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report

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**Agroforestry: a new approach
to increasing farm production**

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1. Introduction

So you want to increase farm production – that's easily solved, walk outside, first look up and then look down – now crop those extra dimensions!

Most farmers think two dimensionally. Farmers look at fields and see the crops or animals on the surface, rarely giving much thought to what exists 2 m above and 1 m below the surface, or the potential there is to utilise this space for crop production. Most crop production systems exist by exploiting sun, air, water and soil nutrients in this relatively thin layer above and below ground.

Combining trees in the system can make much better use of these resources in space and time. Tree roots access nutrients and water at greater soil depth than most farmed crops and branches can make better use of sunlight above an understorey crop.

The secret is to combine complementary components. For example, cereals require most resources from April–June, whereas a later leafing tree species may require most of its water, sunlight and nutrients later in the summer and autumn after the cereal has ripened. This allows the farm to better utilise natural resources and also crop an extra and widely underutilised dimension, upwards!.

So crop the third dimension, but how?

The answer could be agroforestry.



Me – reviewing agroforestry in Missouri USA



2. Background to my study tour - why Agroforestry?

I have always had passion for farming, for nature and for the soil, on which we all rely to feed our growing world population.

However for a long time I have been concerned that we are taking more than we are giving from one of the earth's most precious resources, the soil.

I started life as an engineer, but realised that my love for farming was greater. I retrained via an HND, BSc and an MSc in soil science. I spent a number of years overseas in Africa and India, working with farmers on soil and water management. After getting married, my wife and I returned to the UK and worked in agriculture and advisory positions. In 2005 we purchased some farm land, followed by securing a 15 year tenancy on a farm in Cambridgeshire in 2007. Alongside my role as Director of 'Abacus Organic Associates', providing farm management advice, I manage our 110ha farm land in partnership with my wife Lynn, who is also a Soil Association inspector and provider of environmental management advice to other farms.

Growing crops on our farm and advising other land users on how to grow crops and manage their land and resources provides me with immense satisfaction and purpose. However I have deep concerns for our future. Industrialised farming has risen to the challenge of producing more 'output' over the last 40 years but at what cost to the soil, water, biodiversity and landscape resources that for too long we have taken for granted?

This is partly why I farm organically. Whilst our production output is only circa 75% of where the farm was under a conventional system, our inputs are significantly reduced and our profitability greater. Moreover, the reliance on artificial inputs is significantly reduced and the stewardship of the soil on the farm is, I believe, much improved.

Our global and local challenge is to produce more food whilst simultaneously enhancing and protecting natural resources and biodiversity. Industrialised monoculture systems may achieve this in the medium term, but in doing so will further degrade our soil, water, biodiversity, landscape and natural resources and we will be further reliant on increasing levels of artificial inputs of fertiliser and agrochemicals to sustain productivity. Long term, monoculture is unlikely to be the answer to feeding growing populations - we degrade our natural resources at our peril!

On a more personal note after, in 2007, securing the tenancy of our fen farm, which is blessed with soils with a 23% organic matter content, I was staggered to see the level of soil erosion from wind locally here in the fens. On a 'fen blow' day you can literally see the soil disappearing over the ditch (no hedges here!). As I would rather keep our own soil than give it to my neighbour I started to think about ways we could modify the farming systems. This set me thinking about the direction modern agriculture has taken.

Since the agricultural revolution in the 1800s there has been a gradual intensification, simplification and specialisation in agriculture. In some areas, this change is increasingly characterised by a separation of agriculture and the natural world into 'prairies and parks'. This approach suggests that, to deal with human population growth, agriculture should be concentrated in 'prairie' areas with an even greater intensification of production. At the



same time the natural world would be restricted to 'parks' or reserves for recreation and conservation.

Modern agriculture is now based mainly on massive monoculture of a handful of crop species worldwide (wheat, rice, maize, sugar cane and a few other grass species, together with soya beans, cotton and potatoes). Crop monocultures are only able to perform effectively with large amounts of synthetic 'inputs' (fertilisers, herbicides, insecticides, fungicides, molluscicides, growth regulators) derived from fossil fuel energy, which are becoming more expensive as reserves decline. The scale of these monocultures, covering previously natural landscapes, has largely displaced natural biodiversity which is central to the sustainability of life on the planet.

The importance of natural biodiversity is becoming more recognised in the provision of 'ecosystem services' – ecosystem services are:

- The production of food
- Regulating (carbon sequestration, climate regulation, nutrient cycling through decomposition, purification of water and air, pest and disease regulation);
- Supporting (nutrient dispersal and cycling, seed dispersal) and
- Cultural (intellectual/spiritual inspiration and the biological regulation of planet Earth) services.

Do natural systems offer us some clues? As recognised by farmers over thousands of years, the natural world functions through the interactions of many organisms in soil, water and air. Natural systems, by their very nature, are more complex and difficult to deal with in terms of harvesting, for example. In their purest form, natural systems succeed in a broad range of diverse and complex habitats, from climax forest to low growing species, with an infinite range of annual and perennial plant types, both in plant canopies above ground and in an infinite range of rooting and life below ground. This diversity manages risk, with a natural ability to cope with drought, flood and climate change, modifying species' composition and dominance with resource availability and output. Harvesting this output for human consumption is obviously challenging and not practical. But can farmers take clues from this complexity and adopt more diverse systems which buffer against climate change and continue to provide appropriate levels of productivity and profitability?

Farmers and land managers must move away from monoculture to 'managed complexity'. A simple form already practised by some farmers is: more diverse cropping, bi-cropping (mixing crops in the same field) or multi species cropping. Farming system enhancements can be the addition of field edge buffers, bio-diverse margins, trees and hedgerows to protect and conserve soil and water and increase natural diversity. However this tends to compartmentalise productivity (monoculture in the field) with more natural systems at the field edge (conservation).

Can the two elements be combined to produce equal or even greater productivity with enhanced levels of biodiversity and resource protection? What happens if we bring the trees back into the fields and create a mixture of agriculture (agro) and trees (forestry) - or agroforestry - and how would this work practically? Is it a new approach?



Can we as farmers find a productive compromise - somewhere between monoculture and the natural world approach – to integrate ‘parks’ and ‘prairies’? The challenge is to maximise diversity within a highly productive system whilst minimising the need for inputs, and to mix perennial and annual crops so as to reduce the risks of cropping in a climate changing world.

This is ‘agroforestry’.

Agroforestry is not a new approach. China has a long history of agroforestry; official records document recommendations for combining forestry with livestock and crops during the Han Dynasty (206 BC to AD 220), and the biological and ecological interactions between trees and crops appear in writings of the Yuan Dynasty (13-14th century AD) (*Smith J. et al 2010*). In France, historic documents show agroforestry as a traditional form of land management in the late 19th century. In central Spain and southern Portugal agroforestry still occupies 3.5 million ha, nearly 3% of the land area. The Dehesa is a multifunctional agrosylvopastoral system and cultural landscape in Spain (Figure 1). In Portugal it is known as Montado (*Fra.Paleo 2010*).



Figure 1 The Spanish Dehesa which covers 3.5 million ha, nearly 3% of the land area

The Dehesa and Montado are used for livestock grazing and to produce a variety of non-timber forest products such as mushrooms, honey, cork, wild game and firewood. The tree component is typically oak (*Quercus ilex*) and cork (*Quercus suber*). The Dehesa not only provides a variety of foods, but also a valuable wildlife habitat for endangered species such as the Iberian lynx and the Spanish Imperial eagle (*Joffre 1999; Huntsinger et al. 2004; McGrath, 2007*). The Dehesa system has great economic and social importance on the Iberian peninsula both because of the large amount of land involved and its importance in



maintaining rural population levels. So could Agroforestry provide a realistic production option in the UK? Moreover could it solve the loss of our fen farm soil to our neighbours?

My Nuffield Scholarship aim was to explore “*The adoption of commercial agroforestry and its applicability to UK & temperate farming systems*” in different countries and see what systems and approaches were appropriate for UK farmers.

My intention was to use a Nuffield Scholarship to learn more about how commercial agroforestry is practised in other countries and how successful practices can be applied to temperate agriculture in the UK. I had a vision of using the information gathered to improve the agroforestry system on our own farm and to provide other farmers and the wider agricultural community with a better understanding of how commercial agroforestry systems can be developed and adopted in UK farming systems.

When I embarked on the study, my background research indicated that agroforestry had the potential to improve soil, water and air quality, enhance biodiversity, improve pest and disease control, contribute to sustainable land management and mitigate against climate change.

What I was unsure of was how agroforestry achieved these improvements, what levels of crop productivity were achievable from agro forestry compared to monoculture, plus how or why farmers decide to, or not to, adopt agroforestry. These questions would all be answered.



3. What is Agroforestry?

Agroforestry is an integrated land use system that combines elements of agriculture (agro) and trees (forestry) in a sustainable production system. With an emphasis on managing rather than reducing complexity it promotes functional bio-diverse systems that balance productivity with environmental enhancement and protection.

Agroforestry systems are classified as silvoarable (trees & crops) or silvopastoral (trees & animals). Systems can combine production of a wide range of products including food, fuel, fodder and forage, fibre, timber gums and resins, medicinal products, recreation and ecological services. Tree species can be timber, fruit, nut, coppice or a combination etc., and the alleys in between tree rows can produce cereals, vegetables, fruit, forage, animals etc. Careful selection of crop components is required in relation to market outlets, local climate, soil, alley spacing, tree height, timing of planting and harvesting, tree leaf production and shading etc.

Agroforestry systems modify local microclimatic conditions (temperature, air, water vapour content, evaporation and wind speed) and provide benefits to crops which are grown with the trees by reducing soil degradation and enhancing biodiversity, pest and disease control. Agroforestry also reduces nutrient loss by maximizing internal nutrient cycling through leaf litter return. Other benefits include the regulation of soil, water and air quality, enhancement of biodiversity, pest and disease control.

With both ecological and economic interactions between trees and crops and livestock, the total productivity within these systems is usually higher than in monoculture systems due to complementarity in resource capture.

There is a growing understanding that agroforestry can provide multi-functional land use and environmental benefits, with productivity improvements and resource protection having been clearly documented in a number of global locations. The positive impact of agroforestry on production, resource utilisation and environmental protection could play an important role in maintaining and improving land productivity and protecting resources for future generations. In a climate changing world, these attributes could prove most valuable.

By integrating trees into the agricultural landscape there is also a real potential to impact on the local economy by:

- increasing economic stability
- diversification of local products and economies
- diversification of rural skills
- improving food and fuel security
- improving the cultural and natural environment, and
- landscape diversity

Combined with the positive impact of agroforestry on resource use, resource protection and mitigation against climate change, the benefits of agro forestry are slowly becoming better understood and documented.



However, the impact of using agroforestry systems on farm land, both in productivity and profitability plus its role in protecting the environment and providing ecosystem services, is not yet fully appreciated in the UK.



4. Where I travelled and why

My Nuffield Scholarship aim was to study commercial agroforestry in different countries and see how experiences could be applied to UK farming. With a focus on temperate regions, I chose to travel in the following countries :

- **UK** - to establish agroforestry activity and policy issues relating to agroforestry development in the UK
- **Canada & the U.S.A** (26 days) - I wanted to learn about the long established agroforestry research and to participate in the 12th North American Agroforestry Conference in Athens, Georgia, in June 2012
- **EU – France, Germany, Switzerland, Austria** (32 days) - As European neighbours, I wanted to visit France, Germany, Switzerland and Austria to learn about the agroforestry research being undertaken and how agroforestry fits within farming systems. I wanted to understand how CAP policy is applied in different EU member states and how this affects the adoption of agroforestry
- **China** (21 days) - Agroforestry in China covers more than 3 million ha in the Hebei, Henan, Anhui, Shaanxi and Shandong provinces. I wanted to visit China to learn about the established agroforestry practices combining paulownia and wheat production
- **New Zealand** (Contemporary Scholars Conference) (13 days)

4.1 What my objectives were :

- To discover what agroforestry systems were being used in different temperate countries, to better understand crop and tree combinations and spatial arrangements.
- To understand why there is good adoption of agroforestry in some countries and not in others.
- To bring back the techniques, skills, research and information needed to better inform farmers and land owners about the benefits of agroforestry.
- To develop global and European linkages for improved information and knowledge transfer on agroforestry.
- To be better informed in order to be able to influence UK policy makers on the benefits of agroforestry.
- To return home and implement findings by putting them into practice.
- As a Nuffield Scholar, to share my knowledge with fellow farmers.



5. Summary of main findings

Below is a summary of the main findings from my study tour; these are expanded in more detail in the following chapters.

- Agroforestry in Europe declined during the 20th century, compounded by the Common Agriculture Policy (CAP).
- Agroforestry is working practically on farms in Canada, the USA, China and in more than 18 EU member states.
- Modern agroforestry systems are compatible with present-day agricultural techniques and tree densities c. 100 trees/ha allow alley crop productivity to be maintained
- Agroforestry can be as, or more, productive than monoculture systems, with total productivity increases of up to 30% in biomass, and 60% in final products, achievable.
- Agroforestry is as profitable as monoculture, and often more profitable when high value timber trees (such as walnut, poplar or paulownia) are included.
- Agroforestry tree row spacings of 12 or 18 m were too close and 24 or 36 or 48 m row widths are now typical.
- Nutrient utilisation is more efficient in agroforestry systems, with farmland nitrogen losses reduced by 50% in agroforestry compared to monoculture.
- In the UK there is a disconnect between Defra and the Forestry Commission, with neither party taking ownership of agroforestry.
- EU CAP and member state policy blockages still exist which provide no incentive for adoption or, worse, prevent adoption of agroforestry at farm level.
- Agroforestry is being adopted in the 2012 US and Canadian Farm Bills, and China has integrated agroforestry into mainstream agricultural policy. EU Article 44, Measure 222, makes provision for Agroforestry and many EU member states have agroforestry policies. The UK has not adopted Article 44 or Measure 222, makes no provision for Agroforestry and does not currently have an agroforestry policy.
- There are multiple mature agroforestry research sites globally. A research alliance should be formed to answer questions on productivity, economics, resource protection, climate change mitigation etc.
- Agroforestry is '*climate smart*' agriculture and provides one of the very few options that has the potential to help reduce greenhouse gas emissions, help protect natural resources whilst at the same time producing more food and biomass.

