

Wakelyns Agroforestry: Resilience through diversity



Photo: Maja Lindstrom, paradigshiftfilm.com

Wakelyns Agroforestry, surrounded by a sea of large-scale conventional arable production, is an oasis of trees, alive with bird song and insects. Integrating trees for timber, energy and fruit production into an organic crop rotation, Wakelyns was established by the late plant pathologist, Prof. Martin Wolfe, to put into action his theories of agrobiodiversity being the answer to achieving sustainable and resilient agriculture. For two decades the farm has been the focus of research into organic crop production and agroforestry. In this review, we summarise some of the key theories investigated and the evidence produced by Martin and fellow researchers from the Organic Research Centre.



Martin and Ann Wolfe bought the fields that became Wakelyns Agroforestry in 1992, with the intention of trialling new farming systems and methods that were highly productive and sustainable without the necessity of inputs from outside the farm. Their aim was to provide both scientific evidence and a practical demonstration that alternative ways of food production are not only possible but advantageous.

When bought by Martin and Ann, the farm had been under intensive chemically-aided crop production for many years. Over the next few years they began the process of transforming the fields into the verdant haven that you encounter today when arriving at Wakelyns.

Diversity at all levels underpins the philosophy and approach to the development of Wakelyns Agroforestry. Martin firmly believed that the future of sustainable agriculture was rooted in Darwinian evolutionary processes, where adaptation to the agricultural abiotic and biotic environment leads to increases in overall productivity and resilience. This

would be achieved by moving away from the industrialised monoculture approach towards polycultures with major increases in diversity both within and among crops, trees and livestock. Martin's early research showed how, for example, mixing just three varieties of cereal crop together in one field could restrict disease and stabilise crop yields. This simple principle has been extended to mixtures of species and ultimately to agroforestry systems involving multiple combinations of crops, from annual cereals and vegetables to perennial herbs and trees, together with livestock.

At Wakelyns four different agroforestry systems, based on a maximum use of biodiversity, were developed and contrasted. The agroforestry fields have been the site of many years of research trials and demonstrations, working closely with the Organic Research Centre and other partners, to build up evidence on the production of a wide range of products from the agroforestry systems, and the delivery of a number of important ecosystem services such as maintaining soil fertility and health and biodiversity enhancement.



Timeline of events at Wakelyns Agroforestry:

- 2019:** A lush green field with rows of trees.
- 2017:** A field with rows of trees and a path.
- 2016:** A tractor plowing a field with rows of trees.
- 2013:** A field with rows of trees and a path.
- 2012:** A field with rows of trees and a path.
- 2010:** A field with rows of trees and a path.
- 2009:** A field with rows of trees and a path.
- 2007:** A field with rows of trees and a path.
- 2003:** A tractor plowing a field with rows of trees.
- 2002:** A field with rows of trees and a path.
- 2001:** A field with rows of trees and a path.
- 1994:** A field with rows of trees and a path.

Wakelyns Agroforestry

Wakelyns Agroforestry is a 22.5 ha innovative farm situated right in the arable heartland of eastern England. The farm incorporates four silvoarable agroforestry systems into an organic arable rotation.

Location: Suffolk, East Anglia, 52.36°N, 1.35°E

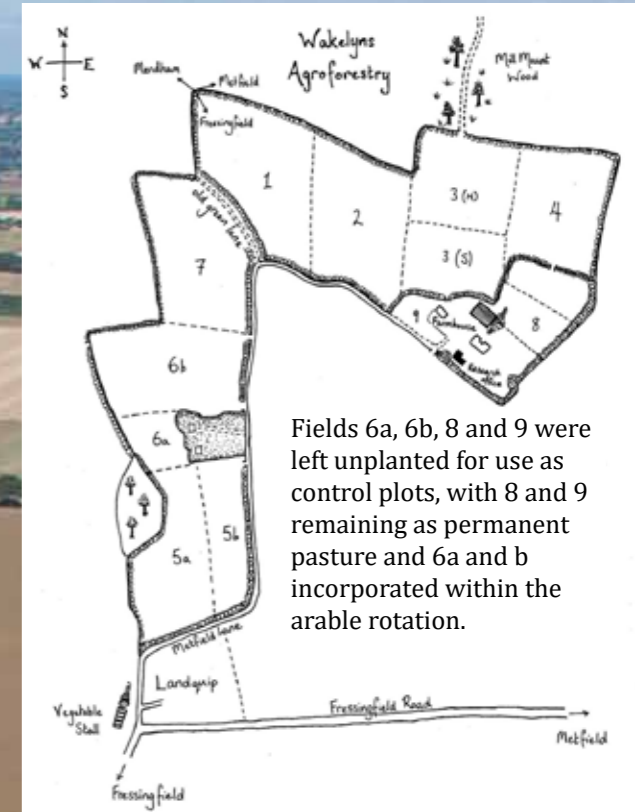
Climate annual averages: Rainfall 606 mm, sunshine 1535 hours, minimum/maximum temperature 6.0 °C / 13.8 °C.

Soils: Clay loam over chalk with clay content of 25-30%, pH 8.0, organic matter approximately 3.5%, and low indices for P and K.

