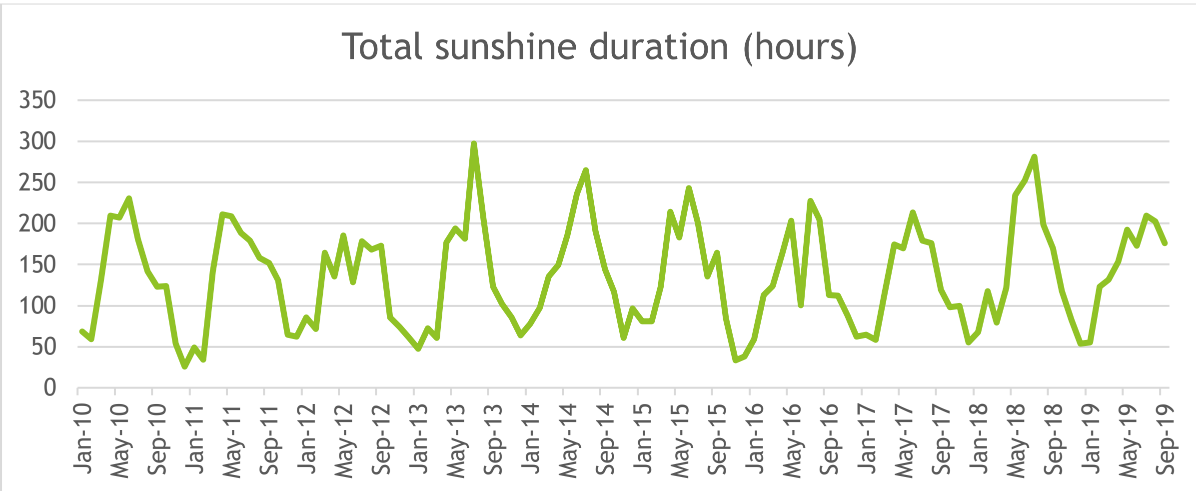


Figure 2. Climate summaries for air temperature, sunshine hours and rainfall from 2010-2019 (Met Office: www.metoffice.gov.uk: Oxford station)

New trees and hedges supported by the Woodland Trust

Introduction

In 2014, Elm Farm was one of the first schemes to be planted under the PUR/Accor Hotels funding stream, delivered in the UK by the Woodland Trust. With Woodland Creation advisor, Hamish Thomson, three different schemes were designed and established: new hedges for bioenergy; a multifunctional tree avenue; and in-field trees. This section documents the process and the lessons learnt, as well as bring together data on establishment rates and growth collected over the years, with new data collected in October 2019.

Why plant more trees?

Elm Farm already had 9 km of existing hedgerows, and sits within a treed landscape, bordering three small woodlands and a neighbouring estate with beautiful parkland. So why increase tree cover? In discussion with our tenant farmer, we identified many reasons to plant trees, including improving the farm business and rural economy, improving the environment and supporting our research and knowledge exchange activities.

Improving the farm business and local economy:

- by increasing productivity on land that doesn't support arable crops
- by producing wood fuel from hedgerows for on-farm bioenergy production
- by planting a tree avenue for timber and fruit and cider from apple and pear trees
- by producing timber and tree fodder from in-field trees and hedgerow trees
- by providing shade and shelter for the livestock
- by supporting rural employment (tree management; cider production).

Improving the environment

- by providing resources and habitat links for biodiversity
- by improving the landscape – the in-field trees will form a parkland habitat which will link up with parkland on the adjacent Hamstead Park and the tree avenue provides a pleasant landscape feature for local residents
- by improving water regulation by trees reducing overland flow of water, increasing infiltration and water storage in topsoil horizons
- by increasing carbon sequestration.

Supporting ORC's research and knowledge exchange activities.

- by acting as a demonstration to farmers and other stakeholders as to the potential for trees on farms
- by providing a research platform for investigating different approaches to management and the impacts of tree planting on the farm business and local environment.

We also identified the main barriers and challenges for tree planting on Elm Farm, which were the costs of fencing and tree protection against livestock and wild animals; on-going management costs; the need for on-going advice regarding management and production; the need for training on tree management; and problems with weed control using organic methods.

Working with Hamish Thomson from the Woodland Trust, we developed three main schemes to fully integrate trees within the farming system and meet the many drivers we had identified (Figure 3). A tree avenue planted alongside a popular public bridleway would provide a productive landscape feature and a link between woodland habitats. Fifty trees planted within four fields would create the next generation of parkland trees, as well as produce timber and tree fodder, provide shade and shelter for livestock and a resource for farmland biodiversity. Over 500 m of new hedges planted with fast-growing species would increase landscape connectivity as well as provide a source of renewable energy for on-farm use, and shade and shelter for livestock. In the following sections we describe the planting and subsequent management of the trees and report on establishment rates and growth.

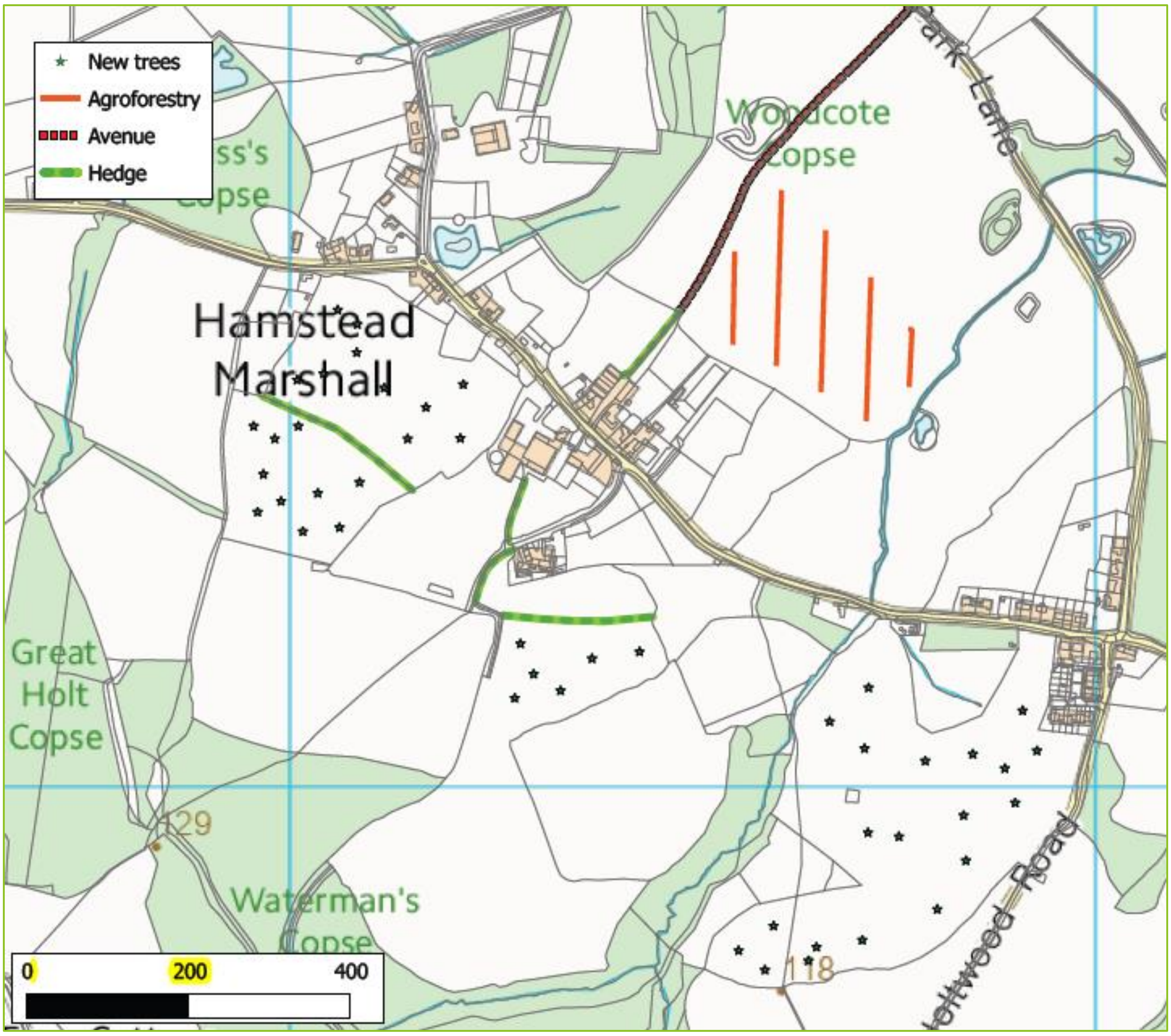


FIGURE 3. MAP OF ELM FARM SHOWING THE LOCATION OF THE NEW TREE PLANTING AND THE SILVOPASTORAL ALLEY CROPPING AGROFORESTRY SYSTEM

Tree avenue

Aim: to create a new landscape feature including fruit trees and cider apples for organic cider production

Species (81 trees): sweet chestnut (*Castanea sativa*) (10), oak (*Quercus robur*) (9), field maple (*Acer campestre*) (8), rowan (*Sorbus aucuparia*) (8), hornbeam (*Carpinus betulus*) (7), cider apples (27), pear (4), dessert apples (7), quince (1)
Spacing: 5m
Protection: 1.2m guards (half with biodegradable fibre tree guards (50), half with standard plastic tree guards). Mulch mats
Data collected: survival rates and tree heights (July 2014, August 2015 and 2016, Oct 2019)

Tree establishment
The trees were planted in March 2014, with weed control using 1 m^2 biodegradable mulch mats held down with biodegradable plastic pegs and woodchip on top. Half of the trees had 1.2 m biodegradable fibre guards with canes, the other half had 1.2 m standard plastic guards with a 1.5 m stake. The fruit trees were planted in groups of at least five to aid in pollination. Cider and dessert apples were maiden trees mostly on M25 rootstocks (final height 8-10 m) with five apple varieties (Harry Masters Jersey, Stoke Red, Charles Ross, Ellison's Orange and Kidds Orange Red) on MM106 rootstocks (final height 4-5 m). See Annex 1 for varieties. The other tree species were 40-60 cm 1-year old bareroot transplants except the sweet chestnut which were seedlings, and the oaks which were two years old. Surrounding grasses and weeds were cut in the first two years and new woodchip was applied around the base of the trees. The fruit trees were pruned in February 2016.

Tree establishment was assessed at the end of July 2014, after the first summer. Eleven trees had died (5 sweet chestnut and 6 rowan), a mortality rate of 13.5%. Of these dead trees, ten were in the biodegradable fibre guards. Between July 2014 and August 2015, when the next assessments were carried out, five more trees died (one oak, three cider apples and one dessert apple). Between August 2015 and August 2016, fourteen more trees died (5 x sweet chestnut, 2 x field maple, 1 x hornbeam and 6 x oak). The gaps were beaten up in 2016 with 3 x cider apples (Black Dabinett), 1 x dessert apple tree (Tom Putt), 5 x field maple, 4 x hornbeam, and 11 x lime. Biodegradable fibre tree guards were also replaced with standard plastic tree guards. Further gap filling took place in 2017 with another three hornbeam planted so that when assessed in October 2019 there were a total of 79 trees. In summary, thirty trees died within the period since planting to the end of October 2019 Table 1).

TABLE 1. TREE SURVIVAL 2014-2019

	Planted	2014	2015	2016	2019
Cider apples	27	27	24	27	27
Dessert apples	7	7	6	7	7
Field Maple	8	8	8	11	11
Hornbeam	7	7	7	10	13
Oak	9	9	8	3	3
Pear	4	4	4	4	4
Quince	1	1	1	1	1
Rowan	8	2	2	2	2
Sweet Chestnut	10	5	5	0	0
Lime	0	0	0	11	11
Total alive	**81**	**70**	**65**	**76**	**79**

FIGURE 4. VIEWS OF THE NEWLY PLANTED TREE AVENUE AT ELM FARM

Height gain 2014-2019

The height of every tree in the avenue was measured in July 2014, August 2015, August 2016 and October 2019. Mean height per species is shown in Figure 5 (all data in Annex 2). Only those trees that survived from planting in 2014 are included in the calculation, except for the lime trees which were all planted in 2016 to fill in gaps.

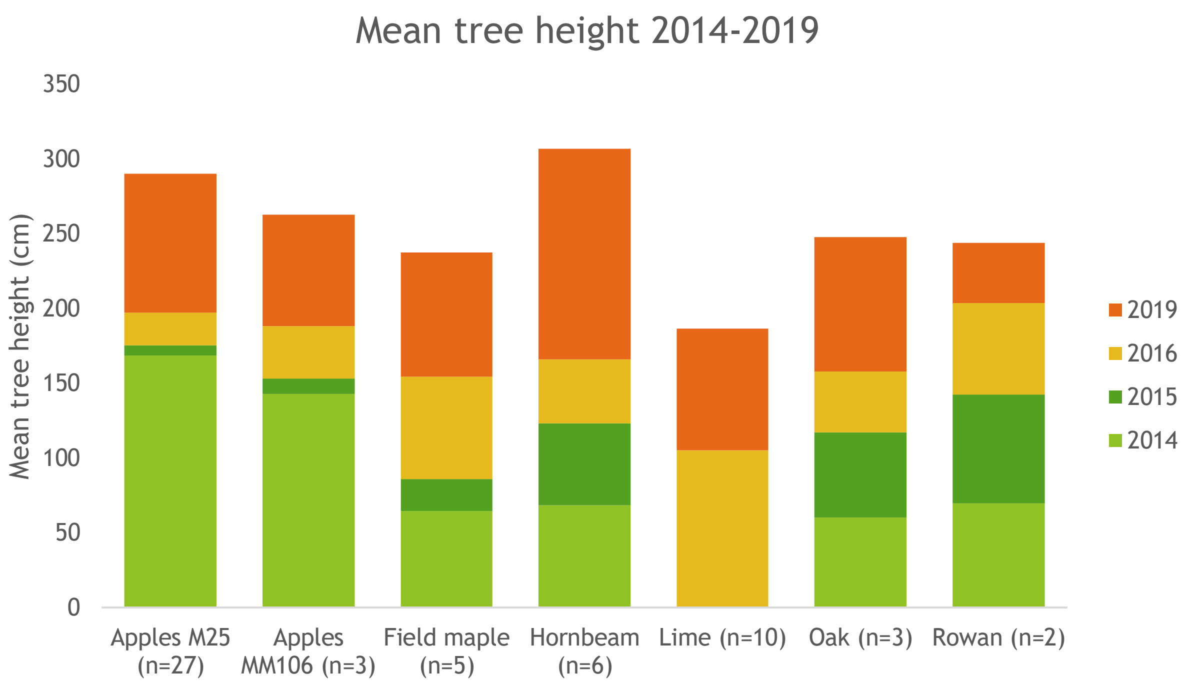


FIGURE 5. MEAN HEIGHT OF TREES IN THE TREE AVENUE BETWEEN 2014 AND 2019

Management experiences

Mortality rate was quite high in the first few years with eleven trees dying in the first summer. These were sweet chestnut and rowan which had been planted in the biodegradable fibre guards tree guards; as elsewhere on the farm, the sweet chestnut failed to establish in the biodegradable fibre guards, probably due to a lack of light as they were planted as seedlings. In the second year we lost four apple trees, three of the same variety suggesting that the variety was not well suited to the land. In 2016, the rest of the sweet chestnut died as well as most of the oaks. It is difficult to identify the key factors for this high mortality, but weed control was an issue after the initial mulch mats and woodchip decomposed.

The apples are not yet fruiting commercially and are in need of some attention and pruning. The original idea had been to partner with a local cider producer who would have responsibility for management and harvesting of the trees in return for paying rent for the land area occupied by the trees. This partnership did not come to fruition, however, but could be a possibility as the trees mature and start fruiting commercially.

Bioenergy hedges

Aim: To establish hedgerows of fast-growing species, straight growth form, no thorns, suitable for bioenergy production.

Species: hazel, sycamore, sweet chestnut, willow. Planting as mixture of 2 hazel: 1 sycamore: 1 sweet chestnut: 1 willow. Standard trees planted at every 20 m (oak, hornbeam, walnut) (ratio 1.5:2:1)
Spacing: 4 plants per metre
Protection: Biodegradable fibre guards and spiral guards, wood chip as weed suppressant. Standard trees 1.2 m standard plastic tubes.
Data collected: survival rates, tree heights and biomass (May 2014, August 2014, October 2014, June 2015, October 2015, October 2017, August 2019)

FIGURE 6. NEW BIOENERGY HEDGES ON ELM FARM SHOWING THE DIFFERENT TREE GUARDS USED AND THE COWS ENJOYING THE NEW YOUNG LEAVES

Hedge establishment

In March 2014 four new bioenergy hedgerows were planted as a double row of fast growing non-thorny species, with 50 cm spacing, and standard trees were included at 20 m spacing. One of the new hedges was planted as a trial with 20 m single species blocks of hazel, willow, sycamore and sweet chestnut, while the other hedges were mixed species. The trees were planted with weed control using 12 m biodegradable mulch mats held down with biodegradable plastic pegs and woodchip on top. Half of the trees had biodegradable fibre guards with canes, the other half had standard spiral guards with canes. The hedge plants were 40-60 cm one-year old bareroot transplants except the sweet chestnut which were seedlings. The standard hedge trees (oak, hornbeam and walnut) were two years old. Surrounding grasses and weeds were cut in the first two years and new woodchip was applied around the base of the trees.

TABLE 2. HEDGE ESTABLISHMENT RATES IN TWO OF THE NEWLY PLANTED HEDGES ASSESSED IN OCTOBER 2014, AFTER THE FIRST SUMMER.

	% alive	% dead
Chestnut	72.5	27.5
Hazel	95.9	4.1
Sycamore	96.2	3.8
Willow	96.2	3.8
Total	90.8	9.2

Mortality was low in all species in Year 1 except for sweet chestnut with a 27.5 % mortality rate in the first year following planting (Table 2). Survival rates for all species remained good between 2016 and 2019 (Figure 7), again with the exception of sweet chestnut; over 50 % of the remaining sweet chestnut trees were lost during this three year period.

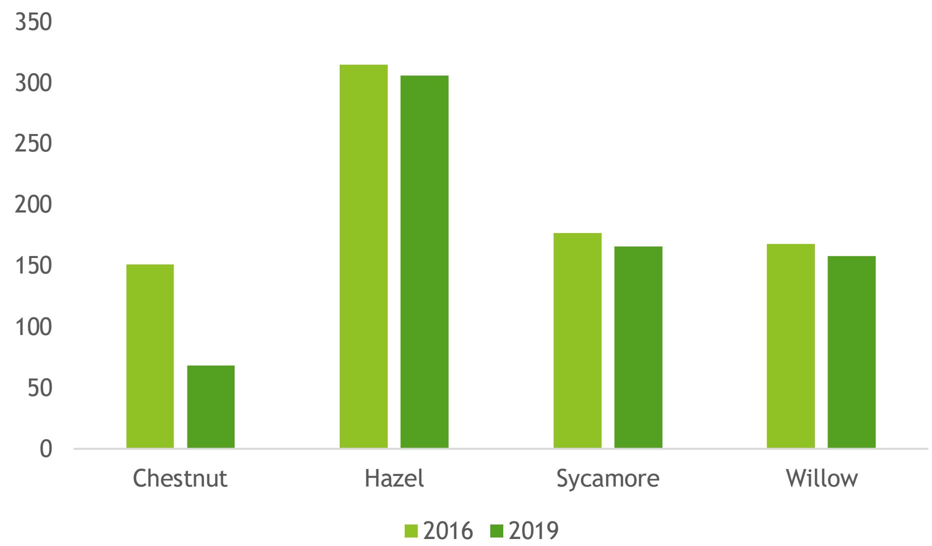


FIGURE 7. HEDGE TREE SURVIVAL RATES BETWEEN 2016 AND 2019

Hedge establishment management trials

During the establishment of a newly planted hedgerow the initial cutting regime influences the hedge’s future structure and development. Although suggestions on the severity of pruning differ, it is generally recommended that newly planted hedges are lightly pruned within the early years of establishment to encourage multi-stemmed production and dense bushy growth. Similarly, multi-stemmed growth is desirable in short rotation coppice (SRC) for woodfuel production and the advice is to coppice short rotation willow coppice in the first winter following establishment (Rolls and Hogan, 2009). The aim of our trial was to determine the effects of light pruning vs coppicing in the early years of establishment on four different hedgerow species intended for woodfuel: hazel, sycamore, sweet chestnut and willow. The trial was carried out on a hedge running across a field from east to west. The hedge is made up of eight 20 m-long single species blocks with two blocks of each species: hazel, sycamore, sweet chestnut, willow. Hedgerow trees (oak, hornbeam, and walnut) were planted and protected with tree guards every 20 m.

Two treatments were tested:

1. Hedge coppiced: cutting each plant over 45 cm in height to 15 cm above ground level in the first winter after planting (February 2015).

2. No coppicing: these are the control plots where no plants are cut in years one, two or three.

All plots were lightly browsed when cattle were present in the adjacent field, but stock fencing prevented excessive damage from the cows. Following the third year of establishment both treatments were side-flailed every two to three years as necessary to prevent encroachment into the field. For each tree species one 20 m block was chosen at random and coppiced and the other 20 m block left as a control. The total height of the trees in each block, the number of stems and tree survival were then monitored.

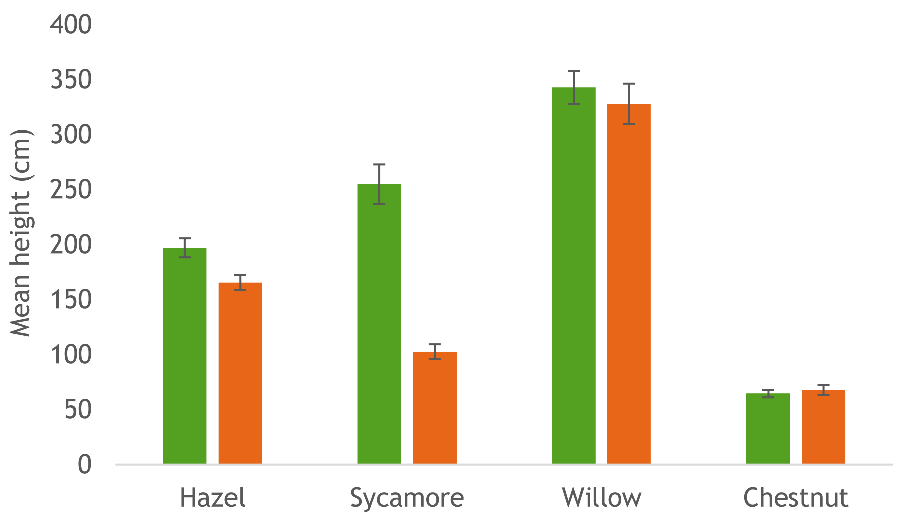


FIGURE 8. MEAN HEIGHT +/- SE OF HEDGE PLANTS IN AUTUMN 2017 (THREE GROWING SEASONS AFTER COPPICING), GREEN SHADING INDICATES CONTROL TREES NOT COPPICED AND ORANGE SHADING THOSE THAT WERE COPPICED IN YEAR 1.

In 2017, three growing seasons after coppicing, the mean heights between treatments (coppiced or not) of all species except sycamore were similar (Figure 8). The coppiced sycamore trees were less than half the height of the uncut trees. Unfortunately, due to the sale of the field adjacent to the trial hedge it was not possible to carry out 2019 biomass assessments on the different treatments.

Hedge establishment management experiences

- Coppicing in year one does not appear to impact the growth of hazel, willow or chestnut, but sycamore responded poorly to coppicing in year one.

- Browsing damage from cattle was an issue in parts of the hedge where the fence was closer to the hedge and the cows were able to reach through the barbed wire strands to access the trees.
- Growth rates of the chosen hedge species were variable; the willow grew significantly faster than the other species and in the mixed species non-trial hedges willow trees were cut back earlier. This is something to take into consideration when planning new mixed species hedges.

Biomass production

Five trees of each species from one of the biomass hedges were coppiced in 2019 and the material from each tree was weighed fresh and then oven dried (Table 3). Hazel and sycamore produced similar quantities of material per tree both fresh and oven dried, while the willow produced approximately four times the quantity of biomass per tree fresh weight and slightly less than four times the quantity oven dry weight, reflecting the higher moisture content of the willow. These quantities are low when compared to the biomass yields from harvesting the mature hedges (Table 5) or the hazel coppice regrowth yields (Figure 21) but it should be taken into consideration that these values are from the first time that this hedge was cut and it would be expected that volumes per tree would increase as the trees mature.

TABLE 3. BIOMASS PRODUCTION FROM A NEWLY PLANTED HEDGE. TREES COPPICED IN 2019, SIX YEARS AFTER PLANTING

Hedge species	Biomass (t/100m @30% mc)	Trees/ 100m	Biomass per tree (kg/tree @30% mc)	Mean kg/tree ODW
Hazel (*Corylus avellana*)	0.87	400	2.18	1.68
Sycamore (*Acer pseudoplatanus*)	0.82	400	2.04	1.57
Willow (*Salix alba*)	3.20	400	8.01	6.16

In-field trees

Aim: To establish the next generation of parkland trees with some to be pollarded for livestock fodder

Species (49 trees): oak (10), small leaved lime (14), walnut (8), hornbeam (4), sweet chestnut (6), sycamore (6), white willow (1)
Protection: spiral guards and tree stockades, woodchip and mulch mats
Data collected: survival rates (August 2016 and Oct 2019) and height (Oct 2019)

Tree establishment

Tree planting was originally planned for March 2014 but was delayed due to the need to install robust and costly tree stockades to protect the new trees from cattle. Stockades were 1 m^2 and 1.8 m high with four round corner posts, two half round rails and stock netting. Quotes for the installation of the stockades (including materials and labour) ranged from £146 per stockade (using sweet chestnut posts) to £87 per stockade. The stockades were installed in winter 2014/15 and the trees planted in March 2015. The 49 trees were planted across five fields on the southern side of the farm, with three trees planted in Home Field, four in Kennels Field, nine in Sunnyside, eight in Creek and 25 in Sheepfield (Figure 3). Trees were one-year old bare root transplants, except the oak which were two years old, and the walnut which were two-year old seedlings, undercut after one year. Spiral guards were used to protect against rodents, and biodegradable mulch mats and woodchip to reduce weed competition. The trees were checked and weeded in August 2016, with extra woodchip added.

TABLE 4. TREE SURVIVAL 2016 AND 2019

	Planted	2016	2019
Hornbeam	4	1	2
Oak	10	9	9
Walnut	8	8	8
Lime	14	13	13
Willow	1	1	6
Sweet Chestnut	6	5	5
Sycamore	6	6	5
Total alive	**49**	**43**	**48**

Tree establishment was generally good, with six trees dying in the first two years (Table 4). Of these, three were in the same field, Home Field. When these trees were checked it was noticed that following a wet year the tree roots were sitting in the high water table, therefore leading to death. It was decided to replace these trees (sweet chestnut, oak and lime) with white willow, and these subsequently established well. In the future, these trees may provide a ready source of tree fodder and pain relief (through salicylic acid) for livestock, as they are located in the field next to the barn. White willow trees were also used to replace dead trees in Sheepfield which were also located in wet areas.

FIGURE 9. IN FIELD TREES AT ELM FARM SHOWING THE TREE STOCKADES THAT WERE INSTALLED TO PROTECT EACH TREE.

Tree heights 2019

Trees were measured in October 2019 (Figure 10, Annex 3). Walnut and hornbeam are currently the shortest trees (just under 140 cm), with lime and willow the tallest (218 and 265 cm respectively).

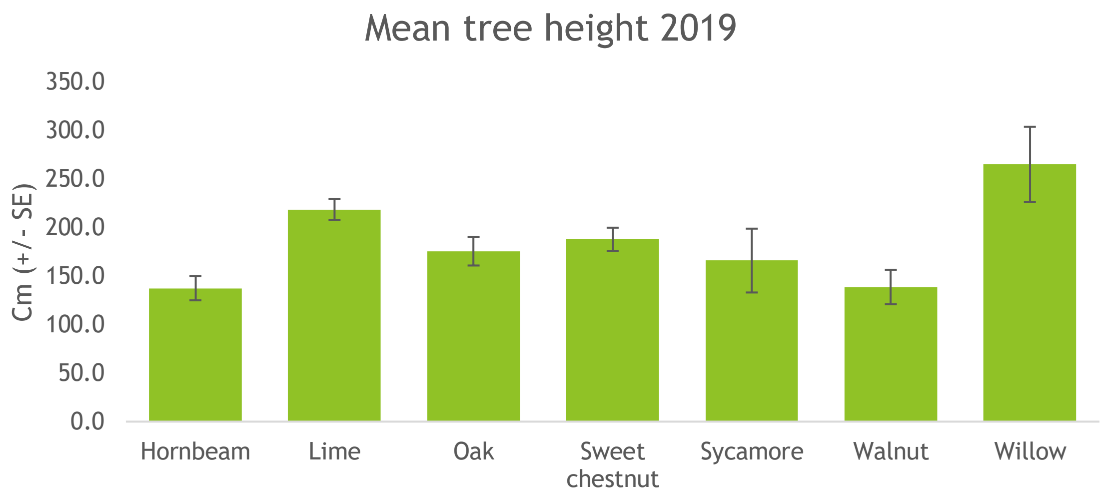


FIGURE 10. TREE HEIGHT OF THE IN-FIELD TREES OCTOBER 2019

In field trees: Management experiences

The biggest challenge with the in-field trees has been providing adequate protection against the cattle. The stockades were expensive but have proved effective, and to date, have needed no maintenance. However, the stockades also make it difficult to check and care for the trees because to gain access, it is necessary to climb up and over the 1.8 m posts. In some cases, the stockades have been colonised by weeds which act as a reservoir for spreading out into the fields. The stockades also make it difficult when cutting hay or silage as the tractor manoeuvres around the trees (Figure 9).

Tree guard trial assessments:

This trial aimed to assess the effectiveness of a new biodegradable fibre tree guard for protecting a newly planted mixed species hedge during the establishment phase. The biodegradable fibre guards were trialled against plastic spiral guards commonly used in tree planting (Figure 11). Assessments and observations were undertaken by on tree growth, survival rates, pests and diseases, and weed control.

The hedge in which the guards were trialled ran across a field from east to west following a historical hedge line. The newly planted hedge consisted of hazel, sycamore, sweet chestnut and willow planted as a mixture with a ratio of 2:1:1:1 respectively, at a density of four plants per metre. Hedgerow trees were planted every 20 metres and include oak, hornbeam and walnut. The guards were located in blocks of 20 biodegradable fibre guards next to 20 spiral guards repeated along the hedgerow.

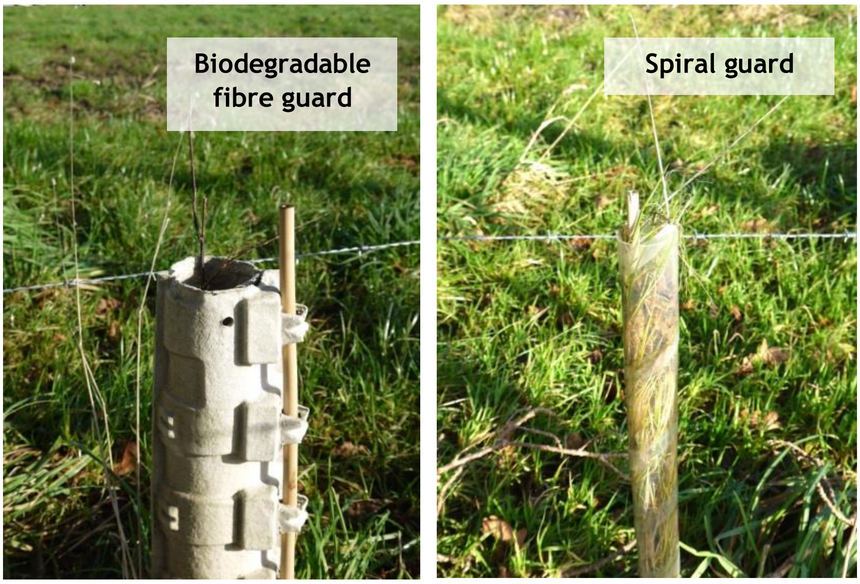


FIGURE 11. TREE GUARDS IN TRIAL.

Plant survival nine months after planting was high for hazel, sycamore and willow (Figure 12). Survival rates for hazel and willow were 100% using both the spiral and biodegradable fibre guards. Survival rates for sycamore were slightly lower using the biodegradable fibre guard (95%) than the spiral guard (100%). Sweet chestnut planted using the biodegradable fibre guard however had a considerably lower survival rate (0%) in comparison to the spiral guard (70%).

Although sweet chestnut establishment within the newly planted hedges has been poor across the farm, differences in survival between the two guards is thought to be due to the limited light conditions within the biodegradable fibre guard (Figure 13) and the small size of the sweet chestnut seedlings planted.

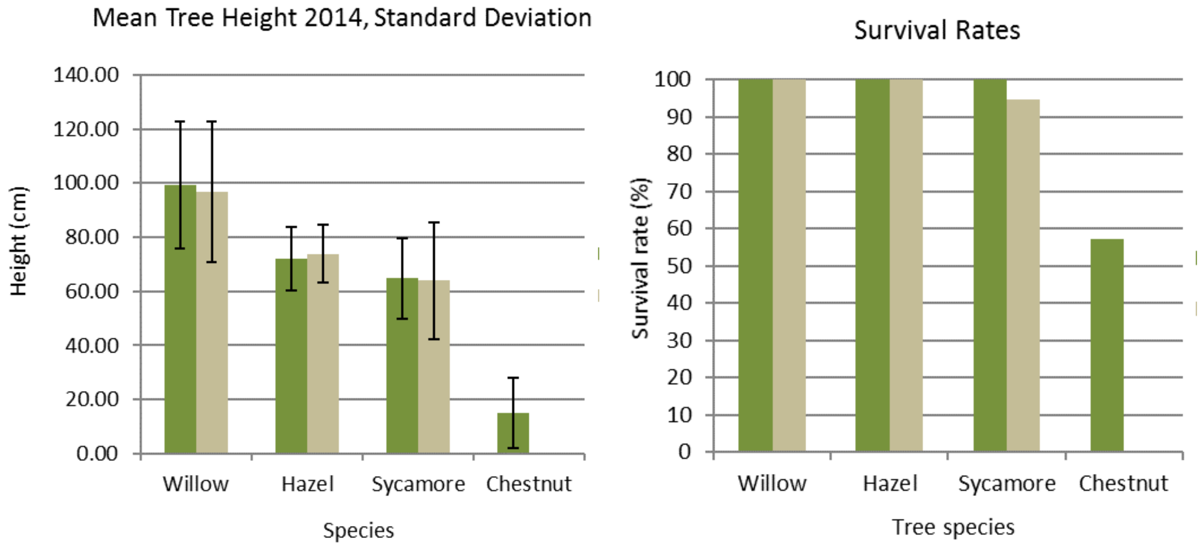


FIGURE 12. TREE HEIGHTS AND SURVIVAL RATES IN 2014 BETWEEN THE DIFFERENT TREE GUARD TYPES. GREEN FOR THE STANDARD SPIRAL GUARDS AND BROWN FOR THE BIODEGRADABLE FIBRE GUARDS

FIGURE 13. (LEFT) LIGHT CONDITIONS WITHIN THE BIODEGRADABLE FIBRE GUARD (RIGHT) DEGRADATION OF THE BASE OF THE BIODEGRADABLE FIBRE GUARD DUE TO WET WEATHER.

Management experiences

From observations the biodegradable fibre guards suppress weeds better than the spiral guards. This is likely to be due to limiting light conditions within the biodegradable fibre guard compared to the transparent plastic spiral guards. No notable differences in mean tree height or pest and disease damage were observed between the two guards except for sweet chestnut where none of the trees planted with the biodegradable fibre guard survived, most likely due to the small size of the trees at planting and lack of light. Following wet weather, the base of the biodegradable fibre guards began to degrade.

Conclusions and lessons learnt from new tree planting

Tree protection is crucial but can be expensive, especially for in-field trees which require individual protection if there is livestock present. Stockades were expensive but effective, however they make it difficult when cutting hay or silage as the tractor manoeuvres around the trees. Where fencing is used to protect hedges and tree lines from browsing livestock the fence should be placed at an adequate distance from the tree to ensure that the animals cannot reach through the fence and damage the trees. Correct placement of the fence can however mean a reduction in the need to side flail the hedges if the livestock can be managed to do this for you. The biodegradable tree guards were effective for most species and appeared more effective at controlling weeds, but this tree guard type should be avoided if trees are very small at planting as they block out sunlight. They did also degrade relatively quickly in wet weather and needed replacing in some areas. Weed suppression is essential when planting new trees to aid establishment.

Tree survival and establishment varied between species, with some species better suited than others to Elm Farm. Mortality rates were relatively high in the first two years; 20% in the tree avenue; 12% for the in-field trees and 6% in the hedges. Factors for this high mortality rate might include competition for light and resources and weed control; trees were planted directly into the existing grass sward and survival rates may have improved if planted into bare soil. Elm Farm soils are relatively heavy with a high clay content and sub-soiling prior to planting may also have been beneficial, particularly in areas where compaction was evident. Sweet chestnut was not found to be well suited to the Elm Farm; this may have been due to the fact that the trees were provided as seedlings and struggled with competition from weeds and access to light. Most sweet chestnut trees were replaced with species better suited to the farm. Conversely white willow established well and grew quickly.

Five years after planting hazel and sycamore produced similar quantities of biomass per tree both fresh and oven dried, while willow had the highest growth rate and produced approximately four times the quantity of biomass per tree in a five year period. This presented some challenges for management in the mixed species hedges with willow trees needing to be cut earlier than the others. Coppicing in year one did not appear to impact the regrowth of hazel, willow or chestnut, but sycamore did not respond well to establishment coppicing and regrowth was slow.

Managing hedgerows for bioenergy production

Introduction

Since 2013 we have been investigating the potential of managing boundary hedgerows by coppicing to produce woodchip for bioenergy, while maintaining their environmental and cultural values. This section summarises the key findings from machinery trials, hedge re-growth and productivity data, economic modelling, and biodiversity impacts.

With around 700,000 km in Great Britain (Carey et al. 2007), hedges are the most widespread semi-natural habitat in lowland Britain. As well as being a characteristic feature of the British countryside, hedges fulfil many functions within the landscape, both ecological and social, and are increasingly recognised for their importance in regulating environmental processes (Wolton et al. 2014). Traditionally, hedges also would have provided a variety of wood products, including wood fuel for energy production; however, this economic function declined from the mid-20th century when fossil fuel replaced wood as the primary source of energy production in Western Europe. Today many hedgerows are in decline, either through under-management, mismanagement or removal. Estimates of hedgerow loss across Europe since the 1950s range from 50-80 % (Reif et al. 2001). The main threat to hedges and the services that they provide are changes in management practices related to agricultural intensification and a reduction in the perceived value of hedges to farmers (Oreszczyn and Lane 2000). In the UK, of those hedges that are still actively managed, the majority are repeatedly flailed at the same height, eventually creating gaps and leading to a decline in hedge condition. Those hedges left unmanaged ultimately develop into lines of trees. The results of both over and under management are detrimental to the structural integrity of hedgerows (Garbutt and Sparks 2002). Hedges need periodic rejuvenation, either through coppicing or hedgelaying.

With the global development of the biofuel sector putting pressure on agricultural land to maximize both food and fuel production, there is a role once again for managing hedges to provide a renewable energy resource within short chain systems that connect the farmed landscape with local communities. In addition, management of hedges for woodfuel provides an opportunity and an incentive for farmers to rejuvenate old unmanaged hedges, restoring not only their economic role but their value to the wider landscape.

However, despite increasing interest in managing hedges for woodfuel and the potential benefits, there is limited data and knowledge regarding the productivity, logistics and potential impacts of such systems. Research at Elm Farm examining the practicalities and impacts of managing a proportion of hedgerows on the Farm for woodfuel production has aimed to address this. Coppicing, cutting all woody growth at ground level on a 15-20 year cycle, is the management technique assessed.

Research focused on:

1. Assessing the feasibility of mechanising the process of coppicing hedges and processing the resulting material for bioenergy.
2. Quantifying coppice re-growth and survival rates between different hedgerow species.
3. Assessing the impact of coppicing hedgerows on biodiversity, carbon and the microclimate adjacent to the hedgerow.

As part of the European Regional Development Funded INTERREG IVB project Towards EcoEnergetic Communities (TWECOM www.twecom.eu), machinery and small plot trials were established at Elm Farm in 2013 and 2014. In the subsequent European FACCE Surplus project SustainFARM (www.sustainfarm.eu) further hedge coppicing trials were carried out in 2016.

At the start of the trials in 2013 the hedges on Elm Farm had not been actively managed for a number of years, asides from occasional side flailing to maintain field sizes and statutory roadside management. There are 45 separate hedges on the farm with a total length of approximately 9.5 km (Figure 14). Results from a survey of all hedges on the farm carried out in July 2013 showed that the dominant woody species is blackthorn (*Prunus spinosa*), with other commonly recorded species being hawthorn (*Crataegus monogyna*), hazel (*Corylus avellana*), willow (*Salix caprea/cinerea*) and oak (*Quercus robur*). Blackthorn, bramble and rose outgrowth is also common, resulting in wide unruly hedges, often with the existing fences being engulfed by this shrubby outgrowth (see Annex 5 for the Elm Farm hedge management plan produced following the survey).

FIGURE 14. AN AERIAL VIEW OF ELM FARM HEDGEROW NETWORK WITH THE LOCATIONS OF THE SMALL PLOT TRIALS MARKED IN YELLOW.

The trials

Single species small trial plots were coppiced in 2013 (3 x 15 m). Harvesting machinery trials were carried out in 2014 (180 m of hedge coppiced) and in 2016 (200 m of hedge coppiced).

Small plot trials

Three single species trial plots were coppiced in 2013. The aims of these trials, which were carried out prior to any machinery trials, were to refine non-destructive methods of assessing the volume of biomass in a hedgerow; to quantify coppice re-growth and survival rates between different hedgerow species; and to assess the impact of coppicing on biodiversity, microclimate and carbon dynamics. Paired 15 m cut and uncut plots were established in three different hedgerow types: blackthorn, hawthorn and hazel dominated. Coppicing was carried out in winter 2013 by hand and all material was chipped, bagged and weighed to give biomass productivity from the plots. Newly coppiced stools were protected from browsing animals for the first year using 1.8 m high deer mesh in addition to the stock and electric fencing routinely used by the farmer.

Machinery trials

Harvesting machinery trials were carried out in 2014 (180 m) and in 2016 (200 m). The aim of these trials was to assess the feasibility, efficiency, costs, and viability of mechanising the process of coppicing hedges and processing the resulting hedgerow biomass as a local and sustainable source of woodfuel.

In the 2014 trial the different machinery and methods were selected to represent a range of machinery sizes, cutting mechanisms, cost and availability and took place over two sites, Elm Farm and Wakelyns Agroforestry (Chambers et al. 2015). Machinery was loosely classified as small, medium and large scale, and one machine of each scale was trialled at each site. The large-scale harvesting machinery trialled were hydraulic shears and a felling grapple with integral chainsaw; medium-scale were assisted fell (manual fell using a chainsaw and excavator) and tractor-mounted circular saw; and small-scale was manual fell at both sites (Figure 15). Two sizes of chippers were also trialled; a large drum chipper and a small disc chipper. All machinery was operated by experienced contractors.

FIGURE 15. HARVESTING AND PROCESSING METHODS USED IN THE 2014 TRIALS

The trials assessed the costs associated with each machinery option and the time taken to coppice or chip a pre-determined length of hedge; the biomass productivity of each hedge; the chip quality in terms of moisture and ash content, calorific value and particle size distribution (ÖNORM and BS EN standards).

After preparing the hedges for coppicing (fence and wire removal, cutting back outgrowth). The locations of the trial sections of hedge to be coppiced by each machinery option (Figure 16) were measured, marked out and allocated to the contractors on the morning of the trial. Trees to be left as standards were marked. Contractors were asked to record their fuel use.