Against this background I have visited some amazing agroforestry systems practised by innovative, forward-thinking farmers across the globe and these are detailed in the following chapters. Agroforestry, by its very nature, is complex, so inevitably the subject matter in the following chapters overlaps on occasion. I have divided it up as best I can for the sake of reference and clarity. I would also emphasise that I have 52 ha of agroforestry on my own farm, so I am not only describing what I saw on my travels, but also interpreting it from personal experience.



6. Discussion

6.1 Why are trees important

Trees have an important role in climate change adaptation, by providing shelter, cooling, shade, controlling rainwater runoff, reducing wind speed - and therefore reducing soil erosion and evapotranspiration from crops. It is well documented that planting trees would (not could) help to reduce greenhouse gas emissions, for example, by reducing the use of nitrogen fertilisers which require a high fossil fuel input in their manufacture, and also by reducing the emissions of the greenhouse gas nitrous oxide from land.

The UK has about three million ha of forest and woodland (see Figure 2 below), or 11% of the land area (66% is agricultural area). International comparisons include Europe (excluding Russia) 37%; North and Central America 33% and Finland 74%. (*Forestry Commission 2009*). New woodland establishment in the UK has averaged about 9000 ha a year over the past five years.

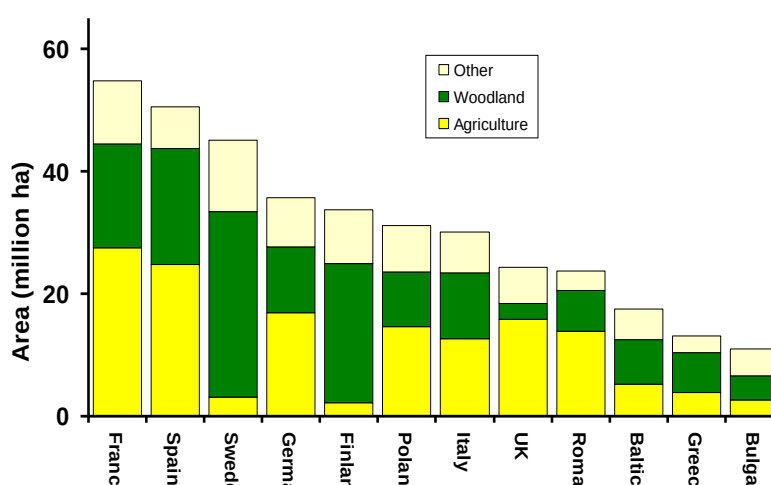


Figure 2: (Eurostat 2009):

Agricultural land data relating to 2006; woodland data relating to 1998

UK: 66% agriculture; 11% woodland.

"Other" includes land of mixed use, infrastructure, built-up land, recreational and other open land

A greater proportion of UK land is used for agricultural production than is the case in any other large state in the EU27.

The first national assessment of the potential of the UK's forests to mitigate climate change conducted by the forestry commission (*Forestry Commission 2009*) stated that If an extra 4% of the United Kingdom's land was planted with new woodland over the next 40 years, it could lock up 10% of the nation's predicted greenhouse gas emissions by the 2050s. Forestry could make a significant and cost-effective contribution to meeting the UK's challenging emissions reduction targets. This would entail the planting of 23,000 ha a year. Over 40 years this would involve changing the use of 4% of the UK's land. The highest recorded annual new planting area in recent times was about 30,000 ha in 1988. Similar levels were recorded in the mid-1970s. To bring woodland cover in the UK from its current 12% of the



land area to 16% (still well below the European average of 37%) this would mean increasing tree planting by 200% on current levels.

With the conflicting pressures on land for food production, energy production and carbon sequestration, the UK target of 16% is unlikely to be achieved from forest planting and the establishment of small farm woodland blocks alone. Agroforestry could make a significant contribution to tree planting targets in agricultural landscapes and be a more acceptable form of tree cover to farmers and landowners, permitting continued food production integrated with trees.

In Europe, both national and regional government policy in France recognise the multifunctional benefits of agroforestry and have embraced adoption and advisory support. Grant aided support is available for tree establishment at c. 70% with a 30% match fund contribution from the farmer. The French have embraced agroforestry through the “Arbre et Paysage” approach (which translates as “Trees in the landscape”). In the Gers region (department 32), Alain Cannet, the Director of “Arbre et Paysage 32” (www.arbre-et-paysage32.com) supports, plants and maintains trees and shrubs in the agricultural landscape. In Gers there are over 500 ‘communities’ (similar to a UK Parish). The organisation has ‘association’ status with government. It receives no core funding and generates income from advisory work for designing and implementing agroforestry, so is semi-autonomous, but driven by government policy. The organisation already works with over 250 farms with agroforestry and supports plantings which encompass all agroforestry uses (riparian buffers, hedgerows and windbreaks, alley cropping, silvopasture etc.) Other similar organisations exist in the 22 French regions and 100 departments.

In Canada, agroforestry research undertaken at the University of Guelph (www.envbio.uoguelph.ca) over the last two decades has been investigating the benefits of silvopasture, silvoarable alley cropping systems and riparian zone management. Riparian management research started with tree planting in 1987 using willow and poplar, and has shown significant improvements in water quality, plus reductions in watercourse nitrate loading, in catchments planted with trees as riparian buffers along watercourses. This research has influenced Canadian environmental policy and is now being adopted throughout the country.

In the USA, watershed research projects are showing how agroforestry buffers can mitigate the effect of sediment, N loading and antibiotic loading into water courses from silvopasture systems and grazing livestock, as well as acting as a flood alleviation measure. Research has shown 48% reductions in sediment loss and 75% reductions in nitrogen loss from catchments under agroforestry.

At the University of Missouri’s Greenley experimental station long term watershed management experiments are being conducted, using whole catchment scale sites to compare contour buffers in maize production, with either (a) no buffer (maize only) (b) grass strip buffers every 30 m in the maize or (c) grass buffers and agroforestry every 30 m in the maize. Rates of sediment, nutrient and pesticide capture are much higher in the trees/grass agroforestry strip treatment compared to the other treatments.

While China remains a communist state, the leaders have focused on market-oriented approaches to economic development. This has led to more than a tenfold increase in GDP since 1978, and the country is now the world’s second largest economy in terms of purchasing power. However agriculture is fairly constrained and dominated by central and



regional government policy. China faces a real agricultural conundrum - do they adopt a western style agriculture with farm consolidations and adoption of large machinery and a high input:high output system? Or do they retain small farms and seek to develop them to improve output with appropriate crops, varieties, machinery etc.? If it's the former then China may have to relocate and find alternative employment for 0.8 billion farmers! This is not a choice that the government currently favours.

Prior to 1978, rural economy in China was organised under the collective system with centralised planning, with workers' pay based on the average production of the whole collective. This system offered little incentive to work and resulted in low productivity and living standards. From 1978, land use rights were transferred from the collectives to individual households, under a scheme known as the household responsibility system (HRS). The HRS gave rural families the right to make their own decisions in regards to farming and marketing. This improved incentives for the farmers and boosted productivity (Yin, 2002), as shown in figure 3 below.

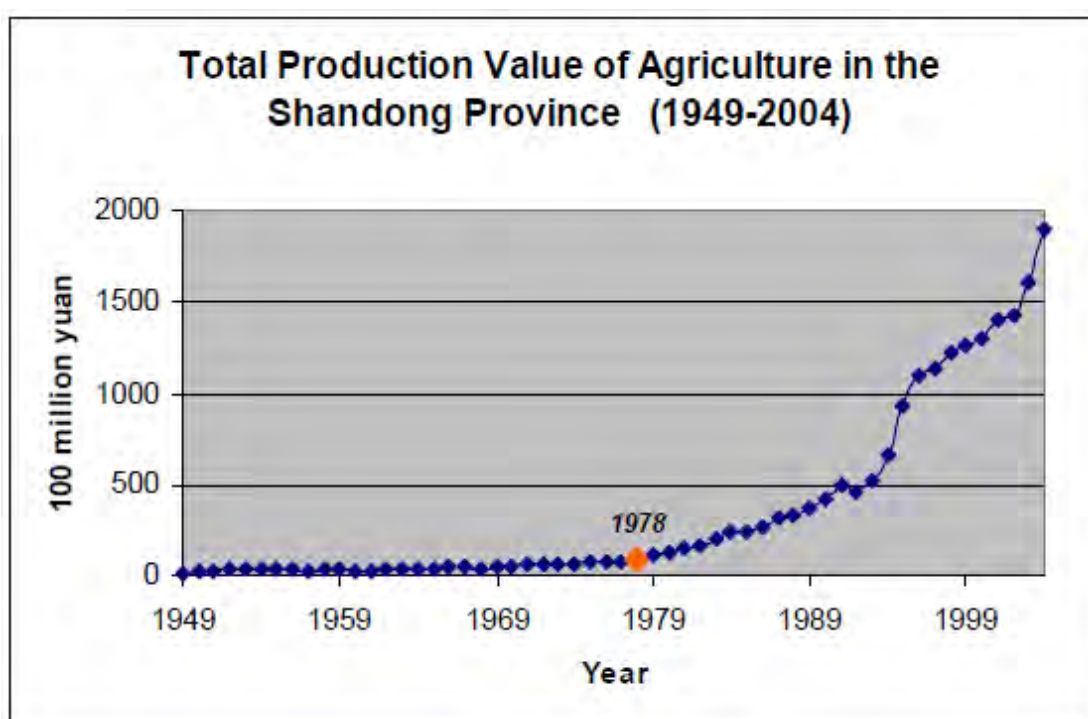


Figure 3 : The rapid increase in Chinese agricultural productivity after the rural reforms in 1978 (Shandong Statistical Yearbook, 2009)

So why are trees and agroforestry important in China? Agroforestry has been practised in China for several thousand years, dating all the way back to the Han Dynasty (206 B.C.- 220 A.D) (Zhu *et al.*, 1991). At the same time as the introduction of the household responsibility system (HRS) in 1978, it was recognised that significant soil degradation was occurring in central and northern China, especially in the main wheat producing provinces adjacent to the Yellow River (Shandong, Henan, Shaanxi, Shanxi etc.). Soil degradation was resulting in millions of tonnes of topsoil being washed into the yellow river from wind and water erosion. Agroforestry was seen as a land use system which could halt and reverse soil degradation whilst simultaneously allowing the production of food and timber crops (Yin, R.S. 1998).



With an increasing population and multiple pressures on land from food production, industry, housing and the effects of soil degradation, China has lost the use of approximately 8 million ha of agricultural land in the last decade, or 6.6% of its arable land. The per-capita arable land in China is now 0.1 hectares, less than 40% of the world average (*Liu, 2006*). Consequently, land use has become the most important problem for agricultural development. In order to maximise the potential of land resources, farmers are continuing to use agroforestry on their land, in order to meet the demand for not only food, but also timber, fodder, fuel and income (*He, 1998*).

In recent decades, agroforestry has undergone rapid development, with intercropping of trees and cereals (wheat), particularly in central and northern China. The two most common types of trees used in intercropping systems in China today are paulownia (*Paulownia spp.*) and poplar (*Populus spp.*).

On visits with farmers and government officials in Henan and Shaanxi provinces, I learnt that Agroforestry has significantly reduced the level of soil degradation occurring and what was in the 1970s eroded, barren land, not capable of supporting crop production, is now productive land producing timber and cereal crops and supporting many rural households with a viable and sustainable income. Timber is used for construction and furniture, plus burnt as a renewable energy source. Flowers and nutrient rich leaves are harvested and used as livestock forage for cattle, pigs and sheep. One 8-10 year old paulownia tree can produce 100 kg of fresh leaves per year. With a density of 100 trees per ha an agroforestry system has the potential to produce a not inconsiderable 10t/ha/year of fresh forage from leaves. Crops of wheat are grown underneath the trees, which are protected from the hot summers and which outperform wheat in monoculture situations. This then exploits a two-tier agricultural production system and utilises the extra dimension alluded to in my introduction.

6.2 So how productive is agroforestry?

Research from North America, Europe and China all indicates that agroforestry can be as, or more, productive than monoculture systems, especially in changing climates. The adoption of agroforestry by farmers also confirms that they view it as a long term productive and profitable system.

Agroforestry is often more profitable when high value timber trees (such as walnut, poplar or paulownia) are included (Figure 4). The annual crops between the trees (cereals, proteins, maize, forage etc.) maintain the annual income for the farmer, while managed low density tree stands provide significant capital for the future.



Figure 4 : Agroforestry with 30-year-old wild cherry trees in western France. The value of the standing volume is estimated to €4000/ha, which matches the value of the land. But the future value of this plantation is much higher and will exceed €10000/ha.

Agroforestry research undertaken in Canada at the University of Guelph established alley cropping research trials in 1993, comparing agroforestry to adjacent monoculture. Four replicated field scale plots on 33 ha were established, with tree rows planted at 12m and 10m spacings. The trees (now mature) are a mix of 10 different species (8 hardwood and 2 coniferous). 7% of the land area is occupied by trees and 93% remains as alley crop. Alley crops grown in between the tree rows rotate between maize, soya bean and wheat with agrochemical and fertiliser inputs typical for the area. Tree rows and alleys were planted at 4 different replicated orientations: N:S, E:W, NW:SE and SW:NE.

For the first 7 years there was no impact of tree growth on wheat, maize or soy bean alley crop performance. Thereafter wheat and soy bean yields remained near or at the monoculture norm until the research finished in 2005. However, with more shading from mature trees, maize yields have declined by 15% as measured in 2005. In other experiments with 25 year old mature trees in agroforestry, maize yields were down 20%, but wheat and soy bean years were comparable to monoculture systems. (*Dr Naresh Thevath & Prof A Gordon pers Com*). The maize crops are therefore more sensitive to shade than the wheat and soy bean crops.

The yield data did exclude the yield harvest from the timber element of the system and any tree product harvest such as nuts, fruit or maple syrup and the carbon captured from the tree growth. These can add significantly to the economic viability of the system and more than compensate for the yield reductions in the alley crops over time.