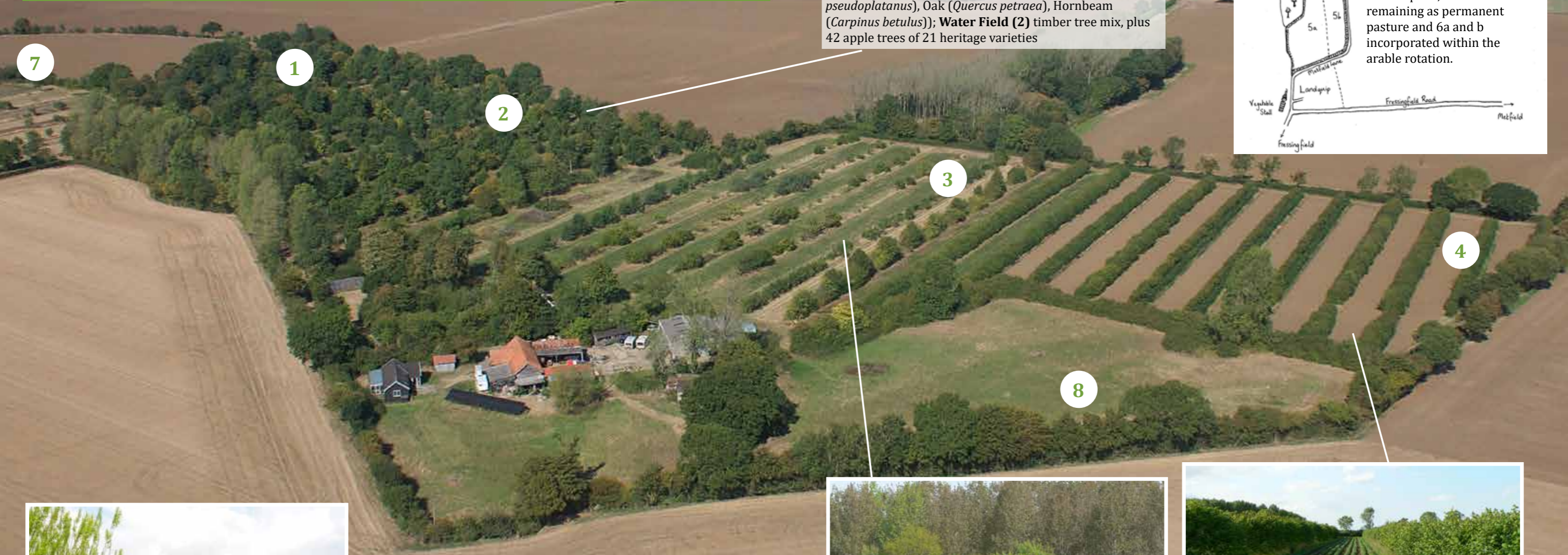
All trees are planted in north-south rows, with an organic arable and vegetable crop rotation grown in the 10-12 m wide alleys between the tree rows. Timber trees were planted in pairs of the same species. Lower limbs have been pruned to maintain form and facilitate crop management. Coppicing of the hazel and willow short rotation coppice is carried out in winter using a circular saw; cut material is then air dried in the field during summer and chipped the following winter to feed a Gilles 20 kW woodchip boiler which heats the farmhouse. Over the years, a wealth of data has been collected on all elements of the different systems including tree growth and productivity, annual and perennial crop yields, pest and disease incidence, functional biodiversity and whole system sustainability.



A mixed hardwood and fruit tree system with eight different species (Fields 1&2): Planted Feb 1994. **Far Field (1)** seven timber species (*Fraxinus excelsior*, Wild Cherry (*Prunus avium*), Italian Alder (*Alnus cordata*), Small-leaved Lime (*Tilia cordata*), Sycamore (*Acer pseudoplatanus*), Oak (*Quercus petraea*), Hornbeam (*Carpinus betulus*)); **Water Field (2)** timber tree mix, plus 42 apple trees of 21 heritage varieties



Fields 6a, 6b, 8 and 9 were left unplanted for use as control plots, with 8 and 9 remaining as permanent pasture and 6a and b incorporated within the arable rotation.



Willow short rotation coppice (Field 5): Planted in March 1998 with a mixture of five fast-growing willow (*Salix viminalis*) varieties; each row coppiced every two years for woodchip production.



5



A fruit and nut tree system (Fields 3&7): Planted February 2001. **Home Field (3)** tree rows partially planted to fruit and nut trees (plum, cherry, apple, pear, quince, apricot, peach, hazel), each of multiple varieties. **North Field (7)** 20 walnut trees and in January 2002 interspersed with varieties of plum and walnuts.



Hazel short rotation coppice (Field 4): Planted in February 1995 with 1200 hazel (*Corylus avellana*) bushes, each individual genetically distinct; alternate rows coppiced every five years for woodchip production.