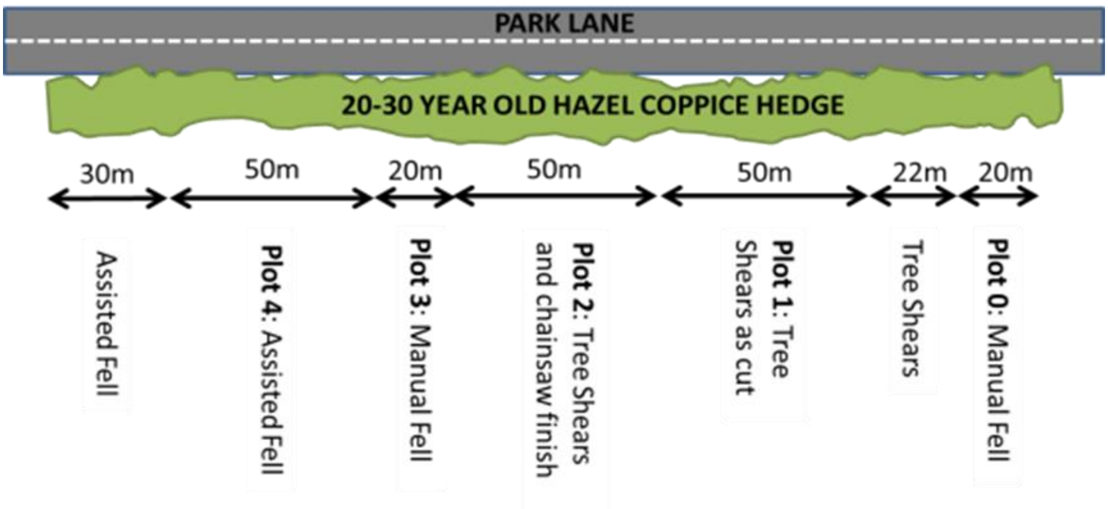


FIGURE 16. 2014 HEDGEROW HARVESTING MACHINERY TRIAL PLOTS AT ELM FARM

All cut material was removed from the hedge and placed in the field with the butts all facing the same way for ease of processing. Half the material was chipped immediately after coppicing using a large-scale crane fed chipper and transported to an open ended barn for storage. The remaining half of the hedgerow material was left to dry in the field for four months and then chipped *in situ* using a small-scale manually-fed chipper before transporting back to the barn. Both the volume and mass of woodchip produced from each trial section of hedge were measured and summed to calculate the total biomass harvested from the hedge. The volume of woodchip was estimated in the trailer used to transport it, having calculated the volume of the trailer and marked the volume at 2 m^3 intervals. The mass of woodchip produced from each trial section was recorded using calibrated weigh load scales.

The maximum efficiency of each machinery option was calculated from the average time taken for each machine to coppice or chip a set length of hedge or hedge material (Figure 17). Harvesting and processing costs per metre of hedge were calculated by dividing the day hire cost by how many metres each machine could harvest or chip in a day, based on seven hours of cutting or chipping time. Assisted fell, where the hedge is cut manually with a chainsaw and a mini digger is used to extract and stack the cut material, was the most efficient method and manual fell the least efficient in terms of the length of hedge harvested per day (Figure 17).

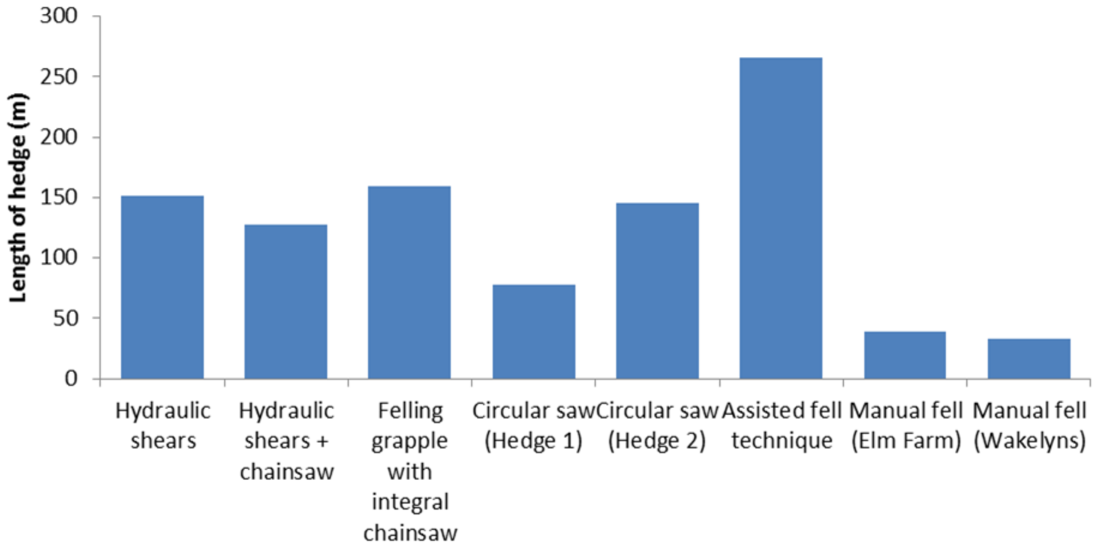


FIGURE 17. THE MAXIMUM EFFICIENCY IN METRES OF HEDGE HARVESTED PER DAY FOR THE HARVESTING MACHINERY TRIALLED IN THE 2014 TRIALS

Both harvesting and chipping costs per metre were calculated by dividing the day rate by the number of metres of hedge each machine can harvest or chip in one day. The average cost to coppice and chip one metre of hedge was £5.67 (range £2.26 to £9.90). The energy cost of hedgerow woodchip ranged from 1.6 to 3.5 pence per kWh depending on machinery options and hedge type (Chambers et al. 2015).

Key conclusions from the 2014 machinery trials:

- The length of hedge to be coppiced that year is a major factor in deciding which method will be the most economic. For all of the harvesting and chipping methods trialled the lowest cost per metre is reached when the hedge length to be coppiced and chipped approaches and equals that of the machines' maximum efficiency in a day (Figure 17).
- Assisted fell is a very quick and effective felling method, making best use of both manual and mechanised felling techniques, but demands an experienced team. Assisted fell and large chipper was found to be the most cost-effective harvesting and processing combination of all the machinery methods trialled when at least 280 m of hedge was coppiced.
- Both the hydraulic shears and felling grapple with integral chainsaw options are better suited to large diameter single stemmed material. Single blade circular saws are optimally designed for small diameter material or short hedges which are less than 4 m in height.

- The assisted fell and manual fell methods have the flexibility to work on most sites and hedges, because the chainsaw has the manoeuvrability to cope with the contours of coppice stools or hedge banks.
- Every hedge is different, so it is difficult to produce precise costs for the various elements of the process. Every hedge has to be assessed and managed on its own merits.

For more detail on the trial methods and results see Chambers et al. 2015.

Hedge regrowth and productivity

Initial assessments of stool survival and then annual coppice regrowth measurements were carried out on the cut stools in both the small plot and the machinery trial hedges to monitor regrowth between different hedge species and to ascertain the impact of different cutting methods on stool health and regrowth.

Fifteen metre monitoring plots were measured out in each of the five hedgerow machinery trial sections (Figure 16): hydraulic tree shears (left as cut), hydraulic shears (with short chainsaw finish), hydraulic tree shears (with long chainsaw finish), assisted fell and manual fell.

For the first year following coppicing re-growth measurements were taken at two-monthly intervals throughout the growing season. As per Croxton et al. (2004), the five longest shoots from each live stool were measured and an average per stool calculated. At the end of the growing season once the leaves had fallen, the total number of shoots on each stool was re-counted along with the length of the five longest shoots to give the total growth in that growing season. In the blackthorn hedge there were root suckers observed emerging from the ground even when no shoots were seen on the adjacent stool. Root sucker regrowth was recorded as associated with a stool if it occurred within 20 cm of the stool. Following the first year after coppicing regrowth measurements were taken annually at the end of each growing season. As the stools regrew it became difficult to estimate the number of shoots and to measure shoot length. Once the hedge was too high to measure using the above method the average height was estimated every 1 m along the 1 5m plot using either a clinometer or using a 2 m pole up against the hedge.

FIGURE 18. COPPICE HAZEL HEDGE IN THE SMALL PLOT TRIAL; APRIL 2014 (LEFT) AND THREE MONTHS LATER IN JULY 2014 (RIGHT).

Hedge regrowth and productivity results

Between the small plot trials and the hedges coppiced for the machinery trials, regrowth of hedges following coppicing was assessed for a total of five different hedges on Elm Farm. Post-harvest all woody material coppiced from each cut section was chipped, subsamples were weighed, and volume was estimated.

TABLE 5. BIOMASS YIELDS PER 100 M FROM COPPICING DIFFERENT MATURE BOUNDARY HEDGE TYPES AT ELM FARM.

Hedge type (dominant species)	Years since last cut	Biomass (t/100m @30% mc)	Biomass volume M^3/100m	Trees/ 100m	Mean kg/tree (ODW)
Hazel	28	6.3	22.1	91	53.25
Blackthorn	39	13.0	45.5	307	32.57
Hawthorn	40	8.2	28.7	113	55.82
Hazel	15	5.5	19.3	127	33.31
Hazel and blackthorn	19	7.3	25.5	91	61.71

The average yield of woodchip from the five hedges sampled was 8.1 tonnes per 100 m at 30% moisture (Table 5), with a large range (5.5 to 13 tonnes) depending on the dominant species and the age of the stems at harvest. These yields are from hedges at the start of a new coppice management cycle. Future yields will vary depending on species and coppice rotation length. A considerable amount of time is needed to get old hedges ready to coppice (removal of outgrowth, old fence lines etc.) and the labour effort for management should reduce once a rotation has been established.

Regrowth rates and response to coppice management varied between hedges and species. Across all the hedgerow species coppiced in the trials, hazel, willow, field maple and hawthorn were all observed to respond positively to coppice management.

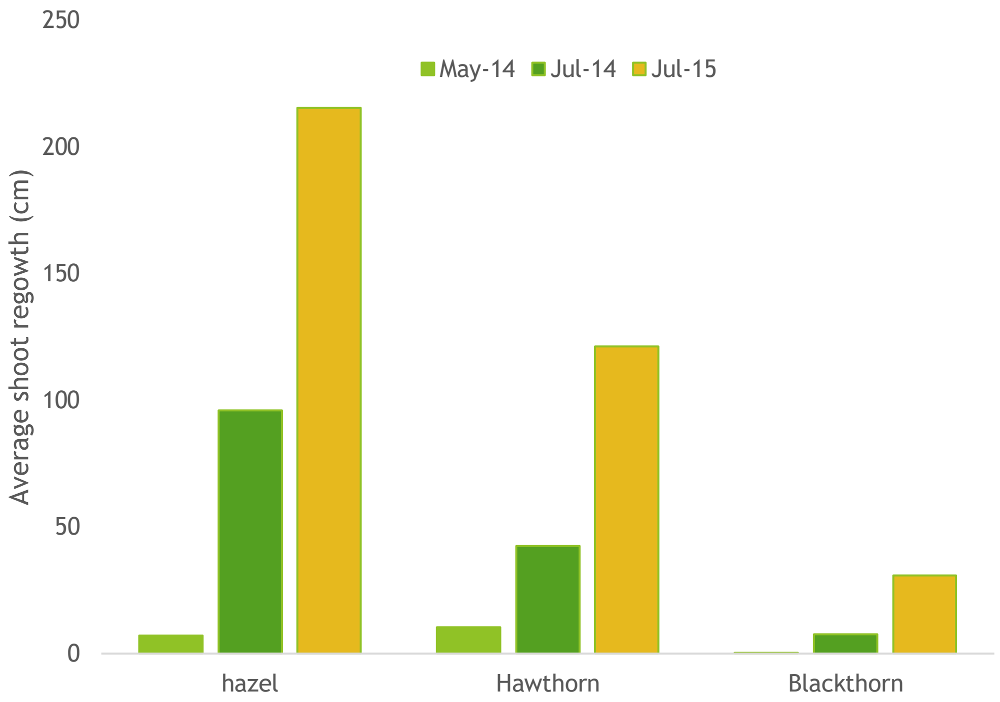


FIGURE 19. AVERAGE SHOOT REGROWTH IN CM OF SMALL SINGLE SPECIES PLOTS AT ELM FARM

Regrowth measurements from the small plot trials showed large differences in average regrowth between different hedge species (Figure 19) in the first two years following coppicing. Blackthorn stools were very slow to regrow, many cut stems did not show any regrowth at all and much of the regrowth that was recorded was from underground suckers. Regrowth in the hazel plots was strong, with an average of 2.15 m by July 2015, and the hawthorn stools also showed relatively strong regrowth.

Regrowth was also monitored in the different sections of the 2014 machinery trials hazel hedge. We were concerned that stems splitting when coppicing with tree shears may affect stool survival and regrowth in future years. Some tree shears sections were finished with a chainsaw (to tidy them up and remove the split stems) and some were left as cut. Average regrowth across all treatments of 1.1 m was seen after seven months, increasing to 1.5 m by end of first growing season, re-establishing the hedge, habitat continuity and wildlife corridor. No significant differences in regrowth were seen between the different cutting methods (Figure 20) with any variations between plots most likely to be due to variation in growing conditions and stool sizes along the hedge or the health of the stools before coppicing.

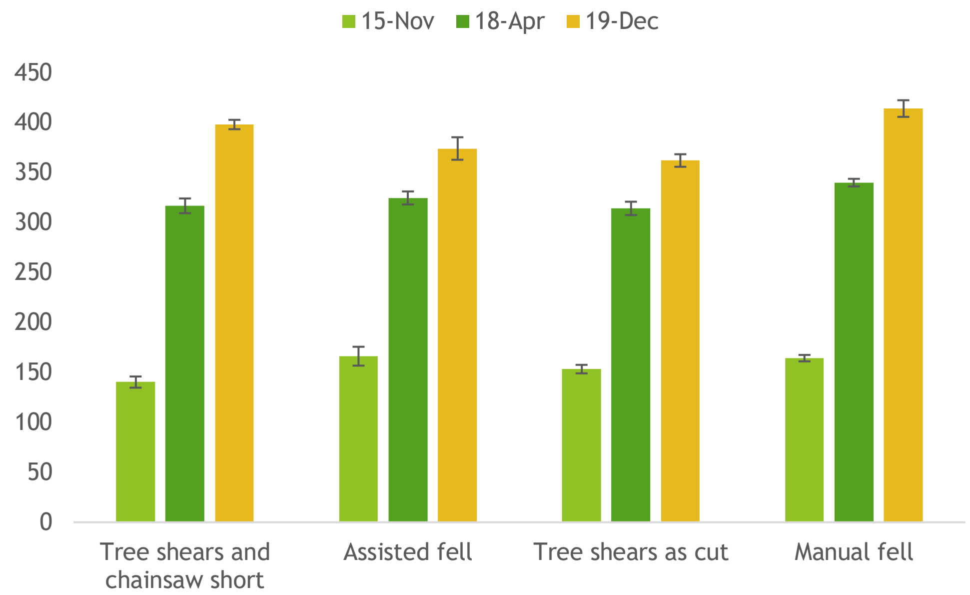


Figure 20. Regrowth of hazel coppice in different machinery trail plots mean height (cm) =/- standard error

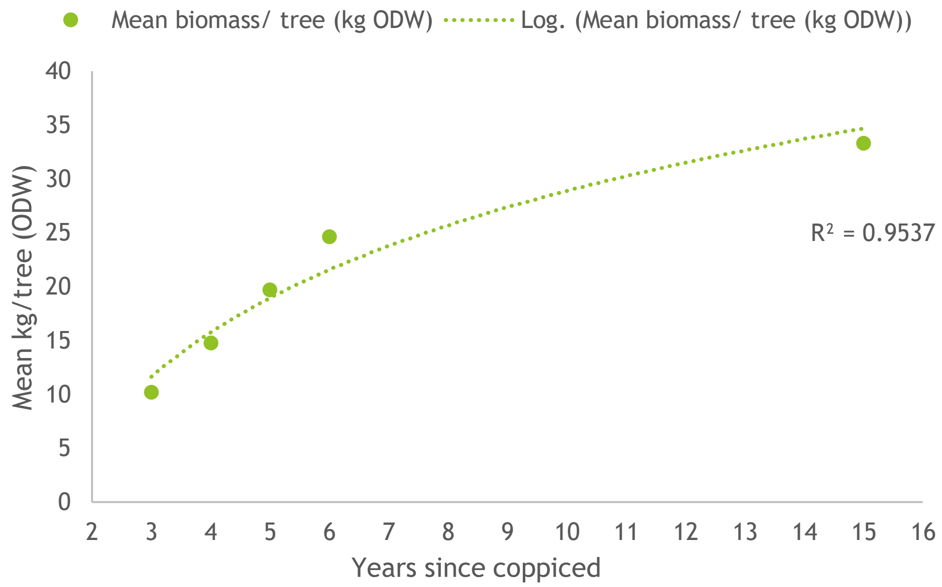


Figure 21. Mean biomass (kg oven dry weight) per hazel coppice stool from coppiced hedge at Elm Farm 3 to 6 years after coppicing and after 15 years growth.

Regrowth from hazel hedges coppiced in 2013, 2014 and 2016 was cut in 2018 and 2019 to give total biomass per coppice stool three to six years following coppicing (Figure 21). The biomass per stool in the three to six year period increased year on year; we would however expect this growth to slow and level off and in a woodland setting it has been shown that hazel stools will reach 80 % of their total weight in 10 years (Forestry Commission, 1956). This levelling off can be seen in the biomass of the hazel hedge that was coppiced approximately 15 years previously (Figure 21).

Woodchip quality

Woodchip quality was assessed from all hedgerows coppiced at Elm Farm. Moisture content (MC) of the woodchip from all the hedges was specified as a percentage of the total sample weight and was determined using a simple oven drying method, where five representative samples of approximately 0.25 kg each were taken from each chip pile, weighed (green weight) and dried in an oven at 100 degrees Celsius until a constant mass was reached (dry weight). The moisture content was then calculated by subtracting the dry weight from the green weight in order to calculate the weight of water. The weight of water was then divided by the green weight to calculate the moisture content of the sample. The average moisture content of the five samples was taken as the average moisture content of the whole chip pile. Chip samples were then sent away to a laboratory for woodfuel quality testing including particle size distribution analysis, calorific value and ash content (Table 6).

While woodchip boiler systems can be designed to burn a variety of woodchip sizes, most are designed to work at high efficiencies requiring woodchip of the correct size, with a low proportion of fine material which would reduce the combustion efficiency and a low proportion of large shards which could jam the feed system. The European biomass industry has accepted woodfuel standards to ensure consistency and quality of woodfuels. The Austrian ÖNORM M7 133 standard for woodchip is widely used and has three standard sizes which are G30 (60 - 100 % of particles: 3 - 16 mm), G50 (60 – 100 % of particles: 6 - 32 mm) and G100 (60 – 100 % of particles: 11 - 63 mm).

The 2016 hedge coppicing trials were undertaken with the specific aim of investigating methods to increase the quality of woodchip from traditional mixed boundary hedges for use as bioenergy through chipping, drying and processing methods. In December 2016 a section of hedgerow was coppiced at Elm Farm and all coppiced material was chipped (Westaway and Smith, 2018). The hedge selected was a predominantly mature hazel (*Corylus avellana*) with blackthorn (*Prunus spinosa*) hedge on the boundary of the farm, where the hazel had been previously coppiced. Counts of the rings on the cut stools indicate that it was last coppiced approximately 19 years ago. All cut material was removed from the hedge and chipped immediately. The two chippers used were a Schleising 220mx (6") and a Bandit 120LD (12"). Both chippers were self-propelled, small, light and manoeuvrable but hand fed and limited in the size of material they can handle. The chipped material was piled up in an open sided barn in the farmyard. The time taken to coppice and chip a specified number of hazel coppice stools using both chippers was recorded as well as fuel use for the whole operation and the number of chip loads and loads volumes. A composite sampling method was used to collect chip samples from locations across the pile in order to provide representative samples of woodchip.

Half of the woodchip produced was sent immediately to the Odiham wood fuel hub, which is part of the Hampshire Woodfuel Cooperative (http://downfarmodiham.co.uk/biomass-woodchip). The woodchip was actively dried from green to 10% moisture content. The chip was then screened to remove smaller dusty material and outsized chip. The chip was passed through a screen with 4 cm^2 holes, the dust stays at the bottom, comes out first and is removed, the oversized chip is screened out and sold as kindling. The middle fraction is the good chip. The other half of the woodchip was left to passively dry in a pile in the barn for six months. After six months the moisture content of the chip was measured using the method described above. Chip samples were collected immediately post drying and also after screening. These samples along with samples of the woodchip passively dried in the barn at Elm Farm were sent to a laboratory to be tested for particle size distribution, ash content and total calorific value in order to assess differences in quality against the costs of each operation

The hedgerow woodchip samples collected from the 2014 trials all passed the BS EN G30 standard for particle size distribution (Chambers et al. 2015). However, later samples collected from the 2016 trials achieved the standard for particle size distribution (Table 6) but failed to attain the G30 wood fuel accreditation standard on the maximum particle length (Westaway and Smith, 2018). To pass

G30 the maximum length must not exceed 8.5 cm. Screened and dried samples were generally more even sizes with less of the sample falling into the large and small categories, but the maximum length was still too large to pass at G30 specification (NB. this parameter was not measured or reported for the 2014 woodchip samples).

The presence of long shards and slithers is one of the biggest issues with hedgerow woodchip. All samples had a relatively high ash content due to the high bark ratio. Despite this, hedgerow woodchip from Elm Farm was sold on the open market to a woodfuel cooperative, where they were satisfied with the quality. The type of chipper used (small or large fuel grade) made only a small difference to overall chip quality.

TABLE 6. WOODCHIP QUALITY ANALYSES USING DIFFERENT CHIPPING AND PROCESSING METHODS (* RESULTS FROM CHAMBERS ET AL 2015)

Site	Drying method	Hedge and chipper	MC (%)	Ash content (%)	Gross Calorific Value	G30 particle size distribution				
						>16	>2.8	>1	<1	Max length
Elm Farm	Chipped green and passively dried in shed	Hazel hedge - large hand fed chipper	26.6	2.2	17.2	7.2	82.7	7.2	2.9	10.9
		Hazel hedge - small hand fed chipper	28.7	2.2	17.3	15.0	75.6	6.8	2.6	14.6
		Hazel hedge - fuel grade chipper *	30.6	3.6	19.1	7.7	83.0	8.0	1.3	
		Hazel plot - small chipper *	31.8	2.3	19.3	9.1	86.3	3.6	0.9	
		Blackthorn plot - small chipper *	26.2	1.1	19.7	18.6	78.9	2.2	0.3	
		Hawthorn plot - small chipper *	31.5	2.2	19.5	16.8	79.2	3.6	0.4	
	Actively dried	Hazel hedge -small chipper	10.0	2.2	17.2	9.5	85.4	4.3	0.8	11.8
	Actively dried and sieved	Hazel hedge -small chipper	10.0	1.8	17.2	6.3	88.1	4.8	0.8	12.9
Wake-lyns	Dried in field chipped 6 months later	Mixed hedge - fuel grade chipper	27.5	2.6	17.2	13.9	81.2	3.8	1.1	11.0
		SRC Willow - small chipper *	24.3	1.7	19.1	1.5	77.2	18.3	3.0	
		SRC Hazel - small chipper *	17.8	2.9	19.4	4.8	85.4	8.0	1.8	

Gross calorific values (Mj/kg) were similar from all of the chip samples (Table 6). They were, however, lower than the 2014 values collected by Chambers et al (2015). The ash content of woodchip that had been left to air-dry in the field for six months ranged from 1.7 % for the willow SRC woodchip to 2.9 % for the hazel SRC. The woodchip produced from the Elm Farm hedge in 2014 had the highest ash content at 3.6 %, the hazel hedge coppiced and chipped in 2016 had a lower ash content of 2.2 %. The blackthorn small plot had the lowest ash content of just 1.1 %. Screening (sieving) the chip reduced the ash content to 1.8 %.

Woodchip quality and marketability conclusions

Due to the high proportion of twiggy material with a high percentage of bark, hedgerow woodchip has a higher ash content and a higher percentage of fine material and long shards than round-wood woodchip from forestry operations. Removing larger diameter cordwood from coppiced material before chipping will therefore negatively impact the quality of the woodchip.

The trials demonstrated that woodchip of reasonable quality saleable on the open market can be produced from hedgerows. It is however important that the woodchip is matched to the right boiler able to cope with the variable nature of hedgerow woodchip, such as fines, shards and higher ash content. Economically, it is better to use the woodchip produced from hedges on-farm than to sell it. Additional savings can be made in reduced flailing costs. Coppicing reduces the need for regular flailing to side trimming every two to three years to control outgrowth (Westaway and Smith, 2019).

The unit energy cost of hedgerow woodchip produced ranged from 1.4 to 3.9 pence per kilowatt hour (p/kWh) depending on machine options and hedge type, and would seem relatively favourable when compared to the cost of other woodfuels (3.43-5.21 p/kWh), fossil fuels (3.5-8.33 p/kWh) and electricity (12 p/kWh) (Forest Fuels, 2015). Using woodchip from hedges on-farm could therefore not only incur savings from reduced flailing but also provide low cost energy, as well as rejuvenate hedges and support wildlife.

Farmers are in a great position to establish woodfuel hubs, waste recycling facilities or local firewood or woodchip enterprises. These sorts of businesses are ideally suited to being locally based, minimising transport costs and therefore firewood and woodchip prices and providing much needed rural employment.

Coppicing hedges: impact on biodiversity, microclimate and carbon sequestration

Hedgerows have many functions and benefits including supporting biodiversity, controlling erosion, buffering natural habitats from agricultural impacts and enhancing aesthetic appeal. Introducing coppice management to hedgerows is likely to influence the species composition of both invertebrate and plant species under and adjacent to the hedgerows as well as impact on other key ecosystem services. Therefore prior to coppicing consideration should also be taken of connectivity and the role that hedges play in the landscape. A biodiversity protocol (Crossland et al. 2015) has been developed based on the work at Elm Farm which enables landowners to assess their resource prior to any new management activities. It identifies hedges suitable for coppicing, those of potentially high biodiversity value as well as those in need of improvement and offers general management recommendations based on different indicators.

To assess the impacts of hedge coppicing on biodiversity, microclimatic conditions and carbon sequestration in different hedgerow types data was collected in the paired coppiced and uncut small plot trials (Figure 22) at Elm Farm.

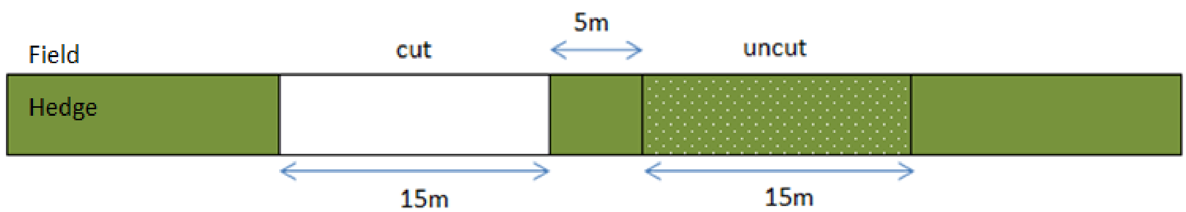


FIGURE 22. SMALL PLOT TRIAL PLOT SET UP: A 15M CUT PLOT NEXT TO A 15M UNCUT PLOT WITH A 5M UNCUT BUFFER BETWEEN

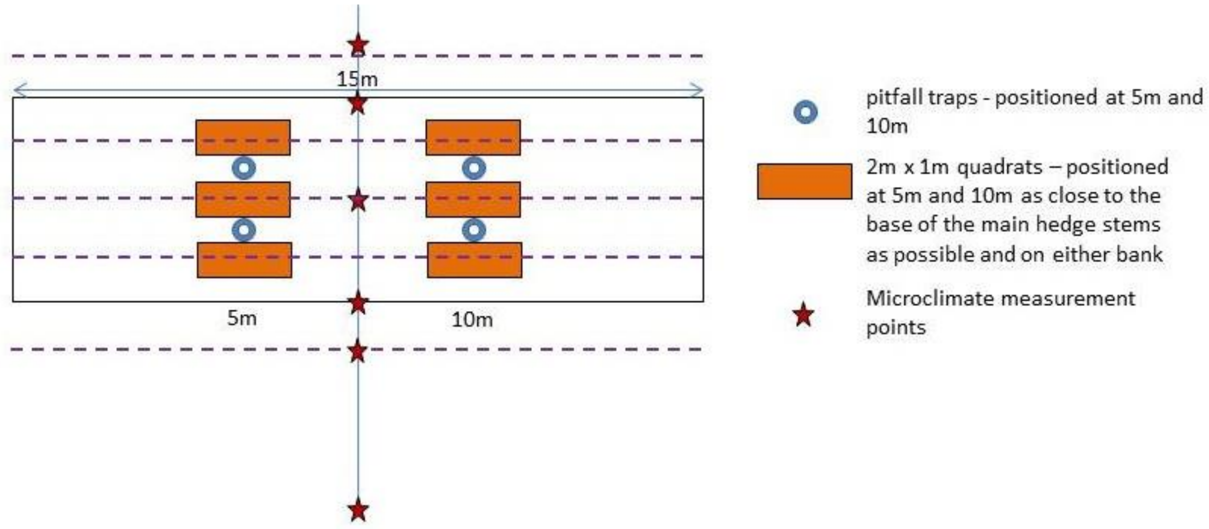


FIGURE 23. SMALL PLOT TRIAL DESIGN SHOWING FIXED DATA COLLECTION POINTS

Biodiversity

Biodiversity assessments in the trial plots used standard protocols to assess the impact of coppicing on two key indicator and functional groups (plants and ground beetles).

Botanical diversity

Botanical data was collected in summer 2014, 2015, 2016 and 2017 at fixed points. The sampling method used for assessing botanical diversity follows DEFRA's standard hedgerow survey method (DEFRA, 2007). This method was also used in the 2013 survey of all hedges on Elm Farm and ensures that data collected was compatible with other local surveys and is able to provide a representative benchmark for future comparisons. The percentage cover of all flowering plant species, plant litter and bare ground were recorded in six fixed 2 m x 1 m quadrats in each plot (both cut and uncut). Quadrats were placed in two transects perpendicular to the hedge across each plot (Figure 23).In the first two years, plots were surveyed twice a year to ensure a complete cover of species was recorded including late flowering grasses. In subsequent years data was collected once a year in late spring, when most species in the hedge are present. ORC intern Jessica Bach collected botanical diversity data from the hedges in 2017 and compared it to the data collected in previous years. Analysis focuses on late spring 2014 and 2017 in order to observe differences over a period of three years following coppicing.

Results

Two environmental variables were identified: the location of the quadrat in the hedgerow (West, Centre, East), and the management (hedgerow cut (i.e. coppiced) or uncut). The analysis investigated the impacts of coppicing hedgerows on species composition to test the hypothesis that following coppicing, woodland specialist species may disappear from coppiced hedgerows in favour of species adapted to more open environments and greater disturbance, and so initially, a difference in species composition between cut and uncut plots would be observed. We also predicted that species composition in the Centre of the hedge will be more influenced by coppice management than the edges and that there will be a difference in species composition along the transect regardless of management, with differences more pronounced between the Centre and the edges of the hedgerow in response to variations in microclimate, e.g. wind speeds, shading, soil moisture. Finally, we predicted that the management impacts have a greater effect in 2014, the year of the coppicing, while the location would have a bigger impact in 2017.

Diversity indices

Two indices of diversity were calculated for each plot: Shannon's index of diversity (H) and Simpson's index of diversity (1-D).

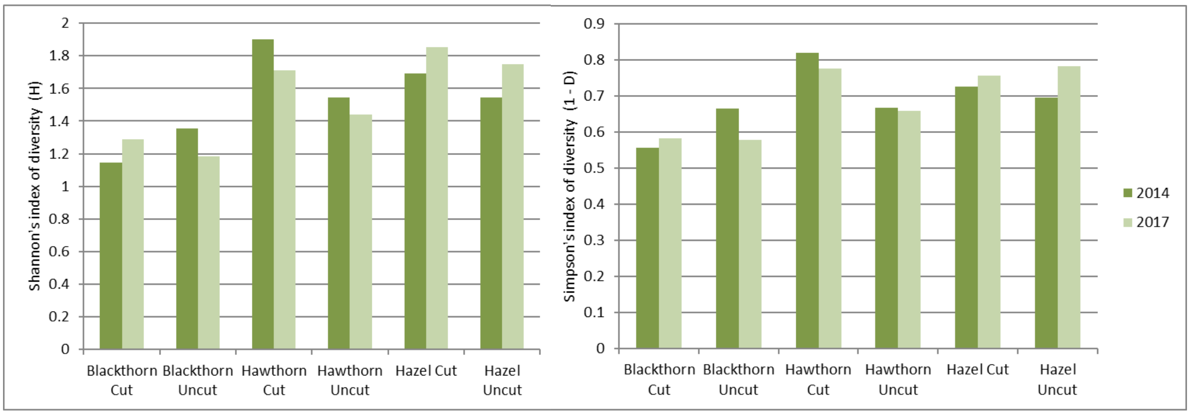


FIGURE 24. SHANNON'S (H) AND SIMPSON'S (1-D) INDICES OF DIVERSITY OF THE VEGETATION OF THE HEDGEROWS IN 2014 AND 2017

To assess whether the environmental variable management (cut or uncut) explained the distribution of species in the different plots between 2014 and 2017 species % cover data were analysed using canonical ordination techniques in Canoco 4.5.1 (Ter Braak & Šmilauer, 2003). Redundancy analysis (RDA) was carried out on the data. For the purpose of this analysis the quadrat location was treated as a covariable.

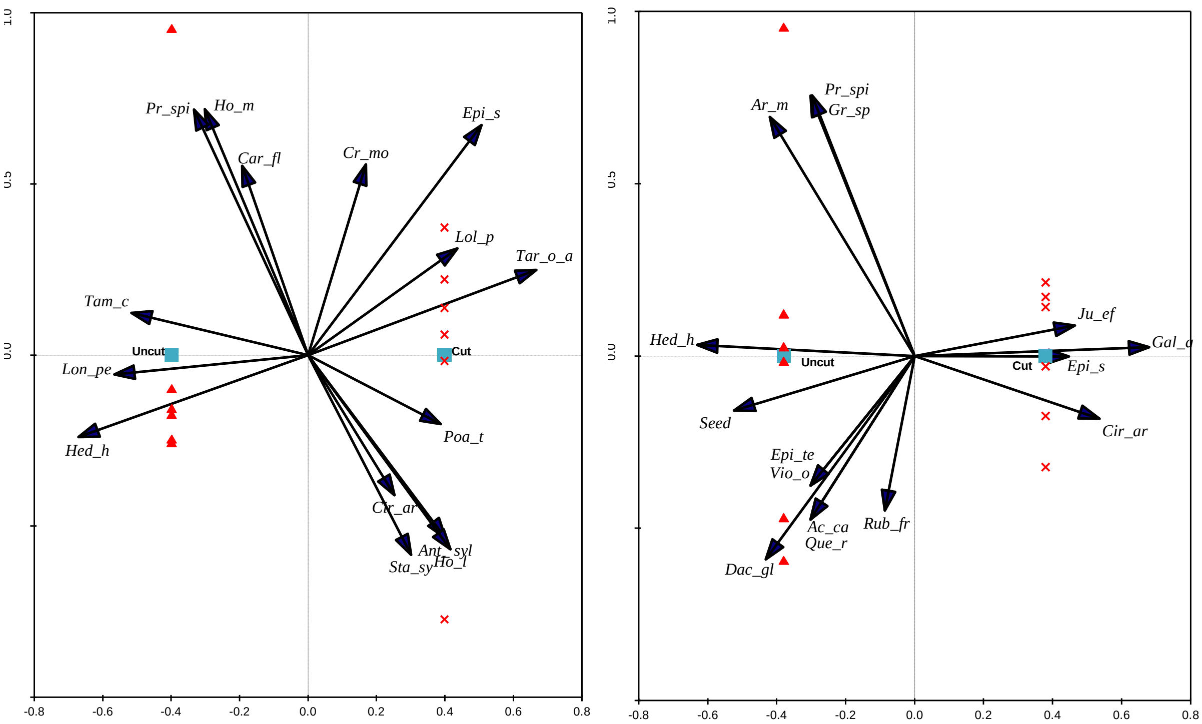


FIGURE 25. REDUNDANCY ANALYSIS (RDA) ORDINATION DIAGRAM SHOWING THE RELATIONSHIP BETWEEN PLANT SPECIES AND MANAGEMENT IN THE HAWTHORN PLOTS (A) 2014, (B) 2017. RED SYMBOLS SHOWING THE INDIVIDUAL PLOTS.

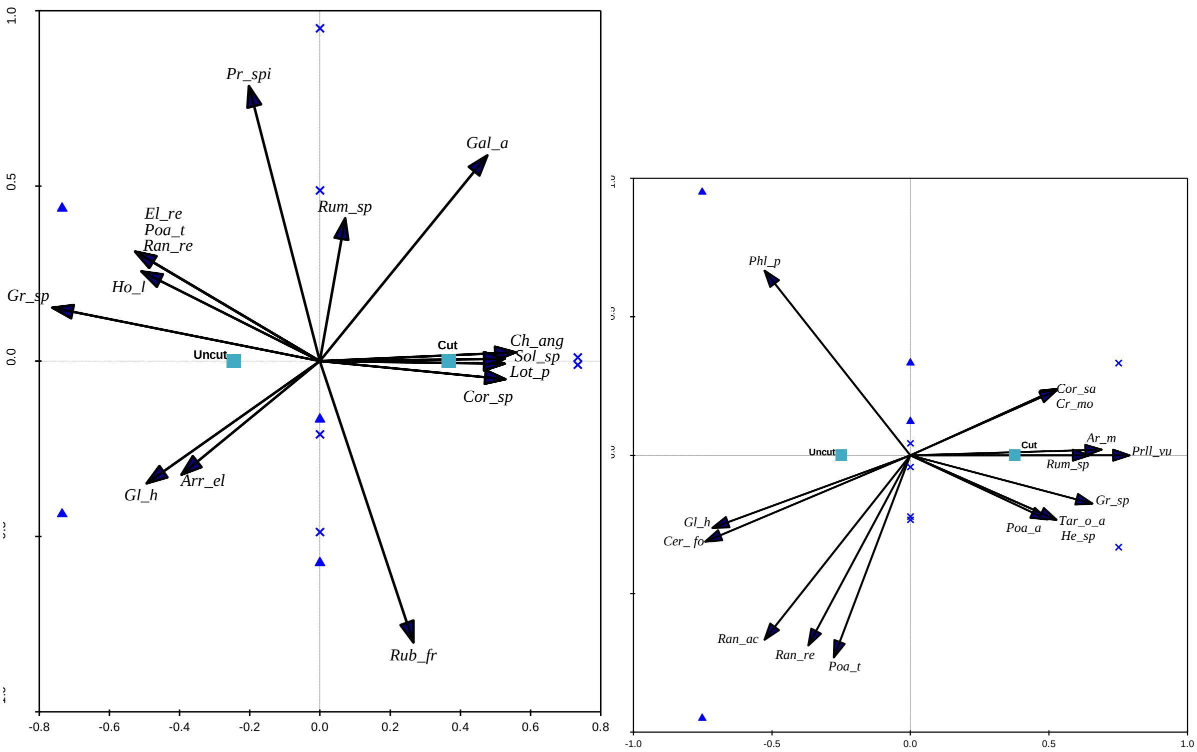


FIGURE 26. REDUNDANCY ANALYSIS (RDA) ORDINATION DIAGRAM SHOWING THE RELATIONSHIP BETWEEN PLANT SPECIES AND MANAGEMENT IN THE BLACKTHORN PLOTS (A) 2014, (B) 2017. BLUE SYMBOLS SHOWING THE INDIVIDUAL PLOTS.

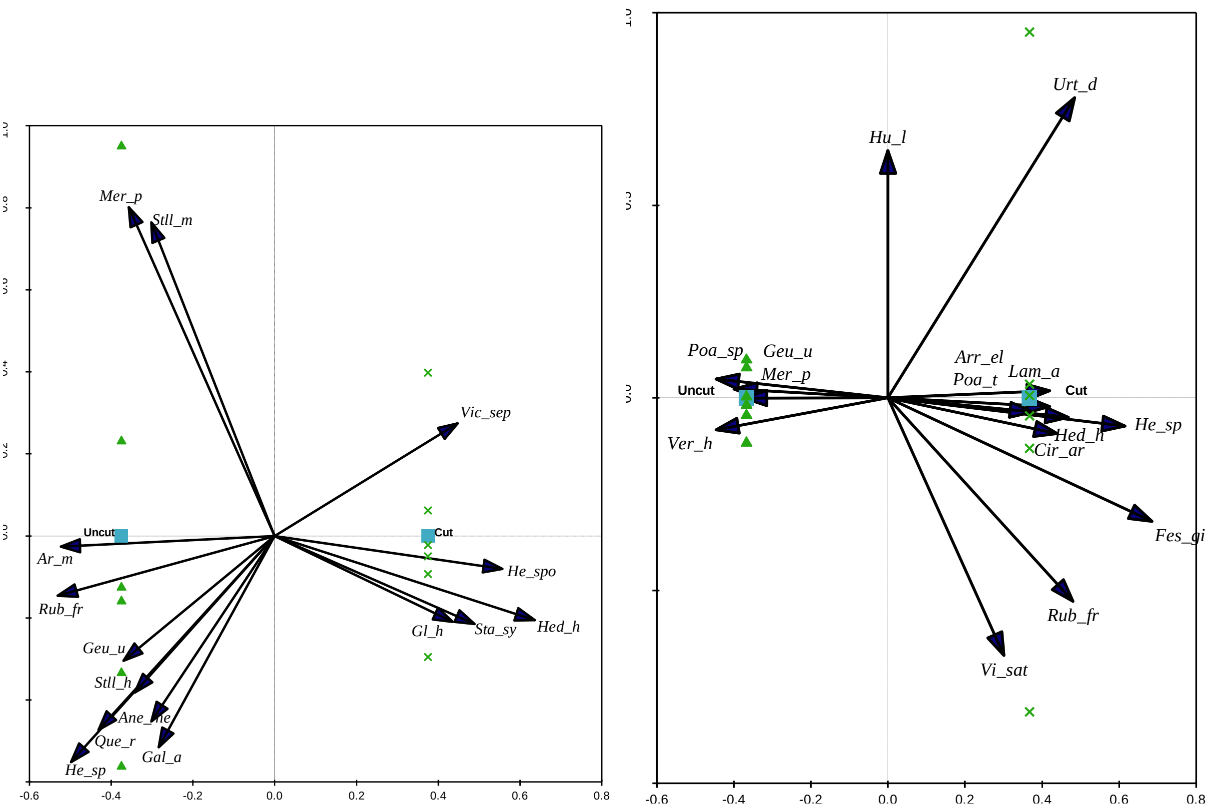


FIGURE 27. REDUNDANCY ANALYSIS (RDA) ORDINATION DIAGRAM SHOWING THE RELATIONSHIP BETWEEN PLANT SPECIES AND MANAGEMENT IN THE HAZEL PLOTS (A) 2014, (B) 2017. GREEN SYMBOLS SHOWING THE INDIVIDUAL PLOTS.

TABLE 7. RESULTS OF THE RDA ANALYSIS TO ASSESS WHETHER THE ENVIRONMENTAL VARIABLE MANAGEMENT (CUT OR UNCUT) EXPLAINED THE DISTRIBUTION OF SPECIES IN THE DIFFERENT PLOTS BETWEEN 2014 AND 2017.

	2014			2017		
	Eigenvalue	F-value	P-value estimate	Eigenvalue	F-value:	P-value estimate
Hawthorn	0.127	1.983	0.0660	0.102	1.267	0.2660
Blackthorn	0.042	0.580	0.5900	0.063	0.506	0.7340
Hazel	0.152	2.457	0.0170*	0.210	0.860	0.0110*

Botanical diversity: Conclusions

The logistics of coppicing multiple small sections of hedge on the farm and the variability of the hedges meant that we were only able to establish one replicate of each of the three hedgerow types included in the analysis. The results seen may therefore be due to previous management or location, rather than the hedgerow species. The conclusions therefore describe general patterns in response to management and orientation.

Both of the diversity indices show an increase in diversity in the hazel plots between 2014 and 2017 in both the cut and uncut plots and a decrease in the hawthorn plots (Figure 24). Blackthorn plots showed a different response to management with a reduction in diversity in the uncut plots over time and an increase in the cut plots.