In France the Restinclières and Vézénobres research sites managed by the French National Institute for Agricultural Research (INRA) were established in 1995 and 1996 respectively, with walnut and poplar tree agroforestry alongside 'control' forest plantations of the same species. Research monitoring alley crop (cereal) yields, tree growth, total biomass production, tree and crop quality and economic performance has been conducted for 18 years. At both sites trees grew more quickly in the 'control' forest plantations during years 1-4 as competition between trees 'forces' tree growth upwards for light. However, from years 4-17, trees in the agroforestry system have grown faster and larger as a result of more established and stronger rooting systems. Alley crop yields were comparable to monoculture systems from years 1-12, with a decline in alley crop yield from years 12-17 with more shading from trees. In 2011 50% of the trees were removed (every other row harvested) and it is expected that alley crop yields will improve as a result.



Figure 5 : The INRA Vézénobres Agroforestry research site in France

In the UK there has been relatively little research on agroforestry productivity. A notable example was a MAFF Agroforestry research programme in the early 1990s designed to prove that agroforestry on set-aside land could be instrumental in "reducing productivity". This was conducted at multiple sites throughout the UK. The results were quite the reverse, with productivity (cereals, forage, livestock, timber etc.) from the agroforestry sites increasing under agroforestry compared to a single land use. This was a triumph for agroforestry although a result at odds with the objectives of the research project.

Chinese research over 30 years shows that as trees increase in size (from years 5-10 onwards, depending on species and location) the shade and competition for light and water from the trees causes decreased yields of alley crops (wheat etc.) in most agroforestry systems. However, despite the reduction in alley crop yield, when the timber yield is also



considered, there is an increase in the total yields of trees and crops combined, leading to increased output and profits.

A 12-year study in northern China by Yin and He (1997) demonstrated the potential economic benefits of agroforestry. They found that intercropping paulownia trees with wheat, corn, beans, and cotton in a 5 x 20 m arrangement gave rise to an increased average yearly income of US\$650.5 over the period. (see Figure 6 below). As the trees grew larger and the volume of timber increased, the agricultural alley crop output decreased. Due to the higher value of paulownia timber, however, the total net returns were greater than they would be if just arable crops were grown as a monoculture.

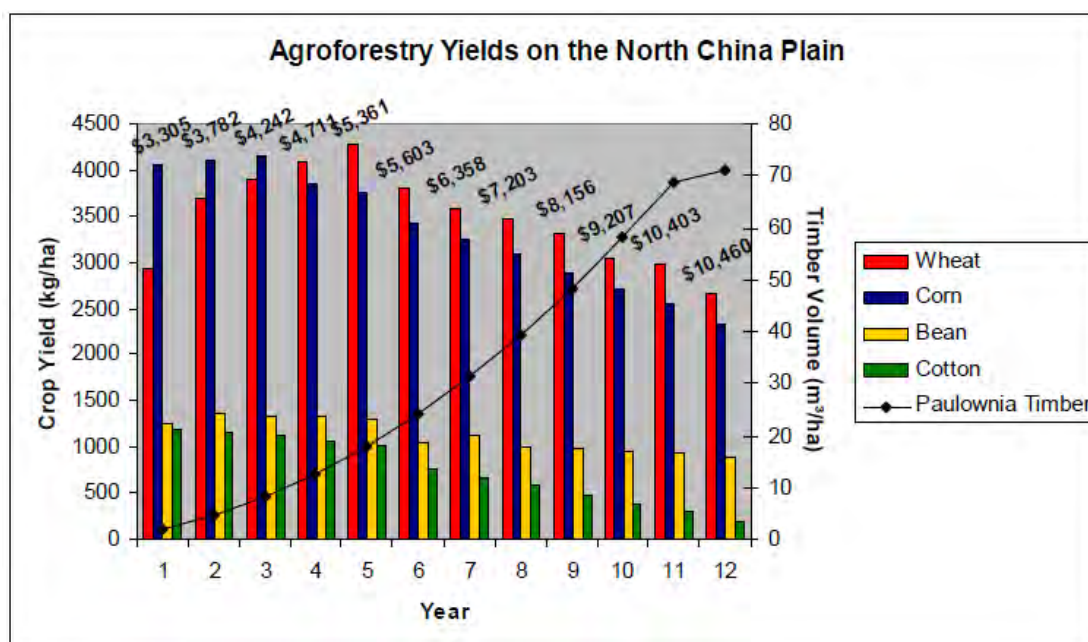


Figure 6. As the paulownia trees mature, arable crop output decreases; however, due to the increase in timber volume, the total combined value of the arable crop and timber increases (The numbers at the top of each year indicate the value of the timber and crops combined). Source - Yin and He (1997)

At a European level the EU funded Silvoarable agroforestry for Europe (SAFE) research project (2001-2005) was coordinated by INRA (France) and involved more than 70 scientists from 8 European countries. The project explored how trees could be maintained or re-introduced in agricultural systems as agroforestry. The project monitored trees and crops in silvoarable systems in France, England, Spain and Italy, looking at impact of tree density, tree size and tree pruning on alley crop productivity, total output and economic performance.

The SAFE project conceded that investment requirements for agroforestry are low compared with most new systems of farm diversification. Farm profitability can increase by 10-50 % with high value trees (i.e. walnut), and from -5 to +15 % with wild cherry and poplar, as compared with an agricultural monoculture system.

When 10% of the farm is planted, any reductions in the farm gross margin never exceed 3% until the first tree harvest (typically 15-18 years). Farm incomes can increase by more than 15% (with both walnut and wild cherry) and farm gross margins can double in the long term where the whole area is progressively planted. But this would have a big impact on cash flow until the first tree harvest.



The main results of the SAFE project were :

- Agroforestry systems are able to capture more resources from the environment than pure crop or pure tree systems: competition induces adaptation, and adaptation results in facilitation, a process that explains why mixed plots are significantly more productive than pure plots.
- Modern agroforestry systems are compatible with present-day agricultural techniques and low final tree densities (30-100 trees/ha) allow crop production to be maintained until tree harvest.
- The average productivity of silvoarable systems is higher than the combined productivity of separate tree and crop systems. Productivity increases of up to 30% in biomass, and 60% in final products have been observed.
- A Land Equivalent Ratio (LER) can be calculated to measure agroforestry productivity (i.e. the overall productivity of the trees and alley crop combined compared to a monoculture on the same land area).
- Economic analysis shows that agroforestry plots are often as profitable as monoculture agricultural plots, and that they are often more profitable when including high value timber trees (such as walnut).
- A survey of more than 260 European farmers in 7 European countries showed that European farmers are surprisingly perceptive in respect to agroforestry. More than 40% would be willing to adopt agroforestry techniques on their farm. In France, 2 years after being interviewed, 12% of the surveyed farmers had planted c. 15% of the cropped land to agroforestry.
- At European scale, 90,000,000 ha are potentially suitable for silvoarable agroforestry and 65,000,000 ha would benefit from silvoarable plantations to contribute to mitigation of some key environmental problems such as soil erosion or nitrate leaching. If 20% of the European farmers adopted agroforestry on 20% of their land, it would result in 2,600,000 ha of silvoarable agroforestry in Europe. Production of grain crops would largely be unaffected, secondary crops of nuts, fruits etc. would be produced and the timber output would help reduce the need for importing tropical timbers.
- Current CAP regulations are not logical with respect to trees on cultivated land. On the one hand, Pillar I CAP payments (Single Payment Scheme) provide incentives to farmers to destroy rural trees to get more payments. On the other hand, Pillar II CAP arrangements (Rural Development Regulation) encourage farmers to protect or introduce trees.
- Current policies prevent European farmers from adopting silvoarable agroforestry: in most cases, farmers currently lose crop payments and are not eligible for any subsidy to plant trees. This makes agroforestry unattractive for European farmers (with the exception of France who has recently adapted its regulations).

6.2.1 Land Equivalent Ratio (LER)

A central benefit of agroforestry is that productivity is higher in agroforestry systems compared to monocropping systems due to complementarity in resource-capture i.e. trees acquire resources that the crops alone would not. The Land Equivalent Ratio (LER) is used to compare productivity of agroforestry systems with that from monocrop systems. The SAFE project (2001-2005) investigated the theoretical and actual on-farm Land Equivalent Ratio (LER) as a measure of productivity to compare the overall productivity of



the trees and alley crop combined, compared to a monoculture of arable crops and pure plantation forest stands on the same land area.

From constructing production models the project was able to estimate a 'land equivalent ratio' (LER) for each system. This is defined as "the ratio of the area under sole cropping to the area under the agroforestry system, at the same level of management that gives an equal amount of yield" (Ong, 1996). The LER is expressed as:

$$\text{LER} = \frac{\text{Tree silvoarable yield}}{\text{Tree monoculture yield}} + \frac{\text{Crop silvoarable yield}}{\text{Crop monoculture yield}}$$

Agroforestry tree densities of between 80-140 trees per ha were compared. A 1:1 ratio would mean no difference between the systems. A 1:5 ratio would mean 50% more total productivity. Tree densities of pure plantation forestry systems ranged from 600 trees per ha at the Spanish sites to 204 and 156 trees per ha respectively at Vézénobres (France) and Silsoe site (England).

The Land Equivalent Ratio can also be used to calculate the area needed under sole cropping (monoculture) to match the productivity output from an agroforestry area at the same management level to obtain a particular yield.

Research has shown that an LER of 1.6 is achievable in early agroforestry stages when trees are small. This reduces to 1.0 in later stages, with mature trees, with an LER over the total rotation of c. 1.29. That is, the total output from 4ha of agroforestry is equivalent to 5 ha of mono crop. The LER is consistent in a wider range of crops and tree species. Research on the SAFE project evaluating yields from 42 different tree and crop combinations is shown in Figure 7 below and for poplar, cherry and walnut shows an LER of 1.2-1.4. Oak and pine performs less well.

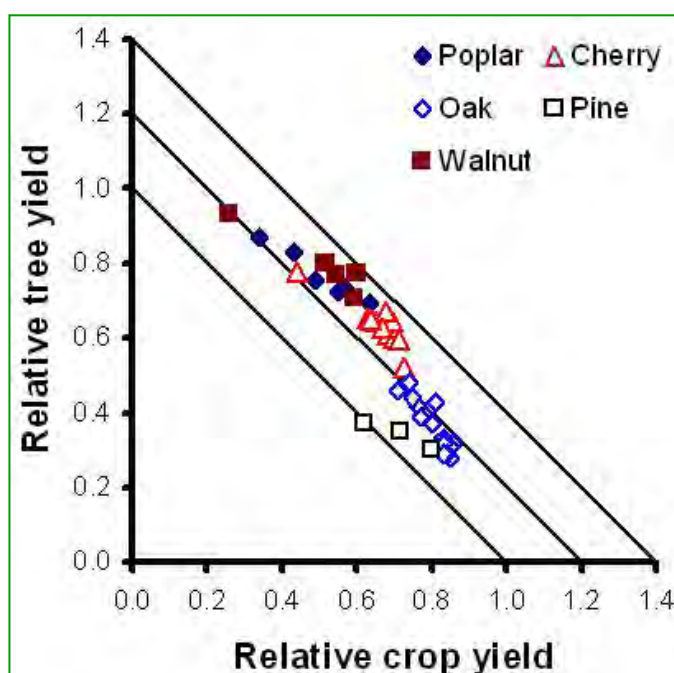


Figure 7. Modelled relative tree and crop yields for 42 tree-crop combinations
<http://www.cranfield.ac.uk/sas/naturalresources/research/projects/safe.jsp>



As shown in Figure 8 below, for agroforestry, the land equivalent ratios increased from 1.02-1.04 with low tree densities of 12-16 trees per ha. For tree densities of 31-50 trees per ha, the LER for agroforestry increased to 1.05-1.06, and 1.16-1.17 for a density of 113 trees per ha. Land equivalent ratios increased from 1.24 at a density of 50 trees per ha, to 1.45 at a density of 139 trees per ha, being the highest value recorded.

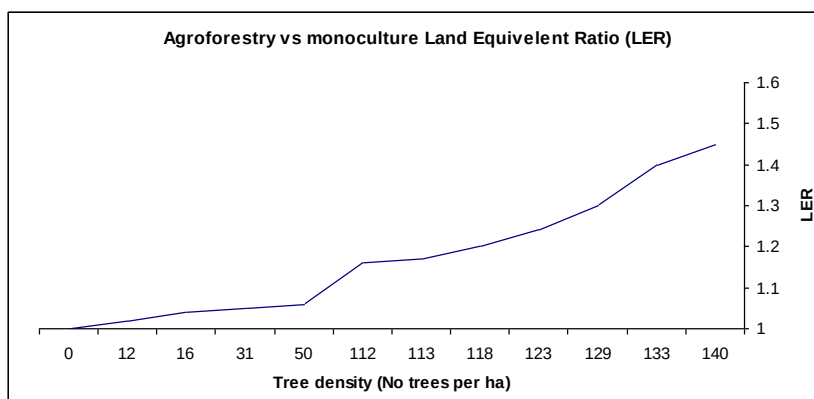


Figure 8 : Land equivalent ratios (LERs) for different agroforestry tree densities

Similar LER values of c. 1.4 for agroforestry have been reported for systems in India and North America (Corlett *et al.* 1992). In France, LERs of between 1.36-1.4 are commonly found when the output of timber, fruit and alley crop are combined (Dupraz *C pers comm*), which is greater than most research conclusions which predict LERs of c. 1.25.

The average productivity of silvoarable systems is therefore higher than the combined productivity of separate tree and crop systems, with productivity increases of up to 30% in biomass, and 60% in final products. A Land Equivalent Ratio (LER) of up to 1.40 (i.e. overall productivity is increased by 40% compared to a monoculture on the same land area) is achievable on-farm, with the LER remaining stable under different climate change scenarios.

The project concluded that best *bio-physical* option is to plant between 80-120 trees per ha (130-200 for poplar). However the best *economic* option is to plant a lower density around 60-90 trees per ha (100-130 for poplar). This means a distance between the tree lines varying between 24-36 m. These recommendations did not take into account the environmental benefits of agroforestry, such as carbon sequestration, nitrogen pollution reductions or biodiversity increases. These could be calculated and their economic equivalents added to the whole profitability of the agroforestry system in line with current theory and policy on rewarding ecosystem services.

6.2.2 Modelling

INRA has been working with other European partners to develop the Hy-SAFE model (SAFE project 2001-2005). This models tree, tree root and alley crop over time for a range of silvoarable system densities of 50 and 113 trees per ha. The model makes provision for 80 tree growth parameter (although only a small number of these have a great impact on model outputs) and can model over a 40 year time frame. A 'Farm SAFE' model has also been developed which uses outputs from the Hy-SAFE model, particularly the Land Equivalent Ratio (LER), to calculate socioeconomic impacts of alley cropping and is very useful for



making comparisons. The Farm SAFE model was developed for use throughout Europe but has been taken up mostly in France.