Aerial photos: Jeremy Gugenheim

Diversity at all levels: from genes to landscape

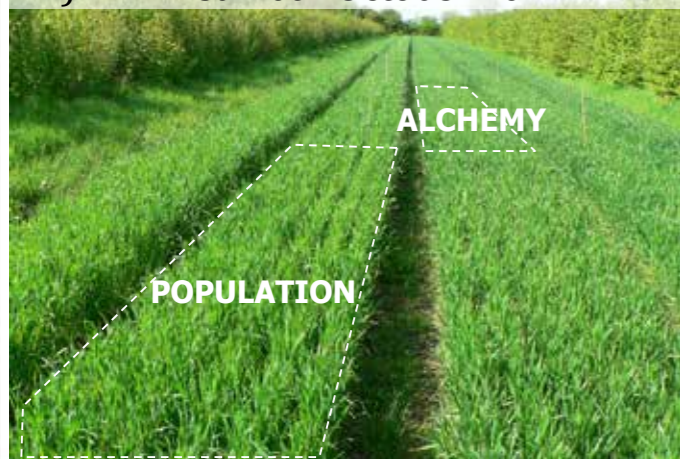
Embedded in ecological theories linking biological diversity to stability in plant productivity and increased resilience, Wakelyns is a model of heterogeneity both at the genetic level as well as in terms of habitat structure. There are various approaches to increasing genetic diversity, including mixing different varieties of the same crop as well as mixing different species.

Cereal populations

Martin went a step further to increase genetic diversity with the development of a 'composite cross population' or CCP in the UK (Döring et al 2015). To produce a CCP parent plants from a range of wheat varieties chosen for particular qualities were crossed, the seeds from each cross multiplied and then combined, rather than separated into pure lines, to produce the first CCP generation. The theory behind this evolutionary plant breeding approach is that natural selection then acts on the genetically diverse crop population leading to local adaptation. Furthermore, genetic diversity can ensure yield stability over time and across different locations. This ability of the Wakelyns wheat CCP to respond to local conditions was demonstrated in 2012 when a wet autumn interrupted drilling of the winter wheat trials at Wakelyns. The cereals drilled at the optimum time all established well (Fig. 1a) but when drilling was delayed a couple of weeks by heavy rain, the plots of the Alchemy variety failed while the CCP successfully established (Fig. 1b).

Growing CCPs under agroforestry could lead to the development of 'varieties' that are particularly well adapted to growing in close proximity to trees or even at different positions in relation to the trees. Pilot work carried out under the AGFORWARD project investigated this concept by comparing yields of a spring wheat CCP that had been developed into three populations based on where they had been harvested (East of the Tree line (EOT), West of the Tree line (WOT), and Centre of the alley (Smith et al, 2017)). Replicated cross-over trials found no difference between the populations in the first year, but in the second year a significant difference was found between the two 'edge' populations, with the EOT selection yielding 35% more than the WOT selection. Whether the EOT selection is better adapted to a silvoarable context, or the WOT may instead accumulate seed-borne diseases due to higher persistence of humidity on the western side of the tree row, is not clear. This experiment indicates that the yield potential of a wheat population can be influenced by the position in an alley where it has been multiplied. However, it may be unrealistic to expect farmers to drill different populations within an alley and the real value may lie in using the microclimatic variation within agroforestry alleys to breed cereals that are more shade tolerant or competitive for obtaining resources.

a) Drilled 16th October 2012



b) Drilled 25th October 2012

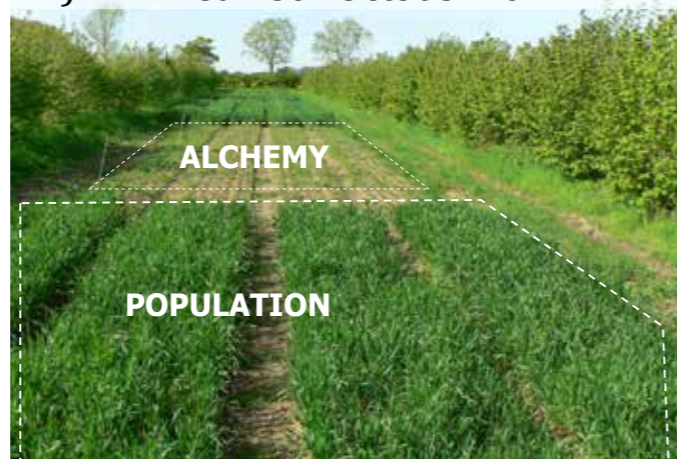


Figure 1: The trials above demonstrate that, unlike the population, the pure-line variety Alchemy failed when drilled only nine days later than the plots in which both crops established well, demonstrating the advantages of the greater genetic diversity in populations.

Species mixtures

As well as aiming to increase within species diversity, various crop trials at Wakelyns have also explored the best ways to optimise species diversity, including diverse fertility-building leys containing up to 15 species (Döring et al, 2013). This trial, which was part of a series of on-farm trials of the same mixture against single species leys, found that by using mixtures of functionally diverse plant species, synergies between agricultural productivity and other ecosystem services can be optimised and fine-tuned to farm-specific needs. Intercropping combinations have also been investigated, combining wheat and beans, and in recent years, lentils and camelina.

Diversity to reduce disease

This species mixture approach was extended to the trees, with eight different species mixed together in the timber system. The benefit of including apple trees in this mix was investigated in 2012 as part of a project investigating alternative approaches to reducing apple diseases (Smith et al 2016). Comparing apples in the agroforestry and a nearby organic orchard, the levels of the fungal disease apple scab (*Venturia inaequalis*) in the developing fruit were twice as high in the orchard as in the agroforestry system (Fig. 2).