RDA analysis showed that management (cut or uncut) explained a significant amount of the variability between the species in both 2014 and 2017 for the hazel plots only (Figure 27, Table 7) The section of hazel hedge that was coppiced was wider than blackthorn or hawthorn hedges and more closely resembled a narrow strip of hazel coppice woodland and woodland species such as dog's mercury (*Mercuralis perennis*), cuckoopint (*Arum maculatum*) and wood avens (*Geum urbanum*) were more strongly associated with uncut plots.

Invertebrate Diversity

The aim of the invertebrate survey was primarily to record presence of ground beetles during their period of peak activity in different hedgerows and to understand the potential impact of coppicing on ground beetle activity. Ground beetles (carabids) were selected as an indicator of wider biodiversity due to their relative abundance and ease of monitoring. Ground beetles are known to react to change in management practices and stages of succession (Blaszkiewicz, 2013, Blake, 1996).

ORC interns Daria Erik and Theo Stenning recorded ground beetle presence using a pitfall trapping method adapted from Desender and Pollet (1988) twice a year, once in summer 2014 (June/July) and then again in winter 2014 (November/December). Pitfall trapping was then repeated in summer 2016 by ORC intern Jessica Bach. Each invertebrate pitfall trap was constructed from two 300 ml, 8 cm diameter and 11 cm height plastic drinking cups. Four traps were placed per plot, positioned at 5 m and 10 m on either side of the hedge. Pitfall traps were left out for a period of four weeks for each sampling occasion. The collected invertebrates were then identified to main taxonomic group and counted. Carabids were separated from the Coleoptera and identified to species level.

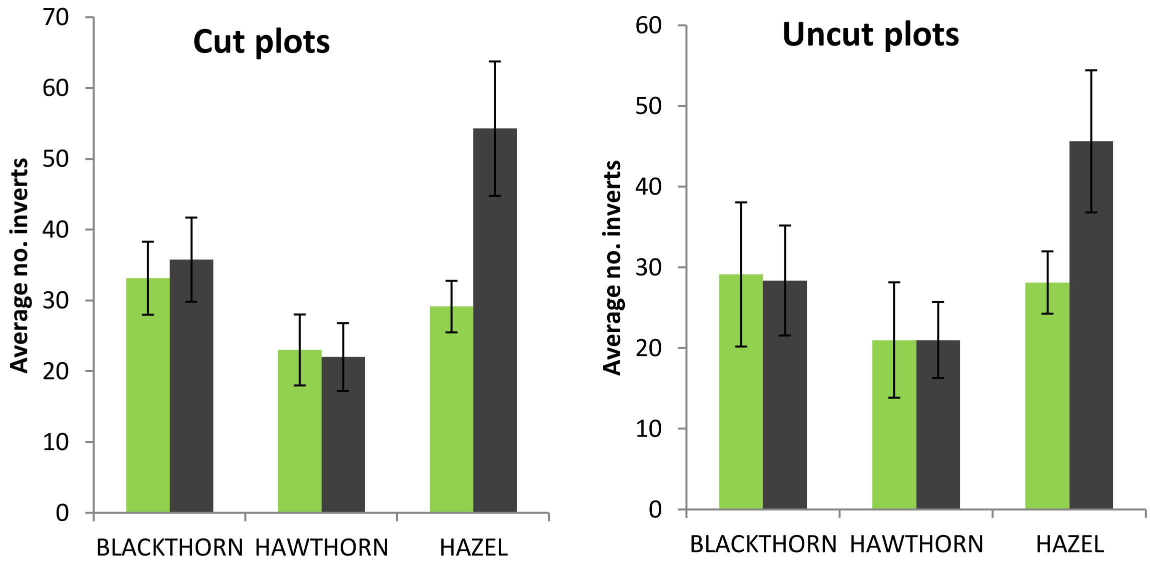


FIGURE 28. MEAN +/-SE NUMBER OF INVERTEBRATES IN THE CUT (COPPICED) AND UNCUT PLOTS IN JULY 2014. GREEN BARS ARE PITFALL TRAPS ON THE EASTERN SIDE OF THE HEDGES AND BLACK ON THE WEST.

The most abundant invertebrate taxonomic class found in the pitfall traps were Diptera (flies) followed by Collembola (springtails) and Arachnids (spiders) then Coleoptera (carabids). More invertebrates were recorded on the Western side of the hedge in the hazel plots and more carabids on the Western side of the hedge in all plots (Figure 28).

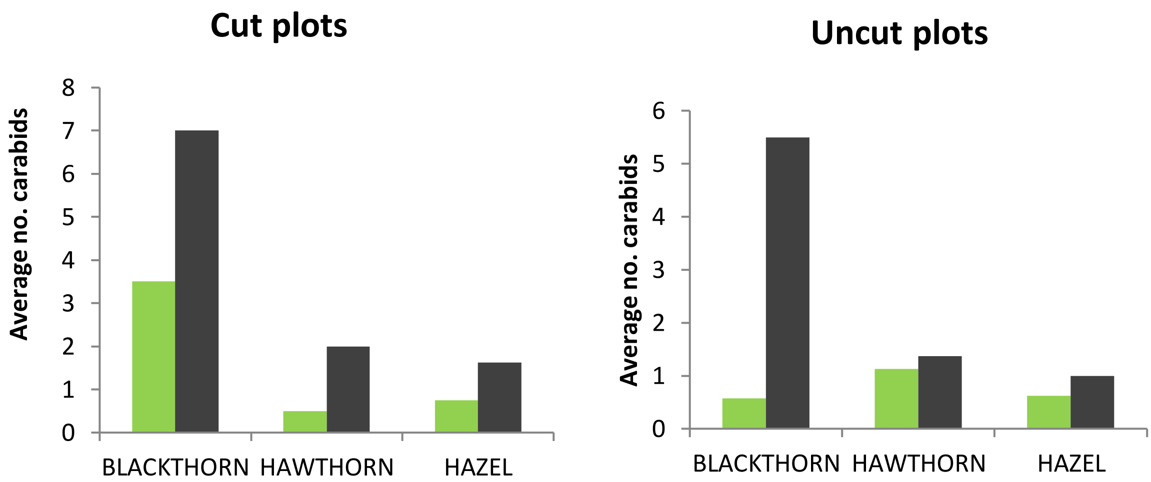


FIGURE 29. MEAN NUMBER OF CARABIDS IN THE CUT (COPPICED) AND UNCUT PLOTS IN JULY 2014. GREEN BARS ARE PITFALL TRAPS ON THE EASTERN SIDE OF THE HEDGES AND BLACK ON THE WEST.

In 2014 more carabids were counted in the coppiced plots, especially the blackthorn plot, where the most carabids overall were recorded (Figure 29). In 2014 the summer survey showed a high abundance of carabids (Figure 30) demonstrating high levels of activity. Coppicing increases light intensity by opening up the canopy and may promote increased activity.

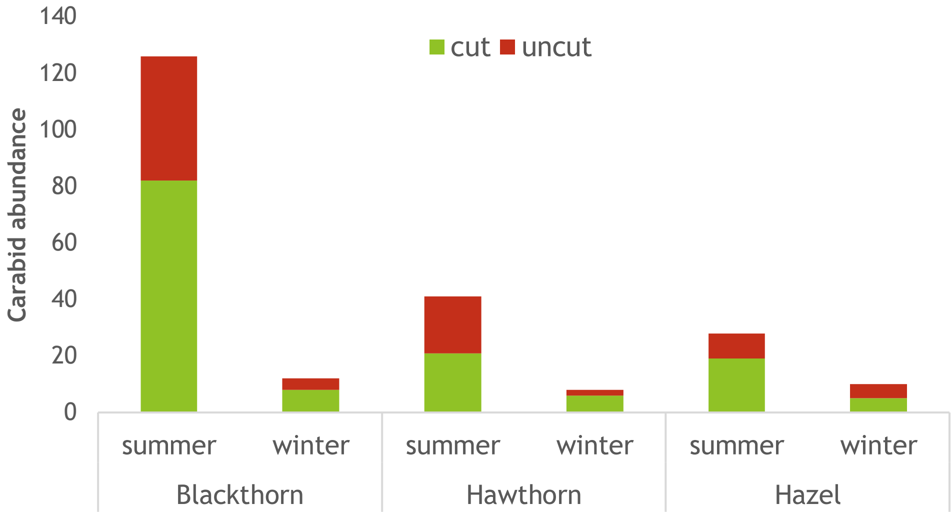


FIGURE 30. CARABID ABUNDANCE WITHIN THE CUT AND UN-CUT PLOTS FROM THREE HEDGEROWS IN 2014 SHOWING DIFFERENCE BETWEEN SUMMER AND WINTER

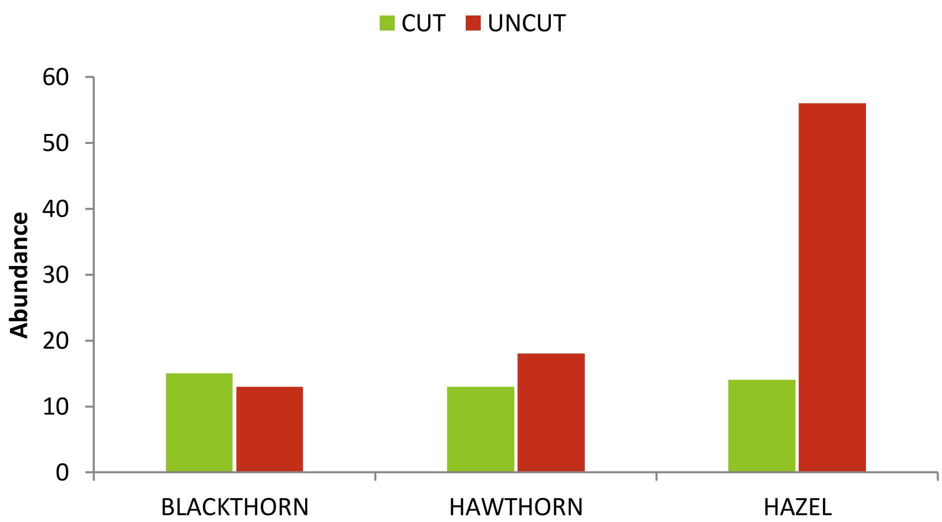


FIGURE 31. CARABID ABUNDANCE WITHIN THE CUT AND UN-CUT PLOTS FROM THREE HEDGEROWS IN SUMMER 2016

Overall, 197 Ground beetles were caught in the summer 2014 and 31 in the winter 2014 (Figure 30). Winter and summer data varied in species diversity. In the summer, the most abundant species was *Bembidion guttula* (Figure 32). In the winter carabid diversity was lower and *Nebria brevicollis* and *Bembidion guttula* were the most common species. When resampled in summer 2016 (Figure 31) and in contrast to 2014 most beetles were found in the un-coppiced hazel plots. This may be a result of seasonal differences and the high levels of mobility in carabids.

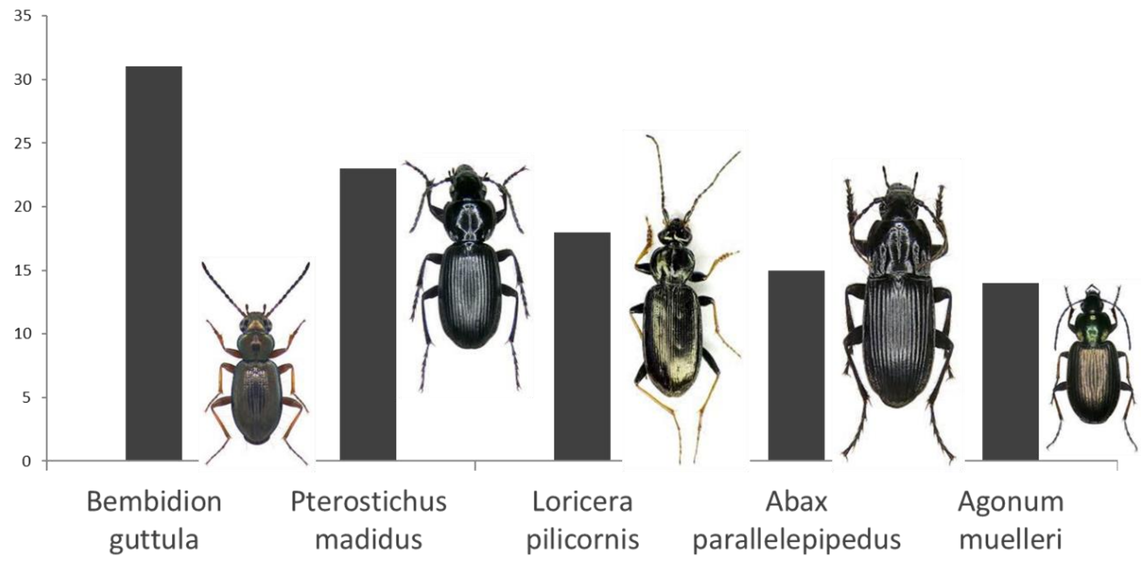


FIGURE 32. THE MOST ABUNDANT CARABID SPECIES IN ALL THE HEDGE PLOTS COMBINED JULY 2014

Results show the impact of coppicing on carabid diversity and abundance in the three sampled hedgerows was determined by seasonal as well as annual variations. In the summer 2014 beetles were more abundant within the cut plots, but in 2016 abundance was higher in the uncut plots. In the winter, abundance was higher in uncut plots, possibly due to differences in microclimate with a more sheltered environment in the uncut plots. A more detailed study over a longer timeframe is needed to draw any firm conclusion on the response of carabid beetles to hedge coppicing.

Carbon sequestration potential of hedges managed for woodfuel

One particular element on which we focused was the potential impact of woodfuel production from hedgerows on carbon sequestration (Crossland et al, 2015). To determine the effects of hedgerow management for woodfuel on carbon sequestration, carbon stocks and flows were estimated for the paired 15 m coppiced and un-coppiced plots, and an existing process-based model (Grogan and Matthews, 2002) of the carbon sequestration under short rotation coppice was adapted to a woodfuel from hedgerows scenario. The impacts of coppice management on carbon storage were then assessed along with the potential to offset fossil fuel use using a carbon budget analysis. Data collected included the biomass productivity of each hedge, current SOC stocks, leaf litter production and measurement of coppice regrowth.

Definition of the system boundaries

For the estimation of carbon stores, model scenarios and carbon budgets, two hedge scenarios (associated with cut and uncut plots) were used and referred to as 'unmanaged' and 'managed'; unmanaged referring to hedges occasionally flailed to control outgrowth and not managed by coppicing, and managed referring to hedges managed on a 15 year coppice rotation for woodfuel.

Managed hedges:

The carbon stores and flows associated with the managed hedge system are depicted in Figure 33. There are assumed to be six main carbon pools within the hedgerow system: two within the above-ground biomass (leaves and stems); two within the below-ground biomass (structural roots and fine roots); and two soil carbon pools (fresh soil carbon and humic soil carbon). Carbon flows between these pools include leaf-litter from the above-ground biomass of the hedge and below-ground fine root turnover. Carbon flows out of the system include soil respiration and woodchip produced from above-ground biomass. Although the woodchip produced substitutes the use of carbon from fossil fuels for energy production, it is burnt and therefore does not store carbon in the long-term. Carbon outputs also consist of direct fossil fuel combustion from fuel used in harvesting and processing machinery, the transportation of the woodchip and the embedded energy of the machinery itself. Energy inputs related to labour were not considered within this study.

Unmanaged hedges:

The carbon stores and flows within the system associated with the unmanaged hedge system are identical to those of the managed system. Carbon flows out of the unmanaged system however exclude those from the production of woodchip and the woodchip itself.

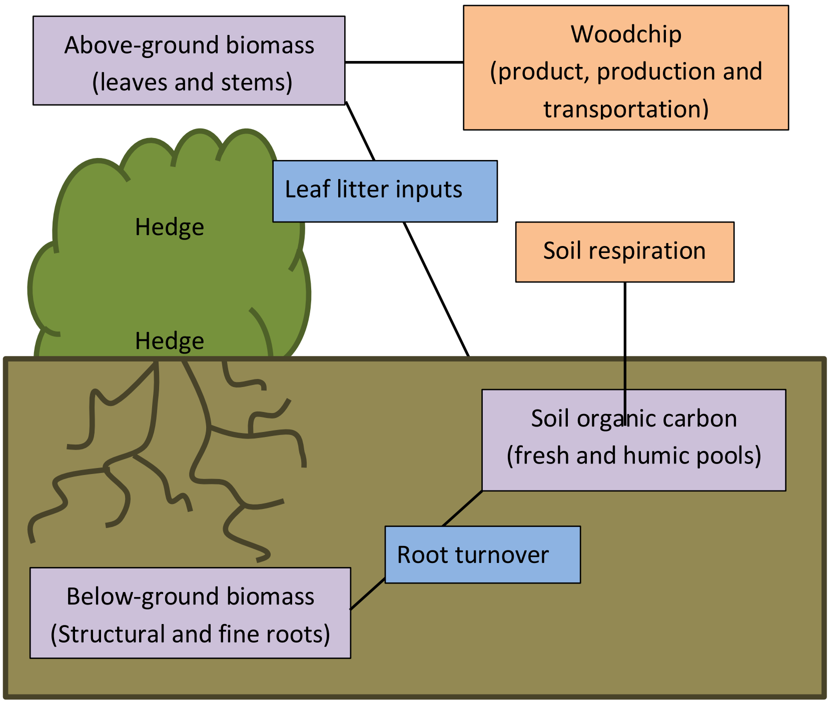


FIGURE 33. SCHEMATIC DIAGRAM OF CARBON STORES (PURPLE), CARBON FLOWS WITHIN THE SYSTEM (BLUE), AND CARBON FLOWS OUT OF THE SYSTEM (ORANGE) UNDER THE MANAGED HEDGE SYSTEM. WOODCHIP (PRODUCT, PRODUCTION AND TRANSPORTATION) IS EXCLUDED UNDER THE UNMANAGED SCENARIO.

Using the dry mass (0 % MC) of woodchip, a carbon content of 0.49 was assumed for the fraction of C within the coppiced biomass (Matthews 1993). These figures were then used to estimate the above-ground carbon store of each unmanaged hedge scenario. Carbon stored within the unutilised coppice stools remaining after coppicing was not measured due to the difficulties of stool excavation. Figures for total carbon stored above-ground may therefore be underestimates. Regrowth measurements were used to determine the above-ground carbon store of the managed hedge scenarios at the end of the first growing season.

Total soil organic carbon (SOC) was determined for both cut and uncut hedge plots using a composite sampling design one year after coppicing. In late January 2014, 25 soil cores per plot were taken in transects across each plot. Each soil core was then divided into four layers determined by depth (0-7.5, 7.5-15, 15-30, 30-50 cm). The distribution of SOC within different soil carbon pools (e.g. fresh and humic) was not determined due to the high resource requirement of fractionation and analysis. Bulk density was determined at three random sites per plot. In each location a 50 cm deep pit was dug and two bulk density cores were taken from the side wall using a cylinder of known volume; one from the 0-25 cm horizon, and one between 25-50 cm.

Carbon stored within hedge roots was not measured directly due to the difficulties of root excavation. Instead below-ground carbon stores were estimated assuming 0.25 of the total net carbon assimilated each year is allocated to root growth (Grogan and Matthews, 2002). Below-ground carbon stores were therefore calculated as a third of the above-ground carbon store.

Although it is assumed that coppicing was followed by dieback of fine roots within the three hedge plots, a conservative figure for the proportion of below-ground biomass lost after coppicing was used as in most tree species, coppicing leads to dieback of fine roots followed by rapid recovery of their biomass (Montagnoli et al., 2012). When calculating the below ground biomass of the recently coppiced hedge only 10 % of the roots are assumed to have died back as to not over-estimate root necrosis.

To determine the potential carbon entering the soil through the foliage pool, leaf litter samples were collected from each plot after leaf fall in December and dry mass determined. A leaf litter carbon content of 0.4 g C (g DM)-1 (Grogan and Matthews, 2002) was assumed.

Modelling

A process-based model developed by Grogan and Matthews (2002) was adapted using key parameters specific to both managed and unmanaged scenarios for each hedge type (blackthorn dominated, hawthorn dominated and hazel dominated). In order to adapt the model developed by Grogan and Matthews to a hedgerow scenario, their original model was replicated in Python (3.4) using the equations and parameters stated in their paper. Key parameters specific to the three hedge types were then applied to their model in order to predict both above- and below-ground carbon pools over 100 years. For each hedge species (hazel, hawthorn and blackthorn) carbon pools were calculated for both managed and unmanaged scenarios. The parameters 'biomass production', 'leaf area index' and 'carbon inputs from canopy and root system' and 'coppice rotation' were adapted to model the hedge specific scenarios; all other parameters remained the same as in Grogan and Matthews' original model.

Carbon budget analyses

Simple carbon savings budgets which capture the emissions from management activities and the substitution of fossil fuel were included. Assuming 5.33 kWh per kg of coppiced hedge material (based on woodchip calorific content analysis carried out at Elm Farm on woodchip produced from a mixed blackthorn and hazel hedge) the length of each hedge type required to produce 20,000 kWh, the typical annual energy consumption of a house (Biomass Energy Centre, 2014), was calculated. For the managed scenarios, the potential carbon sequestration values provided by these hedge lengths over a 15 year period were calculated based on the adapted model's results. The estimated carbon emissions from woodchip production were then subtracted assuming emissions of 0.14 tonnes of carbon per 20,000 kWh worth of woodchip (Biomass Energy Centre, 2014). Biomass energy from coppicing hedges is considered carbon neutral (Djomo et al., 2013). The carbon emissions produced when the woodchip is burnt were therefore assumed to be zero. For the unmanaged scenarios the potential carbon sequestration values provided by these hedge lengths over a 15 year period were once again calculated based on the model results, and the estimated carbon emissions resulting from the use of heating oil (6.28 tonnes) to provide 20,000 kWh subtracted.

Results

Due to the absence of replicates, no statistical analyses were carried out within this study. The unmanaged hedges were estimated to store more carbon than the recently coppiced hedges (Table 8, Table 9, Table 10). This is primarily due to the above-ground biomass having been removed, substantially decreasing above-ground carbon stores. In comparison with the hazel hedge, blackthorn and hawthorn hedges responded poorly to coppicing as shown by their lower above-ground carbon stores one year after coppicing.

Average SOC stores were found to be marginally higher within the uncoppiced blackthorn and hawthorn hedges, and average SOC stores slightly higher in the coppiced hazel hedge compared to the uncoppiced hazel hedge (Table 8, Table 9, Table 10).

Table 8. Estimated carbon stores and flows within and out of the system for blackthorn under both managed and unmanaged scenarios.

	Uncoppiced hedge	1 year after coppicing	Uncoppiced hedge	1 year after coppicing
Carbon stocks	t C ha-1	t C ha-1	t C km-1	t C km-1
Above-ground	131.50	27.62	46.02	0.74
Below-ground	43.83	39.45	15.34	13.81
SOC	111.93	95.31	89.55	76.25
Total stocks	287.26	162.38	150.91	90.80
Carbon flows within	t C ha-1 yr-1	t C ha-1 yr-1	t C km-1 yr-1	t C km-1 yr-1
Leaf litter	35.04	42.62	1.23	1.49
Total flows within	35.04	42.62	1.23	1.49
Carbon flows out				
Woodchip	0	131.50	0	46.02
Total flows out	0	131.50	0	46.02

Table 9. Estimated carbon stores and flows within and out of the system for hawthorn under both managed and unmanaged scenarios.

	Uncoppiced hedge	1 year after coppicing	Uncoppiced hedge	1 year after coppicing
Carbon stocks	t C ha-1	t C ha-1	t C km-1	t C km-1
Above-ground	93.50	25.65	28.05	0.88
Below-ground	31.17	28.05	9.35	8.42
SOC	74.04	66.52	59.23	53.22
Total stocks	198.71	120.22	96.63	62.51
Carbon flows within	t C ha-1 yr-1	t C ha-1 yr-1	t C km-1 yr-1	t C km-1 yr-1
Leaf litter	32.30	26.61	0.97	0.80
Total flows within	32.30	26.61	0.97	0.80
Carbon flows out				
Woodchip	0	93.50	0	28.05
Total flows out	0	93.50	0	28.05

Table 10. Estimated carbon stores and flows within and out of the system for hazel under both managed and unmanaged scenarios.

	Uncoppiced hedge	1 year after coppicing	Uncoppiced hedge	1 year after coppicing
Carbon stocks	t C ha-1	t C ha-1	t C km-1	t C km-1
Above-ground	45.08	34.35	18.03	2.52
Below-ground	15.03	13.52	6.01	5.41
SOC	85.36	88.80	68.29	71.04
Total stocks	145.46	136.67	92.33	78.97
Carbon flows within	t C ha-1 yr-1	t C ha-1 yr-1	t C km-1 yr-1	t C km-1 yr-1
Leaf litter	20.85	8.98	0.83	0.36
Total flows within	20.85	8.98	0.83	0.36
Carbon flows out				
Woodchip	0	45.08	0	18.03
Total flows out	0	45.08	0	18.03

Modelling results

For blackthorn and hawthorn simulations, unmanaged scenarios were shown to sequester more carbon both in above- and below-ground biomass and SOC than managed scenarios (Figure 34). This is due to their slower growth rates following coppicing compared to the hazel hedge. The managed hazel scenario however was shown to sequester larger amounts of carbon in both below-ground biomass and SOC over the 100 year simulation due to its exceptionally good response to coppicing (Figure 34). It is however important to note that the managed scenarios were based on production data from just one year after coppicing and assume a linear increase in biomass. In practice will not be the case, and blackthorn and hawthorn species may just be slow to respond to coppicing. Only with continued long-term monitoring and inclusion of further data points can the accuracy of the model be improved.

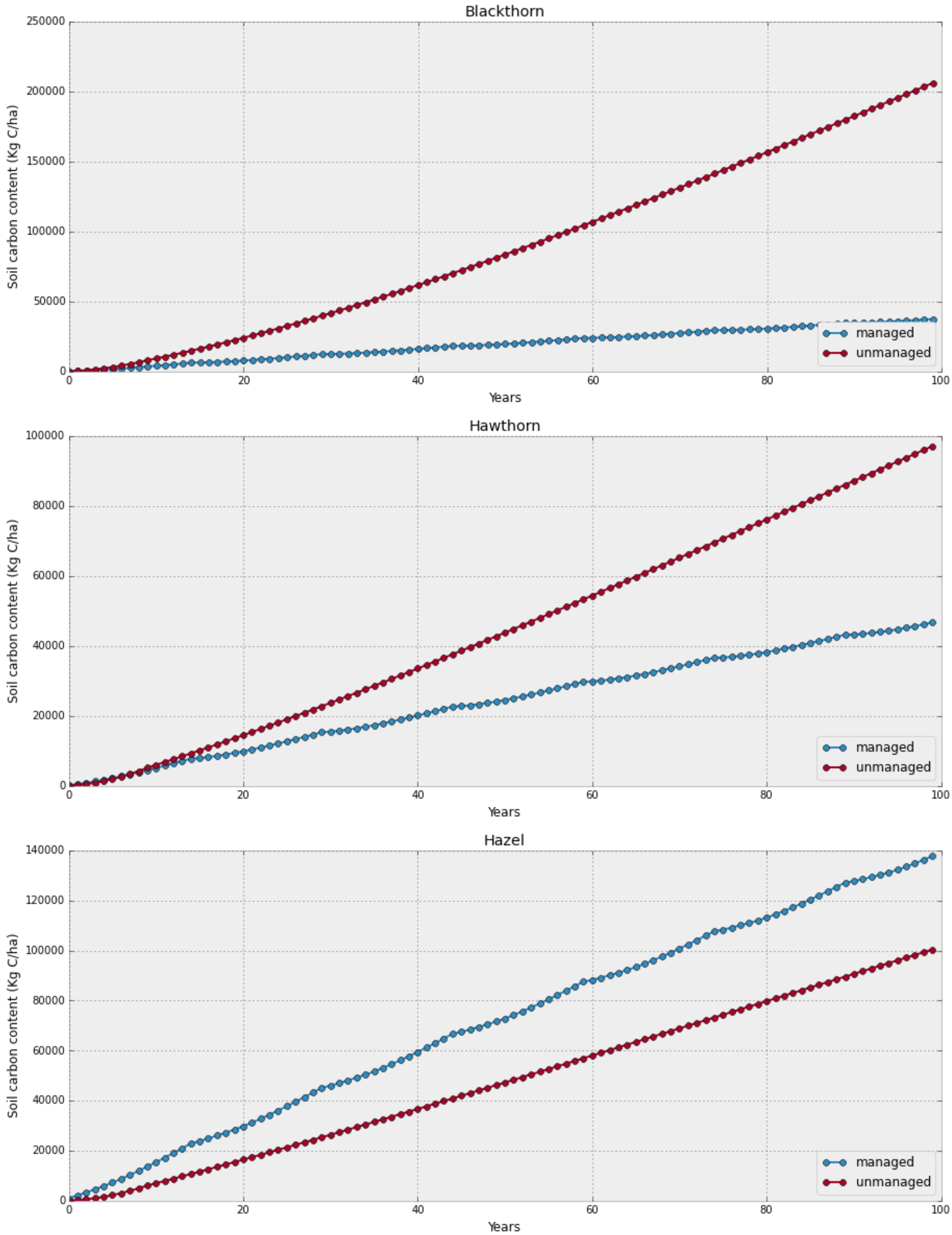


FIGURE 34. PREDICTED SOIL CARBON FOR BOTH MANAGED AND UNMANAGED SCENARIOS FOR EACH HEDGE TYPE OVER 100 YEARS. MANAGED HEDGES ARE COPPICED IN 15-YEAR INTERVALS.

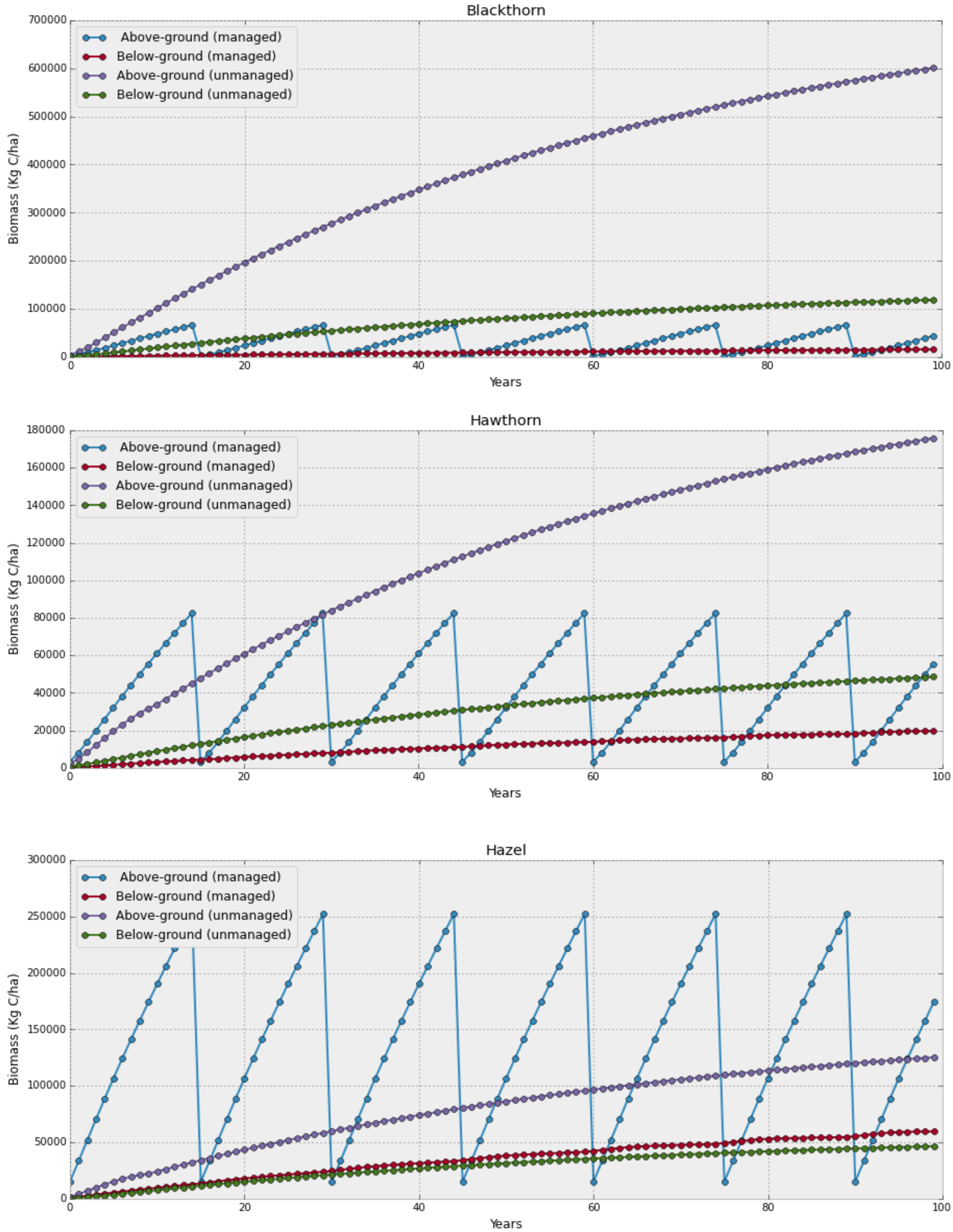


Figure 35. Predicted above- and below-ground biomasses for both managed and unmanaged scenarios for each hedge type over 100 years. Managed hedges are coppiced in 15-year intervals.

Average annual carbon sequestration

Annual carbon sequestration rates were determined using a one-step linear interpolation of the graphs in Figure 35. The sequestration rates (Table 11) are therefore approximated average annual rates over 100 years. Carbon sequestration within above-ground biomass under managed scenarios are however assumed to be zero as above-ground biomass is removed and burnt every 15 years and therefore dose not store carbon in the long-term. As with the previous carbon storage and flow estimates, values on a hectare basis assume a full hectare of hedge and are not based on a set hedgerow density within the landscape.

TABLE 11. APPROXIMATE AVERAGE ANNUAL CARBON SEQUESTRATION RATES (DISPLAYED IN BOTH T C/HA AND T C/KM) OVER 100 YEARS FOR BOTH MANAGED AND UNMANAGED SCENARIOS.

		Unmanaged	Managed	Unmanaged	Managed
		t C ha-1 yr-1	t C ha-1 yr-1	t C km-1 yr-1	t C km-1 yr-1
Blackthorn scenarios	Above-ground biomass	6.00	0.00	2.10	0.00
	Below-ground biomass	1.10	0.15	0.39	0.01
	SOC	2.10	0.38	0.74	0.02
	Total	9.20	0.53	3.22	0.03
Hawthorn scenarios	Above-ground biomass	1.79	0.00	0.54	0.00
	Below-ground biomass	0.50	0.20	0.15	0.01
	SOC	9.90	0.43	2.97	0.03
	Total	12.19	0.63	3.66	0.04
Hazel scenarios	Above-ground biomass	1.25	0.00	0.50	0.00
	Below-ground biomass	0.49	0.65	0.20	0.10
	SOC	1.0	1.39	0.40	0.21
	Total	2.74	2.04	1.10	0.31

Despite all unmanaged hedges sequestering more carbon, all three hedge types save more carbon when managed for woodfuel than when left unmanaged due to the substitution of fossil fuels, as shown by the simple carbon budget results in Table 12.

TABLE 12. SIMPLE CARBON BUDGET FOR BOTH MANAGED AND UNMANAGED SCENARIOS AND THE POTENTIAL CARBON SAVINGS WHEN MANAGED FOR WOODFUEL.

		Managed	Unmanaged
		t C yr-1	t C yr-1
Blackthorn scenarios	C sequestered	0.02	1.93
	C released	0.14	6.28
	Total carbon sequestered	0.12	-4.35
	Carbon saving when hedge managed for woodfuel: 4.47 t C yr-1		
Hawthorn scenarios	C sequestered	0.04	3.62
	C released	0.14	6.28
	Total carbon sequestered	-0.10	-2.66
	Carbon saving when hedge managed for woodfuel: 2.56 t C yr-1		
Hazel scenarios	C sequestered	0.47	1.68
	C released	0.14	6.28
	Total carbon sequestered	0.33	-4.60
	Carbon saving when hedge managed for woodfuel: 4.93 t C yr-1		

Conclusion

The study revealed that while hedges which are not managed by coppicing sequester larger quantities of carbon, total carbon savings are higher when hedges are managed by coppicing due to the substitution of fossil fuels via the production of woodfuel. Although the results presented from this small-scale, short-term study should be viewed as provisional, they present a useful starting point for future enquiry, identifying the need for long-term chronological studies and data collection on carbon sequestration processes specific to hedges. Collection of further empirical data on the carbon sequestration potential of hedgerows will be needed to validate existing estimates and models and to inform decisions not only at a farm management level but also for wider policy.

Microclimate changes as a result of hedge coppicing

Regulation of the microclimate was assessed by taking measurements of soil moisture, air temperature, wind chill, relative humidity and maximum and average wind speed monthly between May 2014 and May 2016.

For each plot (cut and uncut) microclimate measurements (soil moisture, wind speed and temperature) were taken at seven points along a transect running through the centre of each plot perpendicular to the hedge (Figure 36). One measurement was taken in the centre of the hedge, the next one at the edge of hedge, then one 1m into the field and the last in the field the same distance away from the hedge as the height of the uncut hedge (approximately 7m in all plots). Measurements were taken either side of the hedge to give 7 points in total for each plot.

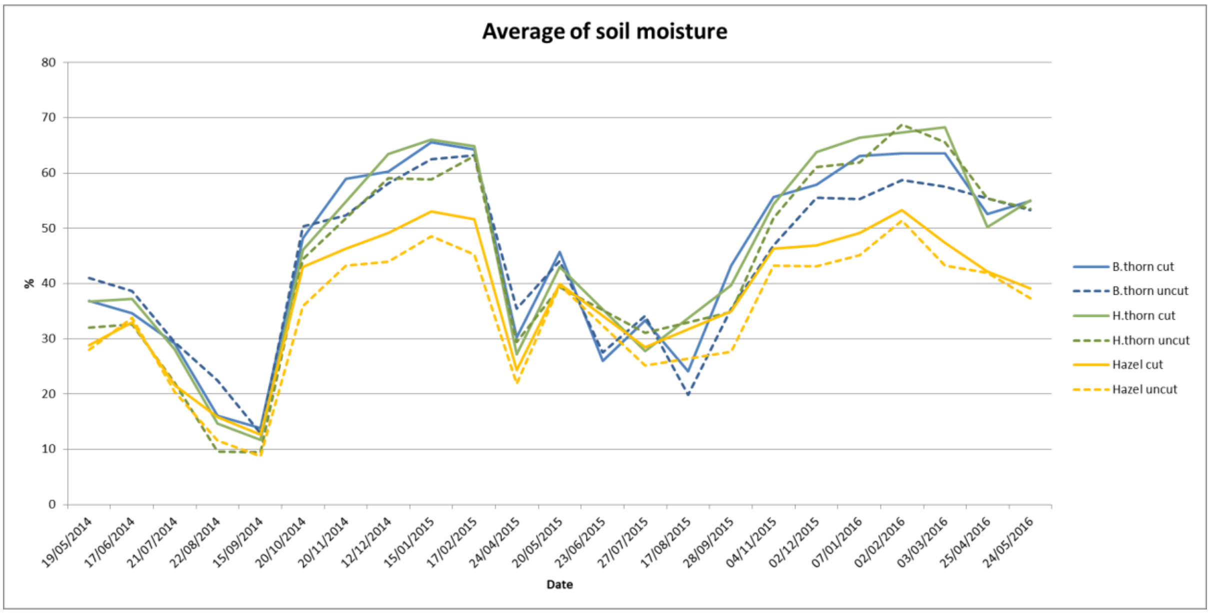


FIGURE 36. AVERAGE SOIL MOISTURE READINGS BETWEEN CUT AND UNCUT PLOTS IN THE PERIOD BETWEEN MAY 2014 AND MAY 2016.

In general soil moisture was higher in coppiced plots particularly in the winter period (Figure 36). The mean difference over a two year monitoring period was 3.24 % higher soil moisture content adjacent to the coppiced hazel compared to the uncut plot, 2.55 % higher soil moisture for the cut hawthorn plots and 1.02 % higher for the blackthorn plots.

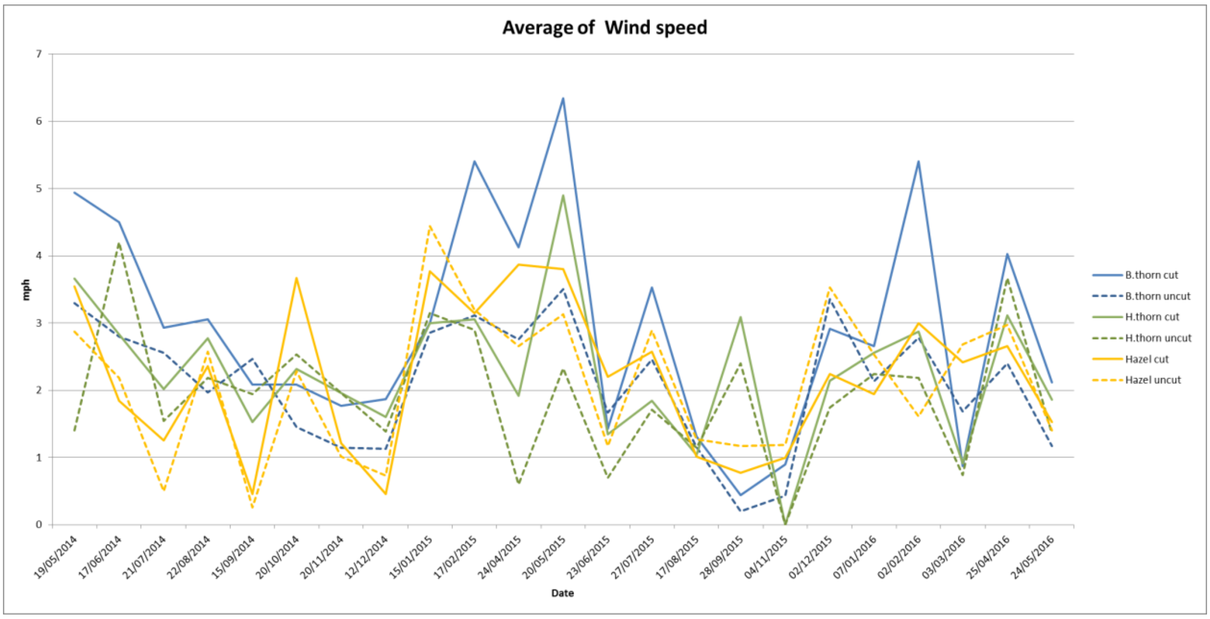


FIGURE 37. AVERAGE WIND SPEED READINGS BETWEEN CUT AND UNCUT PLOTS IN THE PERIOD BETWEEN MAY 2014 AND MAY 2016.

In general, windspeeds were higher in coppiced plots and more variable, particularly during the winter period (Figure 37). The mean difference over a two-year monitoring period was 0.11 mph higher wind speeds adjacent to the coppiced hazel compared to the uncut plot, 0.38 mph higher wind speeds for the cut hawthorn plots and 0.83 higher for the blackthorn plots.

These results indicate that coppicing has short term impacts on the microclimate adjacent to the hedgerow, with the impacts more obvious in the blackthorn plots with the slowest regrowth rates.

Dormice in hedgerows

By Corinne Sreeves, Dormouse monitoring volunteer

During summer 2013, all the hedgerows at Elm Farm were surveyed as part of the TWECOM ‘Towards Eco-Energetic Communities’ project. As a follow on, in autumn 2013, a survey looking for evidence of hazel dormice (*Muscardinus avellanarius*) was carried out in hazel-rich hedgerows. As a result, ten characteristically gnawed dormouse hazelnuts were identified; these were found at five different locations on two adjacent hedgerows (Figure 38). Several of the nuts were sent to and verified by the People’s Trust for Endangered Species (PTES).

FIGURE 38. SAMPLE OF DORMOUSE GNAWED HAZELNUTS FOUND AT ELM FARM (PHOTO: C SREEVES, 2014)

Dormice are protected by law because their numbers and distributional range have declined by at least half during the past 100 years. This decline still continues in some regions. Dormice are important because they are a ‘flagship species’; where dormice occur, the habitat is usually very suitable for a wide range of other species too. They are also important as 'bioindicators' as they are particularly sensitive to habitat and population fragmentation, so their presence is an indication of habitat integrity and sustainable populations of other sensitive species (Bright et al., 2006).