6.3 Alley crop options

Most forage and annual arable crops can be grown in alleys between rows of trees. Crops of grass, clover, cereals, proteins, root crops, vegetables, maize, sunflowers and energy crops such as hemp or short rotation coppice (SRT) willow and alder are all being grown as alley crops in various locations. Choice should consider the use of the crop (grazed vs. harvested etc.), access with planting and harvesting machinery and the shade tolerance of the crop itself.



Figure 9 : Wheat Walnut agroforestry system in Gers, France



Figure 10 : Pecan tree forage agroforestry system of Dan Shepherd in Kansas USA

For smaller farms growing high value vegetables, herbs and root crops, the trees, once established, provide an extra dimension as potential 'support structures'. In SE France I visited a farm near Montpellier where the agroforestry trees were being used to support overhead irrigation pipes and infrastructure with vegetable crops growing underneath. The cost of the irrigation infrastructure was 30% of the cost of installing overhead irrigation and avoided the issues of machinery access and having to move ground based irrigation.

continued over page



Figure 11 : Agroforestry system in SE France being used to support overhead irrigation pipes for vegetable alley crops underneath

6.4 Tree component options and row spacing design

The density of trees and their spacing (between the rows and in the row) can be manipulated so as to ensure adequate crop production for food, as well as timber production for the economic returns (*Fang et al. 2005, Daversa, D. 2005, Dupraz & Ligare*



Pers Comm) and to match the priorities of the farm (i.e. trees or alley crops). The actual density is normally a compromise between capital investment requirements, access for machinery, sufficient area for annual crops and the length of time for trees to reach maturity.

Early agroforestry systems were mainly designed by forestry professionals. Their passion for trees often led to systems with a higher than desirable tree density per ha. In early systems tree row spacings of 12-18 m were employed. These have been found to be too close leading to alley crop productivity declining after a decade. As a general rule, when the tree height equals or exceeds the alley width, the resulting shading of the alley crop results in a production decline (see later section on shading from trees). This seems to occur in a wide range of tree and alley crop combinations including pastoral grassland systems. Systems developed more recently typically operate wider rows of 24, 36 or 48 m row spacing.

Tree options are numerous and choice is dependent on local climate, soils, end use of tree, non timber products (fruit, nuts) production, timescales for tree maturity, eligibility for grant funding and, in the European Union (EU), eligibility for land for continued CAP Pillar I and II support (see details in later sections). Establishment and management grant eligibility (CAP Pillar I and II) may also influence the tree row layout and in-row spacing so as to attain the necessary planting density to secure support (see details in later sections).

Paulownia, poplar, birch, acacia and lime can be used for fast growing timber production, often reaching maturity in 15-18 years. For higher value but slower growing timber, oak, beach, walnut, pecan and cherry can be used and the tree species have the added bonus of also producing fruit with a harvest value. These slower growing trees can take 25-50 years to reach maturity before harvesting. Secure land tenure is therefore more important for slower growing species.



Figure 12 : Wheat and walnut tree agroforestry system Mr C.Jollet, Les Eduts, France



Fruit trees such as apple, pear, cherry, plum can be used as the tree species and provide income from fruit production 3-5 years after planting. When using fruit trees a suitable harvest window for the fruit crop must be considered in relation to the alley crop. In general the fruit crop needs to be harvested after the alley crop has been harvested so as to facilitate access with harvesting machinery. For example, cherry trees with alley crops of wheat or maize in England may not work as the alley crop could prevent access to harvesting cherries in midsummer whereas, if nuts and later maturing fruit like apples and pears follow the summer harvesting of cereals, this works satisfactorily.



Figure 13 : Apple tree barley agroforestry at my own farm in Cambridgeshire

Tree crops grown for energy production such as short rotation coppice (SRT) alder, hazel and willow can be grown as the tree species. These are most often planted as a double row of coppice species, with alternate row harvesting so as to maintain an agroforestry tree stand. Coppice species growth and total biomass production tends to be 15-20% higher under agroforestry compared to a pure species stand as a result of better light, nutrient and water utilisation.

In France much of the alley cropping focus is on black walnut due to the high value of walnut timber. However, walnut trees were not the only species used by farmers (or being researched) with conifers, cherry, pear, ash, alder, poplar, maple, mountain ash and oak all being used.

In China, paulownia has been the main choice for agroforestry from the 1970s to the mid 1990s. Its fast growth, minimal effects on crops, and high quality wood made it attractive. It is also a nitrogen fixing tree, so imparts some fertility to benefit the alley crops beneath. According to He (1998), there were approximately 3 million ha of paulownia intercropping systems in China in the 1980s, most of which were located in the main wheat growing areas of Hebei, Henan, Anhui, Shaanxi and Shandong provinces. In addition, roughly 90% of



farmland suitable for planting paulownia in Henan and Shandong had, in fact, been planted with paulownia, making it one of the most popular models of agroforestry in China.



Figure 14 : Short Rotation Coppice (SRC) Hazel at Waklyns Agroforestry in Suffolk

I visited Henan Province in the middle of China to look at the paulownia tree-wheat intercropping systems. In Henan province alone there are over 1 million ha of wheat-paulownia agroforestry with a standing volume of 5.5 million m³ of timber with an annual incremental increase of 2 million m³ of timber. By comparison, total state timber production from 'state' forest in Henan province is only 160,000 m³ per year of timber, or about 10% of that produced from the paulownia tree-wheat intercropping systems.

According to Wenhau.Li (2001) in China there are currently at least 120 tree species intercropped with agricultural crops with more than 215 combinations, which have worked well and have brought significant benefits to local people. Paulownia and poplar trees are used for a variety of wood products that help to create employment, boost exports, and contribute to social and economic development and sustainable livelihoods in rural areas (Buerkle, 2003).

There are 9 species of paulownia native to China, with Paulownia *elongata* and Paulownia *tomentosa* being the most widely used (Zhu et al., 1986). These deciduous hardwood species grow fast but require little care (El-Showk, 2003). Average height and diameter growths for paulownia are 2 m per year and 4-5 cm, respectively (IDRC, 1998a) (see figure 16 on next page). In intercropping systems, an 11-year-old tree has an average diameter of 38 cm at breast height (dbh) and a height of 12 m (Yin, 2004).



Figure 15 : Paulownia wheat agroforestry in Henan province China

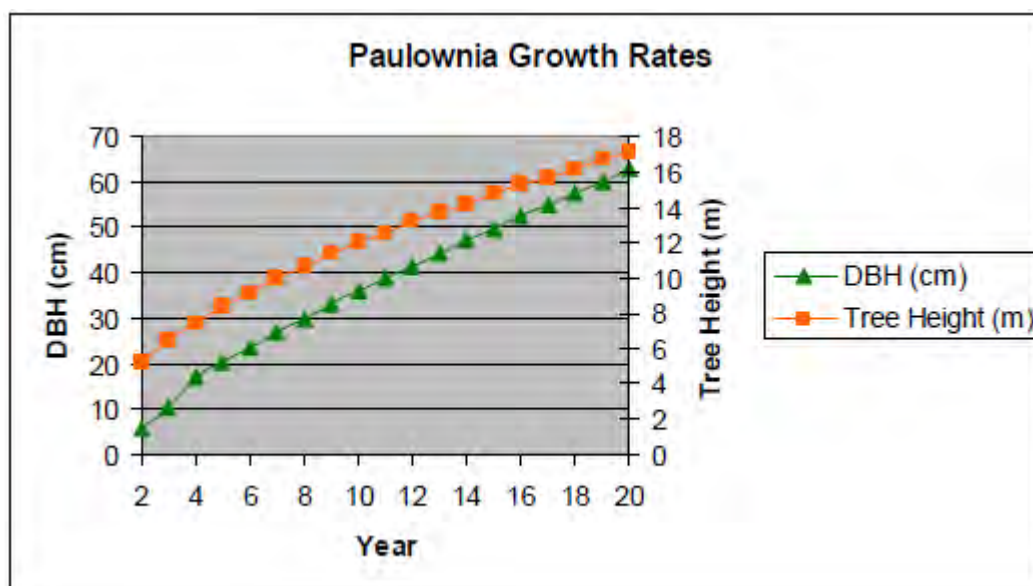


Figure 16 : Paulownia growth in Henan Province China - Zhu (1986)
(measured as diameter at breast height - dbh)

The spacing of paulownia trees in Chinese agroforestry is crucial to achieving farmers' objectives. The distance between trees in each row is always 5 m but the distance between rows can vary from 6- 50 m, depending on whether the farmer considers the crops or the wood harvest to be more important (Yin, 2004). For example, if the trees are planted with



10 m between each tree row, then the yield of wheat would be the same as an open field system. When the distance between the rows of trees is increased to 20 or 40 m, however, the crop yield goes up 7-10% (Yoon and Toomey, 1986). In northern China, over 70% of paulownia agroforestry systems are based on spacings between 5 x 20 m to 5 x 50m (Yin, 2004). In general, the arable crops have very little effect on the growth of paulownia trees, whereas the trees have a significant impact on crop yields.

Paulownia has a deep root system, with most of its roots distributed under the cultivated layer (Yin, 2004). On average, 76% of paulownia roots reach a depth of 40-100 cm with only 12% in the 0-40 cm range. Most crops, however, such as wheat, corn and millet, have 80-95% of their roots distributed in the 0-40 cm range (Yang, 2004). Therefore, competition for water and nutrients between trees and crops is minimised in paulownia intercropping systems.

There has been limited trial work with paulownia in the UK. It is tolerant of a fairly wide range of soil types, drought and harsh cold winters. However its roots do not like wet waterlogged conditions, so it may only be suitable for free draining sites. I believe it does have potential for use in UK agroforestry and should therefore be investigated further for potential use.

Paulownia trees were the most popular agroforestry species in north central China until the early 1990s. The use of paulownia then started to decline, while the use of poplar trees began to increase. China now accounts for 73% of the world's total poplar plantation area, including 49% of the plantations established in agroforestry systems (Ball *et al.*, 2005). Like paulownia, poplar trees are also extremely fast-growing (with harvest every 7-12 years), high-yielding, and easy to propagate. Its wood is used for producing veneer, plywood, tool handles, furniture, pulp, and paper; and its leaves can be used for animal fodder.

The replacement of paulownia by poplar trees was due to four main factors. First, because paulownia was such a popular choice among farmers, the market for paulownia timber became saturated, causing price reductions. Meanwhile, demand for fruits, nuts, crafts, panels, medicinal herbs, and other outputs became strong, prompting farmers to switch from paulownia to fruit and nut trees and other fast growing timber species, such as poplar (Yin, 2004). Secondly, increased winter rainfall led to a greater incidence of soil water logging and a switch to poplar. Paulownia is very drought tolerant, but waterlogged soils can impair its growth. This gave poplar trees, which are more tolerant of flooding, yet another edge over paulownia. The final factor was an inability to stop the spread of the airborne 'witches broom' fungus that attacks paulownia trees and retards growth. Although paulownia is generally very resilient to infection by diseases and pests (El-Showk, 2003), this fungus is a notable exception in China.

Alongside selective breeding, more recent Chinese agronomic advice has been to increase the diversity of varieties of paulownia used and to plant mixed stands of poplar, paulownia and other timber, nut and fruit trees, so as to introduce more diversity and avoid potential pest and disease problems escalating.

6.5 Tree row orientation

The orientation of the agroforestry tree row can have a significant effect on alley crop growth (from shading), wind speed and evapotranspiration from alley crops. The effect on



tree growth itself is negligible in agroforestry systems. The latitude and local climate also have a big influence. Nearer the equator and in hot climates, an E:W orientation is preferred (see section on shading below). In more northerly latitudes such as northern Europe and the UK, a north-south tree row orientation is preferable, to limit shading of the alley crop and to ensure that both sides of the tree row receive sunlight during the day.

Agroforestry research undertaken in Canada at the University of Guelph has found that a SE:NW orientation is best to minimise shading of alley crops. Annual tree pruning was required to improve timber quality and lift the crown for machinery access. This also reduced shading of alley crops.

In SE France at Vézénobres, the research site has 11 ha plantations of walnut and poplar trees at 140 trees per ha with tree rows orientated in both north-south and east-west directions and on both 16 m and 32 m tree rows widths. All the treatments are compared to an adjacent 'forest' treatment of plantation poplar trees. Over a 17 year period, alley crop yields have been lower in east-west orientated tree rows, with more shading reducing crop performance.



Figure 17 : Vézénobres agroforestry site researching E:W & N:S orientations

Tree rows also have to fit the fields and farm. Whilst a N:S or NE:SW orientation is often desirable, field orientation may dictate a slight move away to another orientation. For the UK the aim should be orientate trees as near as possible to N:S or NE:SW.

A N:S orientation also has the benefit that the prevailing south westerly and westerly winds in the UK blow across tree rows at an angle rather than at 90° or straight up the rows. This provides good air flow and retains the 'wind buffer' effect of the tree row on alley crops and for soil protection.



6.6 Tree spacing in the row

Tree spacing in the row is largely a function of the tree species chosen and can range from 3-15 m. Fast growing large trees like poplar and paulownia are typically planted at 5-10 m spacing in the row. Large, slower growing trees like walnut can be planted at 11-15 m between trees, whereas fruit trees like apple and pear can be planted at 2-3 m between each tree in the row.

Tree maintenance and harvesting method (hand or mechanical) of the timber, fruit or nuts also have an influence on tree spacing in the row, with typically closer spacing for hand harvesting. Most timber trees will be planted in a tighter row spacing with a view to thinning midway through the timber rotation.

In China, without the need for large machinery access, tree in-row spacing is generally tighter with paulownia and poplar trees planted at 5 m between trees in the row.



Figure 18 : Paulownia closely spaced at 5m between trees in the row – Henan province China

Within the European Union (EU), grant funding eligibility (CAP Pillar I and II) may also influence the tree row spacing to attain the necessary planting density to secure support (see details in later sections).