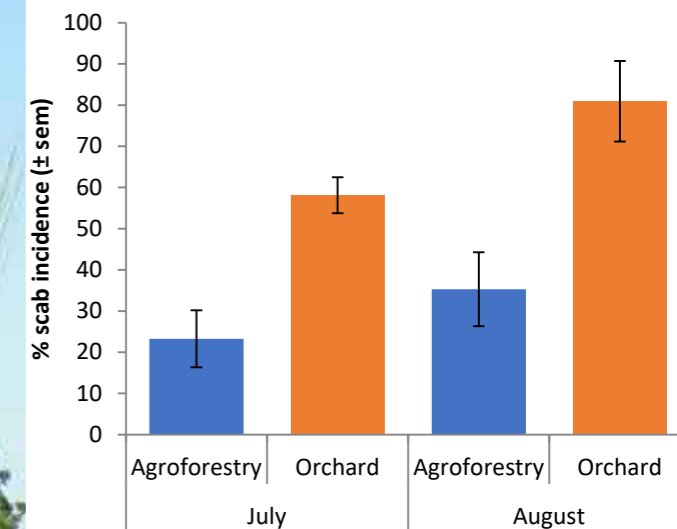


Figure 2: Incidence of scab disease in maturing apples at Wakelyns Agroforestry and a local organic orchard in 2012.

There are a few possible explanations for this disease reduction in the agroforestry apples:

- A greater distance between tree rows in agroforestry systems, with crops in the adjoining alleys, reduces the spread of pathogens.
- Lower densities of trees compared with orchards, favouring increased air circulation; this reduces the severity of scab by reducing leaf wetness duration.
- Regular cultivations within the crop alleys incorporates leaf litter into the soil, thus enhancing decomposition and reducing the risk of re-inoculation from overwintered scabbed leaves the following spring.

Biodiversity

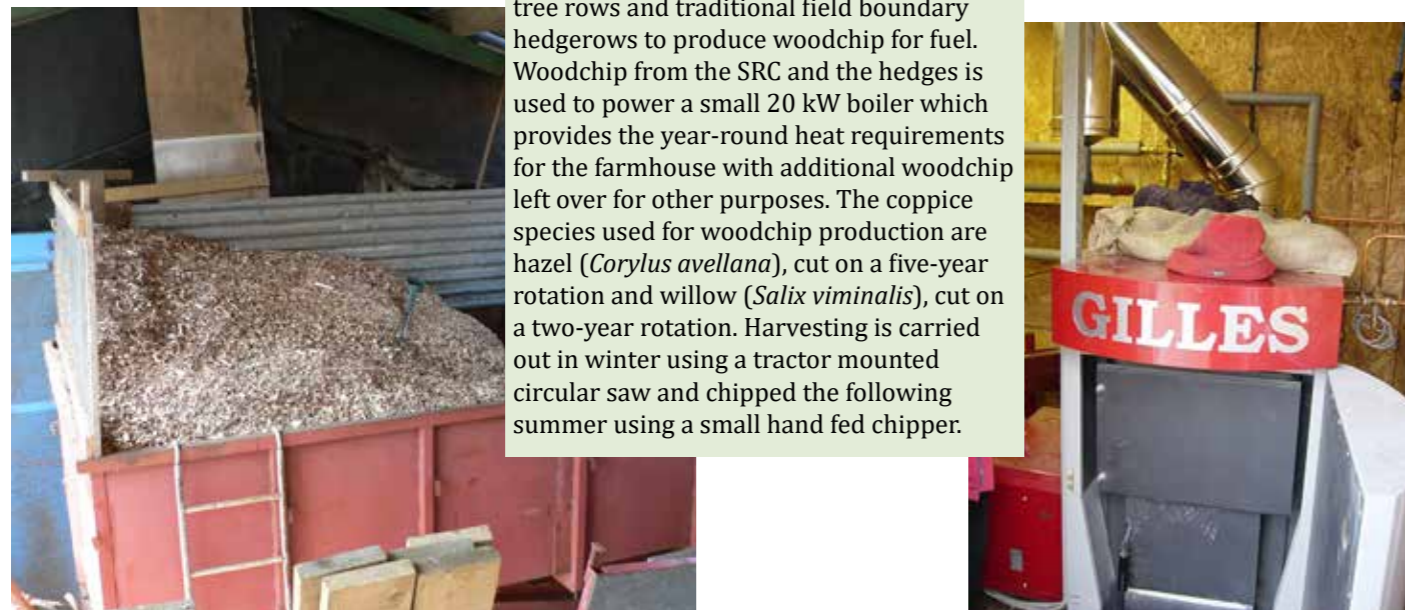
Adding trees into the mixture has increased the diversity of habitats as well as species, leading to the creation of different niches that support higher biodiversity of insects, birds and mammals. An RSPB farm bird survey carried out at Wakelyns in 2010 recorded 43 species, which included eight species on the farmland bird indicator species list as well as several species commonly found in woodlands, orchards, parks and gardens (blackcap, bullfinch, chiffchaff, great spotted woodpecker). This range of species demonstrates the various habitats provided by the agroforestry, appealing to species characteristic of farmed as well as wooded habitats.