As the gnawed hazelnuts provided evidence of the presence of dormice, the PTES provided nest tubes to put up in the hedgerows at Elm Farm in 2014. The role of hedgerows is recognised as of importance as a means for dormice to move around the landscape: both connecting woodlands and providing sources of food and nest sites in their own right. 56 tubes were set up, and following four checks between July and December 2014, 2 yellow necked mice were found in one tube.

FIGURE 39. MOUSE NESTING MATERIAL FOUND IN A NEST TUBE AT ELM FARM HEDGEROWS 2014 (PHOTO: C SREEVES, 2014)

Evidence of dormice using the hedgerows continued between 2014 and 2019 as a further 31 dormouse gnawed hazelnuts were found. Notably in 2015, ten dormouse gnawed hazelnuts were found in one location. Then in 2017 a further six nuts were found (Figure 40).

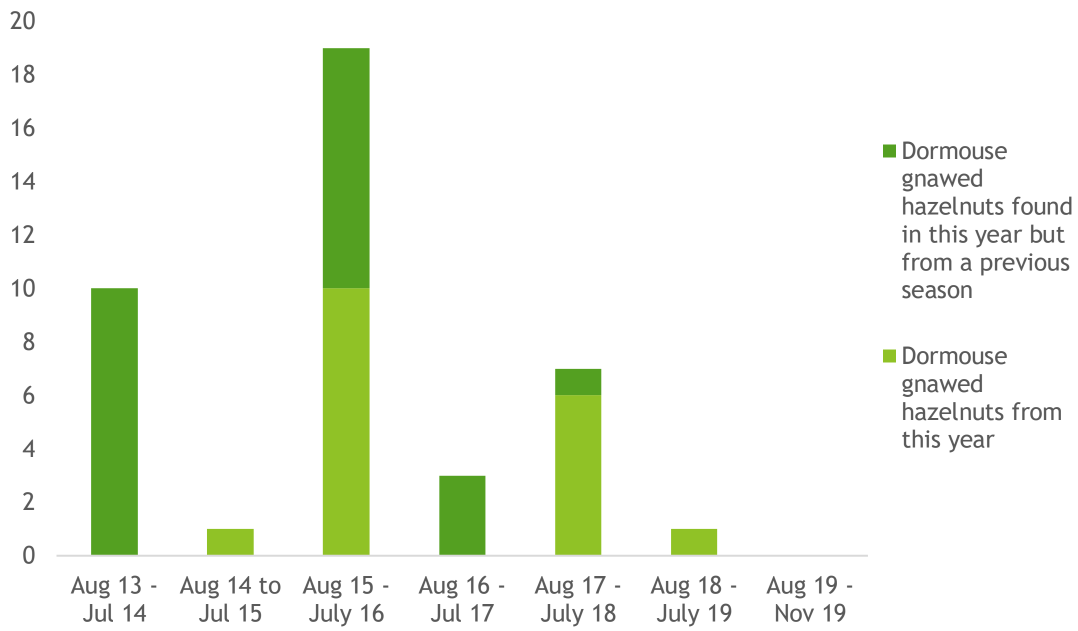


FIGURE 40. STACKED COLUMN CHART SHOWING TOTAL NUMBER OF DORMOUSE GNAWED HAZELNUTS FOUND AT ELM FARM 2013 - 2019

In 2015 ORC joined the PTES National Dormouse Monitoring Programme and 50 dormouse nest boxes were set up to replace the nest tubes (Figure 41). Locations selected included single species hazel hedgerows, an established narrow woodland strip bordering a stream and two shrubby clay pits. Despite the presence of dormouse gnawed hazelnuts no dormice were found during the 41 nest tube and box checks that took place from July 2014 to November 2019. It is possible that the dormouse population in the area is low and fluctuates, or there may be sufficient natural nesting sites in trees. Alternatively, the hedgerows at Elm Farm may be being used for dispersal by juveniles rather than as a permanent habitat.

FIGURE 41. VOLUNTEER PUTTING UP A DORMOUSE NEST BOX AT ELM FARM HEDGEROWS (PHOTO: C SREEVES, 2015)

The box checks included sightings of other small mammals including wood mice, yellow necked mice, and a pygmy shrew. Mice used the boxes both for nesting and caching nuts. The sightings of small mammals in the tube and boxes rose year on year from two in 2014 to twenty in 2018. This number declined dramatically in 2019 to six small mammal sightings. The provision of the nest boxes appeared to be contributing to an increase in the local blue tit population rising from 11 successfully fledged nests in the boxes in 2015 to 16 in 2019. There was in addition a box of great tits in 2019. Tree bumble bees, wasps, copper underwing moths and wax moth larvae were also seen in the boxes. Deer, hare, rat, squirrel and voles were either seen or there was evidence of them using the hedgerows (vole gnawed hazelnuts and rat footprints).

FIGURE 42. (LEFT) COLLECTING DATA ON SMALL MAMMALS FOR THE PTES (PHOTO: R BASHFORD, 2018) (RIGHT) MOUSE FOUND IN A NEST BOX AT ELM FARM HEDGEROWS (PHOTO: C SREEVES, 2017)

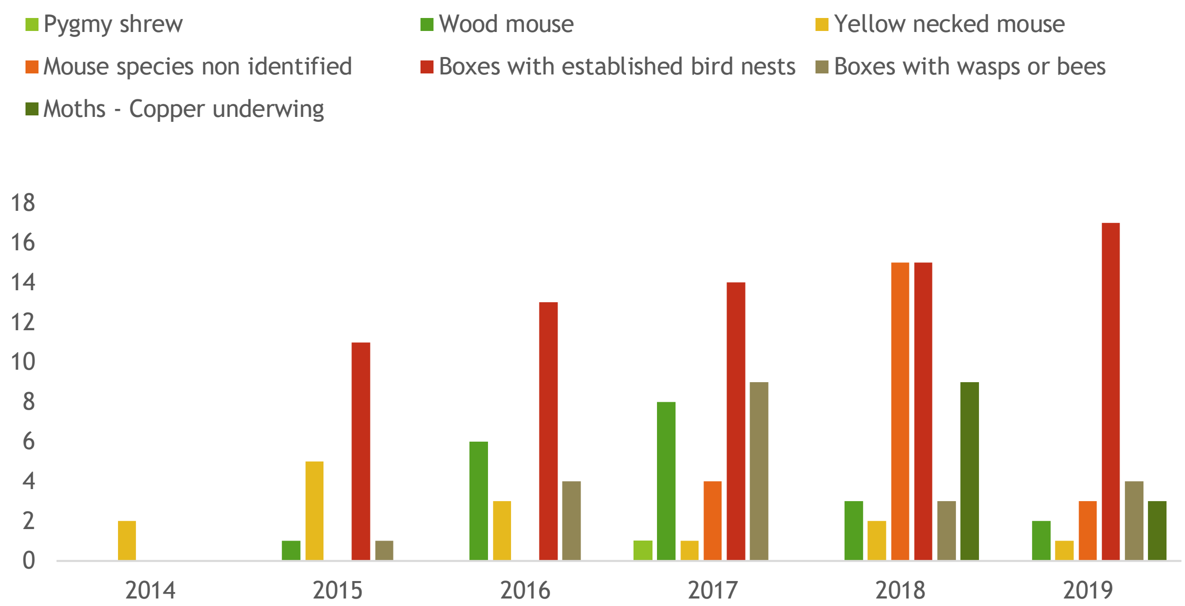


FIGURE 43. CHART SHOWING SPECIES FOUND IN DORMOUSE NEST TUBES AND BOXES AT ELM FARM HEDGEROWS 2014 - 2019

Over the course of seven years over 66 people took part in the dormouse project at Elm Farm Hedgerows. The nut hunts, nest tube and box checks were coordinated by licenced dormouse surveyor Corinne Sreeves who coordinated her team of volunteers. Contact with other local nature conservation organisations, including the Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust (BBOWT) was enhanced at a dormouse training day. An additional training day was also run independently by the Thames Valley Environmental Records Centre (TVERC) at ORC. The box checks contributed positively to the well-being of participants offering social interaction, the sharing of knowledge and expertise; physical exercise and enjoyment of the outdoor environment (Figure 44).

FIGURE 44. SMALL TEAM OF VOLUNTEERS SURVEYING AT ELM FARM HEDGEROWS (PHOTO: R BASHFORD, 2018)

The presence of dormice helped to inform the management of the hedgerows at Elm Farm. Connectivity was kept in mind when scientific field trials were planned, for example being considered when a 170 m section of hedgerow was selected for coppicing as part of a wood fuel harvesting machinery trial in December 2014. Some low impact hedgerow management was carried out by the

West Berkshire Countryside Volunteers with the aim of maintaining connectivity within the hedges. A leaflet with information on how to identify dormouse gnawed hazelnuts, spot natural nests and some guidance for coppicing hazel stools was prepared for the conservation volunteer group.

In November 2019 the nest boxes were removed from the site and reporting to the National Dormouse Monitoring Programme drew to a close following the sale of Elm Farm.

Making hedgerows pay their way: the economics of harvesting hedges for bioenergy

Existing landscape features, such as hedgerows, can contribute to food, fodder, material, and energy production for an EU bio-based circular economy. Our hedgerow coppicing trials demonstrated that hedgerows can be managed to produce woodfuel of a quality that meets industry standards. However, to be attractive to farmers, woodfuel production from hedgerows must be profitable. We used the FarmSAFE model to undertake a financial assessment with data generated from these trials (Smith et al, submitted). The net present value of standard hedgerow management (flailing every two years) was compared with those from alternative hedgerow management scenarios for woodfuel production over a 60-year time horizon. Costs associated with standard hedgerow management by flailing every two years were compared with hedgerows managed on a 15-year coppice rotation over a 60-year time horizon, under different management scenarios including coppicing using: 1) small scale machinery (chainsaw); 2) medium scale machinery (tree shears), and; 3) large scale machinery (Bracke felling head) (Table 13). The impact of excluding or including available hedgerow grants was also examined. Lastly, the effects of different energy prices were assessed assuming that woodchips could be: 1) sold off-farm into a local energy market; 2) used on-farm as a substitute for buying woodchips, or; 3) used on-farm as a substitute for heating oil.

TABLE 13. REVENUE AND COSTS ASSOCIATED WITH HEDGEROW MANAGEMENT ON A £ M^{-1} HEDGE AND A £ M^3 WOODCHIP BASIS

	£ m^{-1} hedge	£ m^3 woodchip
Revenue		
Hedgerow grant	£0.16	
Coppicing grant	£4.00	
Woodchip sale to woodfuel cooperative		£7.59
Equivalent woodchip purchase cost		£21.00
Equivalent heating oil replacement cost		£34.80
Costs		
Flailing (7 passes)	£0.25	
Chainsaw and chipping	£9.20	£36.80
Tree shears and chipping	£4.46	£17.80
Bracke felling head and chipping	£5.63	£22.50

Results

Using data from the hedgerow trials, the results showed that coppicing hedgerows for woodfuel production could provide a profit to the farmer. The sale of woodchips into an off-farm market was found to be profitable if harvesting with tree shears (medium scale harvesting capacity) or a Bracke felling head (large scale harvesting capacity), but chainsaw harvesting (small scale harvesting capacity) was unprofitable (Table 14). When considering the use of woodchips on farm to replace purchased woodchip or heating oil, the financial benefit to the farmer increased. Sensitivity analyses showed that the use of medium scale machinery (tree shears) made the hedgerow enterprise most resilient to changes in prices, grants, and costs. This scale of machinery is appropriate for local energy production whilst also being affordable to farmers and local contractors.

TABLE 14. THE NET PRESENT VALUE (NPV) AT 4% DISCOUNT RATE FOR HEDGE FLAILING AND THREE COPPICE HEDGE SYSTEMS AT THREE DIFFERENT WOODCHIP PRICES OVER A 60-YEAR PERIOD

	Flailed hedge (£ 100m^{-1})	Coppiced hedge for woodfuel		
		Chainsaw (£ 100m^{-1})	Tree shears (£ 100m^{-1})	Bracke head (£ 100m^{-1})
Discounted product revenue:				
1. Assuming off-site sale (at £7.59 m^3)	0	223	223	223
2. Assuming substitution for woodchip purchase (at £21 m^3)	0	617	617	617
3. Assuming substitution for heating oil (at £34.80 m^3)	0	1022	1022	1022
Discounted grant revenue				
All systems	376	846	846	846
Costs				
All systems	553	1269	713	850
Net present value:				
1. Assuming off-site sale (at £7.59 m^3)	-177	-200	357	219
2. Assuming substitution for woodchip purchase (at £21 m^3)	-177	194	751	613
3. Assuming substitution for heating oil (at £34.80 m^3)	-177	599	1156	1018

Scaling it up: farm-scale economics

The net benefit of using woodchip produced on farm in comparison with buying woodchip from an off-farm source or using heating oil to meet the energy needs of the farmhouses are shown in Table 15. At Elm Farm, the farmhouse requires 105 m^3 of woodchip each year and the equivalent cost of heating oil to meet this energy need is £3,654 yr^{-1}. The results showed that on farm production of woodchip using all three systems was more profitable than buying in woodchip or heating oil, with the tree shear system returning the greatest profit.

TABLE 15. THE BENEFIT OF PRODUCING WOODCHIPS ON FARM COMPARED WITH PURCHASING THE WOODCHIPS FROM AN OFF-FARM SOURCE OR PURCHASING HEATING OIL TO MEET THE ENERGY NEEDS OF THE FARMHOUSES.

	£ m^3	**Elm Farm**
Woodchip boiler size		30 kW
Woodchip boiler requirements		105 m^3 yr^{-1}
Cost of one year of heating oil equivalent	£34.80	£3,654.00
Cost of one year of imported woodchip	£21.00	£2,205.00
Cost of one year of woodchip by chainsaw	£36.80	£3,864.00
Cost of one year of woodchip by tree shears	£17.80	£1,869.00
Cost of one year of woodchip by Bracke	£22.50	£2,362.50
Grant revenue for harvested hedge	£16.64	£1747.20
Net benefit vs heating oil		
Chainsaw system	£14.64	£1,537.20
Tree shears system	£33.64	£3,532.20
Bracke system	£28.94	£3,038.70
Net benefit vs imported woodchip		
Chainsaw system	£0.84	£88.20
Tree shears system	£19.84	£2,083.20
Bracke system	£15.14	£1,589.70

Assuming a 2 m^3 woodchip yield from 100 m of hedgerow, a length of 420 m of hedgerow would need to be coppiced every year to meet the needs of the Elm Farm boiler. Thus, on a 15-year harvesting rotation, a total length of 6.3 km of hedgerow would need to be in a coppice rotation to supply the required quantity of woodchips on a continuous basis. Elm Farm has 9.5 km of hedgerow so potentially could meet this requirement although good practice regarding amount of the hedgerow network in a coppice rotation would recommend no more than 50% i.e. 4.75 km.

Our analysis shows that managing hedgerows for bioenergy provides the greatest benefit when the energy is used on farm to replace imported woodchip or heating oil, but this requires investment in a woodchip boiler and space to store the woodchip. These investment costs are not included in our analysis, nor are the establishment costs of planting new hedges included. In addition, our analysis does not take into account potential impacts on crop yields or animal production (positive or negative) of having taller hedges. Taller hedges may provide more shelter for animals and crops but towards the end of the rotation will reduce light availability for adjacent crops or pasture. Our farm-scale calculations demonstrate that it is theoretically possible to meet woodchip needs from on-farm resources for Elm Farm, but it may not be advisable to bring all (or the majority) of the farm hedges into a coppicing rotation. One solution to this may be to reduce the rotation length between coppicing. We based our calculations on a 15-year coppice rotation, but it may be possible to shorten this rotation, especially when there are fast growing species such as willow and hazel within the hedges. Further research is needed on re-growth rates of coppiced hedges to identify optimum coppice rotations.

Managing hedgerows for bioenergy production – key conclusions

These trials have demonstrated that woodchip of reasonable quality that is saleable on the open market can be produced from coppice management of hedgerows. The average yield of woodchip was 8.1 tonnes per 100 m at 30% moisture with a large range (5.5 to 13 tonnes) depending on the dominant species and the age of the stems at harvest. These yields are from hedges at the start of a new coppice management cycle. Future yields will vary depending on species and coppice rotation length. It should be noted that in some cases a considerable amount of time is needed to get old hedges ready to coppice (removal of outgrowth, old fence lines etc.), but that the labour effort for management should reduce once a rotation has been established.

The length of hedge to be coppiced that year is a major factor in deciding which method will be the most economic. For all the harvesting and chipping methods trialled the lowest cost per metre was reached when the hedge length approached the machines' maximum efficiency for a day, with smaller scale methods generally better suited to shorter lengths of hedge. However, every hedge is different, and each hedge should be assessed and managed on its own merits. Regrowth rates and response to coppice management varied between hedges and species. Hazel, willow, field maple and hawthorn all responded positively to coppice management. Blackthorn regrowth was slower and often from underground suckers but the initial biomass collected at first cut from the mature blackthorn dominated hedge was high.

The type of chipper used made only a small difference to overall chip quality. It is however important that the woodchip is matched to a boiler able to cope with the variable nature of hedgerow woodchip. The presence of long shards and slithers is one of the biggest issues with hedgerow woodchip and all samples also had a relatively high ash content due to the high bark ratio. Despite this, the chip from Elm Farm was sold on the open market.

The bulky nature of woodchip and cost of transportation make woodfuel better suited to local use and our analysis shows that managing hedgerows for bioenergy provides the greatest benefit when the energy is used on farm to replace imported woodchip or heating oil. Data from the trials also indicates that although un-coppiced hedges sequester larger quantities of carbon, total carbon savings are higher when hedges are managed by coppicing due to the substitution of fossil fuels via the production of woodfuel.

Using woodchip from hedges on-farm has the potential to provide a local sustainable source of energy, as well as rejuvenating old or unmanaged hedges and supporting wildlife. However, consideration should be taken when coppicing, of connectivity and the role that hedges play in the wider landscape. Introducing new coppice management to hedgerows has an impact on the biodiversity, microclimate and appearance of the landscape, especially when coppiced species (e.g. blackthorn) are slow to regrow. Where possible, hedge management should be left until late winter to maximise the food resources available for wildlife. However, soil conditions can be a limiting factor when considering which machinery is most appropriate, and the heavy soils and poor drainage across much of Elm Farm meant that management activities were best planned in late autumn/ early winter.

Integrated bioenergy and livestock production

Introduction

An innovative alley cropping system integrating short rotation coppice (SRC) for bioenergy and livestock production was established on Elm Farm in 2011 with the aim of assessing the potential impacts of utilising agroforestry for low-input and organic dairy systems. This section reports on the key results of the nine years of research from the early years of establishment through to current day, including tree establishment and performance, tree:crop interactions, pasture and whole crop barley productivity, microclimate impacts, invertebrate and plant biodiversity and financial performance. New data on pasture biodiversity, introduction of sheep, and yield of the SRC was collected during autumn 2019.

There are many conflicting demands for agricultural land: the need for increased food production for a growing population, the demand for renewable energy production from biomass crops and the recognised importance of agricultural land for supporting wider ecosystem services such as protecting soil, water and air quality, mitigating climate change and supporting biodiversity. Combining trees for bioenergy and agriculture on the same parcel of land using an agroforestry approach is seen as a way to meet these conflicting demands. However, evidence on the performance of such systems in the context of European low-input production systems (and the UK in particular) is still lacking. As part of the European FP7 Sustainable Organic and Low-Input Dairying (SOLID www.solidairy.eu) project, a replicated plot trial combining willow and alder SRC with cattle production was planted on Elm Farm to provide economic and environmental (microclimate) data on establishing and managing a system (Smith et al, 2016). Within the subsequent European FP7 Agforward project (www.agforward.eu), further data was collected on the performance of the system (Smith et al. 2017).

Trial description

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 (Figure 46). 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. As the widest equipment used for pasture management is the 9 m wide rake, it was initially decided that the alleys would be 12 m in width from centre of tree row to the centre of the neighbouring tree row (i.e. 9 m pasture alley and 3 m tree row). However, two years into the trial, following feedback from the farmer with regards the difficulties of manoeuvring in the alleys, it was decided to remove every other tree row and thus make the alleys 24 m wide (21 m pasture alley and 3 m tree row). Trees were planted in twin rows, 0.7 m between twin rows and 1.0 m between trees within rows. 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 47). First harvests of the SRC started in spring 2016, with a third of the rows cut in 2016, 2017 and 2018. A diverse sward mix was established in autumn 2018 and grazed by sheep during the summer 2019.

FIGURE 45. THE SILVOPASTURE TRIAL AT ELM FARM FROM THE AIR

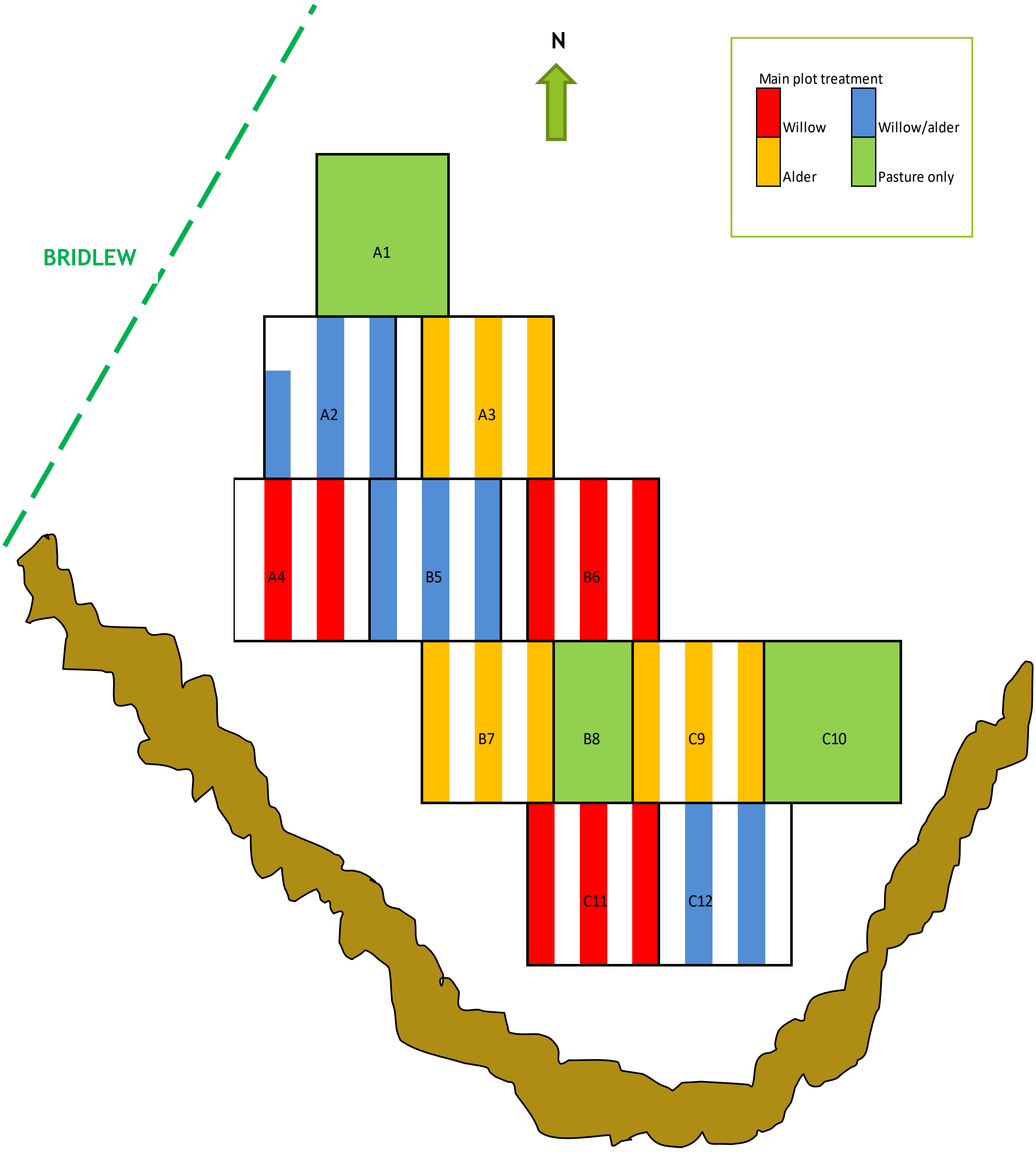


Figure 46. Design of the replicated block silvopasture trial at Elm Farm

FIGURE 47 TIMELINE FOR THE SILVOPASTURE TRIAL AT ELM FARM






2011	
April	Trial site marked out, tree row grass mown short, jute mulch installed and trees planted
June	Early silage cut
Sept	Boundary electric fence installed
Oct	Late silage cut
2012	
March	Black fabric mulch installed, trees planted, woodchip mulch applied
July	Early silage cut
Oct	Late silage cut
2013	
March	Beating up and cutting back. Every other tree row removed. Woodchip on all.
June	Silage cut
Sept	Pasture topped
Dec	12 Cattle grazed for 20 days
2014	
March	Beating up gaps
June	Silage cut
2015	
June	Silage cut
July	Electric fencing installed on tree rows
August	Cattle introduced
2016	
February	Tree rows 3, 6 & 9 coppiced following browsing by cattle
October	Oats for whole crop silage sown at a rate of 185 kg/ha
2017	
January	Tree rows 1,4 & 7 coppiced
June	Oat whole crop silage cut
2018	
February	Tree rows 2, 5 & 8 coppiced
October	Alleys reseeded with diverse sward mixture
2019	
August	Sheep introduced with open access to tree rows

Tree establishment

The establishment of coppice under organic conditions presents particular challenges with regards weed and pest control. In conventional SRC systems glyphosate-based herbicides and insecticides to control leatherjackets are recommended during the establishment phase. As these chemical controls aren't allowed in organic systems, alternative methods of weed and pest control must be considered, and the effectiveness and cost-benefit ratio investigated. For example, weed control using a mulch (biodegradable jute/hessian mulch, composted farmyard manure, straw), a cover crop such as clover or mechanical weeding; and fencing or tree guards to prevent rabbit and deer browsing damage, compared to 'no control'.

Our research compared three options available for organic farmers: direct planting into pasture (the cheapest option); woodchip mulch (using an on-farm or locally available resource) and a fabric mulch barrier (the most expensive option) (Smith et al, 2016). In the first year, a biodegradable jute/hessian fabric was used; in the second year, a photodegradable spun-bonded propylene black fabric was trialled. Both of these were in the form of 1 m wide fabric rolls that were fixed to the ground using biodegradable plastic anchoring pegs. Tree survival, weed biomass and biodiversity, and soil moisture were compared between the different weed control methods to identify the most successful approach.

FIGURE 48. ESTABLISHING THE SILVOPASTURE TRIAL AT ELM FARM

The main plots were divided into three sub-plots (Figure 46), each 16.6m long, and weed control treatments were randomly assigned to each sub-plot (i.e. a split plot design).

Year 1 (2011)

In the first year, prior to tree planting, the grass sward was mown short and the rolls of jute fabric laid down and fixed with anchoring pegs (Figure 48). Slots were cut into the fabric and the alder and willow trees planted in April 2011 by local contractors. The original plan to apply woodchip when the willow cuttings had started shooting was not carried out due to failure of the majority of the willow to establish. Therefore, the trial in 2011 compared tree establishment in jute fabric mulch sub-plots with direct planting into the grass sward. In August 2011, all trees were assessed in the central tree row of each plot and recorded as alive or dead.

Year 2 (2012)

Due to the high rate of failure, all sub-plots of the 'woodchip' and 'no control' treatments were replanted in spring 2012, and dead trees within the 'jute' treatment replaced. Black propylene fabric was fixed, trees planted, and woodchip applied in March. Tree establishment was assessed in October 2012 as before.

Year 3 onwards

Dead trees were replaced, all established trees cut back to 15 cm aboveground, and woodchip applied to all plots in March 2013, and tree establishment assessed in December 2013. Gaps were once again beaten up in spring 2014 and tree establishment, height and number of branches assessed in August 2014. Finally, trees were assessed in July 2015 ahead of introduction of the cattle into the trial.

The statistical analysis was carried out using R version 2.10.0 (R Development Core Team, 2009). To identify the effect of weed control on tree establishment, % tree establishment was analysed for the period 2011-2015 with linear mixed effects models using the R library *lme4*. Weed control treatment and tree species (willow; alder; mix) were included as the fixed factor, and replicate block as the random effect. Likelihood ratio tests were used to determine significance levels of the fixed factors by comparing alternative models. In 2011, tree establishment in jute and direct planting subplots were compared; in 2012, establishment rates were compared between black propylene mulch and woodchip. From 2013 to 2015 when the jute subplots only were assessed, tree species was the fixed factor, and replicate block was the random effect.

Results

2011

The spring of 2011 was exceptionally dry and tree survival rates were low, particularly for willow (Figure 49). Weed control significantly affected tree establishment success (x^2 =20.5, p<0.001) with % survival 42.5 % (± 10.46 standard error) lower in the no-control plots compared with the jute mulch fabric. Establishment also varied significantly depending on species (x^2 =13.7, p=0.001), with alder trees having a much better rate of survival compared with mixed species and willow trees (alder = 59.0 % ± 13.43 standard error, mix = 30.3 % ± 16.71, willow = 24.3 % ± 16.71), but there were no significant interactions between the tree species and weed control treatment.

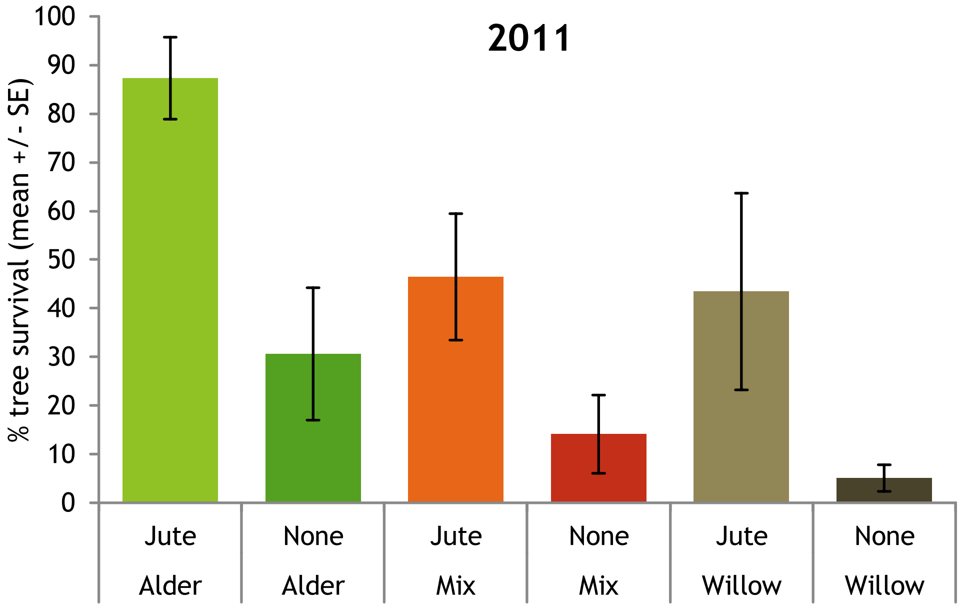


FIGURE 49. MEAN TREE SURVIVAL IN 2011 BETWEEN THE DIFFERENT TREE TREATMENTS

2012

Tree survival rates were higher in 2012, and there were no statistically significant differences between the woodchip and black propylene fabric sub-plots (Figure 50). However, there were significant differences again between different tree species treatments (x^2 = 9.94, p=0.007), with willow trees having a lower rate of survival compared with mixed species and alder tree plots (alder = 63.4% ± 10.98, mix = 58.3% ± 8.50, willow = 37.2% ± 8.50). There were no significant interactions between the tree species and weed control treatment.

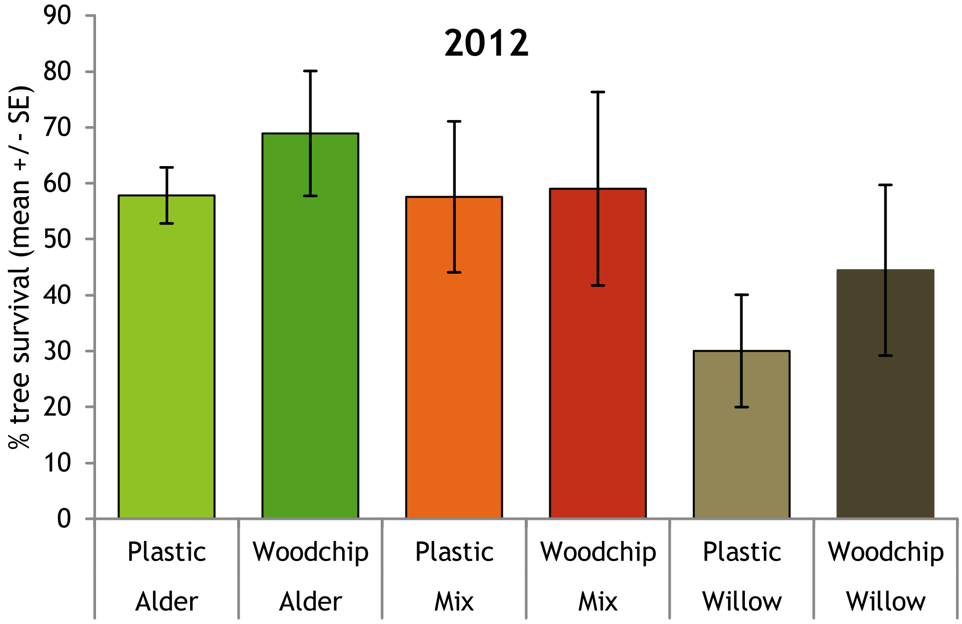


FIGURE 50. MEAN TREE SURVIVAL IN 2012 BETWEEN THE DIFFERENT TREE TREATMENTS

2013-2015

Survival rates in the jute sub-plots were still rather low in 2013, and only by 2015 were they over 90% (Figure 51). There were no significant differences between species in any of the years.

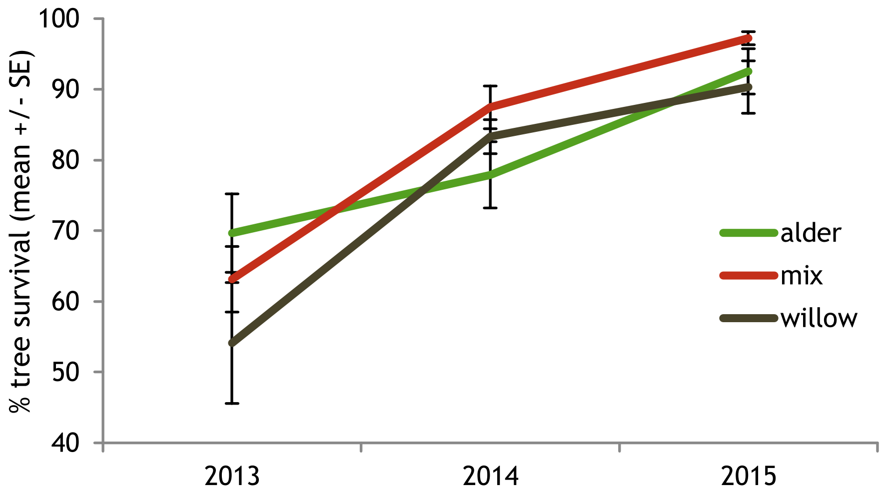


FIGURE 51. MEAN TREE SURVIVAL IN FROM 2013 TO 2015 BETWEEN THE DIFFERENT TREE TREATMENTS

Soil moisture

Soil moisture was measured in each sub-plot in the central tree row and adjacent tree row to the east using a HH2 Moisture Meter with the SM300 soil moisture probe from Delta T (average of three readings per sample point: May-Dec 2012). Soil moisture data from May to December 2012 were analysed monthly using ANOVA, with weed control method and replicated block as fixed factors. *Post hoc* testing to compare means was carried out using the Tukey HSD test.

There were significant differences in soil moisture in the three weed control treatments in August ($F=7.28$, $p=0.002$), September ($F=5.42$, $p=0.007$) and October ($F=5.6$, $p=0.007$) 2012 (Figure **52**). The differences were between the jute and black propylene fabric sub-plots, with soil moisture lower under the jute fabric. Soil moisture was also significantly different in the different replicate blocks in every month; in general, soil moisture was lowest in Block C (bottom of the field) and highest in Block A (data not shown).

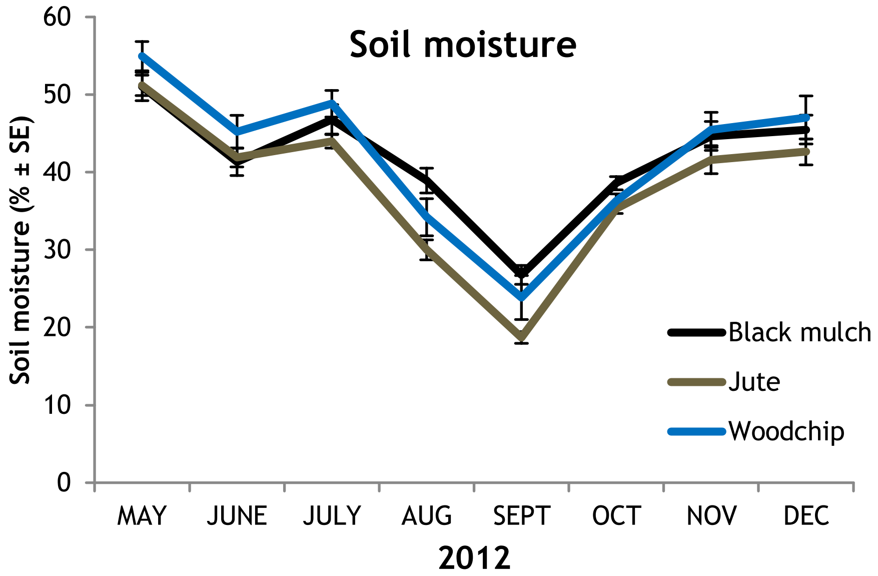


FIGURE 52. PERCENTAGE SOIL MOISTURE FOR THE DIFFERENT MULCH TREATMENTS BETWEEN MAY AND DECEMBER 2012

Weed assessments

To assess weed pressure in the tree rows under different weed control treatments, % cover of all species in 1m^2 quadrats was recorded in June from 2011 to 2015. In 2011 and 2012, two quadrats (one in central tree row, one in adjacent tree row to the east) were assessed per sub-plot in each of the agroforestry main plots. From 2013 to 2015, following the application of woodchip to all plots in winter 2012/13, assessments were made only in the jute sub-plots.

Total % weed cover per m^2 was analysed separately for 2011 and 2012 with linear mixed effects models using the R library *lme4*. Weed control treatment and tree species (willow; alder; mix) were included as the fixed factors, and replicate block as the random effect. Likelihood ratio tests were used to determine significance levels of the fixed factors by comparing alternative models. In 2011 % cover in jute and direct planting subplots was compared; in 2012, % cover was compared between black propylene mulch and woodchip. From 2011 to 2015 when only the jute subplots were assessed, tree species and year were the fixed factors, replicate block was the random effect, and year was included as a repeated measure.

To investigate the effectiveness of different weed control treatments in the five years following tree planting, species % cover data were analysed using canonical ordination techniques in Canoco 4.5.1 (Ter Braak & Šmilauer, 2003). A preliminary DCCA produced short gradient lengths (<2) indicating that linear ordination methods were most appropriate for these data (Lepš & Šmilauer, 2003).

First, the species % cover data from 2011 was analysed using redundancy analysis (RDA) to compare species composition within the tree rows in the jute fabric and no weed control subplots. The interactions between weed control (jute; no control) and tree species (willow; alder; mix) were included as explanatory variables, coded as nominal variables. Monte Carlo permutation tests to determine the significance of all canonical axes were performed, with permutations restricted within replicate blocks. This analysis was repeated for 2012, to compare species composition within the black fabric and woodchip sub-plots.

A final analysis was performed on the jute subplots only, to identify temporal shifts in community composition as the system established and to test whether any temporal trends in the species composition of the tree row understorey were significantly associated with the tree species treatments. Year (2011-2015) was treated as a continuous variable and the interactions between year and treatment (tree species) were statistically tested using Monte Carlo permutation tests (full model, 999 repetitions) with permutations restricted within the five replicates of each plot (i.e. repeated measures). Plot was included as a covariable, thus removing the average (over years) of each plot, so that only the changes within each plot were analysed.

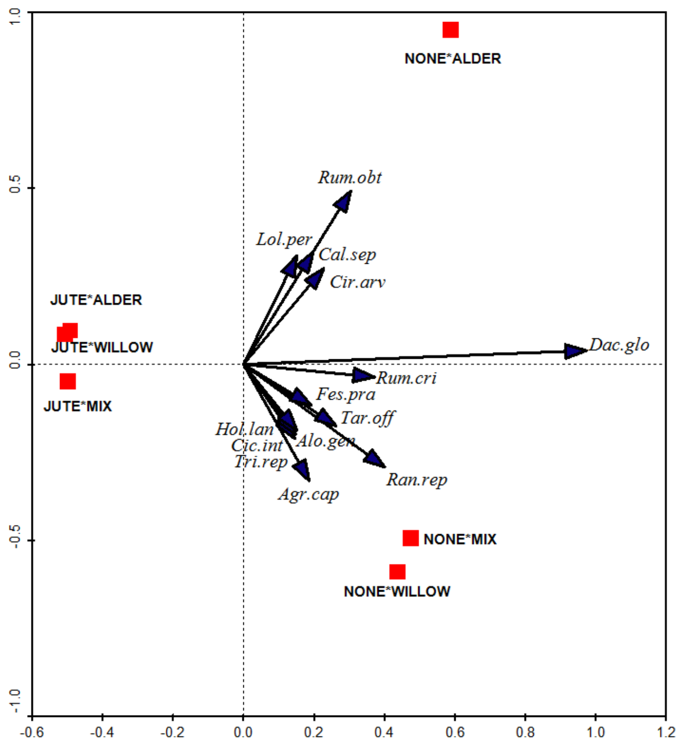


Figure 53. RDA bi-plot of plant assemblages in jute mulch and no-control sub-plots 2011. Axes I and II showing species with a fit greater than 10%.

In 2011, there were significant differences in % vegetation cover between weed control treatments (x^2 = 86.8, p<0.001). Vegetation cover was significantly higher in the no weed control plots (jute treatment = 2.48% ± 7.61, no control = 111.4% ± 5.50). There was no significant difference in vegetation cover between the three tree species treatments. RDA analysis indicated that species composition was significantly different between the jute and no control sub-plots, with the canonical axes (Axes 1-4) accounting for 74.6 % of the variability in the species data (F-ratio = 21.4, p=0.001). The resulting ordination diagram (Figure 53) shows that this difference is primarily due to a higher cover of all species in the no-control plots compared with the jute plots along Axis 1, while Axis 2 separates out the no-control alder plots from the no-control mix and willow plots, due to higher cover of *Lolium perenne* (perennial rye grass), *Rumex obtusifloius* (broad-leaved dock), *Calystegia sepium* (hedge bindweed) and *Cirsium arvense* (creeping thistle).

In 2012, weed control treatment (woodchip and black fabric mulch) significantly influenced vegetation cover in the tree understorey (x^2 = 16.8, p<0.001). Vegetation cover was significantly higher in the woodchip plots (black fabric treatment = 6.28% ± 8.10, woodchip treatment = 57.7% ± 11.45). There was no significant difference in vegetation cover between the three tree species treatments. RDA analysis indicated that weed control treatment (woodchip and black fabric) also significantly influenced species composition in the tree understorey, with the canonical axis (Axes 1-4) accounting for 39.1 % of the variability in the species data (F-ratio = 4.35, p=0.001). The main difference in composition, shown along Axis 1 (eigenvalue = 0.349), was between the black fabric sub-plots and woodchip sub-plots, with higher species cover of all species in the woodchip subplots (Figure 54). Axis 2 (eigenvalue 0.032) separates out the woodchip willow sub-plots from the woodchip alder and woodchip mix plots, due to higher cover of *Ranunculus repens* (creeping buttercup), *Holcus lanatus* (Yorkshire fog) and *Trifolium repens* (white clover).

Vegetation cover in the jute plots increased from 2011 to 2015, with a decrease in 2013 when woodchip was applied to all plots. Percentage cover was significantly different under different tree species (x^2 = 6.78, p=0.034), with alder having lower % cover than the mixed species and willow plots. Year also significantly influenced % cover ((x^2 = 6.97, p<0.008), but there was no significant interaction between tree species and year. (N.B. Total % cover can be over 100% due the three-dimensionality of plant growth).