I was hosted by Yves Gabory, Directeur de Mission Bocage and the Président de l'AFAHC (the French Association of Agroforestry), at 'Abbey Bell Fontaine' in western France. The 80 ha agroforestry system has been established with trees on 30 or 52 m row spacing with 10 m between each tree, creating 2.5 ha alleys between tree rows. A 20 m headland at row ends



is left unplanted for machinery turning. Trees are black walnut with a rotation of lucerne and clover (cut for forage or grazed) and wheat in alleys between tree rows.



Figure19 : New agro forestry at 52m row spacing at 'Abbey Bell Fontaine' in western France

Near Poitiers in France Gilles Corou operates an oak, sweet chestnut, pear, apple, black walnut, elm and cedar agroforestry system with alley crops of wheat and oil seed rape. (See *Figure 20 on next page*). Trees are spaced at 6 m between trees in the row and 26 m between tree rows operating a 24 m alley between trees (with 1 m grass/sprayed strip either side of each tree). Approximately 17% of land is occupied by trees and 83% by alley crops. The system is further enhanced by the planting of truffles at the base of each tree – 'black gold' as the farmer described it.

In the dry south west of the Gers region of France near Auch, Nicolas Petit farms at "la Ferme au Coton". The 40 ha organic farm has 8000 free range poultry in mobile houses as well as acorn-fed pigs, sheep and arable cropping. The average rainfall is c. 600 mm/year. The agroforestry comprises apricot, pear, apple, cherry and prune trees at 24 m row spacing with 6 m between trees in the row. In the alleys, the farm operates a rotation of 2-3 years clover or lucerne followed by a rotation of wheat, triticale, sunflower, beans, soya.

At Saint-Jean-d'Angely, Mr Claude Jollet, the pioneer of modern alley cropping in France, has operated an agroforestry system since 1970. He farms 190 ha of land which is split 150 ha arable with 40 ha under agroforestry trees at 14 m row spacing with 12 m alleys and 7 m between trees in the row. Claude now believes that 11 m between trees would have been better, because the crowns are now interlaced. Nevertheless, the oldest trees, now 37 years of age, are ready to harvest. He is monitoring current markets for walnut, so as to choose the best time to harvest.



Figure 20: Chestnut oil seed rape agroforestry near Poitiers, trees at 24 m row spacing with 6 m between trees in the row - Gilles Corou

At his farm at Laure-Minervois in France, Mr François Gardey of Soos has agroforestry tree rows of 18-24 m apart with tree species mixed in the row for diversity at between 3-9 m.

At Béziers, France, Mr Jerome Feracci (Domaine Perdiguier) operates a 30 ha agroforestry system in which hybrid walnut trees are used in association with cereal crops (wheat/sorghum/maize/oil seed rape), with the trees spaced at 18 m between rows and 9 m in the rows. (See Figure 21 on next page). The trees were planted in 2004 and are expected to be harvested after 30 years. A great deal of work has been done to prune the trees to give a straight trunk, which will give the trees higher value and also minimise interference with farm equipment. This has reduced the crown substantially but with little effect on the tree growth and allows closer in-row spacing.

In northern France at the Centre d'Ecodéveloppement de Villarceaux, La Bergerie, Chaussy (www.bergerie-villarceaux.org) Mr Baptiste Sanson manages a 275 ha commercial farm that has adopted agroforestry. The estate has developed 42 ha of agroforestry growing walnut, cherry, oak and almond trees. Trees are spaced using both 28 m and 52 m spacing between tree rows, with 2 m left as a clover strip either side of the trees resulting in a 24 or 48 m working area for each alley. An organic cropping rotation of 2-3 years clover grazed by cattle is followed with arable crops of wheat, oats and triticale. The agroforestry system is relatively young with trees 6-8 years old, but the farming system remains productive and is already seeing benefits with regard to biodiversity and wildlife associated with the agroforestry area. The main challenge has been managing Saler cattle around young trees, requiring the use of robust steel tree guards or electric fencing.



Figure 21 : Agroforestry at “Domaine Perdiguier” at Béziers, France – trees at 18 m row spacing with 9 m between trees in the row

In Germany most agroforestry systems are employing alnus (alder) or poplar (populus) spp. for the production of timber for woodchip used for heating or energy generation, planted as shelterbelts or at 24-32 m spaced rows, with 6-9 m in-row spacing, with arable crops or pasture in the alleys. Much of the recent agro forestry research has focused on optimisation of tree densities, the impact of trees on wind loading and evaporation and the shade tolerance of understorey species such as clover, medic, rye grass etc. As in other countries, there is a common trend towards moving away from 12-18 m alleys to 24 and 36 m wide alleys, to accommodate large modern machinery.

In the UK, most farmers would seek to establish trees at 24, 36 or 48 m row spacing with trees spaced at 3-9 m in the row – depending on species grown.

6.7 Shading from trees

As trees grow, they shade alley crops to a greater or lesser extent, dependent on the time of year, tree species, canopy type and management, row width and the orientation of rows. Nearer the equator and in hot climates, an E:W orientation is preferred. There is less shading from trees nearer the equator and the E:W orientation provides more shade to drought prone alley crops.



In more northerly latitudes such as northern Europe and the UK, a N:S tree row orientation is preferable to limit shading of the alley crop and to ensure that both sides of the tree row receive sunlight during the day. With the sun low in aspect in the spring and autumn this allows both sides of the tree row plus all of the alley crop to receive sunlight throughout the day at some point.

Observations suggest that with a north-south orientation, the east side of the tree row gets the morning sun and as such remains cooler. The west side of the tree row gets the afternoon and evening sun and tends to be the drier side of the tree row. This can have implications for access and alley crop growth. Figure 22 shows French research on shade under agroforestry



Figure 22 : INRA French research on shade under agroforestry

Taller trees will impose more shade, as will closer spaced tree rows. Shading can be reduced by using smaller trees, wider spaced rows or by active tree pruning.

Canopy management plays a part in managing shade. Lifting the tree 'crown' via regular tree pruning will allow more sunlight to reach the alley crop and also permit access for larger machinery. Tree pruning research undertaken at the INRA Vézénobres site in France regime had a strong impact on light availability on the cropped zone. A 10 m height pruning regime maintained a 50% light availability on the cropped zone. A 7 m height pruning regime resulted in only 30% light availability with east-west oriented trees, and 42% with north-south tree rows (see Figures 23 & 24 on next page)



Figure 23: Impact of the pruning height on the average light transmission on the cropping zone at the Vézénobres experimental site for two tree row orientations in June 2004



Figure 24 : The two different regimes of pruning height : 7 m versus 10 m compared at the Vézénobres Agroforestry plots in France



Trees with smaller leaves (i.e. paulownia and poplar) will allow more light penetration than broader leaved trees like walnut and oak. Equally the phenology of the tree species and when it puts on leaf and sheds leaf has an impact on shading. For the UK, trees which leaf later in the spring and retain their leaves until later in the autumn are better suited to agroforestry systems than trees which leaf early, which will shade crops earlier in the season.

I visited the INRA Vézénobres research site in France on 29th October, 2011, and found the poplar trees used in the agroforestry plots still had significant leaf cover, compared to adjacent plantation trees which had lost all their leaves. Agroforestry, through localised climatic modification and resource use interactions therefore extend the growing season of the agroforestry components, trees and crops.

Acacia species used for agroforestry in Africa have a reverse phenology. The trees leaf in the winter (when no crop is present), then drop leaves prior to alley crops being grown, recycling nutrients through the soil, and remain leafless during the growing period of the alley crop, thereby not shading alley crops such as maize which are sensitive to shading.

Research in Canada at the University of Guelph has demonstrated that maize crops are more sensitive to shade than the wheat and soy bean crops, with maize yields declining by 15-20% as the trees mature beyond 10 years and shade the crop more. This compares to no impact of tree growth on wheat, maize or soy bean alley crop performance (*Dr Naresh Thevath & Prof A Gordon pers Com*).

Conversely, Mr Dan Shepherd of Shepherd Pecan Farms (<http://www.shepherd farms.com/>) in northern Missouri stated that the shade provided midsummer by pecan trees in an agroforestry system, together with the additional nutrient cycling from leaf litter incorporated by worms into the soil over the winter, results in consistently higher grass yields under the agroforestry system compared to a pure pasture with no shade. The forage yields are more consistent throughout the year, with better forage quality, higher protein levels and are 10% more digestible. This is mainly a function of improved water conservation from shading in Missouri.

At the University of Missouri 'Centre of Agroforestry' Horticulture and Agroforestry Research Centre (HARC) at New Franklin, MO, I was hosted by Dusty Walter and Gene Garrett. This 600 acre site is dedicated to Agroforestry Research and has been undertaking innovative 'shade trials' which are evaluating how different plants grow and adapt to different shade levels under agroforestry systems. There are huge variations in crops' ability to cope with shade. Some species and varieties cope well, others reduce photosynthesis and thus their productive potential. There has been very little research in this area and research into alley crop species and different varieties would be very important in further developing agroforestry systems in Europe.

At the INRA Vézénobres research site in France, east-west orientated tree rows resulted in more uneven crop growth in the alleys due to persistent shade on the north side of the tree rows, while crops were more even under north-south tree rows. Some alley crops, such as chickpeas and oil seed rape, were found to have uneven ripening under the alley cropping system, while cereal and legume crops were not affected in that way. Alley crops' performance between north-south orientated tree rows has been comparable to that of adjacent (control plots) monoculture systems from 1995 until 2008-11, when there was a slight decline in yield as a result from shading of the 15 year old walnut trees. It is believed



that the thinning of the trees in 2011 will result in any differences being reduced until the next 10-15 years when alley crop performance reductions will be experienced prior to the estimated walnut tree harvest at year 30-40 at an estimated value, using today's prices, of up to €8,000 per tree (€800,000 per ha) from timber sales.

At Saint-Jean-d'Angely, in western France, Mr Claude Jollet has found that yields from cereals like barley and wheat (8-9 t/ha for wheat) are not significantly affected by the E:W orientation tree shading, but broad-leaf crops like sunflower and oil seed rape do not grow as well under the trees and ripen unevenly, so that harvest timing becomes more difficult.

The spacing of paulownia trees in Chinese agroforestry is always 5 m between trees in the row with the distance between rows varying from 6-50 m. Wenhau.Li (2001) reported that in the 1980s and 1990s, with a high demand for timber, and high prices, farmers often planted trees too densely at 5 x 10 m. This reduced alley crop yields because of too much shading and water competition. A typical planting density of a paulownia agroforestry system is 5 x 30 or 5 x 40 m. While the denser spacing of trees reduces arable crop yields, the income gained from the increased timber production compensates for the alley crop yield and income reduction. However with the reduction in timber value in recent years, farmers are now moving back to more typical spacing of 30 or 40 m between rows.

The thin crown of a paulownia makes it suitable for agroforestry. Its sparse branches and narrow leaves allow a considerable amount of light to pass through to the crops below. The light penetration through Paulownia crowns is 20% more than that of poplar (*Populus tomentosa*) and 38% more than that of black locust (*Robinia pseudoacacia*), two other trees commonly used in Chinese agroforestry (Yang, 2004). The leaf emergence and fall periods of paulownia occur later in the growing season than most of the other tree species. Later leaf emergence favours the growth of summer crops such as wheat, and late leaf fall protects autumn crops from damage (Yin, 2004). However, due to its more expansive canopy, paulownia cannot be planted as densely as poplars.

"As general rule when the tree height equals or exceeds the alley width, the resulting shading of the alley crop results in a production decline. This seems to occur in a wide range of tree and alley crop combinations including pastoral grassland systems. Systems developed more recently typically operate wider rows of 24, 36 or 48m row spacings".

6.8 Temperature regulation

Throughout the EU climatic extremes are becoming the norm. 2011 was the driest on record. England experienced the wettest April on record in 2012. In middle and southern Europe 'thermal stress' in crops, especially in late spring and at 'grain fill' stage is becoming a serious issue.

Research at INRA by Dupraz et al has demonstrated that, compared to monoculture systems, agroforestry reduces late spring 'thermal stress' in crops. This is achieved primarily through shading and reductions in evapotranspiration from reduced wind speed. With later leafing trees, heat stress at grain fill is also reduced through the same mechanisms. Research has also shown that nitrogen stress is reduced in shaded crops compared to crops in full sunlight conditions. To make best use of this effect the best combinations of tree : alley crop found



are short season grain crops i.e. cereals combined with long season tree crops i.e. later leafing.

Chinese research has demonstrated the benefit of increasing the relative humidity of the air above the fields by 7-12%, and reducing the air temperature around the crops by 1-2° C (Yoon and Toomey, 1986). This also significantly reduces the evapotranspiration from the alley crop. These effects on the microclimate help foster the growth and development of crops, creating better growing conditions than in open fields.

In terms of climate change mitigation, this research demonstrates that, with the increasing occurrence of hot, dry springs in Europe, agroforestry is well placed to mitigate against climate change. The trees in agroforestry systems provide some shade to early developing crops, but more importantly, through drawing up moisture through the tree roots and respiring it through leaves, the trees locally increase relative humidity, lower ambient temperature, and reduce crop evapotranspiration, thus reducing soil drying (Dupraz pers Comm. 2011).

6.9 Tree roots and management

Are trees and their roots the same when they are grown in different environments and spatial arrangements? Agroforestry research work has shown clear differences in the rooting pattern and depths of tree roots in agroforestry vs. tree plantations, with the roots of plantation trees being much shallower.

The tree root studies conducted at Restinclières & Vézénobres research sites by INRA involved excavating soil around trees of various ages and comparing the root spread patterns of trees under agroforestry to those of trees of an identical age and species in adjacent plantations.

Lydie Durfour from INRA explained to me the research undertaken which includes tree root, crop performance, shade and soil water studies on a site characterised by a silty loam soil in a river basin. This site is also characterised by a large moisture deficit, as annual precipitation is about 800 mm, and this is exacerbated by strong winds (le mistral) which happen unpredictably and at any time of the year.

Black walnut trees were first established in 1995, planted at 13 m between rows and 4 m between each tree in the row, resulting in c. 200 trees per ha. A 1.0m strip under the trees is left uncropped resulting in a 12 m workable alley between the tree rows. The now 17 year old trees were thinned to c. 100 per ha trees in 2011 by harvesting every other tree in the row.

The investigations have shown that trees in agroforestry root differently by putting roots down deeper. The main tree roots in the forest plantations typically occur in a 0-1.5 m zone around and below the tree. However under agroforestry tree roots extend to 1-3 m around and below the tree. This concurs well with research from other agroforestry sites.