Decentralising food and energy production

A key element of the research at Wakelyns has been to investigate different approaches to decentralise and localise agriculture, food and energy production and to provide a model to both prove the concept and act as a demonstration for others.



Martin and Ann very successfully achieved decentralised local energy by using the short rotation coppice (SRC) agroforestry tree rows and traditional field boundary hedgerows to produce woodchip for fuel. Woodchip from the SRC and the hedges is used to power a small 20 kW boiler which provides the year-round heat requirements for the farmhouse with additional woodchip left over for other purposes. The coppice species used for woodchip production are hazel (*Corylus avellana*), cut on a five-year rotation and willow (*Salix viminalis*), cut on a two-year rotation. Harvesting is carried out in winter using a tractor mounted circular saw and chipped the following summer using a small hand fed chipper.



From field to boiler. Willow harvested, dried and chipped to feed into a woodchip boiler that heats the farmhouse.

Biomass production of the SRC willow has been measured since 2011 and the hazel since 2014 (Smith et al, 2017). The two species of SRC produce very similar yields under current rotations when converted to annual biomass production ($2.87\text{m}^3/100\text{m}/\text{year}$). This gives two options; a willow system where the canopy is removed every other year so reducing the amount of shade on the alley crops, but requiring more frequent harvest (and potentially more competitive with crops for water and nutrients) versus a hazel system with slower growing trees, potentially casting more shade, but with fewer harvests to achieve the same yield.



One of the mature mixed species Wakelyns boundary hedges showing regrowth two years after coppicing; tree ring counts indicated that it had been 21 years since the hedge was last cut.

How many trees are needed to heat a farmhouse?

A typical 20 kW farmhouse boiler such as the one at Wakelyns uses approximately 80m^3 of woodchip/year. Therefore, based on the calculations in Table 1:

- 2800 m of Short Rotation Coppice (SRC) – double rows of willow or hazel – is needed to heat the farmhouse. Converting into field area with 3 m wide tree rows and 10 m wide alleys this equates to approximately 3.62 ha of agroforestry.
- 320 m of hedgerow is needed every year to heat the farmhouse; on a 15-year harvesting rotation, a total of 4.8 km of hedgerow would need to be in a coppice rotation to meet this demand.
- Wakelyns Agroforestry has 3.7 km of boundary hedgerow, 2.18 km (3.2 ha) of willow SRC, and 1.5 km (2.4 ha) of hazel SRC as alley cropping agroforestry, so is easily able to meet this need (Table 1).

Table 1: Woodchip production at Wakelyns (Smith et al. 2017; Westaway and Smith, 2018)

	Length (m) at Wakelyns	Number of trees per m	Volume of woodchip per m (m^3)	Coppice rotation length (years)	Length coppice in one year (m)	Annual woodchip production (m^3)
Willow SRC	2175	1.65	0.0574	2	1087.5	62.42
Hazel SRC	1500	1.33	0.1432	5	300	42.96
Boundary hedge	3700	variable	0.25	15	247	61.75





The diverse range of produce that has originated from Wakelyns over the years demonstrates how truly productive a small plot of land can be. Products have included bioenergy from willow and hazel coppice, timber, fruit, vegetables, cereals and pulses, nuts, cider and craft materials from the willow and hazel.

Martin and Ann's core ethos of decentralising food production led them to work with the local community and local businesses to enable food produced locally to be consumed locally and challenge multinational models of food production and distribution. They helped the local shop remain open as a community shop and worked closely with the champion of UK grown pulses Hodmedod's, playing host to some of Hodmedod's early naked barley trials and pioneering at Wakelyns, amongst other things, British grown lentils.

Lunch was an important part of any event at the farm, with visitors encouraged to enjoy eating the produce from the farm including the wild harvest of sausage rolls made from muntjac deer from the farm in partnership with a local deerstalker.



Trees have the ability to access and cycle soil nutrients in the deeper soil horizons that are not available to annual crops. Harvesting and chipping tree branches and applying this fresh 'ramial' woodchip to the soil increases the availability of these nutrients to vegetable and cereal crops. Ramial woodchip has also been shown to increase soil organic matter and promote soil biological activity (Lemieux and Germain, 2000). ORC has been investigating this potential and using some of the additional woodchip produced at Wakelyns as part of a trial investigating Ramial Chipped Wood (RCW) as a soil improver.



Sampling earthworms in the RCW trial plots at Wakelyns 2018

RCW is made by chipping small (<7cm) diameter branches and twigs with a high proportion of buds and bark and applying the chip fresh to the soil in the ley phase of an organic rotation. It can be produced from hedges or short rotation coppice (SRC) agroforestry and provides a further piece in the jigsaw of decentralising food production. RCW gives the potential ability to grow your own soil fertility and organic matter thereby using perennial crops to improve soils that are part of an annual crop rotation.