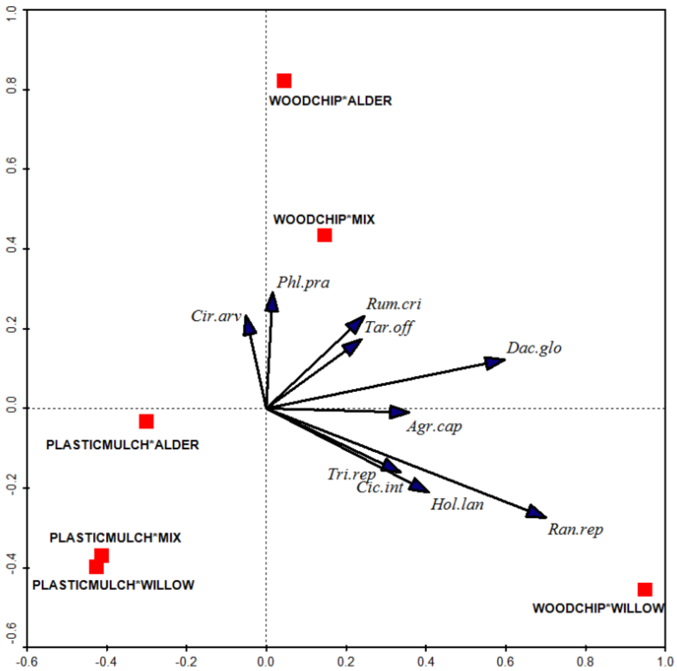


FIGURE 54. RDA BI-PLOT OF PLANT ASSEMBLAGES IN BLACK MULCH (PLASTIC MULCH) AND WOODCHIP SUB-PLOTS 2012. AXES I AND II SHOWING SPECIES WITH A FIT GREATER THAN 10%.

Silvopasture trial establishment conclusions and lessons learnt

Jute fabric mulch significantly increased survival rates of the newly planted trees compared with direct planting into the existing grass sward, with the bare-rooted alders establishing much better than the willow cuttings. Spring 2011 was much drier and warmer than usual, and combined with competition from the existing grass sward, it seems likely that this affected the willow cuttings (which had no roots) more than the alder saplings with their existing rootballs. In 2012, tree survival was similar within the woodchip and black propylene fabric mulch plots, although once again, willow establishment was significantly lower than the alders. However, by 2013 and through the following years to 2015, willow and alder rates of survival were not statistically significantly different from each other, although by 2015, alders were significantly taller than the willows.

Both fabric mulches fell apart quite quickly, with weeds and grass growing through the mulch (Figure 55, left) and there was some evidence of animals (badgers?) digging and tearing apart the fabric (Figure 55, right). Unsurprisingly, vegetation cover was initially much lower in the jute sub-plots when compared with the direct planting sub-plots, but by the second year, it had increased to around 75%. The black propylene fabric sub-plots had significantly lower weed cover than the woodchip sub-plots just three months after both had been applied, but as discussed above, this did not seem to impact on tree establishment. The fabric mulches would probably have lasted longer if laid onto bare soil rather than existing grass swards.

FIGURE 55. DIFFERENT MULCHES USED AS WEED SUPPRESSION FOR THE SILVOPASTURE TREES DURING THE ESTABLISHMENT PHASE

The alder plots had lower vegetation cover than the willow and mixed species plots, possibly because the alder trees were bigger and cast more shade. It is interesting to note that the vegetation community within the alder plots developed into one with higher proportions of cocksfoot, a grass that is fairly shade-tolerant, while within the more open willow plots, white clover increased in cover.

Soil moisture in 2012 was significantly lower within the jute sub-plots compared with the black propylene fabric sub-plots; there were no differences between the woodchip plots and the black fabric mulch. Soil moisture was measured a year after the jute fabric had been installed, and the jute fabric had been laid during the dry spring of 2011, which suggests that the jute inhibits the amount of rainwater penetrating through to the soil.

Some visitors to the site expressed concerns about the possibility of rodents such as voles living under the fabric and damaging the trees, although we found no evidence of this. Browsing by deer was a more obvious problem, with willow seemingly favoured over alder. Electric fencing was installed along the boundary closest to a patch of woodland, which was the likely route of deer entering the field, but in hindsight, all boundaries should have been fenced. At the time, the cost of deer fencing the entire field was deemed too expensive.

There was no soil preparation before planting, and trees were planted directly into the existing grass sward. Tree survival rates are likely to have been much better if trees were planted into bare soil to reduce competition effects and sub-soiling may have been beneficial, particularly in areas where compaction was evident.

With the woodchip being free (from a local tree surgeon), and tree survival rates similar to those in the black fabric mulch sub-plots, this suggests that woodchip provides a good approach to weed control in newly planted agroforestry systems. Applying woodchip using, for example, a feeder wagon, is much less labour intensive than laying the fabric mulch, although there were concerns about damage being caused by the force of the woodchip coming out of the trailer and burying the young trees, and in many cases the trees had to be uncovered by hand. Ideally the woodchip would be topped up annually for the first two to three years after planting. However, one difficulty we experienced is that the window of opportunity for applying the woodchip was very narrow, with the ground too wet to support the weight of a tractor and full trailer for most of the winter, and then by the time it had dried out, the grass was almost ready for ensiling, and it was impossible to access the tree rows without damaging the sward.

Tree height

All established trees were coppiced in March 2013. Tree heights were measured in August 2014 (one year regrowth) and July 2015 (two years regrowth) (Figure 56). 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 (Rows 3, 6 & 9). All trees were measured again in November 2016 (Figure 57). The alder showed good re-growth with heights similar to what they were pre-coppicing (Figure 58a). 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 58b).

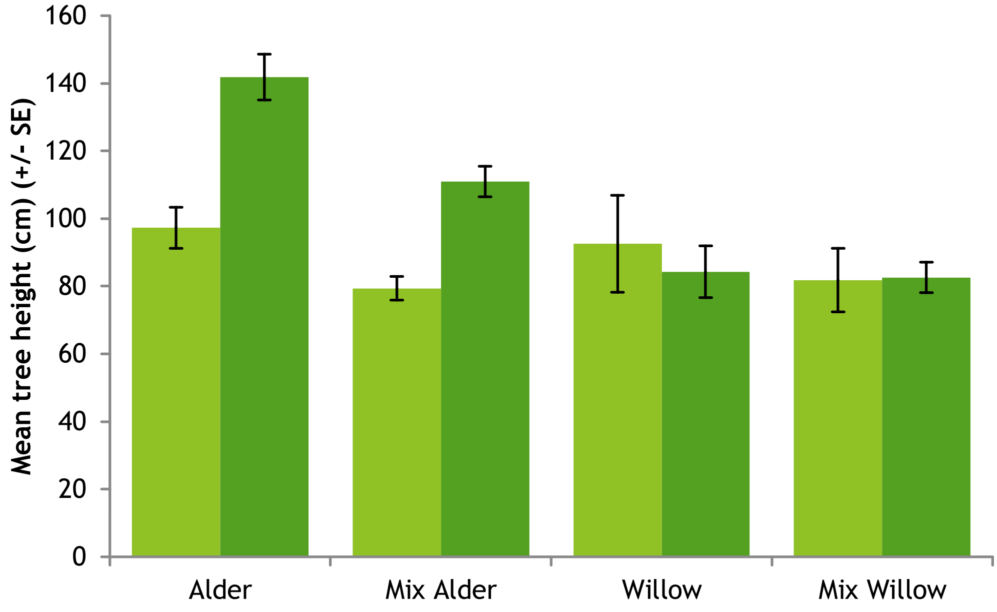
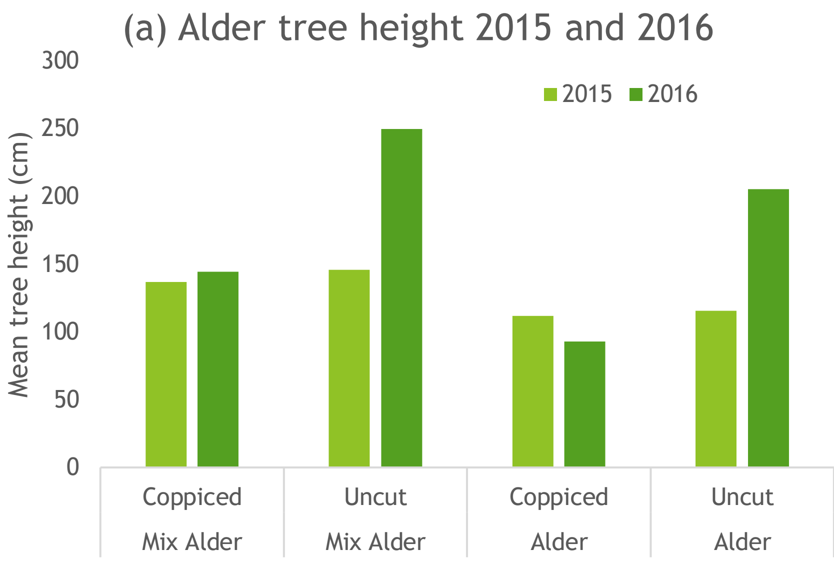


FIGURE 56. TREE HEIGHT IN 2014 (LIGHT BARS) AND 2015 (DARK BARS)

FIGURE 57. MEASURING TREE HEIGHTS, NOVEMBER 2016



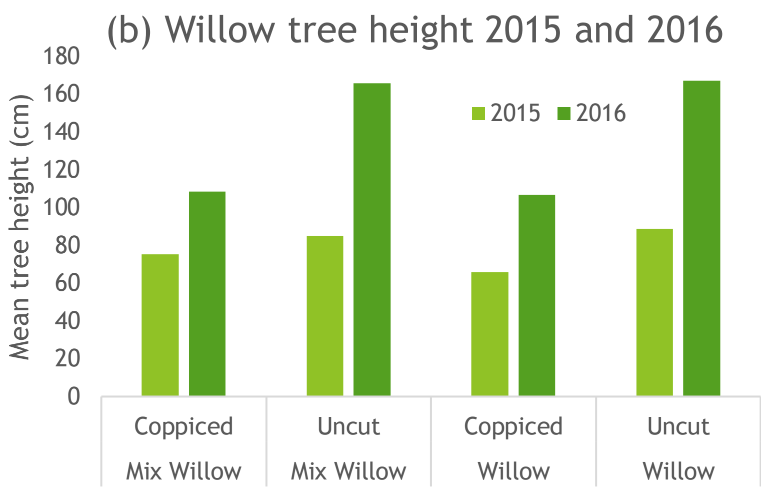


Figure 58. Tree height of (a) alder and (b) willow in 2015 (pre-coppicing) and 2016 (one third of tree rows coppiced)

Trees in Rows 1, 4 and 7 were coppiced in January 2017 and those in Rows 2, 5 and 8 in February 2018. In August 2018, the heights of all 525 alder trees were measured by intern, Ellie Brown (Figure 59). The results show that the trees double in height between the 1st and 2nd year but then slow in upward growth to gain an additional 20 cm between the 2nd and 3rd year.

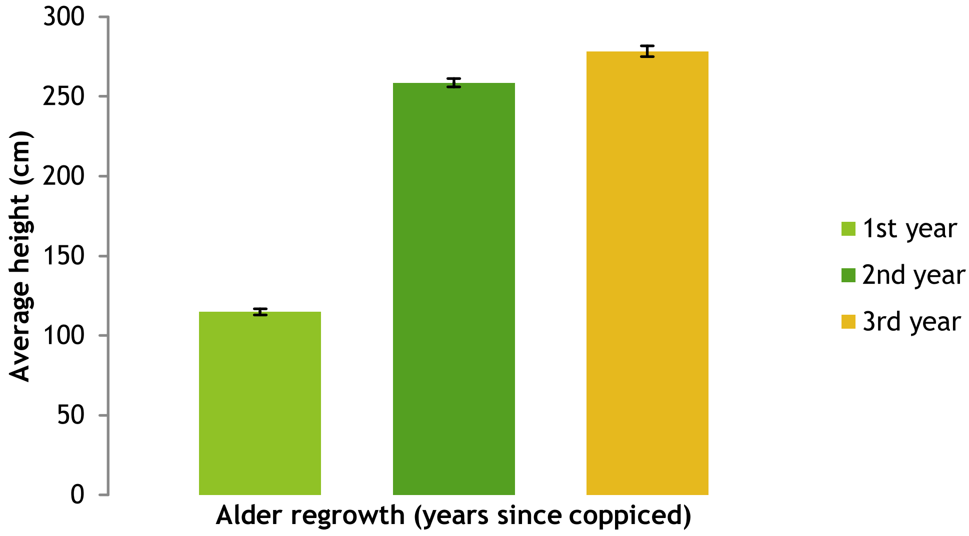


FIGURE 59. AVERAGE HEIGHT OF ALDER REGROWTH THE FIRST, SECOND AND THIRD YEARS FOLLOWING COPPICING

Tree biomass

Trees from plots in three rows (Row 3, 6 and 9) were coppiced by chainsaw in February 2016 after browsing by cattle during summer 2015. No data were recorded as the trees had been selectively browsed by the livestock.

Trees from plots in three rows (Row 1, 4 and 7) were coppiced by chainsaw in January 2017 and dried in the field until chipping in early March 2017. This was the first harvest of these trees since they were coppiced to the ground in March 2013 to encourage multiple branching (i.e. 4 years regrowth). 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.

Trees from plots in three rows (Row 2, 5 and 8) were coppiced by chainsaw in February 2018 and dried in the field until chipping in late March 2018. This was the first harvest of these trees since they were coppiced to the ground in March 2013 to encourage multiple branching (i.e. 5 years regrowth). Woodchip volume per plot was recorded and yields were calculated per tree and per hectare of agroforestry, based on a tree density of 833 trees per ha.

In March 2017, 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). 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 may 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 six years after planting, rather than three as with most willow SRC.

In Spring 2018, yields had increased considerably compared with the previous year (Table 16,), although willow in particular was still lower than standard SRC yields. Now the roots are well established, we expect that productivity will increase, and as can be seen from the re-growth measurements (Figure **58**), tree heights one year after coppicing are already higher than pre-coppicing.

TABLE 16. WOODCHIP YIELDS FROM FIRST HARVEST OF SINGLE SPECIES WILLOW AND ALDER, AND MIXED ALDER AND WILLOW SHORT ROTATION COPPICE IN MARCH 2017 AND MARCH 2018

Species	Age of regrowth	Plots (n)	Volume		Weight (oven dried)	
			cm^3/tree (SE)	m^3/ha	kg/tree	t/ha
Alder 2017	4	3	3560 (960)	2.96	0.61	0.51
Alder 2018	5	2	5855 (2196)	4.88	1.01	0.84
Willow 2017	4	3	270 (70)	0.22	0.03	0.02
Willow 2018	5	2	2794 (1354)	2.33	0.31	0.26
Mix 2017	4	2	1250 (300)	1.04	0.20	0.17
Mix 2018	5	2	4635 (0)	3.86	0.74	0.62

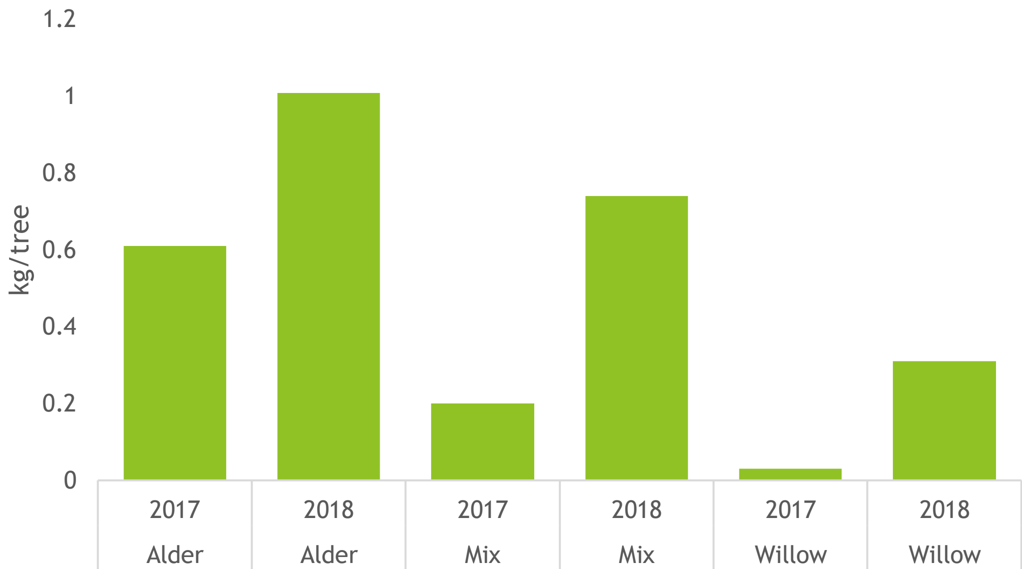


FIGURE 60. BIOMASS YIELDS (KG/TREE) **FOR THE FIRST HARVEST** FROM THE DIFFERENT TREE TREATMENTS IN THE ELM FARM SILVOPASTURE TRIAL

ORGANIC RESEARCH CENTRE ELM FARM

FIGURE 61. COPPICED ALDER SRC MATERIAL IN THE FIELD READY FOR CHIPPING. CHIPPING SRC USING A SELF PROPELLED TIMBERWOLF CHIPPER.

In March and December 2019, we focused on biomass of the alder trees only. In each of the alder plots, five random trees per row were coppiced and weighed in the field (5 trees x 3 ages of re-growth x 3 replicate plots = 45 trees). Sub-samples were oven dried and weight to volume calculated. In March 2019, trees were in their first to third year of re-growth. In December 2019 this was repeated after another season's growth (i.e. second to fourth year of re-growth).

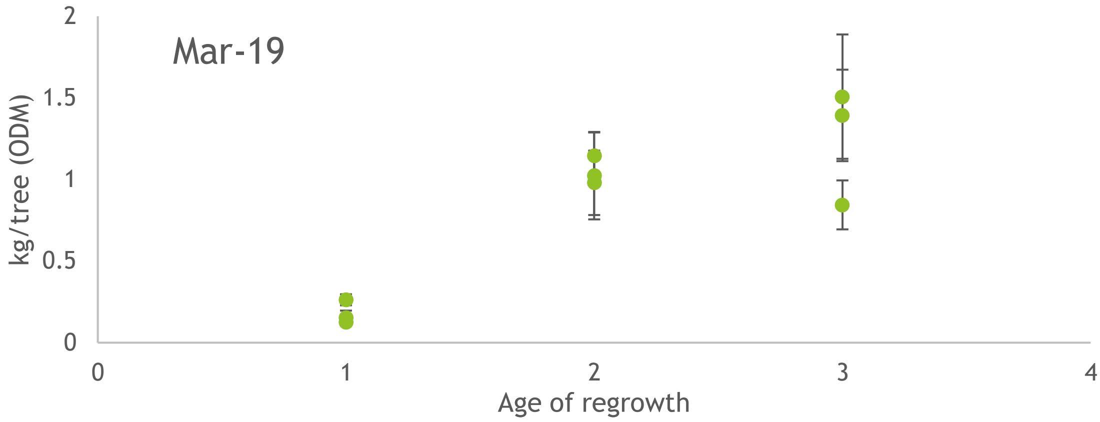


FIGURE 62. REGROWTH OF ALDER COPPICE (KG/TREE ODM) MEASURED IN MARCH 2019 AT THREE DIFFERENT AGES SINCE COPPICING

Figure 62 shows that while there was significantly more biomass in second year regrowth, the gain within the third year was less. However, the data from December 2019, when trees had gone through another growing season, showed that the third year trees were twice the biomass of second year re-growth, with little additional biomass in the fourth year regrowth (Figure 63). There seems to be a lot of variation between plots, probably reflecting underlying soil differences, and it is likely that weather conditions within the growing season may impact biomass gain from year to year.

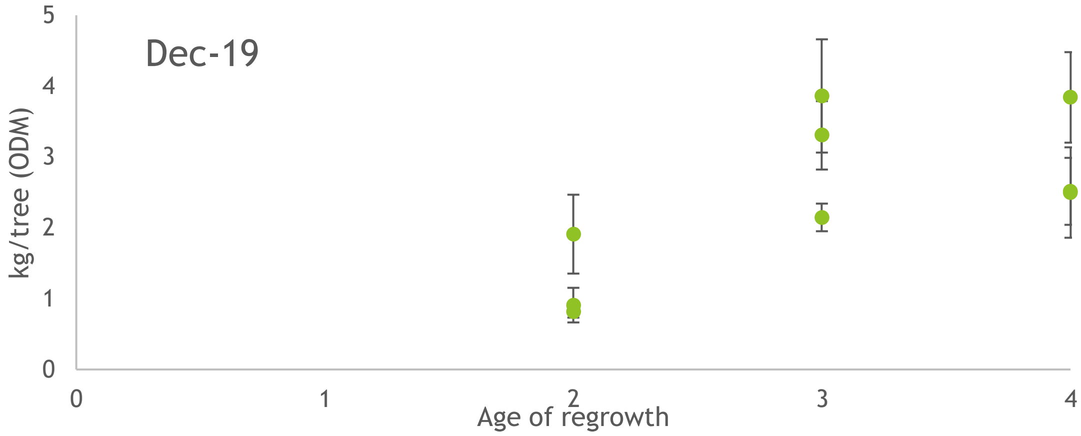


FIGURE 63. REGROWTH OF ALDER COPPICE (KG/TREE ODM) MEASURED IN DECEMBER 2019 AT THREE DIFFERENT AGES SINCE COPPICING

Tree height and biomass conclusions

First cut willow yields in the trial system are much lower than these standard figures for first cut of willow SRC, which may be due to a number of factors including deer damage, competition with grasses during the establishment phase, lower soil fertility (many SRC willow systems are fertilised), or unsuitable species/varieties. In contrast 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.

Alder height gain and biomass increase slowed in the third year after coppicing and biomass gain in the fourth year after coppicing slowed even further, suggesting a shorter coppice rotation may be optimal to gain maximum biomass. However, further research is needed as these results are from a single site with a lot of variation between plots and it is also likely that weather conditions within the growing season may impact biomass gain from year to year.

Tree:crop interactions

Pasture biodiversity and productivity

Agroforestry systems are usually considered as increasing overall productivity due to the complementarity of trees and agricultural component (Cannell et al 1996; Sinclair et al 2000). However, there are concerns within the farming community that integrating trees within pasture will negatively impact on pasture productivity and quality. Within northern temperate regions, the main limiting resource for plants is usually light and studies have shown that shading has reduced yields in temperate silvopastoral systems in both deciduous and evergreen systems (Benavides et al., 2009).

During the early years following tree establishment, it has been shown that trees have few effects on pasture as tree crowns are small (Guevara-Escobar et al., 2000), although this will depend also on growth rates and spacing. Higher pasture yields have been recorded in young agroforestry systems compared to open pasture; beneath a three year old stand of *Pinus radiata*, pasture yields were 16 % higher (Hawke 1991, in Benavides et al., 2009). However, as the system develops, tree effects on pasture productivity may be dramatic. For example, 15 year old poplars at 16-44 stems/ha reduced pasture productivity by 27 % compared to open pasture and mature trees (29-40 years old) at 37 stems/ha reduced yields by 40 %, while in a *Pinus radiata* system at 100 stems/ha, yields were reduced by 41 % at 16 years, and by 73-93 % at 18-20 years (Benavides et al., 2009). However, managing the tree canopy through pruning, thinning, coppicing, or pollarding will reduce canopy effects on pasture productivity (Benavides et al., 2009).

Pasture productivity is also influenced by species composition, and in silvopastoral systems, this can be modified by changes to the microclimate and soil properties caused by trees, as well as the impact of livestock grazing which may also be influenced by the presence of trees (Benavides et al., 2009). It has been shown that there is a shift from pasture assemblages containing legumes and *Lolium perenne*, to a greater dominance of grasses due to greater shade tolerance, tillering ability, phenological development and growth in winter (Benavides et al., 2009). Similarly, at Wakelyns Agroforestry, the sward in the pasture alley developed into a grass-dominated community (even though grasses were not part of the original seed mix, they were probably in the seed bank or invaded from the tree understorey) while the sward in the no-tree control field remained dominated by clovers (Smith et al. 2014).

This section reports on research carried out to investigate the productivity and species composition of the sward within the first five years of a newly established bioenergy agroforestry system at Elm Farm. It was expected that the introduction of the newly planted trees will have had no or minimal impacts on the adjacent pasture in terms of production or species composition as the trees are still small.

Methods

Within each plot, a transect was established within the jute sub-plot, running east from the central tree row to the adjacent tree row to the west. On each transect, $1m^2$ quadrats were located at the east and west alley edges and in the centre of the alley (Figure 64); this design allows spatial and temporal variation within the alleys to be studied as the trees establish and mature. The same design was used in the pasture-only plots. A total of 36 quadrats were assessed (three per plot; four treatments (alder only, willow only, mixed alder and willow, and pasture only); three replicates).

Productivity of the pasture was assessed annually from 2011 to 2015 before the first silage cut was taken. To standardise timings between years, sampling was timed to occur during peak seed head production of cocksfoot (*Dactylis glomerata*). The herbage within each 1 m^2 quadrat was cut to 5 cm above ground in June each year. Herbage was collected into a polythene bag and sealed to prevent water loss. After weighing for fresh weight, a sub-sample from each sample was oven dried at 100°C until a stable weight was reached (oven dried mass: ODM).

To identify changes in species composition in the five years following establishment, species percentage cover within 1 m^2 quadrats (same quadrats as for ley productivity assessments) was assessed each year immediately before the herbage cut.

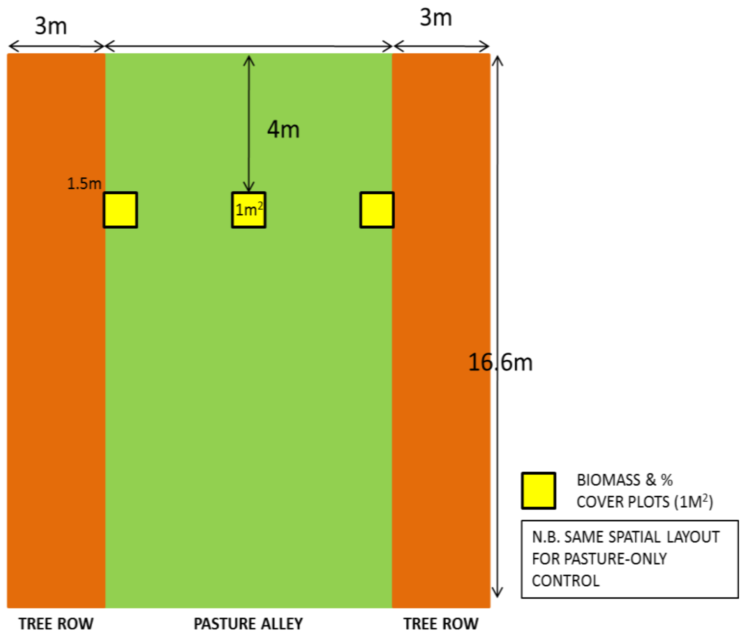


FIGURE 64. SAMPLING DESIGN FOR MEASURING PASTURE PRODUCTIVITY BETWEEN THE AGROFORESTRY ROWS

Statistical analyses

Biomass production

The statistical analysis was carried out using R version 2.10.0 (R Development Core Team, 2009). To identify the effect of planting trees on pasture productivity, total biomass production (ODM) per m^2 quadrat was analysed for the period 2011-2015 with repeated measures linear mixed effects models using the R library *nlme*. Treatment (willow; alder; mix; pasture), location (east, west and centre alley) and year, and the interactions between the three, were included as fixed factors. Year was identified as the repeated measure, and replicate block as the random effect.

Species composition

To investigate changes in pasture species composition in the different treatments five years following tree planting, species % cover data were analysed using canonical ordination techniques in Canoco 4.5.1 (Ter Braak & Šmilauer, 2003). A preliminary detrended canonical correspondence analysis (DCCA) produced short gradient lengths (<2) indicating that linear ordination methods were most appropriate for these data (Lepš & Šmilauer, 2003).

A redundancy analysis (RDA) was carried out on the species % cover data to identify temporal shifts in community composition as the system established and to test whether any temporal trends in the species composition were significantly associated with the tree species treatments. Year (2011-2015) was treated as a continuous variable and the interactions between year and treatment (tree species) were statistically tested using Monte Carlo permutation tests (full model, 499 repetitions) with permutations restricted within the five replicates of each plot (i.e. repeated measures). Plot was included as a covariable, thus removing the average (over years) of each plot, so that only the changes within each plot were analysed. A subsequent analysis of the data with year as the explanatory variable, and permutations restricted within plots as above, was carried out to identify temporal changes in species cover within the system independent of treatment.

A second RDA was performed on the species % cover data to identify spatial variation in species composition within the agroforestry plots only in the final year (2015). The interactions between location (west, centre and east) and treatment (willow, alder, mix) were included as explanatory variables, with location coded as nominal variables. Monte Carlo permutation tests to determine the significance of all canonical axes were performed, with permutations restricted within replicate blocks.

Results

Biomass production averaged 2330 kg DM/ha over the five years with the lowest production in 2011 (1620 kg DM/ha) and highest in 2014 (3210 kg DM/ha). Linear mixed model analyses of biomass from 2011-2015 found no statistically significant effects of tree planting on pasture productivity, indicating that the impact of tree planting on pasture production within the first five years was minimal (Figure 65).

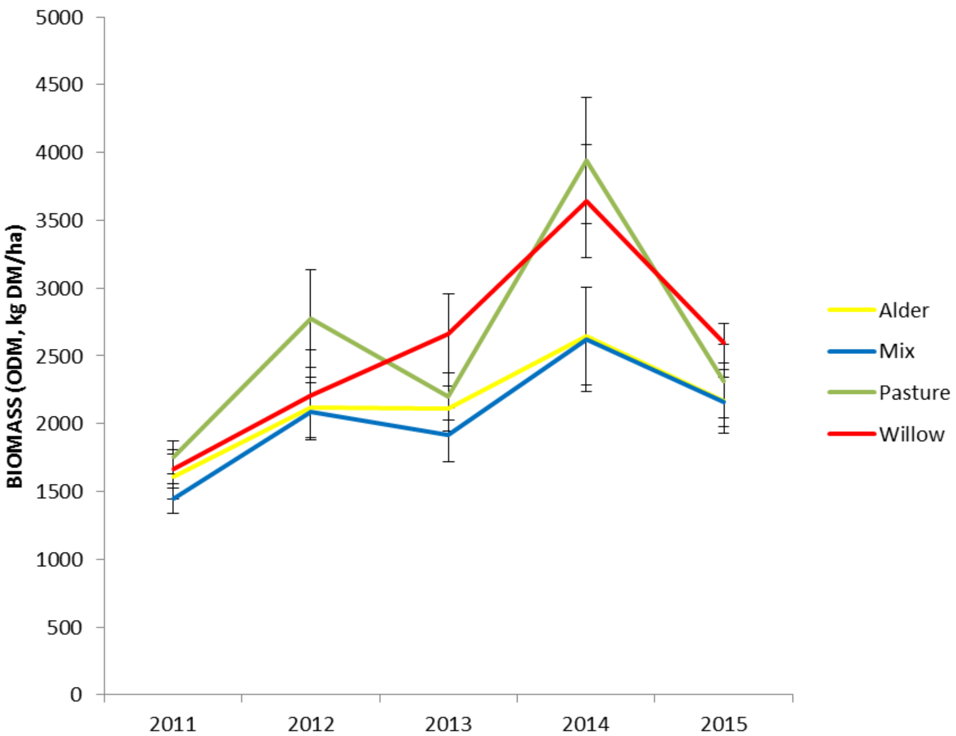


FIGURE 65. PASTURE PRODUCTIVITY FROM 2011 TO 2015 (MEAN +/- STANDARD ERROR)

With regards to species composition, the pasture community was dominated by *Dactylis glomerata*, with high densities of *Ranunculus repens* in certain areas of the field. Other common species included the grasses *Agrostis capillaris* and *Holcus lanatus*. Redundancy analysis found no statistically significant differences between the treatments with regards to changes in the species % cover over the five years with all canonical axes (Axis 1 to 3) accounting for just 2% of the variance in the species cover data (sum of all canonical eigenvalues = 0.02, F-ratio = 1.49, p = 0.124; bi-plot not shown).

A subsequent analysis of the data to identify temporal changes in species cover within the system independent of treatment, with year as the explanatory variable, identified a statistically significant change over time with Axis I (the canonical axis) accounting for 6.6% of the variance in the species cover data (Eigenvalue Axis I = 0.066, F-ratio = 14.93, p-value = 0.001). The resulting ordination diagram (Figure 66; only species with a fit greater than 10% are shown) shows that this difference is primarily due to an increase in the cover of *Holcus lanatus* (Yorkshire fog) over the five years. Yorkshire fog is a common grass in pastures, but is not tolerant of close grazing or heavy trampling

(Grime et al., 2014), so it is likely to have benefitted from the lack of grazing during the first four years of the trial.

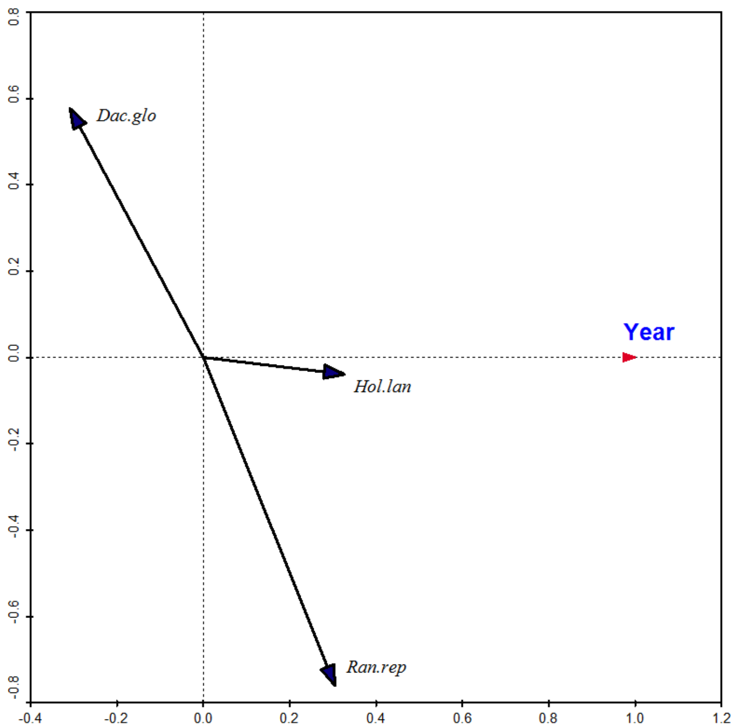


FIGURE 66. RDA BI-PLOT OF CHANGES IN PLANT ASSEMBLAGES IN THE SWARD FOLLOWING ESTABLISHMENT OF THE AGROFORESTRY. AXES I AND II SHOWING SPECIES WITH A FIT GREATER THAN 10%.

RDA analysis of the agroforestry-only data to identify spatial variation in species % cover indicated no significant differences in species composition within the alleys (sum of all canonical axes = 0.188, F-ratio = 0.598, p=0.908; bi-plot not shown). Therefore there is no evidence yet of any edge effects caused by interactions between the trees and pasture.

Discussion and conclusions

Pasture productivity within the agroforestry trial site varied considerably from year to year with the highest production in 2014 following a wet winter and spring, but there were no statistically significant differences found between the different treatments, indicating that for the first five years, the impacts of tree planting on productivity were minimal, and therefore we cannot reject the null hypothesis of no impact (H1). This may be because of the low rate of tree survival in the first three years, and even where the trees did establish, the alley design means that, at this early stage, any impacts of the trees are limited to within the tree rows. In a review of a number of studies on *Pinus radiata* and *Populus* silvopastoral systems in New Zealand, Benavides et al (2009) conclude that up until the middle of a rotation (10-15 years), no significant effects occur at tree densities less than 100 stems/ha. Above 15 years, the reduction in pasture yields increases and this is influenced by tree species and densities, as well as site fertility and climate. For example, pasture yields under 15 year old *Populus* trees were 27 % less than adjacent open pasture, while yields under 16 year old *Pinus radiata* were 41 % less than open pasture. In 14 year old *Pinus radiata* silvopasture at 100 stems/ha, yields under trees planted in rows were 44 % lower than open pasture, compared with 65 % reduction under trees planted evenly across the site (Benavides et al., 2009).

Tree densities in the new SRC silvopastoral system are much higher than the New Zealand systems discussed above, with trees planted in twin rows to give a density of 1000 stems/ha. However, as the trees will be coppiced on a 2-5 year rotation, and thus won't develop full canopies, it is hoped that the impact on pasture productivity will be restricted to the edges of the pasture alleys, and any reductions in yields may be at least partially off-set by positive impacts of the trees on the microclimate. Within the 17 year old short rotation coppice agroforestry system at Wakelyns Agroforestry, we found evidence of competition between the trees and plants at the edge of the alleys (classic 'edge effect'), although the extent of this competition varied depending on weather conditions and stage of rotation of the tree component (Smith et al 2014). The alleys at Wakelyns are only 10 m wide, while at Elm Farm, the alleys are 21 m (allowing for a 3m wide tree row), so there will proportionally be less 'edge' than at Wakelyns.

The observed changes in the species composition of the sward over time are most likely to reflect the reduction in grazing pressure during the first four years following establishment, rather than an effect of the trees *per se*, as there were no differences in species composition between the different treatments. Therefore, we cannot reject the second null hypothesis. As the trees grow, we might expect the sward to become dominated by more shade-tolerant grass species, especially at the edge of the alleys. This is what we observed at Wakelyns Agroforestry, where the alley vegetation developed into a grass-dominated community (even though grasses were not part of the original seed mix, they were probably in the seed bank or invaded from the tree understorey) while the sward in the no-tree control field remained dominated by clovers (Smith et al. 2014).

In conclusion, there were no significant impacts of the trees on pasture production or species composition within the first five years following establishment. Repeating assessments as the system matures will allow us to measure performance of the system, ideally throughout the entire rotation of the system (estimated at 20-25 years for the SRC trees).

Whole crop barley (growth rates, pests and diseases)

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 67). Due to the tree harvesting rotation, it was possible to study the effects of tree height on the oat crop in the alley (Deremetz 2017). 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 67. 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 (1st year regrowth; 2nd year regrowth; un-harvested). Full details are given in Deremetz (2017).

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 were recorded for each sample location. For each sample location, the percentage cover of oats was recorded in a 0.5m^2 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 4m 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 68. HEIGHT MEASUREMENTS OF THE OAT CROP

There were significant differences in terms of growth stages, in response to age of the tree re-growth, 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. 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 69). 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 69). 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.

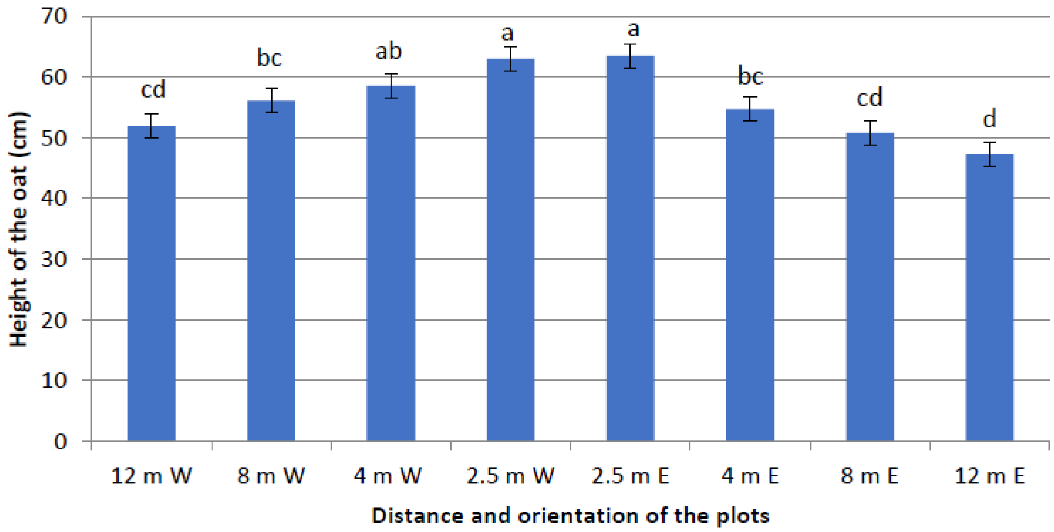


FIGURE 69. CROP HEIGHT AT 2.5 M, 4 M, 8 M AND 12 M EAST (E) AND WEST (W) FROM THE TREE ROWS (DIFFERENT LETTERS SIGNIFY SIGNIFICANT DIFFERENCES)

Total above-ground biomass was sampled using 0.5m^2 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 2m, 6m and 10m 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 70).

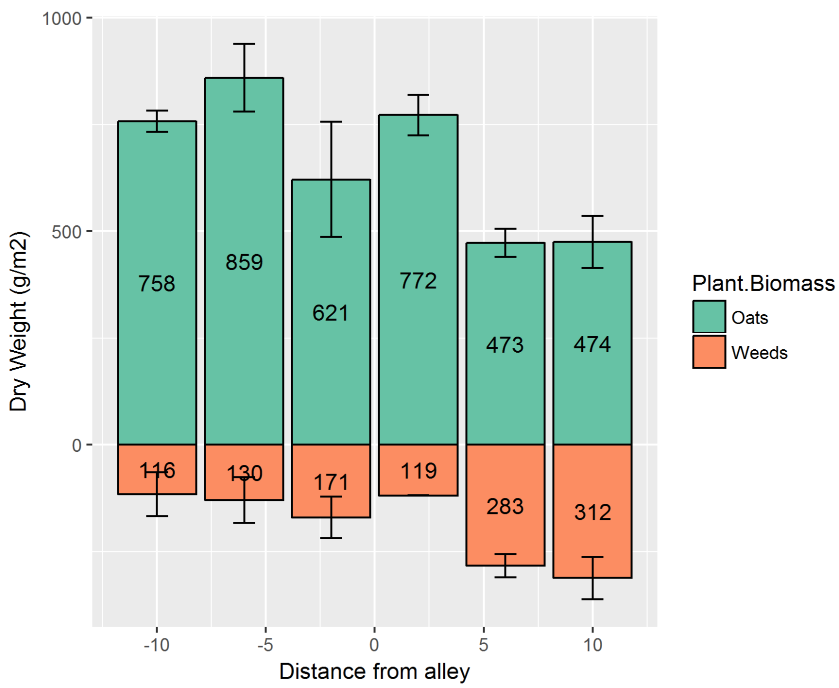


FIGURE 70. BIOMASS OF OATS AND WEEDS AT DIFFERENT DISTANCES FROM THE TREE ROW (0 = EDGE OF TREE ROW; SAMPLES TAKEN AT 2 M, 6 M AND 10 M WEST (MINUS BARS) AND EAST (POSITIVE BARS) OF THE TREE ROW). ERROR BARS ARE STANDARD ERROR, N = 2.

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 0.5m^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 71).

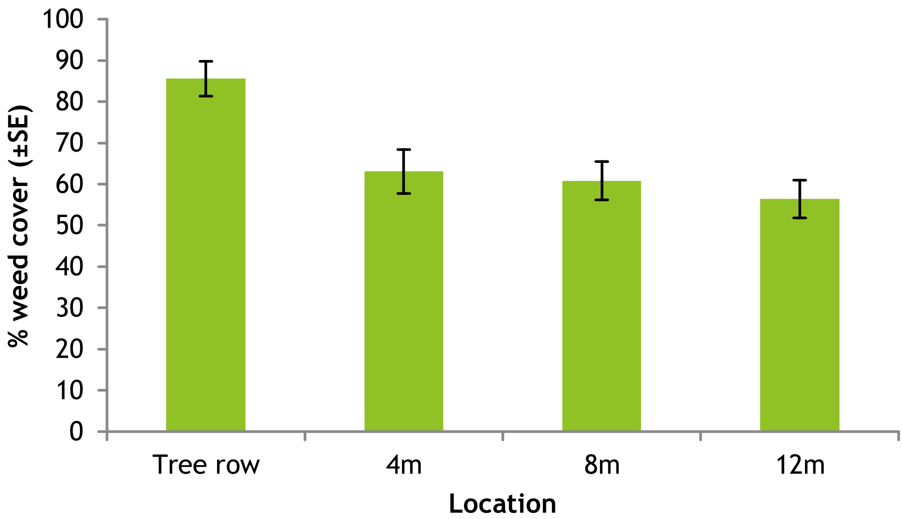


FIGURE 71. PERCENTAGE COVER OF WEEDS IN THE TREE ROWS AND AT 4 M, 8 M AND 12 M INTO THE CROP ALLEYS.