This is partly an effect of the regular cultivations in the alleys which 'root prune' roots in the 40-50 cm area, partly due to the intra-competition of annual crop roots and tree roots, forcing the tree roots to search out water and nutrients deeper in the soil profile plus it is also an effect of the alley crops' demand for water earlier in the growing season than that of



the trees. As a result when the tree needs soil moisture, its roots have to go looking deeper in the soil profile, underneath the alley crop roots. The annual alley crops and cultivations force the tree roots lower into the soil profile. This significantly increases the complementarity of soil resource use in terms of time and space. This is depicted in figures 25 and 26 below.

At the Vézénobres research site, when mature agroforestry was left without an alley crop for 2 years the tree roots quickly re-colonised the cultivated area normally used by the annual crop. This demonstrates that it is the interaction of cultivations and cropping that modifies the rooting patterns of trees under agroforestry.

The larger root expanse has also had a secondary effect with regard to nutrient capture. Experiments at INRA have demonstrated that agroforestry can reduce nitrate leaching by up to 50% compared to monoculture arable systems, with any surplus nitrogen being captured by tree roots and assimilated into growth (carbon) rather than being lost via leaching. This concurs well with research at the University of Guelph in Canada and at the University of Missouri in the USA.

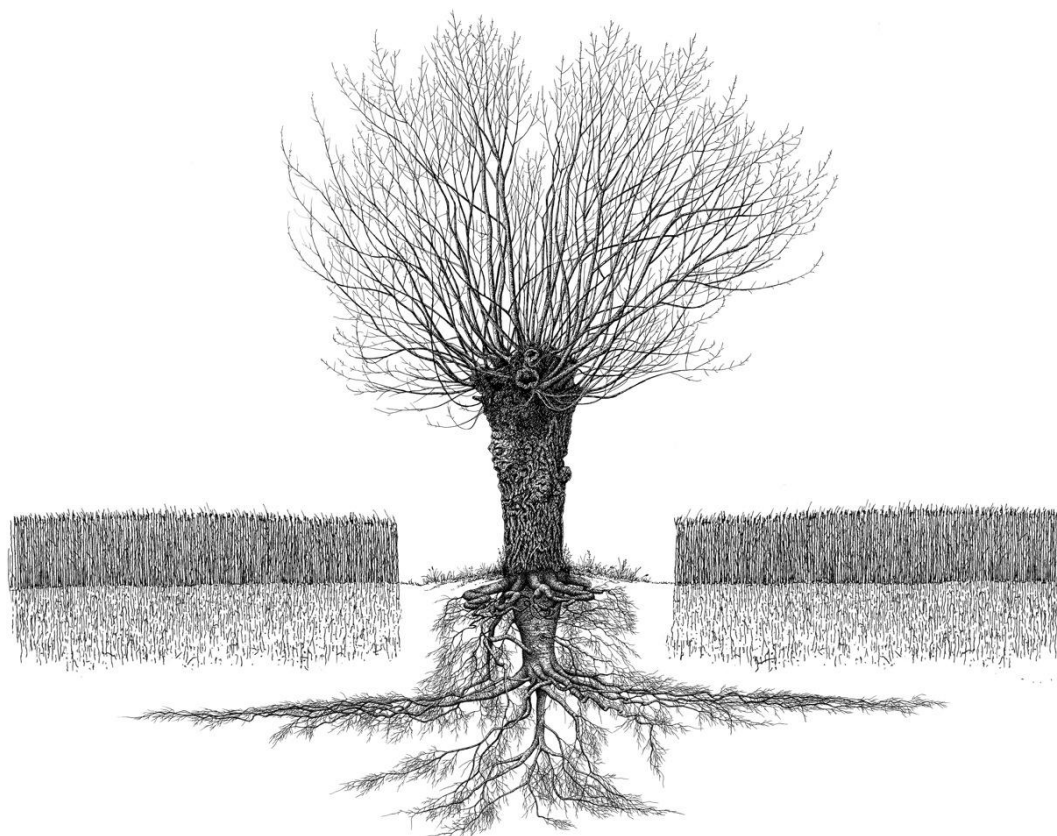


Figure 25 : Deep and expansive tree roots in agroforestry trees utilising soil underneath the alley crop - source A.Cannet - Arbe Pasage 32

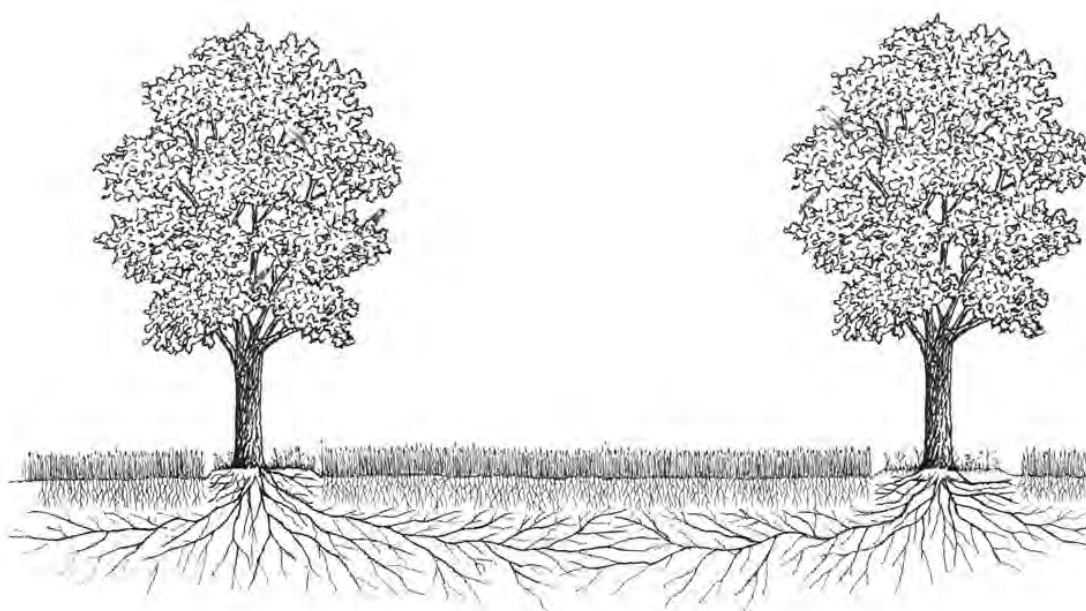


Figure 26 : Deeper tree roots in agroforestry system exploit soil underneath the alley crop which increases the complementarity of soil resource use in time and space



Agroforestry Poplar tree roots
Deeper rooting

Forestry plantation poplar tree roots
Shallower rooting

Figure 27 : Poplar tree roots under (a) Agroforestry (b) plantation forestry – roots are deeper and more extensive under agroforestry - INRA France

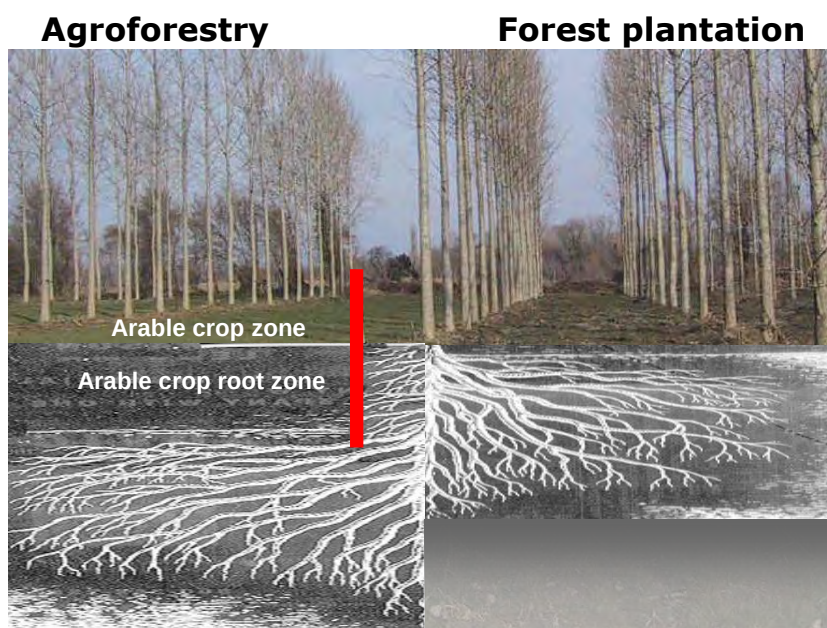


Figure 28 : Agroforestry forces tree roots to use soil below the annual alley crop

Having demonstrated that tree rooting patterns are modified by agroforestry alley cropping systems, INRA research has also shown that it is not only the root spread but also the volume of tree root that is influenced, with root systems up to 30% more extensive than under forestry plantation conditions. Research from the French sites has shown carbon accumulation of 41 t/ha per year from the agroforestry site (alley crops, tree timber, roots, leaves etc.), resulting in 50% more soil organic matter than in a monoculture arable cropping site.

With deeper and more extensive rooting, there is more carbon in the soil, better soil drainage, nutrient cycling and soil stabilisation, with agroforestry trees having been shown to be more able to withstand wind/drought pressure than plantation systems. This was also confirmed by Mr Claude Jollet in western France who stated that, during the intense storms of October 1987, significant damage was wrought to woodland plantations in his region and adjacent to his farm. However, his agroforestry walnut trees remained largely undamaged as a result of deeper, stronger rooting and tree patterns which allowed freer air movement through the trees.

6.10 Water competition

Microclimatic studies have been on-going at the French INRA Restinclières & Vézénobres research sites since 1995. Results demonstrate a 30% reduction in evapotranspiration from agroforestry compared to monoculture. Tree components draw water up from lower in the soil profile and overnight respiration from the trees leads to a recharge of the alley crops. This occurs as annual crops draw this moisture from the air. This process is termed 'hydraulic lift'. This has important implications for climate change, with agroforestry systems locally lowering ambient temperatures in very hot periods (thus reducing evaporation and irrigation need) and conversely locally raising ambient temperatures in very cold periods, encouraging



earlier plant growth and protecting some plants from cold/frost etc. When flooding occurs (frequently at the Vézénobres research site), the trees and their roots greatly improve soil drainage and return alley crops to productive growth faster than is seen on adjacent monoculture sites.

Overall, microclimate interactions were found to increase the complementarity use of water, soil and light, resulting in an overall Land Equivalent Ratio (LER) of 1.4 (i.e. overall productivity is increased by 40% compared to a monoculture on the same land area).

Different tree species have varying levels of competitiveness for water and at different times of the growing season. Different arable alley crops have different competing abilities for water. There is also a difference in water competition between winter and spring planted crops.

Agroforestry alley cropping research undertaken in Canada at the University of Guelph on 33 ha replicated plots with tree rows planted at 12 m and 10 m spacings grew alley crops of maize, soya bean and wheat. The competition for soil water was greater in winter planted wheat compared to spring planted maize. The main rationale for this was that the major demand for water by the winter wheat crop in the late spring coincided with the major water demand of the trees, at leaf emergence. With maize, planted later in the spring, the main water requirement is later in the season after the peak demand by the trees. Matching tree and alley crop components to minimise competition for water is therefore an important design component of agroforestry systems.

When planting trees on under-drained agricultural land there can be concern that tree roots will disrupt field drains. Research at the University of Guelph in Canada has demonstrated that the roots of trees in agroforestry systems do not interfere with field drainage systems, provided that the drainage systems are operational, well maintained and clear. Only when drainage systems become blocked and accumulate water, tree roots may seek out that water, especially in dry periods (*Pers Comm Dr A Gordon*). Field drain maintenance is therefore important where agroforestry is practised.

Tree root distribution also influences competition for water. In China, research on paulownia–wheat systems has shown that the paulownia tree has a deep root system, with 76% of its roots distributed under the cultivated layer at a depth of 40-100 cm (*Yin, 2004*). Only 12% of the tree's roots reside in the cultivated layer (the main rooting area used by annual arable crops) which is 0-40 cm deep. Most crops, however, such as wheat, corn and millet, have 80-95% of their roots distributed in the 0-40 cm range (*Yang, 2004*). Therefore, competition for water and nutrients between trees and crops is minimised in paulownia intercropping systems.

As described above, partly due to the effect of regular cultivations in the alleys which 'root prune' roots in the 40-50 cm area, partly due to the intra-competition of annual crop roots and tree roots which force the tree roots to search out water and nutrients deeper in the soil profile, plus from the effect of the alley crops' demand for water earlier in the growing season than that of the tree, in agroforestry systems the annual alley crops and cultivations force the tree roots lower into the soil profile. This significantly increases the complementarity of soil resource use in time and space.



6.11 Soil protection, nutrient utilisation and loss

The importance of trees for soil protection is well documented. Above ground trees regulate wind speed, rainfall intensity, water infiltration and soil erosion resulting from these processes. Below ground extensive tree root systems improve soil water drainage and infiltration and cycling of water and nutrients.

Agroforestry improves nutrient cycling. Tree roots go deeper in the soil and access minerals that would not normally be available to arable crop roots. Through the process of leaf litter fall and incorporation back into topsoil, these nutrients are made available to arable crops in the alleys. Agroforestry also reduces nutrient losses, with trees using nutrients that are not utilised by annual arable crops, thus reducing leaching and losses to the wider environment.

Agroforestry research undertaken at the University of Guelph in Canada showed that nutrient utilisation is more efficient in agroforestry systems, with farmland nitrogen losses reduced by 50% in agroforestry compared to monoculture (trees taking up any N not utilised by alley crops). This has major implications for environmental protection and pollution.

Mycorrhizal associations in the soil were found to be far greater in the agroforestry system compared to monoculture, resulting in greater phosphate capture and a reduced requirement for phosphate fertilisers.



Figure 29 : Poplar maize crop agroforestry University of Guelph, Canada.

At the Vézénobres agroforestry research site in France, biodiversity surveys over recent years have indicated increased occurrence of earthworms in the alley crop agroforestry systems. Research found 60-70 earthworms per m³ of soil under agroforestry compared to



20 earthworms per m³ of soil under adjacent monoculture arable cropping systems. The threefold increase has significant benefits for soil moisture, soil nutrient cycling and soil structure.

6.12 Wind regulation

Agroforestry systems modify local microclimatic conditions, especially temperature, air, water vapour content, evaporation and wind speed. In North America's great plains and in the Canadian prairies, windbreaks are used to regulate wind and reduce soil erosion. This form of agroforestry is well proven and accepted by farmers and policy makers.