The RCW trial at Wakelyns is one of three on-farm trials in the UK investigating the use of woodchip as a soil improver and is unique in comparing single species SRC woodchip (willow, hazel and poplar) with mixed hedge woodchip and a control of no woodchip input. These trials are ongoing (Westaway 2019) but results so far have been positive and woodchip from SRC agroforestry looks like it could have potential in arable and horticultural cropping systems as an on-farm source of fertility and soil organic matter.



RCW woodchip piles from the three different SRC species at Wakelyns

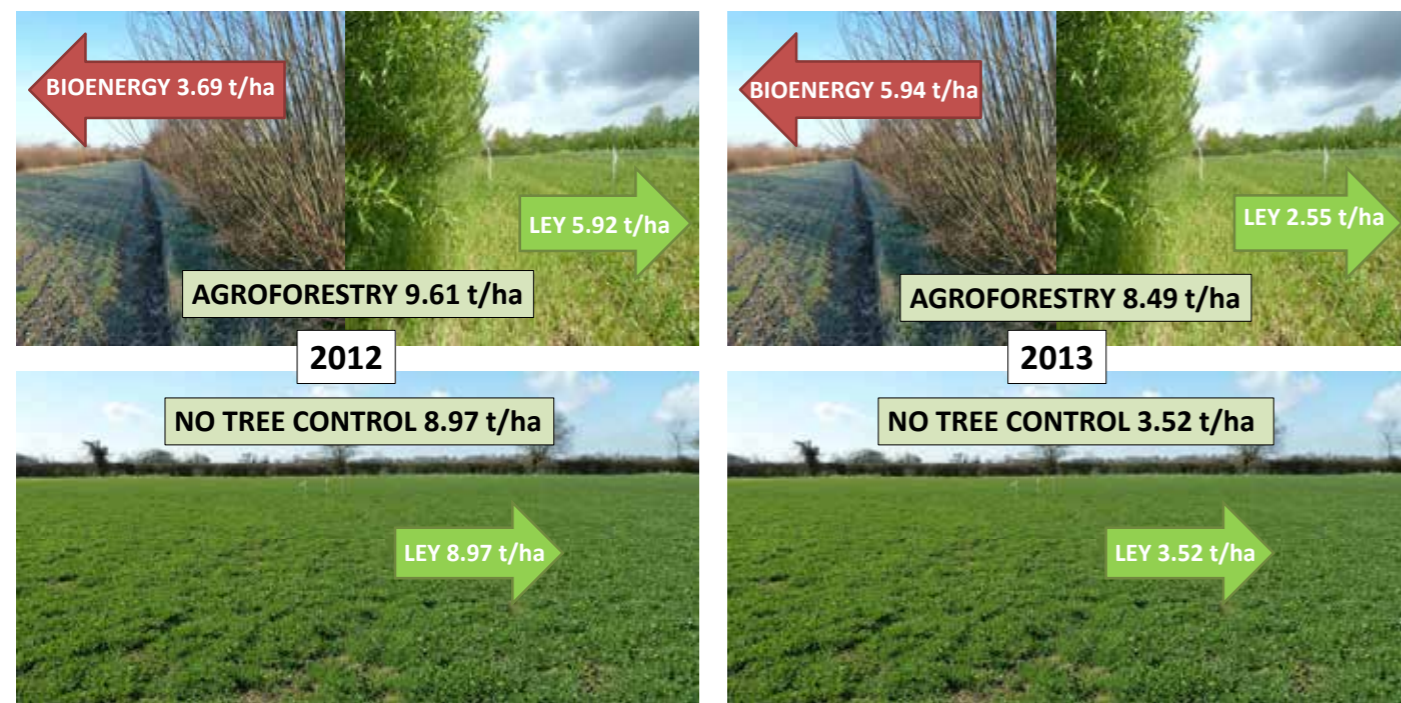
The productivity of an agroforestry system is determined by the balance between positive and negative interactions between the tree and agricultural components. The design and management of agroforestry systems should aim to maximise positive interactions that lead to complementary use of resources and minimise negative interactions that result in competition for resources.

A main hypothesis in agroforestry research is that while productivity from individual agroforestry components may be lower than if grown in a monoculture, overall productivity is higher in agroforestry systems compared to monocropping systems due to complementarity in resource-capture. The Land Equivalent Ratio (LER) is a means of comparing productivity of intercropping (e.g. agroforestry) and monocropping systems. It is calculated as the ratio of the area needed under sole cropping to the area of intercropping at the same management level to obtain a particular yield.

$$LER = \frac{\text{Tree agroforestry yield}}{\text{Tree monoculture yield}} + \frac{\text{Ley agroforestry yield}}{\text{Ley monoculture yield}}$$

An LER of 1 indicates that there is no yield advantage of the agroforestry system compared to the monocrops, while an LER of 1.1 indicates a 10 % yield advantage, i.e. under monocultures, 10 % more land would be needed to match yields from intercropping. The LER reflects the ability of crops to partition resources in space and time. We have calculated the LER at Wakelyns in three different ways: for a specific system over a single growing season; for a full arable crop rotation in a specific system; and for all of the agroforestry systems on the farm for a single year.

Overall productivity (as oven dry weights) in the willow SRC agroforestry system and the no-tree control at Wakelyns was compared using the data collected in 2012 and 2013 on biomass production of the ley and woodchip production from the willow.