Concerning species richness, there was a mean of 3.39 species in the trees row, 4.89 species at 4 m 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.

Discussion and conclusions

No significant differences were seen in the timing of oat growth stages or the cover of oats in response tree regrowth age or distance from the tree row. It may be that the trees are too small to significantly influence the timing of growth stages and the establishment of the oats; as the trees grow taller and denser and cast more shade this may change. However, crops were found to be tallest adjacent to the tree rows with a decrease with increasing distance from the tree row, an effect more noticeable on the east side of the tree rows. 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. A higher cover of weeds was observed in the tree row with more perennial weeds, but the species richness of weeds in the alley was higher than the tree row with more annual weeds. There was no contamination of the alleys from the tree row perennial weed species observed, and where there was dense tree cover in some of the unharvested tree rows, shading had caused the cover of perennial weeds to decline.

To conclude, some interactions between crop and tree row were observed and these are likely to increase as the trees age. The weed communities in particular were different between the tree row and the copping alley reflecting the different habitat and soil cultivations associated with annual cropping. The increased diversity in the weed community of the system increases the biodiversity value of the field.

Elm Farm: integrating productive trees and hedges into a lowland livestock farm

Diverse ley biodiversity

In Spring 2018 the alleys between the agroforestry rows were sown with a multi species ley (Table 17). The success of the sward establishment and the botanical diversity in the sward was measured in October 2019 by monitoring the plant species diversity within 0.5 m x 0.5 m quadrats across three transects in three of the agroforestry plots. The agroforestry plots monitored were the single species alder blocks. Each transect started at the edge of the alley where the cultivated land starts and quadrats were placed at 0.5-1 m from either side of the alley, and 2-2.5 m from either side and in the centre. The percentage cover of each plant species (sown and unsown) and of bare ground was then recorded within these quadrats. Due to the time of year it was not possible to identify grasses to species so grass was recorded as one category

TABLE 17. SWARD MIX SOWN BETWEEN THE AGROFORESTRY ROWS IN SPRING 2018:

	English name	Latin name
Grasses	Creeping red fescue	*Festuca rubra rubra*
	Perennial ryegrass	*Lolium perenne*
	Timothy	*Phleum pratense*
Legumes	Red clover	*Trifolium pratense*
	White clover	*Trifolium repens*
	Birdsfoot trefoil	*Lotus corniculatus*
Forage herbs	Ribgrass (plantain)	*Plantago lanceolata*
	Chicory	*Cichorium intybus*
	Yarrow	*Achillea millefolium*

The main broadleaf weed species observed, all perennial species, were broad leaved dock (*Rumex obtusifolius*), creeping thistle (*Cirsium arvense*), dandelion (*Taraxacum officinalis*) and creeping buttercup (*Ranunculus repens*). With the exception of yarrow (*Achillea millefolium*) all of the legumes and forage herbs that were sown as part of the mix were still present in the sward. The dominant sown broadleaf species was white clover (*Trifolium repens*) with an average cover over all quadrats of 33%.

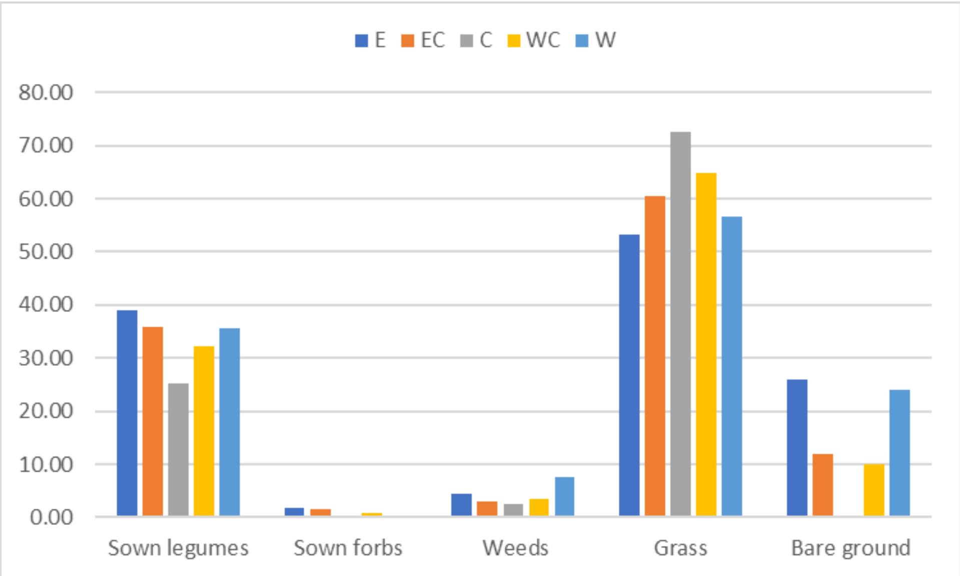


FIGURE 72. THE MEAN PERCENTAGE COVER OF VEGETATION CATEGORIES RECORDED ACROSS THE AGROFORESTRY ALLEYS

More grasses and fewer legumes were seen in the centre of the alleys (Figure 72) possibly indicating the higher competitive ability of grasses in the centre where light is more available. More broadleaf (perennial) weeds and bare ground were seen at the edges of the alleys nearer the tree rows suggesting that the perennial weed species observed in 2017 in the tree rows may be spreading to the edges of the crop alleys.

Microclimate

One of the main perceived advantages of integrating trees into livestock production systems using an agroforestry approach is that trees modify microclimatic conditions including temperature, water vapour content or partial pressure, and wind speed, and these modifications can have beneficial effects on pasture growth and on animal welfare (Bird, 1998; Jose et al., 2004). Trees can reduce wind speeds in the protected area with wind speed reductions extending up to 30 times the height of the windbreak on the leeward side, and 2-5 H (H= shelterbelt height) on the windward side (Tamang et al., 2010; Williams et al., 1997). In Scotland, wind speeds under widely spaced Sitka spruce trees were less than half those in the open (Green et al. in (Sinclair, 1999)). Wind speeds within the 17 year old SRC silvopastoral system at Wakelyns were significantly lower than in the no-tree control plots, and combined with air temperature at 1.5 m, this resulted in lower (cooler) wind chill temperatures in the winter in the control plots (Smith et al., 2014). Soil moisture levels were generally lower in the no-tree control plots than in the agroforestry alley plots and this was attributed to shading effects of the trees reducing evapotranspiration in the alleys, or higher wind speeds in the control plots increasing the moisture loss from the soil (Smith et al., 2014).

This section reports on data collected to investigate the impact of tree planting on air temperature, wind speed, wind chill, relative humidity and soil moisture within the first five years of a newly planted bioenergy agroforestry system at Elm Farm. It was expected that the newly planted trees will have had no or minimal impacts on the microclimate as the trees are still small.

FIGURE 73. ANEMOMETER MEASURING WIND SPEED, AIR TEMPERATURE, WIND CHILL AND RELATIVE HUMIDITY AT THE ALLEY EDGE

ORGANIC RESEARCH CENTRE ELM FARM

Methods

Monthly measurements were carried out at three sample points on transects running east to west across the alleys in the agroforestry and the centre of the control plots from May 2012 to Sept 2015. Sample points were located at the eastern and western edge of the alleys (2m from the centre of the tree rows), and the centre of the alleys (6m from the centre of the tree rows for 2011 and 2012; then 12m from the centre of the tree rows following the removal of every other tree row in March 2013). Air temperature (˚C), average wind speed over 1 minute and wind chill (˚C) were measured at 1.5m above ground using a Kestrel 3500 anemometer. Soil moisture was measured using a HH2 Moisture Meter with the SM300 soil moisture probe from Delta T (average of 3 readings per sample point).

Statistical analyses

The statistical analysis was carried out using R version 2.10.0 (R Development Core Team, 2009). To identify the effect of planting trees on microclimate, wind speed, air temperature, wind chill, relative humidity and soil moisture were analysed for the period May 2012 to August 2015 (July 2015 for soil moisture) with repeated measures linear mixed effects models using the R library *nlme*. Treatment (willow; alder; mix; pasture) and year, and the interactions between the two, were included as fixed factors. Month was identified as the repeated measure, and replicate block as the random effect.

Microclimate key conclusions

There were no significant differences detected between the different treatments, no effect of year, and no interactions between treatments and year, indicating that the trees are not yet having an impact on the climate, although there does appear to be consistently lower soil moisture levels in the pasture control plots (Figure 74).

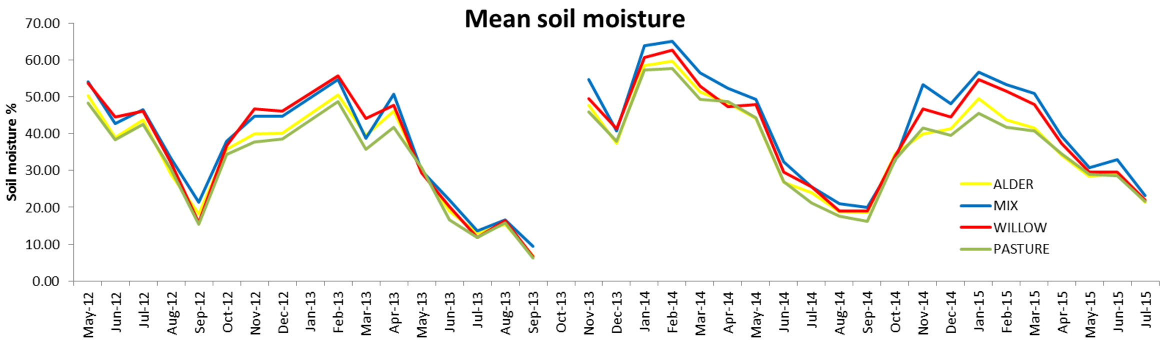


FIGURE 74. MEAN % SOIL MOISTURE OBSERVED IN THE DIFFERENT AGROFORESTRY TREATMENTS BETWEEN MAY 2012 TO JULY 2015

Soil nutrients and organic matter

Soil organic matter

In May 2017, soil cores were taken on transects running perpendicular from the tree rows into the crop alleys, in the un-harvested alder plots only (Deremetz, 2017). 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.

Soil nutrients

In September 2018, composite soil samples were collected by intern Ellie Brown from the alder and willow tree rows, with three replicates of each species (each replicate from a different tree row). Samples were analysed for mineral nitrogen, potassium, phosphorus and magnesium at NRM labs. As alder fixes nitrogen, we were interested to see whether there was higher nitrogen in the soils under the alder trees. Table 18 shows the results, and there are indications of higher nitrate N, available N and Total N in the soils underneath the alder trees, and higher P underneath the willow trees. With such limited sampling, it is difficult to draw any firm conclusions but it provides some preliminary results that should be further investigated to identify if there is a real effect of the alder trees on soil N and if so, whether the effect extends out into the adjacent alley, for the benefit of pasture or crop production.

TABLE 18. SOIL ANALYSIS RESULTS FROM THE ALDER AND WILLOW TREE ROWS TAKEN IN SEPTEMBER 2018

Species	Rep	Nitrate N (+) mg/kg	Ammonium N (+) mg/kg	Available N kgN/ha	Total nitrogen %w/w	Soil pH	mg/l (available)		
							P	K	Mg
Alder	1	11.2	2.4	34	0.328	6.4	11.6	199	134
Alder	2	15.67	2.26	44.8	0.299	6.2	12.2	150	116
Alder	3	10.76	5.6	40.9	0.238	6.4	11.6	102	96
Willow	1	8.78	2.64	28.5	0.276	6.6	19.4	181	112
Willow	2	4.06	2.08	15.4	0.19	6.1	20.6	141	93
Willow	3	4.17	2.51	16.7	0.198	5.9	15.4	120	94

Biodiversity

Earthworm biodiversity

Earthworms are known and prized for their highly influential role in the soil ecosystem through their key participation in organic matter and nutrient cycling as well as their ability to modify the soil structure. Through refinement of soil particles, earthworm casts improve soil aeration and drainage (Sims & Gerard, 1999). Earthworms are also crucial to soil fertility; they redistribute organic materials within the soil and influence nutrient supply. Agricultural practices that constantly disturb the soil, and the abundance and availability of organic matter, can have significant impacts on earthworm populations. In agroforestry systems, the tree row provides a stable and undisturbed habitat which should support higher populations of earthworms than the adjacent crops and pasture alleys.

2012

In October 2012, ORC intern Caitlin Fuller carried out as assessment of earthworm populations in the agroforestry trial, comparing biodiversity and abundance in the different weed control approaches (biodegradable jute fabric, photodegradable spun-bonded propylene black fabric, and woodchip) and adjacent pasture. Focusing on one plot (Plot 5: mixed willow and alder), ten soil cores 25 cm x 25 cm x 10 cm deep) were extracted (two from each tree row) per weed control treatment and pasture control. Earthworms were collected, counted and adults were identified to species. Soil moisture and soil temperature were measured adjacent to each soil core. A total of 1124 earthworms were collected. Total earthworm abundance was greatest under the woodchip weed control, and lowest under the pasture (Figure **75**). The most abundant species overall was *A. caliginosa* closely followed by *A. chlorotica*, the least abundant was *L. friendi* and *L. festivus* as they were each only found once. The total abundance of earthworms was most significantly affected by weed control (p= 0.02) but also by soil moisture (p=0.03) and block (0.04). When weed controls and pasture were compared, the woodchip and the pasture were significantly different from each other (Figure **75**). The epigeic earthworm, *Lumbricus rubellus* was more abundant in the woodchip treatment, which was also correlated with higher soil temperatures (Figure **76**).

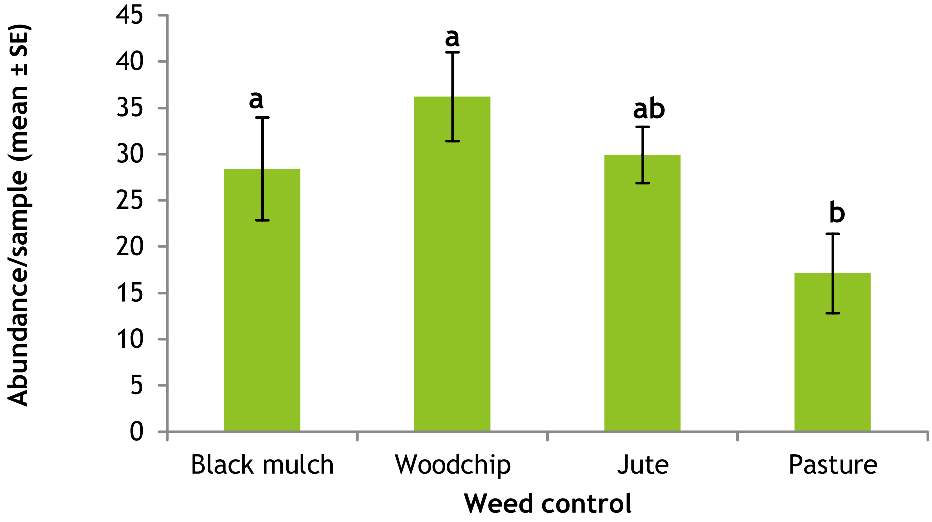


FIGURE 75. THE AVERAGE ABUNDANCE OF ALL EARTHWORMS (± S.E.M) AT EACH WEED CONTROL, SAMPLES TAKEN IN PLOT B5, FLATBOTTOM FIELD, ELM FARM

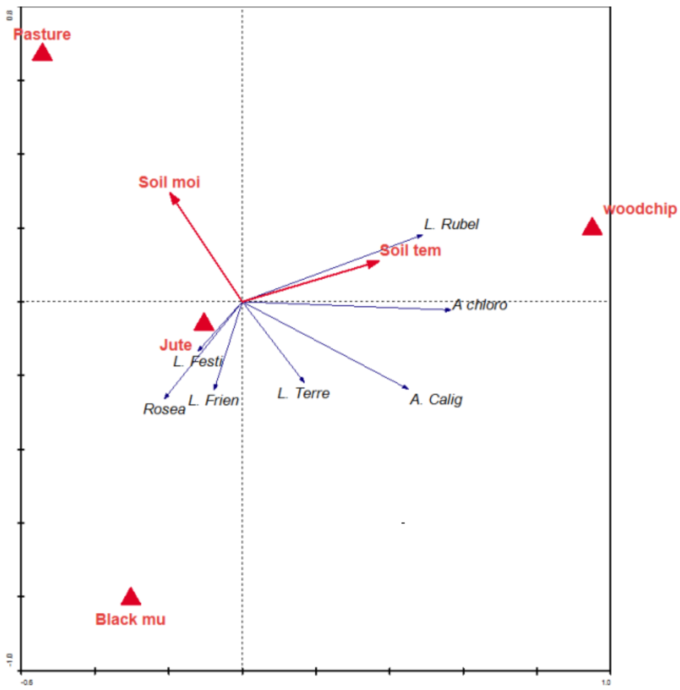


FIGURE 76. RESULTS FROM CONOCO SHOWING DIFFERENT SPECIES RELATIONSHIP WITH EACH FACTOR, SAMPLES TAKEN IN PLOT B5, FLATBOTTOM FIELD, ELM FARM

Samples were taken in April 2017 in the tree row and at 4 m and 9 m from the tree row (Deremetz, 2017). 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^3 and surface area of 0.0182 m^2) at each location and sorting through the soil core by hand, collecting all earthworms and calculating total abundance per m^2. Adult earthworms were identified to species. There were significant differences in mean populations from the different locations (X^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 77). 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 anaecic 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.

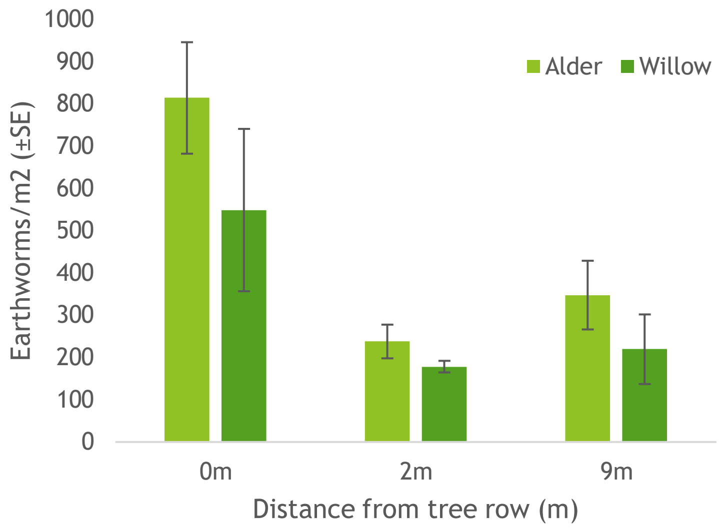


FIGURE 77. EARTHWORM ABUNDANCE AT DIFFERENT DISTANCES FROM THE TREE ROW IN ALDER AND WILLOW AGROFORESTRY PLOTS.

Ground beetle biodiversity

Pitfall traps were used to assess biodiversity of ground beetles (Carabidae), which are important ground-dwelling predators (Deremetz, 2017). 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, 12m) 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 78).

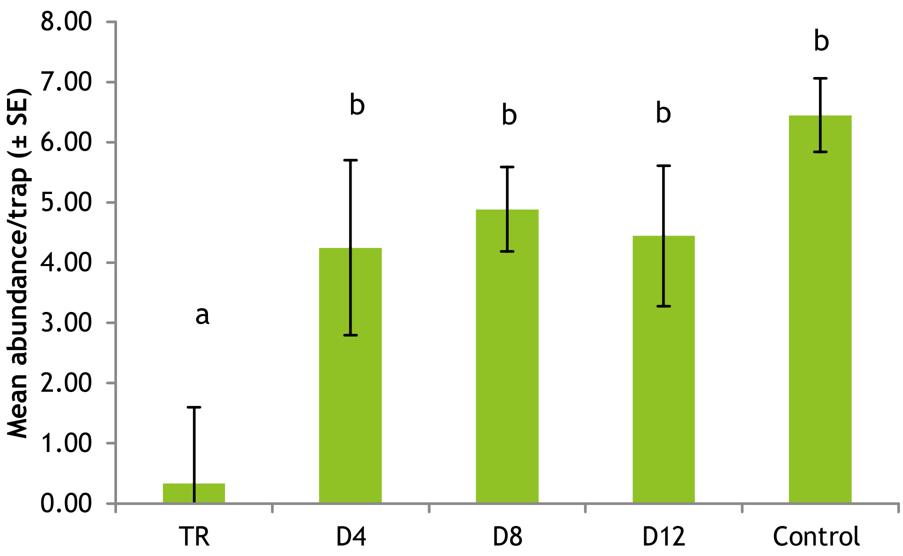


FIGURE 78. GROUND BEETLE ABUNDANCE AT DIFFERENT DISTANCES FROM THE TREE ROW IN NON-HARVESTED ALDER AGROFORESTRY PLOTS AND A CONTROL PLOT. TR = TREE ROW; D4 = 4 M FROM TREE ROW; D8 = 8 M FROM TREE ROW; D12 = 12 M FROM TREE ROW. LETTERS INDICATE SIGNIFICANT DIFFERENCES.

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.

Economics

A study of farmers' perceptions of agroforestry in the UK found that while most interviewed farmers view agroforestry positively, particularly with respect to environmental benefits, adoption is inhibited by uncertainty regarding financial return and a lack of information regarding the economic viability of these systems (Meyer, 2013). A key consideration for farmers considering establishing an agroforestry system is the cost of tree planting. Fernández-Núnez *et al.* (2007, in Rigueiro-Rodríguez et al., 2008) carried out an assessment of initial investments and establishment costs of forestry, agriculture and agroforestry in the Atlantic area of Spain. They found that establishing agroforestry required higher initial investment than the agricultural and forestry systems due to higher initial inputs. Planting widely spaced trees may require more resources, for example fencing individual trees against livestock. This section first collates economic data on the costs of establishing the novel silvopastoral system at Elm Farm, before then modelling on-going system performance using the net present value (NPV) approach.

Costs of planting and weed control

The costs associated with planting the trees and subsequent maintenance for the first five years are presented in Annex 4. These are based on the actual costs incurred during setting up the trial site at Elm Farm, so it must be noted that contractor costs for tree planting will vary regionally, and some other costs (e.g. fencing) will also vary depending on the design.

Trees are planted at distances of 0.7m between rows and 1m within rows, with 200 trees/100 m and five rows of trees per ha, therefore 1000 trees per ha of agroforestry. Assuming a final tree row width of 3 m and 21 m of pasture alley results in the trees covering 15% of the area. Replanting rates are based on actual data collected.

- Year 1: trees planted, mulch fabrics laid or woodchip applied
- Year 2: dead trees replaced, woodchip topped up (in woodchip treatment only)
- Year 3: dead trees replaced, all trees coppiced to encourage multi-stemming, woodchip on all tree rows
- Year 4: dead trees replaced
- Year 5: dead trees replaced, fencing installed (single strand galvanised electric fencing on both sides of tree rows)

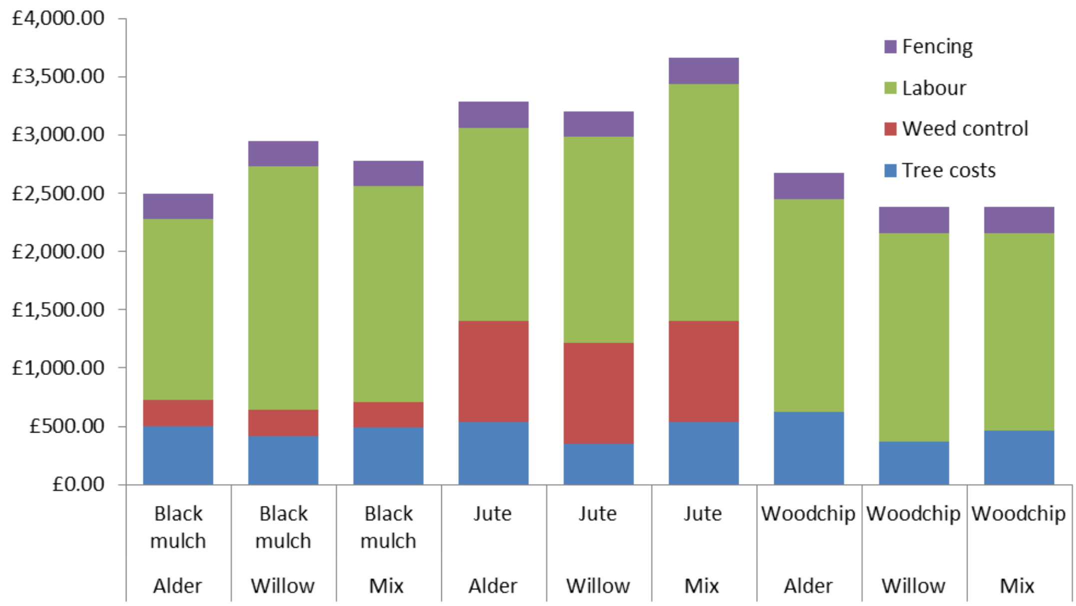


FIGURE 79. TOTAL COSTS PER WEED CONTROL PER HA OF AGROFORESTRY: SPECIES COMBINATION FOR YEARS 1-5

Total costs for the first five years for each of the tree species and weed control combinations can be seen in Figure 79. The willow trees were cheaper than the alders as they were cuttings; while the jute mulch fabric was the most expensive of the weed control approaches. In all cases, labour accounted for over 50% of the total costs. The cheapest options over the first five years were the willow and mixed species with woodchip combinations at £2,380.37/ha and £2,381.00/ha respectively. The most expensive combination was the jute mixed species combination at £3,660.20/ha.

NPV calculation for the Elm Farm agroforestry system

The establishment costs for the agroforestry system at Elm Farm are outlined in Annex 4. However, farmers will also be interested in the long-term financial performance of such systems and in the cashflows (into and out of the business) in individual years. The NPV approach was used to assess the long-term economics of the system at Elm Farm.

Data on costs of establishment were recorded for the Elm Farm system as were management costs for the first few years after establishment. The produce (silage, livestock and coppiced woody material) were used on-farm but standard data (e.g. from the Nix Farm Management Pocketbook) was used to estimate the income from these if they were to be sold off-farm. Similarly, standard data was also used to supply values for ongoing future management costs where it was not possible to estimate these from previous costs.

The data used are listed in full below (all figures listed as "standard" were taken from Nix Farm Management Pocketbook (2014):

1. Tree establishment costs (actual figures)
    - Trees
    - Weed control
    - Labour
2. Tree income (standard data)
    - Income from SRC (yield and wholesale value per tonne)
3. Tree costs
    - Beating up (actual)
    - Fencing (actual)
    - Harvesting (standard)
4. Silage income (standard)
    - Income from sale of silage
5. Silage costs (standard)
    - Additive and sheets
    - Contractor
    - Net variable costs for a 4 year ley
6. Livestock income (taken from "The Organic Farm Management Handbook", 2014)
    - Value per head of finished beef cattle
7. Livestock costs (taken from "The Organic Farm Management Handbook", 2014)
    - Costs per head of finished beef cattle (ignoring forage cost as that is provided by grazing)

The NPV calculation assumed a 20 year lifetime for the agroforestry system (based on the likely lifetime of SRC willow). The data for 2011-2015 were used to estimate cash inflows and outflows in other years based on the following assumptions:

1. Assume 2% inflation annually on all incomes and costs.
2. Assume tree harvest every three years from year 6 onwards.
3. Assume the fencing is erected every time trees are harvested (after the first time assume only labour costs, materials being re-used).
4. Assume a low level of tree replanting needed annually (1% or 66.67 trees).
5. Assume first tree harvest yield is 6.67 tonnes/ha and further harvests are 11.11 tonnes/ha.
6. Assume silage is taken as two cuts for the first 5 years and then one cut once the livestock are using the system.
7. From year 5 reduce silage yield by 1.85% to account for the reduction in yield by 20% on the edge (1m edge effect on either side of the alley with yield in that region reduced by 20%. Edge makes up 9% of the total agroforestry system and 9.27% of the pasture. Thus the yield is reduced by 20% on 9.27% of the pasture so reduce the overall pasture yield by 1.85%)

Other assumptions that are made relate to the livestock component of the system:

1. Assume that the livestock are beef finishing cattle (i.e. perhaps dairy x beef from the dairy enterprise).
2. Assume that 14 cattle graze in the agroforestry system for two months each year (based on the number and timing for 2015).

A discount factor of 4% was used as this figure has been used in previous NPV appraisals of agroforestry systems (Graves *et al.*, 2007) and so this allows comparison with previous research and is a suitable figure for use in discounting agroforestry cashflows.

The calculation was carried out using a Microsoft Excel spreadsheet. The figures used were for the most and least expensive tree species and weed control combinations to compare costs: a mixture of willow and alder using jute; and a mixture of willow and alder using woodchip. The results suggest an NPV for the mixed species: jute combination of £31,296 over the 20 year lifetime of the system, or £1302 per year. Since the agroforestry system covers 3.5ha this gives a value of £8942 per ha for the twenty years and an annual income of £372 per hectare from the system. For the mixed species: woodchip combination, the NPV is £35,220 over the 20 year lifetime of the system, or £1465 per year, or £10,063 per ha for the twenty years and an annual income of £419 per ha.

It is worth noting that there were a large number of assumptions involved in these calculations and these could alter the figures to improve or reduce the final income available from the system. It was assumed here that all products (e.g. silage and woodchip as well as beef) would be sold off-farm. In fact it is more likely that the silage would be used on farm and so would reduce forage costs. The value used here for a silage cost was the value per tonne for large bale hay as that figure was available and seemed the most appropriate; however it may not be representative of the internal value of silage used on farm. Similarly it was assumed that the woodchip produced by coppicing would be sold but, in fact, it is likely that agroforestry SRC systems may be more financially viable if they use wood-chip on farm (thus reducing fossil energy costs) rather than sell it off farm. If the dairy was to purchase a woodchip boiler and use its own SRC woodchip then the reduction in energy costs may be more valuable than if it were to sell the woodchip as assumed here.

On the other hand the yields used here assumed that there were no bad years with poor yields. The figures used for the value of the beef cattle at sale were those for organic finished beef cattle. It's likely that these would be lower for dairy x beef cattle than for pure beef cattle. Furthermore it was assumed that the system could be used for 15 years to take a first cut of silage and then graze 14 cattle for two months. It may be that this would not be possible and that at some point the land would need to be rested and/or inputs added to improve the pasture so that the nutrients aren't constantly mined. In that case the income would be reduced and costs may increase.

Elm Farm: integrating productive trees and hedges into a lowland livestock farm

It is also noticeable from the cashflows that were used in the NPV calculation that the initial establishment is a large cash outflow that is not repaid, in this system, until 5 years after establishment. Despite the fact that the overall NPV is positive this may prove a barrier to many farmers contemplating agroforestry and suggests that support (e.g. from Rural Development programmes (RDPs)) to cover establishment costs may be needed if uptake of agroforestry is to be encouraged.

Economics: key conclusions

Within the current study, establishment costs were influenced by the choice of weed control and tree species and were only repaid five years after establishment. Establishment costs were kept to a minimum in the current system due to limitations imposed by the funding; we would recommend cultivating the sward within the tree row before tree planting, and ideally, deer fencing the system in areas of high deer pressure, which would add considerably to the expense. These measures are likely to increase survival rates of the trees, so the additional costs would be offset slightly against lower replanting costs but are still likely to be higher overall. These high initial costs are likely to deter farmers from establishing agroforestry systems, and this supports the need for external funding e.g. from Rural Development Programmes, or from conservation charities looking to increase tree planting, to cover establishment costs.

The positive NPV of the system over its 20 year lifespan suggests that agroforestry can be a financially viable approach to integrating bioenergy and livestock production. It is recommended that the additional products from the silvopastoral systems i.e. woodchip and tree fodder, should be used on-farm to maximise financial benefits, rather than selling externally. The NPV does not account for environmental or animal welfare benefits, which are likely to increase as the system develops. There may be scope for including these types of systems in RDP agri-environment schemes in recognition of the benefits to these wider ecosystem services, which would enhance overall profitability.

Integrated bioenergy and livestock production: key conclusions and lessons learnt

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.

These results from this trial suggests that establishing trees within a pasture has negligible impact on pasture production and biodiversity, and the microclimate within the first five years, although this may be due primarily to the low establishment rate and subsequent growth of the trees. Controlling competition from weeds and grasses is essential for promoting better tree establishment and using woodchip mulch from on-farm or a locally available resource was found to be the best option.

Low yields of woodchip from the SRC willow and alder reflect earlier problems during the establishment phase, and the *Salix viminalis* in particular did not establish well, suggesting that this species (or these 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 in 3-5 years' time.

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 re-growth 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 for pasture productivity in the alleys, 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.

The trial also provided useful economic data on establishing a new SRC agroforestry system, showing that labour costs account for over 50% of total costs. Net present value (NPV) calculations showed that while overall the NPV is positive, the initial establishment is a large cash outflow that is not repaid, in this system, until 5 years after establishment; this may prove a barrier to many farmers contemplating agroforestry and suggests that support (e.g. from RDP) to cover establishment costs may be needed if uptake of agroforestry is to be encouraged.

Elm Farm: integrating productive trees and hedges into a lowland livestock farm

Trees for feed: browsing trials and tree fodder analyses

Introduction

Browse from trees and shrubs plays an important role in feeding ruminants in many parts of the world, particularly in the tropics, and there has been considerable research into the nutritional potential and limitations of many tropical fodder species (Devendra, 1992). However, comparatively little is known about the potential of temperate browse species. Traditionally, tree fodders have been important for ruminant nutrition, and still remain significant in some European farming systems, particularly in Mediterranean countries for goat, sheep and pig production. For example, deciduous oak leaves are shredded and dried for sheep fodder in Greece, while in Crete and Sicily, carob pods are stored for fodder (Eichhorn et al, 2006). The most extensive silvopastoral system in Europe is the dehesa (scattered cork oaks) which covers 3.5 million hectares in the south-west of the Iberian peninsula (Casals et al, 2008; Olea et al, 2005) and produces high quality hams from the Iberian black pigs that feed on the acorns and natural grass. Pollarding (cutting branches from trees two to three metres above ground level) for fodder was particularly common in northern Europe and mountainous areas such as the Pyrenees, Alps and high pasture areas of the Basque country.

Traditionally, many species of deciduous trees have been used for fodder, in particular Wych or Scots Elm (*Ulmus glabra*), ash (*Fraxinus excelsior*), silver birch (*Betula pendula*), downy birch (*Betula pubescens*) and goat willow (*Salix caprea*) (Austad & Hauge, 2006). In Norway, cattle and pigs were primarily fed leaves of *Ulmus glabra* and *Fraxinus excelsior* while leaves of *Betula* sp. and *Alnus* sp. were given to sheep and goats (Austad & Hauge, 2006). Important fodder resources in Mediterranean systems include natural woody plant communities such as the maquis, garrigues and dehesa, and cultivated species including leguminous shrubs such as bladder senna (*Colutea arborescens*) and tree medic (*Medicago arborea*), as well as the C4 perennial saltbushes (*Atriplex halimus* and *A. nummularia*) (Papanastasis et al, 2008a). Fodder resulting from olive tree pruning has been used traditionally for feeding sheep and goats for hundreds of years .

More recently, the productivity and nutritional value of novel species such as black locust (*Robinia pseudoacacia*), tagasaste or tree lucerne (*Chamaecytisus palmensis*), and thornless honeylocust (*Gleditsia triacanthos*) have been the subject of investigation, particularly in silvopastoral systems of North America and the Mediterranean (Barrett et al, 1990; Burner et al, 2008; Burner et al, 2005; Papanastasis et al, 2008b).

ORC research into the value of trees as feed for livestock has been underway since 2011, and includes both analyses of tree leaves for their feed value as well as browsing trials of livestock within the agroforestry trial at Elm Farm:

2011: SRC willow from Wakelyns Agroforestry. The nutritional value of two ages (1st and 2nd year re-growth) of SRC willow was assessed in two seasons; late spring (June) and late summer (Sept) in 2011. The first year regrowth material was also used to evaluate the possibilities of ensiling the willow.

2015: Browsing trials at Elm Farm. Cattle introduced into the silvopastoral trial. Three levels of tree protection were trialled (1 strand of electric fencing, 2 strands of electric fencing and 'no fencing' control), and observations of cattle interactions with the trees recorded over a 19 day period.

2015-2016: Tree leaf analyses. Nutritional analyses of the SRC willow and alder from the silvopastoral trial, and from ash, goat willow and elm trees on Elm Farm including samples air-dried over the winter.

2017: In collaboration with University of Reading, leaf and branch samples were collected from five individual trees of oak, goat willow and field maple on Elm Farm, monthly from June to September. Analysed at University of Reading for in-vitro digestibility and total tannins and tannin profile.

2018: In collaboration with the University of Reading, the Game and Wildlife Conservation Trust, Bangor University, Nottingham University and the Woodland Trust. Leaf and branch samples were again collected from five individual trees of oak and goat willow on Elm Farm, monthly from June to

September. Samples were also collected from four individual trees of SRC common alder in the silvopastoral trials. Goat willow leaf samples analysed at the University of Reading for *in-vitro* digestibility and total tannins and tannin profile (oak to be analysed in summer 2020). June and September samples of the three species were analysed at the University of Nottingham for trace elements and iodine and at University of Bangor for energy and protein analyses.

Browsing trials 2015

During the initial years following planting of the SRC, cattle were restricted from grazing in the agroforestry area although the alleys were harvested for silage, and 12 cattle had access to the site for 20 days in December 2013. It should also be noted that local wild deer did access the area and browsed the willow in particular. In the summer of 2015, it was decided to give cattle access to the agroforestry system for the first time. To investigate measures which farmers could take to restrict browsing in such a system two levels of electric fencing were used (single strand and two strands of electric wire) along with a no-fence control. To record the impact that this had, observations were made of cattle behaviour with regards to browsing of the trees and reactions to the fencing. The impact of the cattle on the trees was measured by assessing tree damage post-grazing.

Methods

The cattle were 16 dairy/beef cattle: 14 cows and two bulls. Two cows were removed from the field shortly after the observations began (for tuberculosis testing) and the remaining 14 cattle stayed in the field for the duration of the period. The two bulls are Fresian x short horns, born March 2014; the cows are Fresian x Jersey heifers, born March 2013, in calf with dairy replacements.

It was decided to record all occurrences of the key behaviours that were observed (i.e. to carry out behaviour sampling; (Martin & Bateson, 2007)) rather than concentrate on focal animals as the behaviours may only be demonstrated by one or two animals and so may be missed if those were not the focal animals (Martin & Bateson, 2007; Mitlohner et al., 2001; Ransom & Cade, 2009). Additionally, there were only 16 cattle in the field (reduced to 14 after the first few days) and they tended to remain in a herd so the entire group could be observed with relative ease. Observations took place over an hour and one-zero time-sampling techniques were used (Martin & Bateson, 2007): the hour was split into 60 intervals of one minute and at the end of each minute it was recorded whether or not the behaviour pattern had occurred during the last minute. The observer also noted how many animals had carried out the key behaviour during that period.

The key behaviours were defined as:

1. Browsing – defined as animals' heads being in the tree line and ideally animals being observed to eat the leaves, twigs, etc. of the trees.

2. Aversive behaviour triggered by the electric fences – e.g. animals jumping and pulling away from the tree line, animals showing signs of caution in approaching the tree line.

3. Damaging trees e.g. walking through trees, scratching against trees.

Initially it had been planned that observations would be carried out every two days for two one-hour periods during the day: morning (9am – 10am) and afternoon (3pm - 4pm). However, after a trial period it soon became clear that the cattle were very inactive in the morning. This was confirmed by the farm manager who stated that the cattle were active at first light (mainly grazing) but then were inactive for most of the rest of the morning. The observation periods were then changed to 3 - 4pm every week-day afternoon.

Trees in every tree row of each plot were assessed post-grazing for evidence of browsing. Alder and willow were analysed separately, with the % trees browsed data analysed using ANOVA, using R version 2.10.0 (R Development Core Team, 2009). Fencing treatment and replicate block were fixed factors. *Post hoc* testing to compare means was carried out using the Tukey HSD test.

Results and discussion

While the main focus of the observations was the question of whether the cattle would browse the trees in the agroforestry system, a number of other interactions with trees were observed. These included, lying in tree rows, walking through tree rows, damaging trees and using trees as scratching posts. This highlights the multiple purposes that trees might serve on a livestock farm.

FIGURE 80. CATTLE BROWSING THE ELM FARM SILVOPASTURE TRIAL

With regards to browsing behaviour, at the start of the three week observation period the browsing that was observed was either browsing of the mature boundary hedge or browsing of the willow within the agroforestry system (Figure 80). The first observation of cattle browsing on alder was of them browsing on a branch that had been cut 5 days before and was dead. This occurred on the 5th of August. It is suggested that this may have been due to reduced tannins in the dead alder making it more palatable (Gonzalez, personal communication, 2015). However, later on in the three week observation period cattle were also observed browsing on live alder.

The electric fencing (one strand and two strands) appeared to have been effective in keeping the cattle out of the tree rows. The observations of browsing and interactions with trees occurred in tree rows that were unfenced. There were a small number of electric shocks recorded but generally cattle seemed to respect the fences and not get close enough to be shocked. At least one of the shocks occurred when cattle were grazing the understorey of the trees. Grazing of the understorey was observed during four observation sessions. This suggests that with optimal placement of electric fencing it may be possible to encourage cattle to graze the understorey, thus providing weed control, while still protecting the trees from damage due to browsing, scratching or walking.

There was a statistically significant difference between fencing treatments for both alder (F= 2593, p=<0.001), and willow (F= 529, p=<0.001), but no significant differences between replicate blocks or interaction between blocks and fencing treatments. With both willow and alder, significantly more trees were browsed where there was no fencing compared with the fenced plots (Figure 81), but there were no differences between the level of browsing within the one-and two-strand fenced plots. This suggests that one-strand fencing is sufficient to protect the trees from cattle. However, there may be a case for two-strand fencing when deer, particularly muntjac, are common, as they can move under the single strand.

The cattle browsed both willow and alder, although it was interesting to note from the observations of the animals that there was a clear preference for willow initially. As larger trees, the alders were subjected to use as scratching posts and several of them had their main stem snapped as a result.

FIGURE 81. ALDER PLOT SHOWING DAMAGE FROM CATTLE BROWSING AND RUBBING AGAINST TREES.

Key conclusions from 2015 browsing trial

In conclusion, it is clear that fencing is essential in order to protect the trees from damage caused by the cattle, and a single strand is sufficient to keep cattle away, whilst at the same time allowing them to reach grass in the understorey of the tree row. The cattle showed a preference for willow over alder, which reinforces previous observations that the willow was being browsed by deer while the alder was not attacked. Willow has traditionally been used as a fodder for livestock (Austad & Hauge, 2006), and research has shown that willow can have organic matter digestibility levels similar to hay and grass silage (Musonda et al., 2009; Pitta et al., 2007). However, after a few days, the cattle also started browsing the alder trees, suggesting that as they get more familiar with browsing tree leaves, their acceptability of different species increased. Experiments have shown that the diameter of stems selected by ruminants increases with time after initial introduction to the tree-fodder; after 10 weeks, willow selected by lambs increased in diameter from 3 to 4.2 mm diameter (Diaz Lira et al., 2008), while cattle selected willow increasing in diameter from 4 mm initially up to 8 mm in diameter after 81 days (Moore et al., 2003). In this last trial the amount eaten also increased over time, from approximately 1.5 kg/cow/day at the start to 3.5 kg/cow/day after 81 days (Moore et al., 2003).

The use of trees to provide cattle fodder is likely to conflict with the production of woodchip for bioenergy, although one possibility would be to allow the cattle access to the trees in the months leading up to harvest in order to strip the leaves – they would also take branches up to 10mm in diameter but this is unlikely to make much difference to the woodchip yield. Otherwise, tree fodder may have a role to play when grass is in short supply, e.g. during summer droughts, when any loss in woodchip yield would be compensated by avoiding the expense of buying in forage.