The tree species, canopy type, height and spacing between rows has a major impact on the degree to which wind speed is modified. As a general rule, wind patterns are influenced by trees to a distance away from the tree approximately 10 times the height of the tree, a 1:10 ratio.

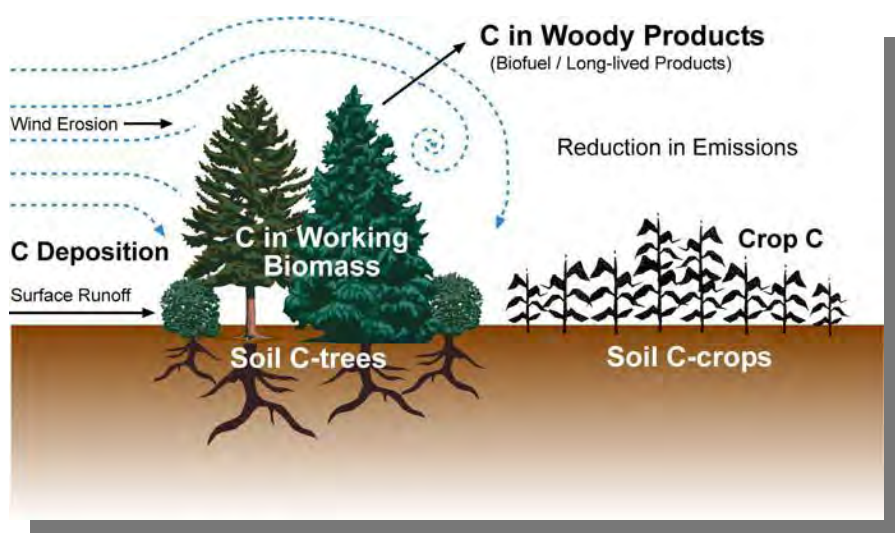


Figure 30 : Wind speed regulated by agroforestry - Source Schoeneberger, 2008

Therefore if the tree is 5m tall, wind speed and airflow will be modified by 50 m either side of the tree row as shown in figure 31 below. This is a major consideration when designing agroforestry systems where there is a desire to influence wind patterns.

continued overleaf

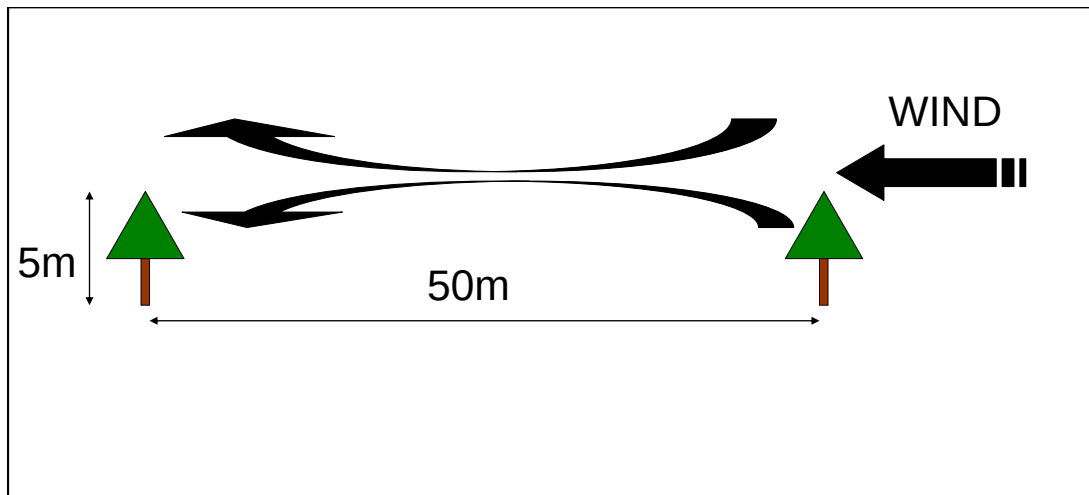


Figure 31 : Agroforestry modifies wind on a 1:10 ratio. With a 5 m tall tree, wind speed and airflow will be modified by 50 m either side of the tree row

Chinese research has demonstrated that agroforestry systems with paulownia trees intercropped with wheat can cut wind speeds by 30-50% (depending on the spacing of the trees). (Yoon and Toomey, 1986). These effects on the microclimate also help foster the growth and development of crops, creating better growing conditions than in open fields.



Figure 32 : Paulownia trees intercropped with wheat in Henan province, China

Microclimatic studies have been on-going at the French INRA Restinclières & Vézénobres research sites since 1995. With agroforestry trees reducing wind speed, 30% reductions in evapotranspiration from the reduced wind speed has been recorded in agroforestry compared to monoculture. This reduction in evaporation from the crop area significantly reduced the need for irrigation.



Agroforestry trees have deeper and more extensive rooting than trees in plantation systems. They have been shown by research conducted by INRA in France to be more able to withstand greater wind pressure (from storms) than plantation systems. This was also confirmed by Mr Claude Jollet in western France who stated that, during the intense storms of October 1987, significant damage was wrought to woodland plantations in his region and adjacent to his farm. However, his agroforestry walnut trees remained largely undamaged as a result of deeper, stronger rooting and tree patterns which allowed freer air movement through the trees.

In the UK, a N:S tree row orientation (used to minimise alley crop shading) will be at an angle to the prevailing south westerly and westerly winds. Wind will blow across tree rows at an angle rather than at 90° or straight up the rows. This provides good air flow and retains the 'wind buffer' effect of the tree row on alley crops and for soil protection.

Using the principle of a 1:10 ratio effect on wind, with our own agroforestry system in Cambridgeshire apple trees will be managed to grow to c. 3 m tall (for picking). The trees will influence wind patterns for 30 m either side. The tree rows have been located at 27 m row spacing with 24 m alley crop areas in between.

The apple trees in our own agroforestry system in Cambridgeshire are only 3 years old. As they grow we expect that there will be significant reduction in localised wind speed which will reduce wind erosion of the soil.

6.13 Pest & disease issues

Natural systems are self regulating in terms of pest and disease control, whereas monoculture environments are more prone to damage from pests and diseases. Agroforestry aims to harness the benefits of natural diversity whilst retaining productive cropping output as a managed complexity. The mixture of trees and crops helps prevent any disease infection spread by the creation of regular barriers of different species and by interrupting spread of, for example, disease spores via wind, with trees creating a barrier to spread.

Research undertaken in Canada at the University of Guelph comparing agroforestry systems adjacent to monoculture cropping, concluded that there were significant reductions in pest and disease incidence in the alley crops in the agroforestry system.

In Germany most agroforestry systems are employing alnus (alder) or poplar (populus) spp., planted as shelterbelts in 24-32 m spaced rows, with 6-9 m in-row spacing, with arable crops or pasture in the alleys. Recent agroforestry research has focused on the shade tolerance of understorey species such as clover, medic, rye grass etc. Of particular concern to German researchers was a strong correlation between an understorey of black medic and purple rust in the poplar tree leaves. They do not have a current explanation for this and further research is on-going.

When establishing agroforestry in an otherwise open landscape, there is a significant landscape change over time. Whilst agroforestry brings many benefits it can also present some unforeseen impacts on pests. In France, the main problem now facing Mr Claude Jollet at his farm in Saint-Jean-d'Angely, is tree and soil damage by "les sangliers", wild boars,



which prefer woodland edge (and hence agroforestry) to open landscape. Their movement through cereal crop to get to the trees can cause localised damage to crops.

At our own farm in Cambridgeshire and as found by other farmers around the globe, planting trees in fields does provide roosting for larger birds (pigeon, crows, rooks hawks etc.) which can cause damage to trees by breaking branches in the early years. Adequate support for young trees must be provided. New trees will also attract, rabbits, hares, deer etc. and adequate guarding must be used.

6.14 Impact of agroforestry on insects, invertebrates, pollinators

The introduction of trees into an open landscape can have significant benefits to insects, invertebrates and pollinators, providing over-wintering refuges and feeding and breeding habitat. When combined with the regular spacing of trees in agroforestry a springboard for beneficial insects is provided in-field allowing better regulation of harmful pests and improved pollination of crops.

Terrell Stamps from the University of Missouri detailed ecological and economic monitoring work at the 12th North America Agroforestry Conference in June 2011, which identified that significantly more beneficial insects were found in agroforestry systems compared to monoculture. Typically 25% more beneficial predators and 40-50% more pollinators are present in the agroforestry systems. When comparing 12 and 24 m alley widths, there were no significant differences in insect numbers between the two alley widths suggesting that even at 24 m between alleys significant environmental benefits accrue from agroforestry systems. Similar work is being conducted in the UK on 6 linked agroforestry farms (including our own farm – WHF in Figure 33). Preliminary data from a PhD study by A.Varah at Reading University shows a comparison of species richness between agroforestry (AF) and monoculture (mono) at 6 farms in England in 2011.

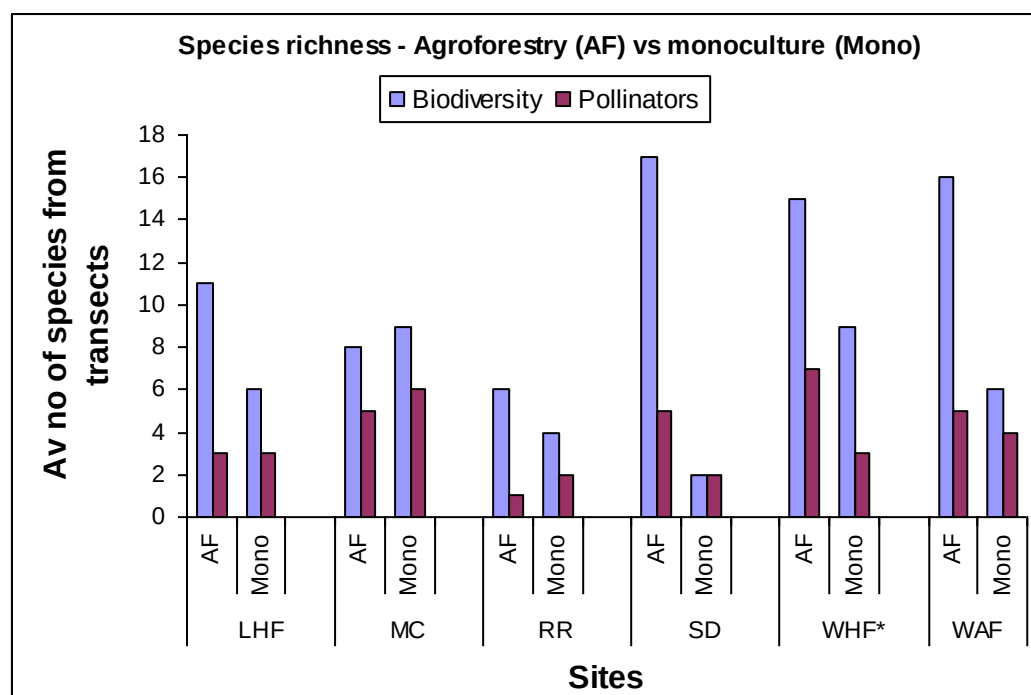


Figure 33 : Comparison of species richness between agroforestry (AF) and monoculture (mono) at 6 farms in England in 2011.

Preliminary data courtesy of A Varah Reading University *WHF = Whitehall Farm (my own farm)



At the Vézénobres agroforestry research site in France, biodiversity surveys over recent years have indicated increased occurrence in the alley crop agroforestry systems, of earthworms as well as carabid beetles, bats, syrphid wasps and other insectivores, which have helped to reduce aphid populations.

Further enhancement of agroforestry systems can be achieved by planting the area underneath the trees with species that provide a range of habitat for beneficial insects. Pollen and nectar rich species are particularly useful in this respect and can assist in attracting pollinators which can be useful when fruit trees are used for the agroforestry tree species as shown in figure 34.



Figure 34 : Pollen and nectar rich species under fruit agroforestry

6.15 Harvesting crops from agroforestry systems and alley access, alley access and tree strip weed management

With the introduction of trees into fields, additional complexities are introduced with regard to access for harvesting alley crops, tree nuts and/or fruit and timber. The following should be considered when designing the agroforestry system.

- Tree row ends – Sufficient space must be left at the end of tree rows to allow machinery for cultivating, planting etc. to turn between rows, typically 12, 24 or 48 m.
- Timing & access – If alley crops are harvested prior to nuts, fruit or timber, the tree or its produce can be harvested when there is no crop present. Where a crop will be present at tree harvest time it may be necessary to design access strips alongside trees to allow access to harvest tree nuts and/or fruit and timber.



Figure 35 : Alley access alongside agroforestry trees to allow harvesting of tree nut produce



*Figure 36 : Agroforestry trees without alley access
with harvesting of tree or its produce taking place after alley crop has been harvested*

In planning systems, care must be taken to programme access to the tree crop and alley crop. This may be at different times or it may require a permanent grass strip alongside trees to facilitate access without damaging either crop elements.

The strip under the trees can be planted with grass or pollen rich species (i.e. clovers) and managed by mowing to control growth and weed levels. Alternatively herbicides can be used to control growth in the tree strip. However, in the future tighter legislation may limit the use of herbicides adjacent to trees.

6.16 Innovative agroforestry use

Fruit Vines - At Laure-Minervois, near Carcassonne in South East France, Mr François Gardey of Soos runs a 80 ha agroforestry farm using walnut, almond, peach, persimmon, plum, honey locust and mulberry trees (for silkworms). He is one of the first farmers to introduce an integrated agroforestry vineyard system, using almond, walnut and honey locust trees in rows between grape vines. The trees help influence the local climate, reduce wind speed and evaporation and make better use of scarce water in the summer. They impart some protection against hail damage and in the winter assist with frost management. All grapes from the vines and fresh almonds from the trees are harvested and sold as fresh fruit and/or direct retailed as processed products. After extracting juice for wine production, all grape pulp and skins are returned to the soil as a fertiliser and make an excellent soil conditioner.

See Figure 37 on next page.



*Figure 37 : Fruit vine agroforestry of Mr François Gardey
at Laure-Minervois in South East France*

Hops - In Hamilton, Ontario, Canada, a 2010 Nuffield Scholar, Shane Eby, operates a 50 acre community supported agriculture (CSA) farm enterprise. He grows vegetables, vines and fruit and has developed small scale agroforestry intercropping pulse crops and vegetables between rows of hop vines.