Biomass production in the agroforestry and no-tree control in 2012 and 2013 (a standard SRC willow plantation yield of 8.33 t/ha was used for the no tree control)

The LER for 2012 was 1.10 (LER = (3.69/8.33) + (5.92/8.97)) and in 2013 was 1.44 (LER = (5.94/8.33) + (2.55/3.52)). This equates to a 10 % yield advantage for agroforestry in 2012 and a 44 % yield advantage in 2013. These calculations demonstrate that while there was a reduction in ley productivity, probably due to competition at the alley edge, and a reduction in land area under ley (77 % of land area), overall productivity was higher in the agroforestry system in both years. In 2013 when ley productivity was low in both systems, overall productivity was much higher in the agroforestry (8.49 odt/ha compared with 3.52 odt/ha, and an LER of 1.44), with increased wood biomass production compensating for the lower ley yields in the agroforestry. This suggests that an agroforestry

approach can help buffer against fluctuations in yields by spreading the risk across a number of components.

The LER for a full arable crop rotation (and three willow SRC harvests) of six years (spring wheat/ley/potato/ley/winter squash/ley) was calculated using a modelling approach (Smith et al 2017). Using a special agroforestry model called Yield-SAFE, it was possible to model and thus compare the yields that might be expected at Wakelyns as a pure arable system, a pure willow SRC system and a willow-arable agroforestry system. The LER was calculated as:

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

And finally the LER combining all of the agroforestry systems on the farm for one year was calculated using the SustainFARM Public Goods Tool (see Page 14). This returned an LER of 1.34, suggesting that there is a 34% yield advantage for agroforestry compared to when the components are grown separately as monocultures.

Looking forward

As the agroforestry systems at Wakelyns age, the interactions between the trees and crops are changing. In the SRC systems, the regular coppicing of the trees means that aboveground competition for light is controlled and it is likely that arable cropping can continue in the alleys for years to come, potentially until the trees need replacing. In contrast, the timber trees have grown to heights of up to 13m (Figure 3) and viewed from above, the system is now starting to resemble a woodland (Figure 4). The shading impacts on crop yields are likely to mean that commercial arable cropping will be eventually unviable; however, over recent years, Martin introduced pollarding to manage the tree canopies and provide more light into the alleys. An alternative approach would be to selectively thin or harvest

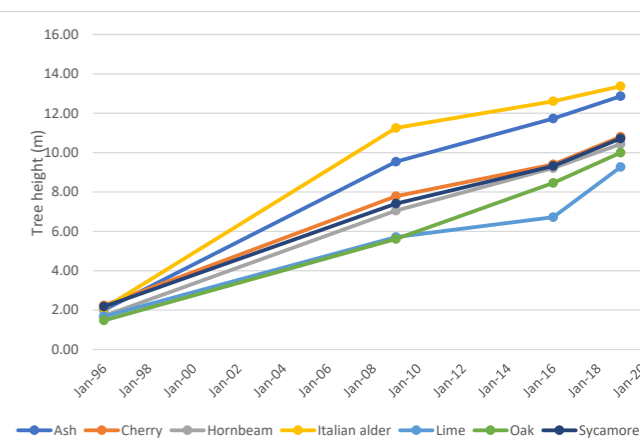


Figure 3: Tree height (m) of the timber trees at Wakelyns, planted in 1994

the trees to reduce tree densities and open up the canopy or to convert the alleys to pasture and introduce grazing animals to the system. Natural tree regeneration has been occurring between the planted trees and when you look across the tree rows, you can now see a wonderfully diverse, mixed-age, low-density deciduous woodland.



Figure 4: Aerial view of the mixed timber system. Photo: Jeremy Gugenheim.

Agroforestry systems such as Wakelyns are often promoted as sustainable alternatives to the highly industrialised agricultural model with its associated negative environmental externalities. However, our research often focuses on just a single factor (or limited range) of sustainability measures. A combined approach applying a range of tools and metrics can help to reveal costs and benefits from a range of perspectives (environmental, economic, social) and help determine the extent to which contrasting agroforestry systems can deliver on a range of sustainability objectives.

ORC used a comprehensive sustainability assessment tool, the SustainFARM Public Goods Tool, which is modified for agroforestry systems, to consider the many aspects of sustainability (ORC 2019; Smith 2019). The assessment takes a broad approach, using information that a farmer would have in their farm records already and covers a specific 12-month period. It takes between 30 minutes and an hour to complete, depending on the complexity of the farm. It assesses a farm on a number of areas (spurs) which may be impacted by agricultural management practices and are related to public goods such as water quality, air quality, etc.