It was interesting to note that while there is not yet any apparent impact of the trees on the microclimatic conditions (wind speeds, air temperatures etc.) as discussed above, the cattle were often seen close to or in the tree rows where there was no fencing. This may be because the trees offered some shade from the sun, or provided some cover or protection from more dominant members of the herd.

Browsing observations – sheep 2019

By Lindsay Whistance, Senior Livestock Researcher, Organic Research Centre

In 2018, the cattle at Elm Farm were replaced with a flock of Exlana sheep. In 2019, the flock lambed in April and the fields were grazed according to the share farmer's grazing plan. The silvopasture field was grazed by ewes and lambs for one short period in August and the lambs were grazed there a second time at weaning. The second grazing period lasted for approximately three weeks with the lambs being removed on 10th October 2019. No observations of direct browsing were conducted but the willow and alder were inspected for signs of animal interactions on the same day that the lambs were moved to an adjacent pasture.

In contrast to the study with cattle, no electric fencing was present to guard the trees from browsing though one short section of alder was flanked either side by a thick row of thistles and had not been browsed (Figure 82).

FIGURE 82. TREES PROTECTED FROM BROWSING BY THISTLES

Both the willow and alder had been browsed clean to approximately 75 cm high (Figure 83). The standing browse height typically cited is 120 cm for sheep and here, the lower browse height presumably reflects the limited reach of the juvenile animals.

Figure 83. Alder and willow browsed by sheep to a height of approximately 75 cm

Although it is not possible to state the sheep and lambs' preference for either willow or alder in terms of when each species of tree was browsed, some of the willow – and particularly the short row of younger, more flexible white willow – was browsed much higher than standing browse height and up to 200 cm, indicating a different strategy being employed to access the higher parts. Sheep are known to bring browse down to browse height by using their front legs and then to hold it down using their own body weight. Evidence of damage to the willow, in the form of broken branches supports this and offers an indication of a higher preference for willow by the animals (Figure 84).

Figure 84. Damage to willow tree caused by dragging down branches to browse on

A second observed difference in browsing between willow and alder was the eating of twigs. Whilst leaves had been browsed from both species, many more twigs had been bitten off the willow down to approximately 3 mm diameter (Figure 85), compared to the alder where each leaf was browsed individually from the trees with minimal twig damage (Figure 86). The reason for this is unclear though alder is known to be lower in palatability compared to willow and willow bark is known to contain high levels of salicylic acid – a chemical with multiple medicinal properties including analgesia. However, other than the biting of twigs, no further bark stripping was observed.

FIGURE 85. WILLOW TWIGS EATEN BY SHEEP TO APPROXIMATELY 3 MM DIAMETER

FIGURE 86. MINIMAL EVIDENCE OF LAMBS BROWSING ON THE TWIGS OF ALDER

Other than browsing, minimal evidence of lamb interactions was observed on or around the trees with no evidence of trampling or lying behaviour to suggest prolonged occupation of the site for resting or for shade or shelter, although sheep were observed taking shelter from the sun during August (Figure 87). Additionally, minimal evidence of body maintenance behaviour in the form of rubbing was observed. Although Exlana is a wool-shedding composite breed who utilise trees to rub off any loose fleece when moulting, at approximately six months, the lambs were not yet old enough to have reached a moult stage.

FIGURE 87. SHEEP TAKING ADVANTAGE OF THE SHADE FROM THE TREES IN AUGUST 2019

Tree fodder analyses

SRC willow at Wakelyns Agroforestry 2011

The feed value of the willow is likely to vary depending on the age of re-growth and season of the year, and a better understanding of this variation is necessary in order to identify its potential for contributing to livestock nutrition. The nutritional value of two ages (1st and 2nd year re-growth) of SRC willow was assessed in two seasons; late spring (June) and late summer (Sept) in 2011 (Smith et al, 2014). The first year regrowth material was also used to evaluate the possibilities of ensiling the willow for subsequent use for livestock as one additional benefit from the system.

We tested the following hypotheses:

> *H1: Willow will be of highest nutritional value in spring, declining as plants mature through the summer and fibre and lignin contents and structural carbohydrates increase while crude protein content decreases.*
>
> *H2: 2nd year re-growth will have a lower feed value compared to 1st year re-growth.*
>
> *H3: Ensiled willow will be suitable for livestock feed*

FIGURE 88. HARVESTING WILLOW IN UK (PHOTO: K. LEACH) AND SUBSEQUENT WILLOW LEAF SILAGE AFTER A STORAGE OF HALF A YEAR (PHOTO: M. RINNE).

Methods

Willow samples were manually collected from Wakelyns Agroforestry, on 29th June and 14th September 2011 from both 1st and 2nd year re-growth of willow (Figure 88). Samples were taken from 5m long plots, with four replicate plots of each age class (total of 8 plots). The samples consisted of leaves and stems up to 8 mm in diameter as cattle have been shown to eat willow of 4-8 mm diameter (Moore et al, 2003). Samples were oven dried at 60 °C until a stable weight was reached. For the ensiling experiment, another sample was prepared including leaves only from 2 plots of the first-year re-growth only. Subsamples of fresh willow material weighing approximately 200 g were chopped to a length of approximately 1 cm and ensiled in evacuated polythene bags.

Both dried raw material and silage samples were analysed. Analysis of the silage took place after approximately six months. The feed value and fermentation quality of the samples were analysed at MTT Agrifood Research Finland using standard laboratory methods. The organic matter digestibility (OMD) of the samples was determined using a pepsin-cellulase method, and the solubility values were converted to represent *in vivo* digestibility values using the general equation presented by Huhtanen *et al* (2006).

The concentration of free (FreeT), protein-bound (PT) and fibre-bound (FT) condensed tannins were determined in feed samples using the procedure proposed by Pérez Maldonado and Norton (1996). Condensed tannins from quebracho powder (Roy Wilson Dickson Ltd., Mold, U.K.) were used as a standard.

Statistical analyses

The statistical analysis was carried out using R version 2.10.0 (R Development Core Team, 2009). A two-way analysis of variance (ANOVA) with Year and Season as fixed factors was performed on the chemical composition and OMD of fresh willow samples harvested from 1st and 2nd year re-growth in late spring (June) and late summer (Sept) 2011.

Results

Chemical composition and digestibility of the fresh willow material

There were significant differences in the chemical composition of the different ages and seasons of fresh willow samples (Table 19). As expected, crude protein levels were highest in late spring and higher in 1st year than 2nd year re-growth. There was a statistically significantly higher level of lignin in the late spring samples, and organic matter digestibility (OMD) was higher in late spring than late summer. There was no difference between 1[st] and 2[nd] year re-growth in levels of NDF (neutral detergent fibre), ADF (acid detergent fibre), lignin and *in vitro* OMD (Table 19).

TABLE 19. CHEMICAL COMPOSITION AND IN VITRO ORGANIC MATTER DIGESTIBILITY (OMD) OF FRESH WILLOW SAMPLES HARVESTED FROM 1ST AND 2ND YEAR RE-GROWTH IN LATE SPRING (JUNE) AND LATE SUMMER (SEPT) 2011.

	1st year		2nd year		Statistical significance		
	June	Sept	June	Sept	Year	Season	Y*S
n	4	4	4	4			
Dry matter (DM; g/kg)	265	378	359	420	**	**	**
In DM[a] (g/kg DM)							
Ash	70.8	72.5	63.6	63.7	*	NS	NS
Crude protein	167	127	125	99	**	**	NS
Neutral detergent fibre	573	492	548	503	NS	**	*
Acid detergent fibre	410	341	395	357	NS	**	*
Lignin	184	136	168	135	NS	**	NS
In vitro OMD	0.405	0.383	0.399	0.369	NS	**	NS

* significant at $P<0.05$ and ** significant at $P<0.01$

Chemical composition and digestibility of the ensiled willow material

The chemical composition and *in vitro* digestibility of leaf + stem silage and the leaf only silage is presented in Table 20. The CP (crude protein) concentration was relatively high in leaf + stem silage and even higher in leaf only silage and the fibre concentration was relatively low, and the OMD determined by *in vitro* cellulose method was low (0.421 for leaf + stem silage and 0.511 for leaf only silage).

TABLE 20. CHEMICAL COMPOSITION AND IN VITRO DIGESTIBILITY OF WILLOW ENSILED ON 29 JUNE 2011.

	Leaf + stem		Leaf only silage	
	Mean	S.D.[1]	Mean	S.D.
n	8		4	
Dry matter (DM; g/kg)	276	20.2	282	3.8
In DM (g/kg DM)				
Ash	73	3.7	94	5.4
Crude protein	182	12.8	219	13.1
Water soluble carbohydrates	7.9	1.66	15.4	5.03
Neutral detergent fibre	440	18.4	287	7.3
Acid detergent fibre	317	14.3	199	8.2
Lignin	85	6.7	52	5.6
Based on *in vitro* pepsin-cellulase solubility				
OMD	0.421	0.0257	0.511	0.0106
D-value[2] (g/kg DM)	390	24.6	463	11.7

[1]S.D. = Standard deviation [2]Digestible organic matter

Ensilability

During ensiling, concentrations of water-soluble carbohydrates (WSC) and the fibre fractions decreased clearly (Table 20). During the fermentation process, WSC are converted to fermentation acids, which explains the decrease. A decrease in fibre fractions is also often seen in e.g. grass silages, and it can be explained as a result of acid hydrolysis. The large extent of fibre degradation in this material with relatively high pH is, however, surprising.

The appearance and smell of the silage samples at opening of the vacuum plastic bags was pleasant with minor deteriorations (probably yeasts) visible (Figure 88). The fermentation quality of the willow silages is reported in Table 21. The extent of fermentation was low and pH high (5.79) for a rather low DM material (DM concentration 276 g/kg). The WSC of the raw material (35 g/kg DM) and the residual WSC concentration in silages was relatively low, which at least partly explains the restricted production of fermentation acids. Possibly the CT (condensed tannins) present in the material also play a role. The fermentation profile was heterofermentative (acetic acid dominated instead of lactic acid).

TABLE 21. FERMENTATION QUALITY OF WILLOW SILAGES ENSILED ON 29 JUNE 2011.

	Leaf + stem silage		Leaf only silage	
	Mean	S.D.[1]	Mean	S.D.
pH	5.80	0.225	5.78	0.064
In dry matter (g/kg)				
Lactic acid	3.9	3.09	2.5	0.50
Acetic acid	6.3	1.36	4.7	1.27
Propionic acid	0.4	0.58	0.1	0.02
Butyric acid	0.4	0.47	0.2	0.02
Isobutyric acid	0.0	0.01	0.0	0.00
Isovaleric acid	0.1	0.02	0.1	0.02
Valeric acid	0		0	
Capronic acid	0		0	
Ethanol	0		0	
Ammonium N (g/kg total N)	45	12.5	19	3.0

[1]S.D. = Standard deviation

Condensed tannins of ensiled willow

The concentrations of free, protein-bound, fibre-bound and total condensed tannins in the silages are presented in Table 22. The concentrations of all tannin fractions were almost twice as high in the leaf only silage compared to leaf + stem silage.

TABLE 22. CONCENTRATIONS OF DIFFERENT TANNIN FRACTIONS IN WILLOW SILAGES ENSILED ON 29 JUNE 2011.

	Leaf + stem silage		Leaf only silage	
	Mean	S.D.[1]	Mean	S.D.
Tannins (g/100 g dry matter)				
Free	4.7	3.40	10.3	3.19
Protein-bound	1.8	0.88	2.7	0.33
Fibre-bound	0.8	0.50	1.5	1.01
Total	7.3	3.64	14.6	3.87

[1]S.D. = Standard deviation

Feed value of fresh willow

As regards Hypothesis 1, while crude protein levels were highest in late spring as expected, we were surprised also to find higher levels of lignin, NDF and ADF in the late spring samples of willow. This is because we expected lignin, ADF and NDF content to increase as the willow grew through the season. One possible explanation is that there was a greater proportion of stems in the late spring samples as the early growth stems would be more likely to be smaller in diameter than the 8mm limit. As expected, OMD was higher in late spring than late summer, but overall was rather low at 0.38 to 0.41. This compares poorly with values from the research literature which recorded values for willow of up to 0.74 (Musonda et al, 2009; Pitta et al, 2007). Typically dairy cow forages have a much higher OMD (hay 0.47-67; grass silage 0.52-0.67; grazed grass 0.64-0.75 (Ministry of Agriculture Fisheries and Food, 1990)). However, it is very likely that the values of digestibility estimated in this work with the pepsin-cellulase technique underestimate the true digestibility of the willow as normally performed in vitro, and of course with in vivo direct measurement.

As regards Hypothesis 2, crude protein levels were higher in 1st year than 2nd year of re-growth, but other feed values were not statistically different. This may be explained by the fact that branches mainly from the current growing season were harvested as the limit of the diameter of the branches collected was 8mm and older branches would have exceeded this width.

Digestibility generally decreases over the growing season; for example, Papachristou and Papanastasis (1994) measured *in vitro* OMD of a range of Mediterranean species over the growing season. This ranged from 0.535 for *Corylus avellana* to 0.666 for *Carpinus orientalis* for fresh growth in spring (average 60.7% for 7 species) and declined over the season to an average of 0.468 as the leaves senesced in September. McWilliam et al (2005) found that while the digestibility of willow and poplar tree fodders declined from late spring to autumn, the decline in OMD was much smaller than the decline in digestibility of grass-based pastures in New Zealand over the same period, thus making these tree fodders effective supplements to livestock grazing drought pastures.

In vitro OMD of poplar and willow in New Zealand was recorded by Kemp et al (2003) as 0.697 and 0.692 respectively, with significantly higher levels in spring than summer. A decline over the season of approximately 0.10 was attributed mainly to maturing of the thin stems as the digestibility of the leaves decreased by only 0.03 units over the growing season. Willow leaves have a higher OMD than the edible stems (<5 mm diameter); the difference varies depending on species, but OMD of leaves can be twice that of the edible stems (Oppong et al, 2001).

The *in vitro* method we used has not been validated to be used on woody materials and there are some uncertainties related to its use. In literature, the reported OMD values for woody material averages around 0.5, but the range is wide. However, it must be remembered that predicting nutritive value of tree material reliably from chemical analysis is difficult, because of the interference of condensed tannins and other phenolic compounds with the digestibility of the fibre fraction (Tolera et al, 1997). McWilliam et al (2005) validated a reasonably reliable calibration curve for prediction of *in vivo* digestibility of willow by sheep, from the results of *in vitro* analysis based on the enzymatic method of Rougham and Holland (1977), across a limited range of composition. This gave slightly different predictions from those derived using a calibration curve for grass-clover herbage and was therefore deemed preferable.

Digestibility needs to be ultimately measured *in vivo*. OMD measured in cryptorchid lambs in New Zealand fed fresh tree fodder twice daily, ranged from 0.64 to 0.70 for willow and from 0.62 to 0.67 for poplar over one growing season (McWilliam et al, 2005). Intake of these lambs was between 0.75 and 1.12 kg DM/ day for poplar and 0.91 and 1.01 kg DM/day for willow (McWilliam et al, 2005). However, due to the expense of *in vivo* measurements, the majority of data is obtained from *in vitro* methods.

Ensiled willow

As regards Hypothesis 3, the crude protein concentration was relatively high in leaf + stem silage and even higher in leaf only silage and the fibre concentration was relatively low. However, the OMD determined by *in vitro* pepsin-cellulase method was low (0.421 for leaf + stem silage and 0.511 for leaf only silage) and it cannot be considered a suitable feed for lactating dairy cows. It might be suitable for other animal groups with lower energy requirements and other species that can better utilise poor quality feeds with low digestibility such as goats.

One of the limitations of using tree fodder as a feed is that the nutritive value and digestibility peaks in spring and decreases through to autumn. The results show that willow material has some potential for ensiling, but it should be verified in larger scale experiments. Baertsche et al. (1986) carried out ensiling trials of several short rotation coppiced hardwood species. They found that all species apart from elm and willow ensiled adequately after 24 days. Willow and elm samples developed a mould growth and deteriorated rapidly, which was attributed to their high levels of dry matter (over 40 % after wilting) and lower leaf-to-stem ratios compared to other species. This meant that insufficient moisture and soluble carbohydrates were available for rapid fermentation to take place, and it was difficult to pack silos tightly so preventing completely anaerobic conditions. The chemical composition of the other species changed little with ensiling, although crude protein decreased slightly.

Secondary compounds

Although tree fodder is generally higher in protein and minerals than dry season pasture, the presence of tannins and other phenolic compounds may reduce digestibility and availability of protein, and palatability and intake (Tolera et al, 1997). The concentration of the anti-nutritional factors (ANF's) crucially affects the productive outcome of this effect. At low concentrations, some condensed tannins can in fact have a beneficial influence, by reducing protein degradation in the rumen and increasing the flow of protein and essential amino acids to the intestine (Rogosic et al, 2006). The acceptable limit for condensed tannin concentrations is <5 g CT/100 g DM, but sheep have been observed browsing readily on leaves with higher CT concentrations than this (Oppong et al, 2001). The influence of anti-nutritional factors introduces variability to *in vitro* evaluation of tree fodders, and some uncertainty into the prediction of animal performance based on *in vitro* analyses (McWilliam et al, 2005; Papachristou & Papanastasis, 1994).

Levels of condensed tannins vary considerably between plant species. Secondary compound concentrations can vary also between different species of the same genus (e.g. CT concentration of *Salix kinuyanagi* was four times higher than *Salix matsudana x alba* (Oppong et al, 2001)) and even between cultivars of the same species (Kemp et al, 2003). Environmental conditions can influence the level of secondary compounds; total CT concentrations from willow leaves in a New Zealand silvopasture varied between 45 and 303 g/kg DM with the higher concentrations recorded from willow grown in more hostile sites (low soil fertility, low temperatures and strong winds) (Oppong et al, 2001). Also, the concentration of condensed tannins varies between different parts of the plant, normally being present in higher levels in those parts that are prone to be eaten by animals. This may explain the greater content observed in leaf only silage as compared to leaf+steam silage (14.6 vs. 7.3).

Other secondary compounds have importance in particular tree species. For example, although the phenolic glucoside salicin is well known to be a component of willow and to have anti-inflammatory properties, it has not been widely evaluated in terms of its content within tree fodders or consequent effects on animal performance. Salicin content is known to influence selection of willow and poplar by herbivores including sheep (McKinnon et al, 2000, in Kemp et al, 2003). However, the balance between rejection of plant species or varieties on the basis of palatability (Boeckler et al, 2011), and the intermittent positive selection by animals of certain species (presumed to be for self-medication or meeting particular metabolic needs), which is anecdotally reported, is not well explained in the scientific literature.

Tree fodder

Experiments have shown that the diameter of stems selected by ruminants increases with time after initial introduction to the tree-fodder; after 10 weeks, willow selected by lambs increased in diameter from 3 to 4.2 mm diameter (Diaz Lira et al, 2008), while cattle selected willow increasing in diameter from 4 mm initially up to 8 mm in diameter after 81 days (Moore et al, 2003). In this last trial the amount eaten also increased over time, from approximately 1.5 kg/cow/day at the start to 3.5 kg/cow/day after 81 days (Moore et al, 2003). These increases may have been influenced by familiarity and the availability of alternative forage.

Tree management also influences chemical composition of fodder; for example, management by short rotation coppicing produces fresh growth with a high leaf-to-stem ratio, low in lignin and with high potential feeding value compared with mature trees (Baertsche et al, 1986).

Questions related to harvesting, storage and feeding technology are obviously key points that need to be addressed in order to effectively use trees for fodder in a larger scale. Manual cutting and transporting is laborious and time consuming, while direct browsing requires careful management that balances keeping tree height accessible to livestock with minimizing damage to the tree. Innovative dairy farmers in the Netherlands have been investigating silage making as a means of preserving willow coppice for feeding to dairy goats (see www.voederbomen.nl/oogst for a film of the process). Fodder blocks of trees can be established on unproductive land (e.g. willow grows well in wet areas), and regular coppicing or direct browsing maintains the blocks at a manageable height. Alternatively, pollarding promotes tree growth above livestock grazing height and reduces canopy effects on pasture productivity (Benavides et al, 2009).

Key conclusions/lessons learnt

While it is apparent that the feed value of the willow within this integrated system is limited, willow as a fodder may have a role to play as a buffer feed when grass is in short supply or of poor quality. In addition, moderate concentrations of secondary compounds such as condensed tannins found in tree fodder can have a beneficial influence by reducing protein degradation in the rumen and increasing the flow of protein and essential amino acids to the intestine (Rogosic et al, 2006) although at high levels, these compounds may reduce digestibility and availability of protein, palatability and intake (Tolera et al, 1997).

Although the feed values were low, willow may have a role in multifunctional systems, where it can provide additional values in grazing situations such as microclimate benefits for livestock and a range of ecosystem services. For easy and efficient use in animal production, controlled browsing might be used; otherwise methods for harvesting and preservation need to be developed. There seems to be some scope for ensiling willow material.

The unpredictability and variability in feed supply from agroforestry systems is one of the biggest challenges to their use at present as there are so many different species available and the seasonal variation is so great. However, fast growing trees like willow provide the potential for a large quantity of material. Another challenge is the lack of structured preparation and distribution, and mechanisation for harvesting/handling - both for preparation and feeding. Using a silvopastoral approach needs a change in the mindset of the farmer and several practical issues in the production system need to be solved and it appears that also the animals may need to get used to it

Tree fodder Elm Farm 2015-2016

To gain a better understanding of the nutritional value of tree leaves, since 2015 we have been sampling and analysing various species of trees on Elm Farm. 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 (Smith et al, 2017). 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. In March, leaf samples were taken from the air-dried bundles, before the bundles being fed to housed cattle and young stock (Figure 90 and see video at https://vimeo.com/217077820).

FIGURE 89. HARVESTING TREE FODDER FROM AN ASH TREE, JUNE 2016

FIGURE 90. 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). 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 23). Similarly low levels (42.1%) were recorded in *Salix viminalis* samples from a UK silvoarable SRC system (Smith *et al*, 2014). However, DOM of the other species were higher (Table 23) 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 23. 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	*Salix viminalis*	Aug-15	33	37.29	22.12	11.33	55.29
Common alder	*Alnus glutinosa*	Aug-15	38	37.61	24.76	13.51	76.19
Ash	*Fraxinus excelsior*	Jun-16	39	29.59	14.84	5.02	85.68
Goat willow	*Salix caprea*	Jun-16	35	32.15	20.57	8.77	73.51
English elm	*Ulmus minor*	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 24). 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 24. 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	*Salix viminalis*	Aug-15	18.8	3	2.23	1.8	4.1	10.4
Common alder	*Alnus glutinosa*	Aug-15	13.3	2.2	3.16	2.5	1.9	9.1
Ash (fresh)	*Fraxinus excelsior*	Jun-16	12.8	3.1	1.78	2.2	1.8	14.1
Ash (air-dried)	*Fraxinus excelsior*	Jun-16	16	3.7	2.21	2.7	2.3	20
Goat willow (fresh)	*Salix caprea*	Jun-16	10.2	4.2	2.66	1.9	2.1	13.9
Goat willow (air-dried)	*Salix caprea*	Jun-16	14.5	5.5	2.16	2.7	2.6	19.0
English elm (fresh)	*Ulmus minor*	Jun-16	11	2.3	2.23	1.9	1.3	14.7
English elm (air-dried)	*Ulmus minor*	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 25) 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 more effective than drenching (Anderson et al., 2012).

TABLE 25. 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	*Salix viminalis*	Aug-15	73	284	5.5	245	36.7
Common alder	*Alnus glutinosa*	Aug-15	92	129	11.2	53	28.9
Ash (fresh)	*Fraxinus excelsior*	Jun-16	91	25	7.4	18	15.7
Ash (air-dried)	*Fraxinus excelsior*	Jun-16	116	32	9.6	23	17.5
Goat willow (fresh)	*Salix caprea*	Jun-16	76	36	7.6	118	12.7
Goat willow (air-dried)	*Salix caprea*	Jun-16	142	46	10.9	144	18.2
English elm (fresh)	*Ulmus minor*	Jun-16	138	37	6.5	32	19.3
English elm (air-dried)	*Ulmus minor*	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 25). *Salix viminalis* and *Alnus glutinosa* contained substantially higher levels of manganese than did other tree species (Table 25). 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.

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.

Tree fodder Elm Farm 2017-2018

Building on these initial results, in 2017 we established a collaboration with Dr Sokratis Stergiadis at the University of Reading to investigate total tannin levels and tannin profiles of oak, goat willow and field maple throughout the summer months. These species were chosen as they represented three stages in ecological succession (goat willow = early; field maple = mid and oak = late succession) and therefore have different approaches e.g. to defence against herbivore attacks, which may affect leaf characteristics. These species are also common in the surrounding area. We were interested to find out if concentrations of tannins varied between species, and also throughout the summer season as leaves matured.

Method

Branches less than 10mm diameter were collected from five individual trees of each species spread across Elm Farm, monthly from June to September (four months x five trees x three species = 60 samples). Where possible, branches were collected from all orientations in the tree, and were at a reasonable height that would permit livestock grazing. Once collected, leaves were plucked off the branches by hand with a target weight of 600g fresh weight of leaves. Associated twigs were weighed to calculate twig:leaf ratios and both components oven dried at 40°C until a constant weight was achieved.

In 2018, we repeated the sampling protocol to collect a second year of samples from the goat willow and oak trees, from June to September. The collaboration was also extended to include Chris Stoate from the GWCT, Nigel Kendall from University of Nottingham Veterinary School, Andy Smith from Bangor University with support for laboratory analyses from the Woodland Trust. With this larger group, we coordinated sample collection so that leaves and twigs were collected in June and September from goat willow, oak and a third species, common alder, from three sites (Elm Farm, Henfaes (Bangor University Farm, North Wales) and GWCT Allerton Project (Leicestershire)). Mineral analyses were carried out on the leaf samples by Nottingham University and energy and protein analyses by Bangor University.

Results

Key results have been presented in a Woodland Trust research briefing (Kendall et al. 2019). Willow leaves from all sites were found to contain higher concentrations of zinc and cobalt than sheep requirements for these minerals. Selenium concentrations were found to be more dependent on the site than the tree species, with Elm Farm having higher levels than the other two sites. Metabolisable energy of leaves sampled was greatest in alder, while higher crude-protein content was associated with spring in all species. Full results and analyses will be reported in a per-reviewed paper (Kendall et al, in prep). Analyses of the tannin results carried out by the University of Reading are not yet complete.

Trees for feed: Conclusions and lessons learnt

Fencing is essential to protect the trees from livestock, and one strand of electric fencing was sufficient to keep cattle away, whilst at the same time allowing them to reach grass in the understorey of the tree row. Cattle showed a preference for willow, but over time adapted to browsing alder trees too; controlled browsing of SRC at certain stages of the tree rotation, or when grass is in short supply, would be one way to balance production of bioenergy with livestock production. While the main focus of the observations was the question of whether the cattle would browse the trees in the agroforestry system, a number of other interactions with trees were observed. These included, lying in tree rows, walking through tree rows, damaging trees and using trees as scratching posts. This highlights the multiple purposes that trees might serve on a livestock farm.

The use of trees to provide cattle fodder could conflict with the production of woodchip for bioenergy, one possibility would be to allow the cattle access to the trees in order to strip the leaves prior to biomass harvest. Tree fodder may also play an important role as a buffer feed when grass is in short supply or of poor quality.

There were significant differences in the chemical composition of the different ages and seasons of fresh willow samples from the established short rotation coppice willow Wakelyns. Crude protein levels and organic matter digestibility (OMD) were highest in late spring and higher in 1st year than 2nd year re-growth.

Although the feed values were low, willow may have a role in multifunctional systems, where it can provide additional values in grazing situations such as microclimate benefits for livestock and a range of ecosystem services. For easy and efficient use in animal production, controlled browsing might be used; otherwise methods for harvesting and preservation need to be developed. There seems to be some scope for ensiling willow material.

In addition, moderate concentrations of secondary compounds such as condensed tannins found in tree fodder can have a beneficial influence by reducing protein degradation in the rumen and increasing the flow of protein and essential amino acids to the intestine (Rogosic et al, 2006) although at high levels, these compounds may reduce digestibility and availability of protein, palatability and intake (Tolera et al, 1997).

The unpredictability and variability in feed supply from agroforestry systems is one of the biggest challenges to their use at present as there are so many different species available and the seasonal variation is so great. However, fast growing trees like willow provide the potential for a large quantity of material. Another challenge is the lack of structured preparation and distribution, and mechanisation for harvesting/handling - both for preparation and feeding. Using a silvopastoral approach needs a change in the mindset of the farmer and several practical issues in the production system need to be solved and it appears that also the animals may need to get used to it.

The value of tree leaves as livestock fodder is of increasing interest to farmers, as a buffer climate impacts on forage yields and quality. Research at Elm Farm have shown 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.

References

Anderson, CWN, Robinson, BH, West, DM, Clucas, L and Portmann, D (2012). Zinc-enriched and zinc-biofortified feed as a possible animal remedy in pastoral agriculture: Animal health and environmental benefits. Journal of Geochemical Exploration 121: 30–35

Austad, I and Hauge, L (2006). Pollarding in western Norway. 1er colloque europeen sur les trognes, 26-28 October, Vendome.

Baertsche, SR, Yokoyama, MT, Hanover, JW, (1986). Short rotation, hardwood tree biomass as potential ruminant feed-chemical composition, nylon bag rumen degradation and ensilement of selected species. Journal of Animal Science 63, 2028-2043.

Barrett, RP, Mebrahtu, T, Hanover, JW (Eds.) (1990). Black locust: a multipurpose tree species for temperate climates. Timber Press, Portland, OR.

Benavides R, Douglas GB, Osoro K (2009). Silvopastoralism in New Zealand: review of effects of evergreen and deciduous trees on pasture dynamics. Agroforestry Systems 76: 327-350

Biomass Energy Centre (2014). Carbon emissions of different fuels. Available from: www.biomassenergycentre.org.uk/portal/page?_pageid=75,163182&_dad=portal&_schema=PORTAL

Bird, PR (1998). Tree windbreaks and shelter benefits to pasture in temperate grazing systems. Agroforestry Systems, 1998. 41: p. 35-54.

Blair R (2011). Nutrition and feeding of organic cattle. CABI, Wallingford UK.

Boeckler, GA, Gershenzon, J, Unsicker, SB (2011). Phenolic glycosides of the Salicaceae and their role as anti-herbivore defences. Phytochemistry 72, 1497-1509.

Blake, S (1996). Effects of management practises on the carabid faunas of newly established wildflower meadows in southern Scotland. Annales Zoologici Fennici 33:139-147. University of Glasgow.

Błaszkiewicz, M and Schwerk, A (2013). Carabid beetle (Coleoptera: Carabidae) diversity in agricultural and post-agricultural areas in relation to the surrounding habitats. Baltic Journal of Coleopterology. 13. 15-26.

Bright, P, Morris, P and Mitchell Jones, T (2006). The dormouse conservation handbook – second edition. English Nature Publications

Burner, DM, Pote, DH, Ares, A, (2005). Management effects on biomass and foliar nutritive value of Robinia pseudoacacia and Gleditsia triacanthos f. inermis in Arkansas, USA. Agroforestry Systems 65, 207-214.

Burner, DM, Carrier, DJ, Beleskey, DP, Pote, DH, Ares, A, Clausen, EC, (2008). Yield components and nutritive value of Robinia pseudoacacia and Albizia julibrissin in Arkansas, USA. Agroforestry Systems 72, 51-62.

Cannell, MGR, Van Noordwijk, M and Ong, CK (1996). The central agroforestry hypothesis: the trees must acquire resources that the crop would not otherwise acquire. Agroforestry Systems, 1996. 34: p. 27-31.

Carey et al., (2007). Countryside Survey: UK Results from (2007). CEH Project Number: C03259

Casals, P., et al., Chapter 8 Silvopastoral Systems in the North-eastern Iberian Peninsula: A Multifunctional Perspective, in Agroforestry in Europe: Current Status and Future Prospects, A. Rigueiro-Rodríguez, et al., Editors. 2008, Springer.

Chambers, EM, Crossland, EM, Westaway, S, and Smith, J (2015). Hedgerow harvesting machinery trials report for TWECOM. The Organic Research Centre

Clarke J, Ginsburg D, Kelly C and Tonguc L (2015). The encyclopaedia of arable weeds. HGCA and BASF plc

Crossland, M (2015). The carbon sequestration potential of hedges managed for woodfuel. Organic Research Centre publication.
http://www.organicresearchcentre.com/manage/authincludes/article_uploads/project_outputs/TWECOM%20ORC%20Carbon%20report%20v1.0.pdf

Crossland, M, Westaway, S, Smith, J and Gerrard, C (2015). A report of the development of the Hedgerow Biodiversity Protocol. Organic Research Centre Publication. https://tinyurl.com/ya2whbtz

Croxton, PJ, Franssen, W, Myhill, DG and Sparks, T (2004). The restoration of neglected hedges: A comparison of management treatments. Biological Conservation. 117. 19-23. 10.1016/S0006-3207(03)00258-1.

Deremetz, V (2017). Study of the effects of the age of trees on the agro-ecosystem in SRC agro-silvopastoral system. Internship report. Organic Research Centre.

Desender, K and Pollet, M (1988). Sampling pasture carabids with pitfalls: evaluation of species richness and precision. Mededelingen (Rijksuniversiteit te Gent. Fakulteit van de Landbouwkundige en Toegepaste Biologische Wetenschappen) 53.

Defra (2007) Hedgerow Survey Handbook. A standard procedure for local surveys in the UK. Defra, London.

Devendra, C, (1992). Nutritional potential of fodder trees and shrubs as protein sources in ruminant nutrition. In: Speedy, A, Pugliese, PL (Eds.), Legume Trees and Other Fodder Trees as Protein Sources for Livestock. FAO, Rome.

Devon Hedge Group (2014). Wood fuel from hedges. Devon Hedge Group and Tamar Valley AONB.

Diaz Lira, CM, Barry, TN, Pomroy, WE, (2008). Willow (Salix spp.) fodder blocks for growth and sustainable management of internal parasites in grazing lambs. Animal Feed Science and Technology 141, 61-81.

Djomo Njakou S, El Kasmioui O, De Groote T, Broeckx LS, Verlinden MS, Berhongaray G, Fichot R, Zona D, Dillen SY, King JS, Janssens IA, Ceulemans R (2013). Energy and climate benefits of bioelectricity from low-input short rotation woody crops on agricultural land over a two-year rotation. Applied Energy, 111: 862-870.

Eichhorn, MP, et al. (2006). Silvoarable systems in Europe - past, present and future prospects. Agroforestry Systems, 2006. 67: p. 29-50.

Fernández-Núnez *et al.* (2007). in Agroforestry in Europe: Current Status and Future Prospects, A. Rigueiro-Rodríguez, et al., Editors. 2008, Springer.

Forestry Commission (1956). Utilisation of Hazel Coppice. Bulletin No. 27

Garbutt RA, Sparks TH (2002). Changes in the botanical diversity of a species rich ancient hedgerow between two surveys (1971–1998). Biological Conservation 106: 273-278

Golbach HE, Huang LB, Wimmer MA (2007). Boron functions in plant and animals: recent advances in boron research and open questions. In Xu F et al. (eds) Advances in Plant and Animal Boron Nutrition. Springer, Dordrecht. pp. 3-25.

Graves, AR, et al. (2007). Development and application of bio-economic modelling to compare silvoarable, arable and forestry systems in three European countries. Ecological Economics, 2007. 29: p. 434-449.

Grime JP, Hodgson JG, Hunt R (2014) Comparative Plant Ecology: A Functional Approach to Common British Species: Springer.

Grogan, P and Matthews, R. (2001). Review of the potential for soil carbon sequestration under bioenergy crops in the U.K. Scientific Report.

Guevara-Escobar, A, et al. (2000) Tree water use and rainfall partitioning in a mature poplar-pasture system. Tree Physiology, 2000. 20: p. 97-106.

Hawke, MF and Knowles, RL (1997) Chapter 3. Temperate Agroforestry Systems in New Zealand, in Temperate Agroforestry Systems, A.M. Gordon and S.M. Newman, Editors. 1997, CAB International: Wallingford.

Huhtanen P, Nousiainen J, Rinne M (2006) Recent developments in forage evaluation with special reference to practical applications. Agricultural and Food Science 15: 293-323

Jose, S, Gillespie, AR, and Pallardy, SG (2004). Interspecific interactions in temperate agroforestry. Agroforestry Systems, 2004. 61: p. 237-255.

Kemp, PD, Barry, TN and Douglas, GB (2003). Edible forage yield and nutritive value of poplar and willow. New Zealand Grassland Association, 2003. Workshop Proceedings.

Kendall, N, Smith, J, Whistance, LK, Stergiadis, S, Stoate, C, Chesshire, H, and Smith, AR. (2019) Tree leaves as supplementary feed for ruminant livestock. Woodland Trust Research Briefing.

Lampkin, N, Measure, M and Padel, S (2014). The Organic Farm Management Handbook 2014. 10th edition. The Organic Research Centre.

Lepš, J and Šmilauer, P (2003). Multivariate Analysis of Ecological Data Using CANOCO. Cambridge University Press, Cambridge.

Luff ML (2007). The Carabidae (ground beetles) of Britain and Ireland (2nd edition). Handbooks for the Identification of British Insects. Field Studies Council.

Martin PA, Bateson P (2007) Measuring behaviour: an introductory guide: Cambridge University Press.

Matthews, G (1993). The Carbon content of trees. Technical Paper 4. Forestry Commission, Edinburgh.

McDonald P, Edwards RA, Greenhalgh JFD, Morgan CA (1995). Animal Nutrition. 5th Ed. Addison Wesley Longman Limited, Harlow UK.

McWilliam, E.L., T.N. Barry, and N. Lopez-Villalobos (2005) Organic matter digestibility of poplar (Populus) and willow (Salix) forage trees and its in vitro prediction. Journal of the Science of Food and Agriculture. 85: p. 1098-1104.

Meyer C (2013) Agroforestry: A study of farmer attitudes and perceptions in England. MSc Rural Land and Business Management Thesis, School of Real Estate and Planning, Henley Business School, University of Reading

Ministry of Agriculture Fisheries and Food (1990). UK tables of nutritive value and chemical composition of feedstuffs. Rowett Research Institute, Aberdeen.

Mitlohner FM, Morrow-Tesch JL, Wilson SC, Dailey JW, McGlone JJ (2001) Behavioural sampling techniques for feedlot cattle. Journal of Animal Science 79: 1189-1193

Montagnoli, A., Terzaghi, M., Di Iorio, A., Scippa, G.S. and Chiatante, D. (2012). Fine-root seasonal pattern, production and turnover rate of European beech (Fagus sylvatica L.) stands in Italy Prealps: Possible implications of coppice conversion to high forest. Plant Biosystems, 146, 4, 1012-1022.

Moore, KM, et al. (2003). Willow (Salix sp.) as a supplement for grazing cattle under drought conditions. Animal Feed Science and Technology, 2003. 104: p. 1-11.

Musonda, K, et al., (2009) Grazing willow (Salix sp.) fodder blocks for increased reproductive rates and internal parasite control in mated hoggets. Animal Feed Science and Technology 150(1): p. 46-61.

Nix J. (2014) Farm Management Handbook. 44th Edition

Olea, L., Lopez-Bellido, RJ, Poblaciones, MJ, (2005). European types of silvopastoral systems in the Mediterranean area: dehesa. In: Mosquero-Losada, M.R., McAdam, J., Riguero-Rodriguez, A. (Eds.), Silvopastoralism and sustainable land management: proceedings of an International Congress on Silvopastoralism and Sustainable Management held in Lugo, Spain, 2004. CABI Publishing, Wallingford.

O'Neill MA, Ishii T, Albersheim P, Darvill AG (2004). Rhamnogalacturonan II: Structure and function of a borate cross-linked cell wall pectic polysaccharide. Annual Review of Plant Biology 55: 109-139.

Oppong, SK, et al. (2001) Browse yield and nutritive value of two Salix species and Dorycnium rectum in New Zealand. Agroforestry Systems. 51: p. 11-21.

Oreszczyn, S and Lane, A (2000). The meaning of hedgerows in the English landscape: Different stakeholder perspectives and the implications for future hedge management. Journal of Environmental Management 60: 101-118

Papachristou, TG and Papanastasis, VP (1994). Forage value of Mediterranean deciduous woody fodder species and its implication to management of silvo-pastoral systems for goats. Agroforestry Systems, 1994. 27: p. 269-282.

Papanastasis, V.P., et al. (2008). Chapter 5 Traditional Agroforestry Systems and Their Evolution in Greece, in Agroforestry in Europe: Current Status and Future Prospects, A. Rigueiro-Rodríguez, et al., Editors. 2008, Springer.

Pérez Maldonado RA and Norton B (1996). The effects of condensed tannins from *Desmodium intortum* and *Calliandra calothyrsus* on protein and carbohydrate digestion in sheep and goats. British Journal of Nutrition 76 (4): 515-533

Pfiffner L, Luka H (2000), Overwintering of arthropods in soils of arable fields and adjacent semi-natural habitats. Agriculture, Ecosystems and Environment 78: 215-222.

Pitta, DW, et al. (2007) Willow fodder blocks - an alternative forage to low quality pasture for mating ewes during drought? Animal Feed Science and Technology. 133: p. 240-258

R Development Core Team. (2009) R: A language and environment for statistical computing. In R Foundation for Statistical Computing (ed.), Vienna, Austria.

Ransom JI, Cade BS (2009) Quantifying equid behaviour – A research ethogram for free-roaming horses, Vol. 2-A9: US geological survey Techniques and Methods

Reif A, Bazin P, Degmair J, Tourret V, Schmutz T, Walentowski H (2001) Planting and maintaining hedges in Europe. In: Barr C, Petit S (eds) Hedgerows of the World: Their Ecological Functions in Different Landscapes. IALE (UK), University of Birmingham, pp 289-297

Robinson, B, Mills, T, Green, S, Chancerel, B, Clothier, B, Fung, L, Hurst, S & McIvor, I (2005) Trace element accumulation by poplars and willows used for stock fodder. New Zealand Journal of Agricultural Research 48: 489-497.

Rolls, W & Hogan, G (2009). Information Sheet 3 Short Rotation. Coppice Biomass Energy Centre and Forestry Commission.

Rogosic, J., Pfister, J.A., Provenza, F.D., Grbesa, D., 2006. Sheep and goat preference for and nutritional value of Mediterranean maquis shrubs. Small Ruminant Research 64, 169-179.

Sherrell CG (1983). Boron nutrition of perennial ryegrass, cocksfoot, and timothy. New Zealand Journal of Agricultural Research 26: 205-208.

Sims, R and Gerard, B (1999). Earthworms. The Field Studies Council, Shrewsbury.

Sinclair, F.L., W.R. Eason, and J. Hooker, Chapter 3. Understanding and Management of Interactions, in Bulletin 122. Agroforestry in the UK, AM Hislop and J Claridge, Editors. (2000) Forestry Commission: Edinburgh

Smith, J, Leach, K, Gerrard, C and Padel, S (2014). Assessment of an agroforestry system in terms of feed supply and multifunctionality. Part 1: Deliverable for FP7 project Sustainable Organic and Low Input Dairying. www.solidairy.eu

Smith, J, Gerrard, C, Zaralis, K and Padel, S (2016). Assessment of an agroforestry system in terms of feed supply and multifunctionality. Part 2: Establishing a novel system. Deliverable for FP7 project Sustainable Organic and Low Input Dairying. www.solidairy.eu

Smith, J, Whistance, L, Costanzo, A and Deremetz, V (2017). Lessons learnt: agroforestry for ruminants in England. Report for H2020 project AGFORWARD. www.agforward.eu https://www.agforward.eu/index.php/en/agroforestry-with-ruminants-uk.html

Smith, J, Westaway, S, Mullender, S, Giannitsopoulos, M and Graves, A (submitted to Agroforestry Systems journal Dec 2019) Making hedgerows pay their way: the economics of harvesting hedges for bioenergy

Tamang, B, Andreu, MG, and Rockwood DL (2010) Microclimate patterns on the leeside of single-row tree windbreaks during different weather conditions in Florida farms: implications for improved crop production. Agroforestry Systems.

Ter Braak, CJF and Šmilauer, P (2003) CANOCO for Windows. Centre for Biometry, Wageningen.

Tolera, A, Khazaal, K, Ørskov, ER (1997) Nutritive evaluation of some browse species. Animal Feed Science and Technology 67, 181-195.

Wolton, R, Pollard, K, Goodwin, A and Norton, L (2014). Regulatory services delivered by hedges: The evidence base. (LM0106). Report produced for Defra and Natural England.