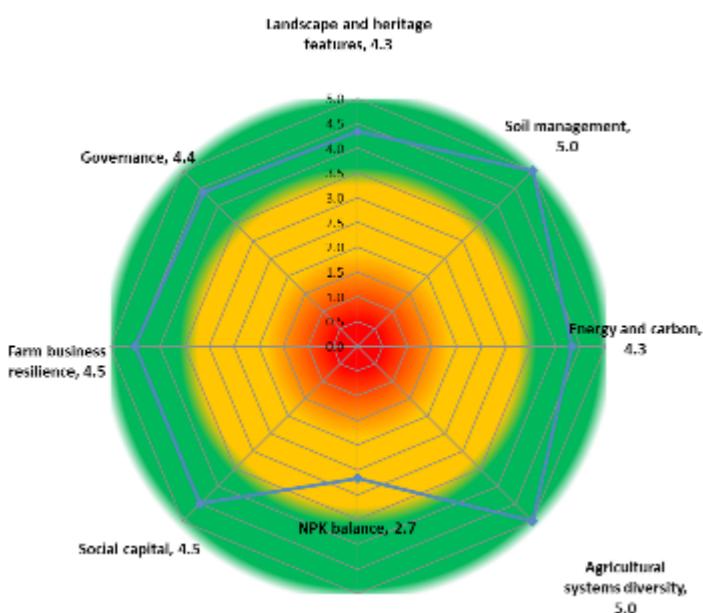


Figure 5: Radar diagram showing the results of the SustainFARM PG Tool assessment at Wakelyns.



Aerial view of the short rotation coppice willow. Photo: Jeremy Gugenheim.

As a diverse organic farm, Wakelyns scores highly across nearly all the spurs (Fig. 5), achieving a top score in soil management and agricultural systems diversity. Its lowest score is for the NPK balance; currently the fertility building legume ley fixes more nitrogen than is exported in crops, thus risking leaching of nitrogen from the farm.

An energy and emissions audit was carried out at Wakelyns in 2009; this assessed energy production and consumption of the farm business including the domestic property (Smith, 2009). The whole estate energy production, including woodchip from the SRC, was 1086 GJ, while the whole estate energy consumption was 189 GJ. This gives a production:consumption ratio of 5.1:1. Energy benchmarking using the SustainFARM PG Tool found that while the arable enterprise uses only 61% of arable benchmark systems, the domestic energy use is considerably higher than an average farmhouse (367% of benchmark). The farmhouse at Wakelyns is a beautiful, but old and leaky building that is hard to insulate. 80% of the farm energy use is from renewable sources (photovoltaic panels and woodchip from the agroforestry system), and the CO₂ balance is -10.2 tonnes CO₂ equivalent per year.

As a research site, Martin relied on research funding to maintain the trials and farm. Going forward, Martin's sons, David and Toby, are working closely with farm managers Paul and Mark Ward to demonstrate that organic agroforestry is also financially viable, and therefore all-round sustainable.

Since Martin and Ann first started planting trees, Wakelyns has played host to thousands of visitors from across the world, inspiring and motivating farmers, foresters, growers, students, researchers, bakers, artists, politicians, industry, conservationists..... Although he must have given literally hundreds of tours of the farm over the years, Martin still retained and conveyed his enthusiasm for sharing the Wakelyns message.

Kimberley Bell

Kimberley Bell of the Small Food Bakery first visited Wakelyns in 2017; this visit changed not only her bread, but the whole philosophical framework around the bakery:



"As bakers, we went to Martin looking for a sustainable wheat, having read a snippet about agroforestry online and thinking that growing the alley cropping system could be the answer. We got so much more than we bargained for, the outputs from Wakelyns were certainly as diverse and productive as the agricultural system being proposed! The YQ, a heterogeneous 'Population' he created and grew amongst trees at Wakelyns defied the status quo on every level."

Stephen Briggs

Stephen Briggs, pioneering organic farmer and advisor, took inspiration from Wakelyns when designing and planting 4500 apple trees as UK's largest commercial silvoarable system on his farm in the Cambridgeshire fens:

"Martin was a pivotal sounding board with whom to discuss my ideas of developing commercial agroforestry at Whitehall Farm. Sharing ideas and experiences helped shape our direction. Martin's quiet wisdom encouraged us all to look more deeply at Nature and try and take lessons to shape our farming systems – his inspiration will live on long through many."

Mark Lea

Shropshire organic farmer, Mark Lea, has been growing the ORC Wakelyns wheat population for the last few years, because of the increased resilience to pest, disease and climatic risks gained from having so much genetic diversity in the mix:

"I feel so privileged to have known Martin and been able to integrate his work into our farming system. With YQ he completely changed the direction of wheat growing here and our avenues of hazel for coppicing and walnuts will be here long after we are. His influence and his wisdom changed me and this farm for the better!"

Acknowledgements

In memory of the late Prof. Martin and Ann Wolfe, Wakelyns Agroforestry, and with thanks for their enthusiasm, support and cooperation in this research. Thanks to Jeremy Gugenheim and Maja Lindstrom (paradigmshiftfilm.com) for permission to use their photos. Thanks also to David Wolfe and the Wakelyns farm team, Paul and Mark Ward for their help over the years of data collection.

Maria Finckh

Maria Finckh, professor of organic farming at University of Kassel, based at Witzenhausen, has been part of the Wakelyns story from the start:

"Some very special times were the planting of trees at Wakelyns in 1994 and 1995 and the beginnings of the work with the CCPs. Martin's vision was to enhance diversity among crops and within crops. This has inspired scientists across Europe and the wheat composite cross populations (CCPs) are now in the F18, growing from Hungary to the UK."

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- Wakelyns Agroforestry: www.wakelyns.co.uk

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