Westaway, S, Wolton, R, Smith, J and Wolfe, M (2013). Hedges: an ecological approach to biofuel production. Aspects of Applied Biology, 121, 89-96.

Westaway, S, Chambers, M, Crossland, M, Wolton, R and Smith, J (2016). Managing traditional hedges for biofuel. 12th European International Farming Systems Association Symposium 'Social and technological transformation of farming systems: Diverging and converging pathways'. Harper Adams, UK

Westaway, S and Smith, J (2018) Assessing, harvesting, chipping and processing techniques for improving the quality of woodchip from hedgerows and agroforestry. SustainFARM Project Deliverable 4.2.

Westaway, S (2019). Ramial woodchip for soil health and fertility. ORC Bulletin 130: Winter 2019 pp6-7

Westaway, S and Smith, J (2019) Productive Hedges: Guidance on bringing Britain's hedges back into the farm business. https://zenodo.org/record/2641808#.XRClv497nct)

Williams, PA, et al., Chapter 2. Agroforestry in North America and its role in farming systems, in Temperate Agroforestry Systems, A.M. Gordon and S.M. Newman, Editors. 1997, CAB International: Wallingford.

Zadoks, JC, Chang, TT and Konsak CF (1974) A decimal code for the growth stages of cereals. Weed Research, 14: 76-9

Appendices

1. Fruit tree varieties
2. Tree avenue: height gain
3. In-field trees: height 2019
4. Costs of silvopastoral establishment
5. Elm Farm draft hedge management plan

Annex 1. Fruit tree varieties in the Tree Avenue

Variety	Rootstock	Number planted 2014
Cider Apples	Maidens	
Apple Black Dabinett M25	M25	2
Apple Browns M25	M25	3
Apple Fair Maid of Devon M25	M25	2
Apple Foxwhelp M25	M25	3
Apple Hangy Down M25	M25	2
Apple Harry Master's Jersey MM106	MM106	3
Apple Kingston Black M25	M25	3
Apple Major M25	M25	2
Apple Somerset Redstreak M25	M25	2
Apple Stoke Red	MM106	3
Apple Yarlington Mill M25	M25	2
Dessert Apples	Maidens	
Apple Charles Ross MM106	MM106	1
Apple Egremont Russet M25	M25	1
Apple Ellison's Orange MM106	MM106	1
Apple Kidds Orange Red MM106	MM106	1
Apple Rosemary Russet M25	M25	1
Apple Tom Putt M25	M25	2
Pears and Quinces	2 yr	
Comice Pear Quince c	Pear	2
Conference Pear	Pear	1
Williams Pear	Pear	1
Quince Vranja	Quince	1

ORGANIC RESEARCH CENTRE
ELM FARM

Annex 2. Tree height gain (2014-2019): tree avenue

(starting from southern-most tree)

	29.07.2014	cm	11.08.2015	cm	24.08.2016	cm	03.10.2019	cm
1	Apple Foxwhelp	195	Apple Foxwhelp	198	Apple Foxwhelp	245	Apple Foxwhelp	300
2	Apple Somerset Redstreak	177	Apple Somerset Redstreak	178	Apple Somerset Redstreak	240	Apple Somerset Redstreak	336
3	Apple Somerset Redstreak	182	Apple Somerset Redstreak	181	Apple Somerset Redstreak	134	Apple Somerset Redstreak	251
4	Apple Fair Maid of Devon	198	Apple Fair Maid of Devon	197	Apple Fair Maid of Devon	186	Apple Fair Maid of Devon	268
5	Apple Foxwhelp	201	Apple Foxwhelp	202	Apple Foxwhelp	156	Apple Foxwhelp	192
6	Sweet chestnut	57	Sweet chestnut	70	Lime	105	Lime	167
7	Oak	62	Oak	52	Field maple	75	Field maple	100
8	Apple Black Dabinett	204	Apple Black Dabinett	216	Apple Black Dabinett	245	Apple Black Dabinett	325
9	Apple Browns	182	Apple Browns	191	Apple Browns	208	Apple Browns	298
10	Apple Stoke Red	189	Apple Stoke Red	186	Apple Stoke Red	184	Apple Stoke Red	335
11	Quince Vranja	210	Quince Vranja	215	Quince Vranja	238	Quince Vranja	230
12	Field Maple	70	Field Maple	129	Nothing	0	Nothing	0
13	Field Maple	55	Field Maple	66	Field Maple	173	Field Maple	249
14	Apple Tom Putt	137	Apple Tom Putt	148	Apple Tom Putt M25	161	Apple Tom Putt	271
15	Apple Foxwhelp	188	Apple Foxwhelp	185	Apple Foxwhelp M25	185	Apple Foxwhelp	283
16	Apple Stoke Red	173	Apple Stoke Red	175	Apple Stoke Red	169	Apple Stoke Red	234
17	Apple Kingston Black	140	Apple Kingston Black	152	Apple Kingston Black M25	160	Apple Kingston Black	240
18	Apple Stoke Red	135	Apple Stoke Red	128	Apple Stoke Red	150	Apple Stoke Red	198
19	Apple Fair Maid of Devon	184	Apple Fair Maid of Devon	194	Apple Fair Maid of Devon M25	180	Apple Fair Maid of Devon	285
20	Rowan	49	Rowan	77	Lime	95	Lime	207
21	Rowan	71	Rowan	147	Rowan	189	Rowan	218
22	Comice Pear Quince	170	Comice Pear Quince	176	Comice Pear Quince	177	Comice Pear Quince	305
23	Williams Pear	205	Williams Pear	228	Williams Pear	231	Williams Pear	270
24	Apple Black Dabinett	164	Apple Black Dabinett	167	Apple Black Dabinett	185	Apple Black Dabinett	289
25	Apple Yarlington Mill	176	Apple Yarlington Mill	178	Apple Yarlington Mill	200	Apple Yarlington Mill	295
26	Apple Hangy Down	148	Apple Hangy Down	153	Apple Hangy Down	186	Apple Hangy Down	214
27	Apple Harry Master's Jersey	137	Apple Harry Master's Jersey	117	Apple Tom Putt	136	Apple Tom Putt	197
28	Apple Harry Master's Jersey	143	Apple Harry Master's Jersey	135	Apple Black Dabinett	120	Apple Black Dabinett	242
29	Apple Tom Putt	164	Apple Tom Putt	149	Apple Black Dabinett	133	Apple Black Dabinett	193
30	Sweet chestnut	2	Sweet chestnut	62	Lime	122	Lime	170
31	Sweet chestnut	14	Sweet chestnut	48	Hornbeam	69	Hornbeam	114
32	Field Maple	67	Field Maple	143	Field Maple	200	Field Maple	300
33	Field Maple	46	Field Maple	91	Field Maple	207	Field Maple	283
34	Hornbeam	56	Hornbeam	98	Hornbeam	146	Hornbeam	289
35	Hornbeam	66	Hornbeam	110	Hornbeam	150	Hornbeam	338
36	Sweet chestnut	12	Sweet chestnut	83	Lime	80	Lime	201
37	Sweet chestnut	16	Sweet chestnut	26	Silver birch	35	Hornbeam	169
38	Sweet chestnut	17	Sweet chestnut	75	Lime	119	Lime	223
39	Oak	69	Oak	152	Oak	186	Oak	298
40	Oak	56	Oak	66	Oak	141	Oak	201

41	Oak	55	Oak	133	Oak	146	Oak	244
42	Apple Charles Ross	133	Apple Charles Ross	150	Apple Charles Ross	200	Apple Charles Ross	266
43	Apple Yarlington Mill	173	Apple Yarlington Mill	175	Apple Yarlington Mill	224	Apple Yarlington Mill	330
44	Apple Harry Master's Jersey	132	Apple Harry Master's Jersey	125	Apple Black Dabinett	163	Apple Black Dabinett	207
45	Apple Major	176	Apple Major	183	Apple Major	174	Apple Major	280
46	Apple Kidds Orange Red	153	Apple Kidds Orange Red	164	Apple Kidds Orange Red	186	Apple Kidds Orange Red	259
47	Sweet chestnut	47	Sweet chestnut		Nothing	0	Hornbeam	116
48	Rowan	37	Rowan	40	Nothing	0	Hornbeam	104
49	Rowan	68	Rowan	138	Rowan	218	Rowan	270
50	Comice Pear Quince	166	Comice Pear Quince	168	Comice Pear Quince	223	Comice Pear Quince	295
51	Conference Pear	144	Conference Pear	170	Conference Pear	200	Conference Pear	286
52	Apple Rosemary Russet	146	Apple Rosemary Russet	170	Apple Rosemary Russet	235	Apple Rosemary Russet	338
53	Apple Kingston Black	143	Apple Kingston Black	162	Apple Kingston Black	240	Apple Kingston Black	340
54	Apple Browns	170	Apple Browns	176	Apple Browns	203	Apple Browns	340
55	Rowan	16	Rowan	77	Lime	120	Lime	179
56	Rowan	10	Field maple	65	Nothing	0	Hornbeam	109
57	Oak	103	Oak	40	Lime	81	Lime	202
58	Oak	71	Field Maple	53	Field Maple	137	Field Maple	198
59	Apple Ellison's Orange	143	Apple Ellison's Orange	145	Apple Ellison's Orange	179	Apple Ellison's Orange	gone
60	Apple Hangy Down	162	Apple Hangy Down	171	Apple Hangy Down	225	Apple Hangy Down	336
61	Apple Major	154	Apple Major	156	Apple Major	192	Apple Major	333
62	Hornbeam	73	Hornbeam	120	Hornbeam	162	Hornbeam	226
63	Hornbeam	81	Hornbeam	135	Hornbeam	152	Hornbeam	270
64	Field Maple	71	Field Maple	56	Field Maple	72	Field Maple	75
65	Field Maple	74	Lime	61	Lime	111	Lime	136
66	Rowan	81	Field Maple	58	Field Maple	80	Field Maple	90
67	Oak	64	Oak	57	Nothing	0	Nothing	0
68	Apple Egremont Russet	133	Apple Egremont Russet	163	Apple Egremont Russet	196	Apple Egremont Russet	290
69	Apple Kingston Black	145	Apple Kingston Black	160	Apple Kingston Black	214	Apple Kingston Black	293
70	Apple Browns	174	Apple Browns	187	Apple Browns	245	Apple Browns	343
71	Hornbeam	61	Hornbeam	144	Hornbeam	186	Hornbeam	338
72	Sweet Chestnut	72	Sweet Chestnut	102	Hornbeam	169	Hornbeam	266
73	Hornbeam	74	Hornbeam	131	Hornbeam	200	Hornbeam	380
74	Field maple	83	Field maple	73	Field Maple	120	Field Maple	280
75	Rowan	53	Lime	57	Lime	89	Lime	195
76	Field Maple	63	Field Maple	36	Field Maple	97	Nothing	gone
77	Oak	73	Oak	49	Lime	131	Lime	185
78	Oak	90	Field Maple	48	Field Maple	80	Field Maple	172
79	Hornbeam	65	Field Maple	63	Field Maple	120	Field Maple	332
80	Sweet Chestnut	82	Sweet Chestnut	132	Hornbeam	154	Hornbeam	230
81	Sweet Chestnut	36	Sweet Chestnut	70	Hornbeam	77	Hornbeam	135

ORGANIC RESEARCH CENTRE ELM FARM

Annex 3. Tree height (Oct 2019): in-field trees.

Field	Hornbeam	Sycamore	Lime	Oak	Willow	Walnut	Sweet chestnut	Total
Kennels	125	120	160	195				4
Sheepfield	150	220 65	250 250 250 205 185 190 175 240	245 220 175 175	245 340	75 150 150 110 80	185 180	24
Sunnyside		180	280 220 175	110 115		230	220 150	9
Creek		245	260	185 160	210	150 165	205	8

Annex 4. Costs of silvopastoral establishment

YEAR 1		Trees			Weed control			Labour - trees (days)					TOTAL
Species	Weed control	£/each	#/ha	£/ha	£/m	m/ha	£/ha	Weed control	£/day	Plant-ing	£/day	£/ha	£/ha
Alder	Black mulch	£0.25	1000	£250.00	0.445	500	£222.50	2	55.15	5	140	£810.30	£1,282.80
Willow	Black mulch	£0.15	1000	£150.00	0.445	500	£222.50	2	55.15	5	140	£810.30	£1,182.80
Mix	Black mulch	£0.20	1000	£200.00	0.445	500	£222.50	2	55.15	5	140	£810.30	£1,232.80
Alder	Jute	£0.25	1000	£250.00	1.728	500	£864.00	2	55.15	5	140	£810.30	£1,924.30
Willow	Jute	£0.15	1000	£150.00	1.728	500	£864.00	2	55.15	5	140	£810.30	£1,824.30
Mix	Jute	£0.20	1000	£200.00	1.728	500	£864.00	2	55.15	5	140	£810.30	£1,874.30
Alder	Woodchip	£0.25	1000	£250.00	0	0	£0.00	0.5	55.15	5	140	£727.58	£977.58
Willow	Woodchip	£0.15	1000	£150.00	0	0	£0.00	0.5	55.15	5	140	£727.58	£877.58
Mix	Woodchip	£0.20	1000	£200.00	0	0	£0.00	0.5	55.15	5	140	£727.58	£927.58

Year 2		Trees			Labour (days)					TOTAL
Species	Weed control	£/each	#/ha	£/ha	Weed control	£/day	Plant-ing	£/day	£/ha	£/ha
Alder	Black mulch	0.25	127	£31.75	0	55.15	0.64	140	£88.91	£120.66
Willow	Black mulch	0.15	566	£84.85	0	55.15	2.83	140	£395.95	£480.79
Mix	Black mulch	0.2	535	£107.09	0	55.15	2.68	140	£374.83	£481.93
Alder	Jute	0.25	422	£105.43	0	55.15	2.11	140	£295.22	£400.65
Willow	Jute	0.15	311	£46.63	0	55.15	1.55	140	£217.61	£264.24
Mix	Jute	0.2	700	£139.97	0	55.15	3.50	140	£489.89	£629.86
Alder	Woodchip	0.25	556	£138.88	0.5	55.15	2.78	140	£416.44	£555.32
Willow	Woodchip	0.15	424	£63.65	0.5	55.15	2.12	140	£324.60	£388.25
Mix	Woodchip	0.2	410	£81.96	0.5	55.15	2.05	140	£314.43	£396.38

Table 6.3. Costs in Year 3

Year 3		Trees			Labour (days)							TOTAL
Species	Weed control	£/each	#/ha	£/ha	Weed control	£/day	Coppicing	£/day	Plant-ing	£/day	£/ha	£/ha
Alder	Black mulch	0.25	360	£90.00	0.5	55.15	0.15	55.15	1.80	140	£287.86	£377.86
Willow	Black mulch	0.15	580	£87.00	0.5	55.15	0.15	55.15	2.90	140	£441.87	£528.87
Mix	Black mulch	0.2	400	£80.00	0.5	55.15	0.15	55.15	2.00	140	£315.86	£395.87
Alder	Jute	0.25	220	£55.00	0.5	55.15	0.15	55.15	1.10	140	£189.86	£244.86
Willow	Jute	0.15	490	£73.50	0.5	55.15	0.15	55.15	2.45	140	£378.86	£452.37
Mix	Jute	0.2	370	£74.00	0.5	55.15	0.15	55.15	1.85	140	£294.86	£368.86
Alder	Woodchip	0.25	300	£75.00	0.5	55.15	0.15	55.15	1.50	140	£245.86	£320.86
Willow	Woodchip	0.15	510	£76.50	0.5	55.15	0.15	55.15	2.55	140	£392.87	£469.37
Mix	Woodchip	0.2	390	£78.00	0.5	55.15	0.15	55.15	1.95	140	£308.86	£386.87

Table 6.4. Costs in Year 4

Year 4		Trees			Labour (days)					TOTAL
Species	Weed control	£/each	#/ha	£/ha	Weed control	£/day	Plant-ing	£/day	£/ha	£/ha
Alder	Black mulch	0.25	300	£75.00	0	£55.15	1.50	140	£210.01	£285.01
Willow	Black mulch	0.15	460	£69.00	0	£55.15	2.30	140	£322.02	£391.02
Mix	Black mulch	0.2	370	£74.00	0	£55.15	1.85	140	£259.01	£333.02
Alder	Jute	0.25	300	£75.00	0	£55.15	1.50	140	£210.01	£285.01
Willow	Jute	0.15	300	£45.00	0	£55.15	1.50	140	£210.01	£255.01
Mix	Jute	0.2	460	£92.00	0	£55.15	2.30	140	£322.02	£414.02
Alder	Woodchip	0.25	460	£115.01	0	£55.15	2.30	140	£322.02	£437.02
Willow	Woodchip	0.15	370	£55.50	0	£55.15	1.85	140	£259.01	£314.52
Mix	Woodchip	0.2	370	£74.00	0	£55.15	1.85	140	£259.01	£333.02

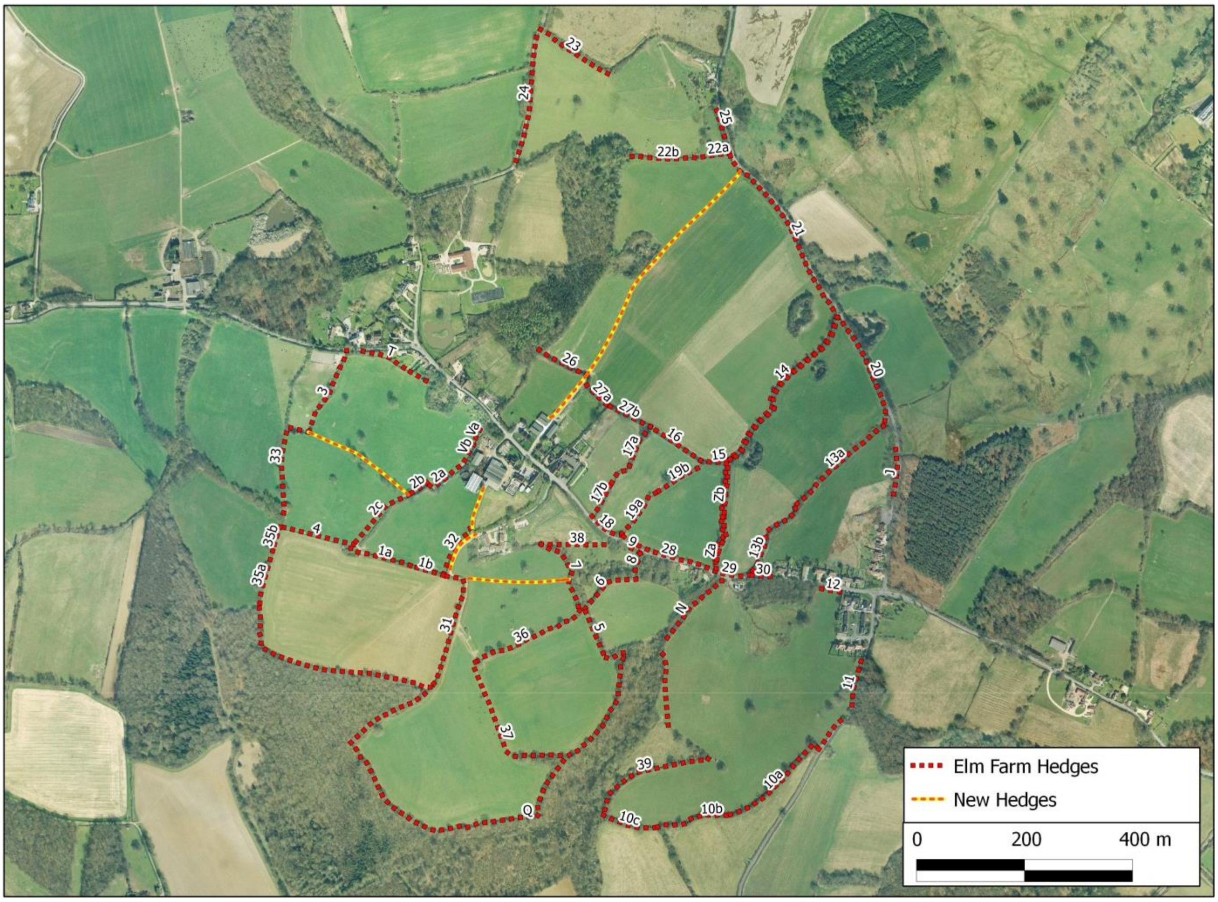
Table 6.5. Costs in Year 5

YEAR 5		Trees			Labour (days)					Fencing				TOTAL
Species	Weed control	£/each	#/ha	£/ha	Weed control	£/day	Plant-ing	£/day	£/ha	Materials	Labour (days)	£/day	£/ha	£/ha
Alder	Black mulch	£0.25	220	£55.00	0	£55.15	1.10	£140.00	£154.01	£165.00	1	55.15	£220.15	£429.16
Willow	Black mulch	£0.15	170	£25.50	0	£55.15	0.85	£140.00	£119.01	£165.00	1	55.15	£220.15	£364.66
Mix	Black mulch	£0.20	130	£26.00	0	£55.15	0.65	£140.00	£91.00	£165.00	1	55.15	£220.15	£337.16
Alder	Jute	£0.25	220	£55.00	0	£55.15	1.10	£140.00	£154.01	£165.00	1	55.15	£220.15	£429.16
Willow	Jute	£0.15	220	£33.00	0	£55.15	1.10	£140.00	£154.01	£165.00	1	55.15	£220.15	£407.16
Mix	Jute	£0.20	170	£34.00	0	£55.15	0.85	£140.00	£119.01	£165.00	1	55.15	£220.15	£373.16
Alder	Woodchip	£0.25	170	£42.50	0	£55.15	0.85	£140.00	£119.01	£165.00	1	55.15	£220.15	£381.66
Willow	Woodchip	£0.15	130	£19.50	0	£55.15	0.65	£140.00	£91.00	£165.00	1	55.15	£220.15	£330.66
Mix	Woodchip	£0.20	130	£26.00	0	£55.15	0.65	£140.00	£91.00	£165.00	1	55.15	£220.15	£337.16

Annex 5. Elm Farm Hedgerow Management Plan - Updated: July 2018

Elm Farm is an 85 hectare organic livestock farm in West Berkshire in the South East of England. The farm is owned by the Organic Research Centre and currently managed by a local tenant farmer predominantly as a base for raising beef cattle (British white x Jersey). The farm is on gently sloping land ranging from 95 to 130m above sea level and has an average annual rainfall of 71cm. The soil type is mainly Wickham Series clay, poorly drained clay loams susceptible to structural damage. The farm has approximately 9.5km of hedgerows, several wooded clay pits, some ancient trees within the fields and two sites of importance for nature conservation (SINCs – wet grasslands). There are 3 public rights of way across the farm and there is also a permissive farm trail open to the public.

Elm Farm Hedges: Most hedges on the farm have not been actively managed for a number of years, asides from occasional side flailing to maintain field sizes and statutory roadside management. There are 45 separate hedges on the farm with a total length of approximately 9.5km. The dominant woody species is Blackthorn (*Prunus spinosa*), with other common species being Hawthorn (*Crataegus monogyna*), Hazel (*Corylus avellana*), Pussy Willow (*Salix caprea/cinerea*) and Oak (*Quercus robur*). Blackthorn, bramble (*Rubus fruticosus*) and rose (*Rosa sp.*) outgrowth from the hedge is also a common feature, resulting in wide unruly hedges, often with the existing fences being engulfed by this shrubby outgrowth.



The Elm Farm Hedge Survey 1983-1994

When Elm Farm was bought by the Progressive Farming Trust in the early 1980s a hedge survey was undertaken by Lyndall Foster. In 1994 a similar survey was undertaken by Chris Smith following the same methodology. Both surveys split all the hedges into 30m sections for sampling purposes. The

1994 survey built on the data collected in the original 1983 survey which focussed exclusively on botanical composition. In 1994 one soil pH measurement was taken from each 30m section, an assessment of the gappiness of each hedge was carried out and a full tally of all the hedges trees was completed.

The Elm Farm hedge network was completely intact between 1994 and 1983 surveys. The structural integrity of the hedge network on Elm Farm and links with adjoining habitats make the Elm Farm hedges an important landscape feature. Asides from roadside hedges and hedge 4 (laid in late 80s) all hedges had been allowed to grow up and some to spread laterally. The 1994 survey highlighted the need cut back some of the more rampant hedges to free the overshadowed hedge bottom flora. In general the Elm Farm hedges showed an overall increase in botanical species richness between 1983 and 1994. However, increases in species such as docks, cleavers, stinging nettles and cow parsley in some hedges indicated that eutrophication of some field boundaries.

The Elm Farm Hedge Survey 2013

A further complete survey of all the hedges on Elm Farm was undertaken in 2013 as part of a project investigating the use of hedgerow management methods to produce woodfuel (TWECOM). In summer 2013, prior to carrying out any hedge management, all hedgerows were surveyed. DEFRA hedge survey methods were followed (DEFRA, 2007) which in addition to the botanical composition include an assessment of hedge structure and management history. Data was collected by a team of volunteers. Condition assessments were carried out using the criteria defined by the national hedgerow Habitat Action Plan and additional information was collected in order to estimate the volume of biomass in the hedgerow and to assess the significance of each hedge in the landscape.

When compared with the earlier surveys the results of this survey show that the Elm Farm hedge network still very much intact, with a diverse range of hedges both in terms of species and structural diversity. However, most hedgerows on the farm have still not been actively managed for a number of years and although currently 75% are in favourable condition, without suitable management they will decline. Of the 25% which are not currently in favourable condition all were considered too open at the hedge base, as measured by a basal canopy height greater than 50 cm. Introduction of coppice management or an alternative rejuvenation method, where suitable, would increase the basal growth and help to close these gaps.

THE ORGANIC RESEARCH CENTRE ELM FARM

Description of individual hedges

Hedge	Hedge description	Previous management	Management recommendations	Length (m)
3	Wide shrubby untrimmed hedge with a line of trees. Bramble and blackthorn dominate hedge and outgrowth. Dead Elm in hedge.	No signs of recent management	Control outgrowth, rejuvenate by laying or coppicing, to prevent Elm growing too high.	168.79
4	Good dense mixed species shrubby untrimmed hedge	Recently flailed. Part laid winter 2013/14 - previously laid c.20 years ago. Grazed up to hedge base	Continue laying, remove tree guards. Side trim any sections left unlaid	139.73
5	Shrubby untrimmed hedge with a line of trees. Bramble and blackthorn dominate. Becoming gappy at base. Livestock tracks through hedge - needs fencing	Previously flailed. Grazed up to hedge base	Side flail. Rejuvenate by laying or coppicing and plant up gaps.	88.02
6	Wide shrubby untrimmed hedge with a line of trees on the edge of an area of scrub. Some large oak trees. Bramble and blackthorn dominate. Some gaps and becoming gappy at base.	Previously flailed. Grazed up to hedge base	Side fail. Rejuvenate by laying or coppicing and plant up gaps under trees with shade tolerant species.	119.06
7	Shrubby untrimmed hedge with a line of trees. On a large bank on the edge of an area of woodland/scrub with more mature trees. Hawthorn and blackthorn dominate. Becoming gappy at base.	Some planting/ gapping up over 10 years ago. Grazed up to hedge base	Side fail. Rejuvenate by laying or coppicing.	157.43
8	Short trackside section of hedge. Hawthorn and blackthorn dominate. Becoming tall and leggy. West side overgrown with nettles.	Recently flailed, signs hedge has been previously laid	Side fail. Long term rejuvenate by laying or coppicing. Nettles indicate nutrient enrichment which may need managing.	52.09
9	Short roadside section of hedge. Tall wide and shrubby, becoming gappy at base. Mixed species with willow dominating.	No signs of management	Roadside - cut as required. If possible rejuvenate by coppicing.	32.24
11	No longer a hedge. Bramble undergrowth with some mature trees.	No signs of management	Gap up/ replant. Roadside - cut as required	162.23
12	Tall wide short roadside section of hedge. Mixed species hazel dominates, some blackthorn outgrowth	Recently flailed. Grazed up to hedge base	Roadside - cut as required. Flail to control blackthorn. Long term rejuvenate by coppicing if possible.	48.55
14	Tall wide shrubby untrimmed hedge with mature trees. Previously coppiced hazel stools dominate, blackthorn and bramble outgrowth in places. Hedge on double bank with a deep ditch/ stream in centre.	Previously coppiced over 10 years ago. Grazed up to hedge base	Hazel plot in this hedge. Continue rotational coppice management. Cutting one bank at a time. Control blackthorn outgrowth by flailing.	723.87
15	Tall wide shrubby untrimmed hedge with mature trees. Hazel and field maple dominate. Becoming gappy at base.	Signs hedge has been previously laid. Grazed up to hedge base	Side flail and rejuvenate by laying or coppicing.	48.80
16	Wide untrimmed shrubby hedge. Becoming gappy at base. Mixed species with blackthorn and field maple dominant species.	Previously coppiced. Grazed up to hedge base	Side flail. Coppice in the future if possible. Adjacent field part of 2013 land sales	112.50
18	Short shrubby hedge. Blackthorn dominates.	Recently flailed. Grazed up to hedge base	Roadside hedge. Adjacent field part of 2013 land sales - management no longer EF responsibility	68.03
20	Good dense species rich shrubby hedge. Blackthorn dominant species.	Recently flailed and coppiced c.10 years ago. Grazed up to hedge base	Roadside - cut as required. Bring cutting line up and long term rejuvenate by coppicing if possible, cutting one side at a time.	225.03
21	Good dense species rich shrubby hedge. Hazel and blackthorn dominant species. Becoming gappy at base in places.	No signs of management. Grazed up to hedge base	Roadside - cut as required. Bring cutting line up and long term rejuvenate by coppicing if possible, cutting one side at a time.	333.15
23	Tall wide untrimmed shrubby hedge. Becoming gappy at base. Blackthorn and bramble dominate	Previously flailed. Grazed up to hedge base	Flail to control blackthorn and gap up	156.58
24	Shrubby untrimmed hedge with a line of trees. Bramble and blackthorn dominate hedge and outgrowth. Becoming gappy at base.	Previously flailed. Grazed up to hedge base	Roadside - cut as required. Flail to control blackthorn and gap up where needed.	261.54
25	Roadside section of hedge. Tall, wide, shrubby untrimmed hedge with a line of trees. Very overgrown, blackthorn and bramble dominate hedge and outgrowth.	No signs of management. Grazed up to hedge base	Roadside - cut as required. Flail to control blackthorn and bramble.	97.47
26	Wide untrimmed shrubby hedge with line of mature trees. Blackthorn and bramble dominate hedge.	Previously flailed and coppiced over 10 years ago. Grazed up to hedge base	Side flail. Coppice in the future if possible. Adjacent field part of 2013 land sales	102.18
28 A/B	Dense untrimmed shrubby hedge with mature trees. Blackthorn dominant species.	Previously flailed.	Roadside - cut as required.	
29	Short roadside section. Shrubby untrimmed hedge. Blackthorn and bramble dominate hedge and outgrowth.	Previously flailed. Grazed up to hedge base	Roadside - cut as required.	63.29
30	Short roadside section. Tall, wide shrubby untrimmed hedge with mature trees. Blackthorn and field maple dominate. Becoming gappy at base.	No signs of management. Grazed up to hedge base	Roadside - cut as required. If possible rejuvenate by coppicing.	38.20

Description of individual hedges

	Hedge description	Previous management	Management recommendations	Length (m)
1a/b	Mixed species hedge on bank. Tall and leggy and becoming gappy.	Previously flailed and part coppiced over 10 years ago.	Electric way leave runs parallel to hedge, coppice and plant up gaps. Then keep short by laying or regular trimming	180.00
2a	Dense, shrubby untrimmed hedge. Hawthorn and blackthorn dominant species. Some mature trees.	No signs of management. Grazed up to hedge base	Side flail and rejuvenate by laying or coppicing.	76.00
2b	Dense, shrubby untrimmed hedge. Hawthorn and blackthorn dominant species.	Previously flailed. Some planting/ gapping up over 10 years ago. Grazed up to hedge base	Side flail and rejuvenate by laying or coppicing.	41.19
2c	Dense, shrubby untrimmed hedge. Hawthorn, willow and blackthorn dominant species.	No signs of management. Grazed up to hedge base	Hawthorn plots. Side flail and rejuvenate by laying or coppicing	139.89
3	Wide shrubby untrimmed hedge with a line of trees. Bramble and blackthorn dominate hedge and outgrowth. Dead Elm in hedge.	No signs of recent management	Control outgrowth, rejuvenate by laying or coppicing.	168.79
4	Good dense mixed species shrubby untrimmed hedge	Recently laid by volunteer group.	Side flail and control blackthorn outgrowth	139.73
5	Shrubby untrimmed hedge with a line of trees. Bramble and blackthorn dominate. Becoming gappy at base. Livestock tracks through hedge - needs fencing	Previously flailed. Grazed up to hedge base	Side flail. Rejuvenate by laying or coppicing and plant up gaps with shade tolerant species.	88.02
6	Wide shrubby untrimmed hedge with a line of trees on the edge of an area of scrub. Some large oak trees. Bramble and blackthorn dominate. Some gaps and becoming gappy at base.	Previously flailed. Grazed up to hedge base	Side fail. Rejuvenate by laying or coppicing and plant up gaps under trees with shade tolerant species.	119.06
7	Shrubby untrimmed hedge with a line of trees. On a large bank on the edge of an area of woodland/scrub with more mature trees. Hawthorn and blackthorn dominate. Becoming gappy at base.	Some planting/ gapping up over 10 years ago. Grazed up to hedge base	Side fail. Rejuvenate by laying or coppicing.	157.43
8	Short trackside section of hedge. Hawthorn and blackthorn dominate. Becoming tall and leggy. West side overgrown with nettles.	Flailed, signs hedge has been previously laid	Side fail. Long term rejuvenate by laying or coppicing. Nettles indicate nutrient enrichment which may need managing.	52.09
9	Short roadside section of hedge. Tall wide and shrubby, becoming gappy at base. Mixed species with willow dominating.	No signs of management	Roadside - cut as required. If possible rejuvenate by coppicing.	32.24
10a	Tall, wide, dense, shrubby, untrimmed hedge. Blackthorn dominant with mature trees	Previously flailed. Grazed up to hedge base	Side flail. If possible coppice and plant up gaps - possible boundary dispute	219.52
10b/c	Tall, wide, shrubby, untrimmed hedge. Mixed species with mature trees	Previously flailed. Grazed up to hedge base	Side flail. If possible coppice and plant up gaps - possible boundary dispute	243.00
11	No longer a hedge. Bramble undergrowth with some mature trees.	No signs of management	Gap up/ replant. Roadside - cut as required	162.23
12	Tall wide short roadside section of hedge. Mixed species hazel dominates, some blackthorn outgrowth	Flailed. Grazed up to hedge base	Roadside - cut as required. Flail to control blackthorn. Long term rejuvenate by coppicing if possible.	48.55
13a/b	Tall, wide, untrimmed hedge with deep central ditch. Mixed species with mature trees, aspen dominant in one section. Becoming gappy at base. Livestock tracks through hedge - needs fencing	No signs of management. Grazed up to hedge base	Rejuvenate by coppice management. Fence hedge following coppicing. Possibly cut one bank at a time.	387.00
14	Tall wide shrubby untrimmed hedge with mature trees. Previously coppiced hazel stools dominate, blackthorn and bramble outgrowth in places. Hedge on double bank with a deep ditch/ stream in centre.	Previously coppiced over 10 years ago. Grazed up to hedge base	Hazel plot in this hedge. Continue rotational coppice management. Cutting one bank at a time. Control blackthorn outgrowth by flailing.	723.87
15	Tall wide shrubby untrimmed hedge with mature trees. Hazel and field maple dominate. Becoming gappy at base.	Signs hedge has been previously laid. Grazed up to hedge base	Side flail and rejuvenate by laying or coppicing.	48.80
16	Wide untrimmed shrubby hedge. Becoming gappy at base. Mixed species with blackthorn and field maple dominant species.	Previously coppiced. Grazed up to hedge base	Side flail. Coppice in the future if possible. Adjacent field part of 2013 land sales	112.50
17a/b	Mixed species hedge, untrimmed, becoming gappy at base. Some gaps	Previously coppiced over 10 years ago. Grazed up to hedge base	Adjacent field part of 2013 land sales - management no longer EF responsibility	205.00
18	Short shrubby hedge. Blackthorn dominates.	Recently flailed. Grazed up to hedge base	Roadside hedge. Adjacent field part of 2013 land sales - management no longer EF responsibility	68.03
19a	Shrubby untrimmed mixed species hedge, dry ditch in centre. Becoming gappy at base.	Signs hedge has been previously laid. Grazed up to hedge base	Adjacent field part of 2013 land sales - possibly rejuvenate by coppicing/ laying if new owners agree	101.99
19b	Tall wide leggy hedge. Willow dominant species. Becoming gappy at base.	No signs of management.	Adjacent field part of 2013 land sales - possibly rejuvenate by coppicing/ laying if new owners agree	106.90
20	Good dense species rich shrubby hedge. Hazel and blackthorn dominant species.	Coppiced 2017	Control blackthorn on field side. Coppice again once regrown	225.03
21	Good dense species rich shrubby hedge. Hazel and blackthorn dominant species. Becoming gappy at base in places.	Coppiced 2014	Control blackthorn on field side, Coppice again once regrown	333.15
22a	Dense shrubby hedge. Blackthorn and hawthorn dominant species. Some mature trees.	Previously coppiced over 10 years ago. Grazed up to hedge base	Side flail and rejuvenate by laying or coppicing.	58.03
22b	Dense wide shrubby mixed species hedge. Central ditch. Unfenced, cattle access to base, becoming gappy	Signs hedge has been previously laid. Grazed up to hedge base	Side flail and rejuvenate by laying or coppicing, plant up gaps and fence.	118.76
23	Tall wide untrimmed shrubby hedge. Becoming gappy at base. Blackthorn and bramble dominate	Previously flailed. Grazed up to hedge base	Flail to control blackthorn and gap up	156.58
24	Shrubby untrimmed hedge with a line of trees. Bramble and blackthorn dominate hedge and outgrowth. Becoming gappy at base.	Previously flailed. Grazed up to hedge base	Roadside - cut as required. Flail to control blackthorn and gap up where needed.	261.54
25	Roadside section of hedge. Tall, wide, shrubby untrimmed hedge with a line of trees. Very overgrown, blackthorn and bramble dominate hedge and outgrowth.	No signs of management. Grazed up to hedge base	Roadside - cut as required. Flail to control blackthorn and bramble.	97.47

ORGANIC RESEARCH CENTRE ELM FARM

Description of individual hedges

	Hedge description	Previous management	Management recommendations	Length (m)
26	Wide untrimmed shrubby hedge with line of mature trees. Blackthorn and bramble dominate hedge.	Previously flailed and coppiced over 10 years ago. Grazed up to hedge base	Side flail. Coppice in the future if possible. Adjacent field part of 2013 land sales	102.18
27a/b	Shrubby, untrimmed short hedge. Blackthorn and bramble dominate	Previously flailed.	Flail to control blackthorn and replace fence line. Blackthorn plot in this hedge, potentially coppice in future. Replant Western end.	145.00
28a/b	Dense untrimmed shrubby hedge with mature trees. Blackthorn dominant species.	Previously flailed.	Roadside - cut as required.	
29	Short roadside section. Shrubby untrimmed hedge. Blackthorn and bramble dominate hedge and outgrowth.	Previously flailed. Grazed up to hedge base	Roadside - cut as required.	63.29
30	Short roadside section. Tall, wide shrubby untrimmed hedge with mature trees. Blackthorn and field maple dominate. Becoming gappy at base.	No signs of management. Grazed up to hedge base	Roadside - cut as required. If possible rejuvenate by coppicing.	38.20
31	Dense, wide untrimmed shrubby hedge. Blackthorn and hazel dominant species. Ditch down centre, multiple fences with thick blackthorn outgrowth.	Previously flailed. Grazed up to hedge base	Flail to control blackthorn and replace fence line. Blackthorn plot in this hedge, potentially coppice in future.	241.77
32	Trackside, shrubby untrimmed hedge dominated by hawthorn and blackthorn. Some gaps.	Flailed	Side flail and plant up gaps, possibly coppice in future and extend hedge down track	102.83
33	Shrubby untrimmed hedge with mature trees. Dominated by blackthorn and bramble. Some gaps.	Flailed	Flail and plant up gaps	202.16
35a	Short shrubby untrimmed hedge adjoins woodland, very overgrown. Bramble dominant species	No signs of management. Grazed up to hedge base	Flail brambles and plant up gaps	109.18
35b	Short shrubby untrimmed hedge, very overgrown with nettles and bramble. Blackthorn dominant species	No signs of management. Grazed up to hedge base	Flail and plant up any gaps	46.13
36	Shrubby mixed species under line of mature oak trees. Some planting in gaps c. 10 years ago, still some gaps.	Previously flailed. Grazed up to hedge base	Plant up gaps with shade tolerant species. Look to rejuvenate by coppicing in the future.	219.58
37	Young shrubby mixed species hedge planted c.10 years ago	Some planting/ gapping up over 10 years ago. Grazed up to hedge base	Remove tree guards. Lightly flail to encourage bushy growth. Look to rejuvenate by laying or coppicing in the future.	295.20
38	Scrub edge - fence but currently no hedge as such	n/a	Long term plant new hedge along this boundary	132.19
39	Dense untrimmed, shrubby hedge on woodland edge, gappy with mature trees. Blackthorn dominant species.	Previously flailed. Grazed up to hedge base	Flail and plant up gaps. Look to rejuvenate by laying or coppicing in the future.	243.08
J	Tall, wide, shrubby hedge with mature oak trees and blackthorn outgrowth.	No signs of management. Grazed up to hedge base	Flail to control blackthorn. Roadside - cut as required. Potentially rejuvenate in the future by laying or coppicing.	93.16
Q	Hedge adjoins woodland.		Side flail and potentially rejuvenate in the future by laying or coppicing.	1406.57
N	Wide hedge/ woodland boundary with deep ditch/ stream in centre. Mixed species, some very large hazel stools. Blackthorn outgrowth in places.	Previously coppiced over 10 years ago. Grazed up to hedge base	Flail to control blackthorn. Coppice selected stools to minimise disturbance.	299.89
T	Short, dense trimmed hedge, running behind houses. Blackthorn and hawthorn dominant species.	Previously flailed.	Flail every 2/3 years, bring cutting line up and long term rejuvenate by coppicing/ laying	135.02
Va	Mixed species hedge planted c.20 years ago. Becoming tall and leggy and gaps developing at base.	No signs of management.	Screening farm buildings. Side flail every 2/3 years, bring cutting line up and long term consider rejuvenating by laying	28.17
Vb	Wide shrubby untrimmed mixed species hedge	No signs of management.	Screening farm buildings. Flail every 2/3 years, bring cutting line up and long term consider rejuvenating by laying	63.51
Za/b	Wide hedge/ woodland boundary with deep ditch/ stream in centre. Mixed species, some very large hazel stools. Blackthorn outgrowth in places.	Selective coppicing of old hazel stools and removal of scrub by volunteer group.	Flail to control blackthorn. Coppice selected stools to minimise disturbance.	212.53

New Hedges

Four new sections of hedgerow were planted at Elm Farm in early 2014. These hedges were planted with fast growing non-thorny species with the intention of managing them for fuel. The species mix used consisted of hazel (40%), hybrid willow (20%), sweet chestnut (20%) and sycamore (20%) planted as a double row, with 50cm spacing, standard trees (oak, hornbeam, walnut) were included at 20m spacing. The new hedges were all planted as mixed species hedges with the exception of the hedge running behind the Dogs Trust across 'kennels field' which has been planted as a trial hedge, with 20m single species blocks - one block at standard spacing; 4 per m (i.e. double row at 0.5m spacing) and one block at 0.75 spacing between plants (3 per m). Many of the sweet chestnut trees did not survive and these have been replaced with hazel or willow.

Management considerations

Consideration should be taken, especially when coppicing, of connectivity and the role that hedges play in facilitating movement of wildlife in the landscape. There is some evidence that dormice are using some of the hedges and dormouse nesting boxes have been placed in hedges Za/b, 14 and 15 to monitor the population.

The heavy soil and poor drainage in many fields on Elm Farm mean that management activities are best planned in late autumn/ early winter. Where possible, i.e. road or track side hedges, and where farm management activities allow, hedge management should be left until late winter to maximise the food resources available for wildlife.