This optimises alley utilisation and makes good use of the 8-10 m space above the ground (with the hops), with the pulse crops in the alleys providing nitrogen which the hops then utilise.

Agrovoltaic - At Montpellier in southern France INRA is developing, with financial and other support from a solar power company, Sun'R (www.sunr.fr) an 'agrovoltaic' system. The 'agrovoltaic' combines elements of agroforestry (agro) and photovoltaic (PV) technologies together. This gives crop production with the added bonus of simultaneous electricity generation.

This is achieved with an array of solar panels erected at about 4.5 m above the ground, in which the amount of light reaching the ground is variable, depending on the density and arrangement of the panels (i.e. 25%, 50% & 75% cover by PV panels). Under the panels, research plots of selected arable and vegetable crops are grown with research monitoring of microclimatic conditions at crop level, crop response, yield, quality and other response variables. The study is based on the presumption that crops could be grown under reduced light, as long as the light was sufficient for daily photosynthetic requirements, while the quality of some crops, like lettuce, would be enhanced. At the same time, electricity could be generated from the excess light. The array was open on the sides, so that absolute humidity



was unlikely to be affected in a major way but it reduced temperature and thus, increased relative humidity, would likely result in greater water use efficiency. Early results suggest that there is no crop yield decline with a PV cover of 25% and little impact with a 50% PV coverage. This type of system has potential for complementary land use activities and improving 'output', especially on smaller farms with high value cropping.



Figure 38 : Agrovoltaic system in development at INRA Montpellier in France

6.17 Markets for agroforestry and wood products

There are well established markets for top fruit and soft fruit crops. Markets for nuts and vine crops are more specialised but both are options for agroforestry.

There are many tree species options for agroforestry. Timber species such as poplar, ash, hornbeam, Italian alder, paulownia, lime, sycamore, cherry, walnut and oak, plus many others can all be used. Some take longer to reach maturity than others. All can produce timber products. Fast growing poplar and paulownia species have been used in mainland Europe and China. They provide rapid growth and a timber harvest in 16-18 years. Paulownia wood has many favourable characteristics. It is lightweight, strong, and is very easy to work with. It dries easily and does not crack, warp, or suffer other effects of high humidity (El-Showk, 2003).

The Forestry Commission (*Forestry Commission 2009*) suggests that if the market for wood construction products continues to grow at its current rate over the next 10 years, there is the potential to store an estimated additional 10 Mt of carbon (equivalent to 36.7 Mt CO₂) in new and refurbished homes by 2019 from the harvest of wood products.



Choosing coppice species (willow, poplar, ash, alder, hazel, silver birch, sycamore, sweet chestnut and lime) as the agroforestry tree species can provide a shorter term regular income from coppicing. Short Rotation Coppice (SRC) energy crop is becoming increasingly lucrative as a renewable crop with regular income, especially with the increasing costs of fossil fuel energy. SRC energy crop is well suited to agroforestry systems and a wide range of tree species can be used for harvesting.



Figure 39 : Waklyns agroforestry Suffolk, Willow Short Rotation Coppice (SRC) agroforestry

The Forestry Commission (*Forestry Commission 2009*) argues that over a 5 year period, sustainably produced wood fuel has the potential to save the equivalent of approximately 7 Mt of CO² emissions per year by replacing fossil fuels.

In England, the Energy Crops Scheme (ECS), which is operated by Natural England, provides establishment grants for approved Short Rotation Coppice (SRC) energy crops (willow, poplar, ash, alder, hazel, silver birch, sycamore, sweet chestnut and lime). Funding covering 50% of costs can be covered under this scheme.

Energy crops grown in the alleys between trees is also a real option for farms. Miscanthus, willow, hemp etc. can all be grown as an alley crop between timber species in agroforestry systems. Research at the University of Guelph in Canada is evaluating SRT willow as an alley crop in agroforestry systems. (See Figure 40 on next page.)



*Figure 40 : Agroforestry alley crop of SRT willow between rows of poplar
at the University of Guelph in Canada*



7. Policy influencing agroforestry and its adoption

7.1 Global policy

Agroforestry systems are being used by farmers all over the globe. The majority of use has historically been in tropical agriculture, with larger climatic variations and resource availability. In these environments agroforestry has been used to buffer against drought, flood and nutrient scarcity to regulate cropping environments and facilitate crop production.

Tropical agricultural systems are increasingly adopting agroforestry systems which reduce the cropping risks in regions of climatic volatility. Dr Dennis Garity from the International Centre for Agroforestry (ICRAF) in Kenya, outlined his ideas on an 'evergreen agriculture' during the 12th North America Agroforestry Conference in June 2011. This two-storey agricultural approach uses agroforestry to provide perennial green cover mixed with annual crops present at ground level, providing greater productivity from multi-storey canopies which improve photosynthetic capture utilisation and reduce cropping risk.

He emphasised that in many 'southern countries' other than using agroforestry there are very few options which provide more food, better land management, plus reduced Greenhouse Gas Emissions (GHG) for a growing population. He believes that input based fertiliser agriculture just does not deliver in developing countries. He cited examples from Malawi, Kenya, Niger and Ethiopia where tree planting and intercropping for multi-storey agricultural systems is now increasing rapidly as a stable means of food production.

Adoption of agroforestry in more temperate regions has been slower. With increasing recognition of climate change and more regular occurrence of weather extremes all over the globe, there is increasing interest in agroforestry use in temperate regions.

At the North America agroforestry conference in June 2011, Dr Kathelen Merrigan - Deputy Secretary of State for Agriculture - stated that in the USA there is a firm commitment to agroforestry, with the United States Department of Agriculture (USDA) recognising the benefits that agroforestry delivers. The 2008 US Farm Bill increased support for forestry, including agroforestry, with most agricultural and forestry programmes being modified so as to allow the inclusion of agroforestry during the period 2008-2011.

In the 2012 US Farm Bill there is likely to be an even greater recognition of agroforestry and, importantly, agroforestry will be included as a section for recording in the agricultural census and it will have a more visible profile through USDA policy and activity.

Jamshed Merchant, the Canadian assistant Deputy Minister of Agriculture, has stated that the benefits of agroforestry were well understood in Canada with agroforestry providing "local solutions applicable on a global basis". Canadian agricultural policy is looking at integrated use of trees in agriculture, using trees in different ways and with new approaches to solving agricultural food production and climate change.

China occupies a total land area of 9.3 million sq km. Latest estimates are that 23% of the earth's population is Chinese, roughly 1.34 bn people. 20% of the population live in cities, with 80% being rural 'farming' households. China therefore has over 1.1 bn farmers. These farmers grow a wide range of crops including rice, wheat, maize, vegetables, fruit etc. from the tropical south to the desert-like north - all is for human consumption. However farmers



typically only farm 0.5-1.0 ha each and are largely told what food crops to grow by the centralised agricultural support systems. When I asked ministry officials what the top three priorities for farming in China were, the answer was (i) Food security/increased productivity (ii) Food safety/quality (iii) there is no number 3!.

I visited China in Feb/March 2012. Agroforestry is firmly imbedded in agricultural policy in China with more than 3 million ha in the Hebei, Henan, Anhui, Shaanxi and Shandong provinces.

7.2 EU land use policy and influence of the Common Agricultural Policy (CAP)

Agroforestry systems are part of the history of European Union (EU) rural landscapes. Old photographs show that these systems had been general and traditional in the late 19th century (Figure 41).



Figure 41: Agroforestry systems in France in the early 20th century at Nogent-le-Rotrou, just northeast of Le Mans. Note that trees were included in various patterns in the plots (on the boundary, isolated or aligned trees inside the plots)

During the 20th century, trees were progressively removed from cultivated land as a result of mechanisation and intensification, but also as a consequence of land consolidation schemes to increase the size of agricultural parcels. Farm policy over the last 60 years under the Common Agricultural Policy (CAP) has also encouraged farmers to simplify their cropping systems by removing trees.

During the last 40 years, two opposing trends have been apparent. On the one hand, the role of trees has been progressively recognised, and schemes to preserve trees and plant new woodland on farms have been implemented. On the other hand, the main CAP crop and animal support regulations have ignored the existence of trees outside of woodlands and forest. Direct Pillar I payments have only been available on 'treeless' land parcels. In some instances this led to the unfortunate (and probably unforeseen) consequence of removal of



trees from cultivated or grazing land to maximise levels of subsidies. With the enlargement of the EU to include new member states from Eastern Europe, the same process has occurred, with some farmers removing trees to ensure full eligibility for CAP Single Payment Scheme (SPS) payments.

Following the Common Agricultural Policy (CAP) 2002 mid-term review, Agriculture Commissioner Franz Fischler presented legislative proposals for the CAP reform in January 2003. The main issues were:

- decoupling of direct aid from production, with farmers receiving a single payment, thereby removing incentives to overproduce.
- cross-compliance with a number of food safety and animal welfare regulations, and with newly defined minimum standards of 'good agricultural and environmental condition'.
- 'modulation' of support from the first "pillar" of the CAP (direct aids and market support) to the "second pillar" (rural development), as an instrument to "green" the Common Agricultural Policy.
- cuts in intervention prices for several sectors.

Under Common Agricultural Policy (CAP) regulations between 2001-2008, to remain eligible for Pillar I Single Farm Payments, land could not contain trees at more than 50 trees per ha. In July 2004, for the first time, the European CAP Regulations supporting Rural Development included a full article on agroforestry systems :

(http://europa.eu.int/comm/agriculture/capreform/rurdevprop_en.pdf).

The introduction section of the document stated that " Agroforestry systems have a high ecological and social value by combining extensive agriculture and forestry systems, aimed at the production of high-quality wood and other forest products. Their establishment should be supported".

7.3 Current EU & UK Policy

There are internationally accepted definitions of 'forest' or 'forest land' used by the UN-ECE/FAO which use threshold values of crown cover, tree height at maturity, minimum area and bounding areas. However 'woodland' as used in EU Regulations is less well defined. If agroforestry is to be recognised as an accepted land use, a clear definition of an agroforestry plot still needs to be introduced. Previous suggestions (*SAFE project 2005*) suggested that agroforestry systems could be defined by a tree plantation design and management that allows significant crop or grass production (at least 50% of the reference yield without trees), and with a tree density of less than 200 trees/ha (only trees with a diameter at breast height above 15 cm are included).

This suggestion still conflicts with EU Guidance Document AGRI/2254/03 that states that any plot with more than 50 trees/ha (irrespective of their size) would be 'woodland', and therefore excluded from the SPS system. This remains the current position in the UK, despite the guidance document also stating : "The Commission services take the view that wood within this meaning should be interpreted as meaning areas within an agricultural parcel with tree-cover (including bushes etc.) preventing growth of vegetative under-storey suitable for grazing." If this approach is extended to silvoarable systems, agroforestry is clearly not 'woodland'.



However, in many EU countries, including the UK, under current EU regulations, land planted with trees can be classed as 'non agricultural' land and is not eligible for Pillar I or II support under the CAP. Currently only clearly defined land planted with top fruit trees (apples, pears, plums etc.), nut trees, vines and nursery tree crops is eligible for CAP pillar I Single Farm Payment (SPS) support.

In the UK, the interpretation of the CAP regulations for Pillar I and II support is implemented by the Department of Environment Food and Rural Affairs (Defra) and the Rural Payments Agency (RPA). Pillar I support is provided through the Single Payment Scheme (SPS) and the latest scheme rules and guidance can be found in the Single Payment Scheme (SPS) Handbook for England 2011 and 2012. The UK rules and guidance with regard to agroforestry (set out below) are at best confusing and unclear and at worst are conflicting and ambiguous.

UK 2012 rules and guidance for SPS eligibility with reference to agroforestry

In 2012, the latest SPS rules and guidance for the UK state that land remains eligible for the SPS when it is used for : fruit, including permanent fruit (such as top fruit and nuts); vines, other permanent crops, including lavender, miscanthus and reed canary grass; nursery crops; short rotation coppice including: alder, birch, hazel, ash, lime, sweet chestnut, sycamore, willow and poplar. **This would seem to allow for agroforestry?**

The latest SPS rules and guidance for the UK states that any 'forest' including: woodland, trees and most Christmas trees (except in nurseries), short rotation coppice and land in forestry schemes is not eligible for SPS. **If agroforestry is defined as woodland, this would make agroforestry land ineligible for SPS**

When 'woodland' is grazeable it is eligible for SPS if it has fewer than 50 trees per ha. If it has more than 50 trees per ha, SPS can be claimed where it can be shown that there is a history of grazing or it is a new planting and trees have been protected from grazing. **Agroforestry land may or may not be eligible for SPS depending on if it is grazeable or has a history of being grazed?**

For woodland that is not grazeable (i.e. arable crop land) and which is not in a woodland scheme, it is not eligible for SPS if there are more than 50 trees per ha. However, it is eligible for SPS if it is planted with short rotation coppice (SRC) or where trees are planted, as long as you can carry out agricultural activities there in the same way as you would on land without trees in the same area. **For agroforestry if there are more than 50 trees per ha it would not be eligible for SPS. The ability to 'carry out agricultural activities' is unclear?**

If there are more than 50 trees per ha, the area of trees must be declared as an SPS permanent ineligible feature. The only exception is if it is grazed woodland, but even if it is grazed, the area taken up by tree trunks must be removed from an SPS claim if it adds up to 0.01 ha or more. **For agroforestry if there are more than 50 trees per hectare, only the area taken up by tree trunks must be removed from an SPS claim?**

The UK SPS rules and guidance with regard to agroforestry (above) are confusing, unclear, conflicting and ambiguous. There is an urgent need to clarify the position of agroforestry



with regard to eligibility for SPS as this will be a major stumbling block for farmers in adopting agroforestry practices.

In Germany the CAP rules have been interpreted somewhat differently with land remaining eligible for pillar I SPS support if 'trees' are planted and they are under 10 years old and at a density below 200 trees per ha. This allows for Short Rotation coppice (SRT) and agroforestry practices to be operated on land and still retain Pillar I support.

In France, CAP rules have been interpreted differently again. Land planted with all timber trees 'as part of an agroforestry system' remains eligible for Pillar I Single Farm Payment (SPS) support. However, they have not included fruit trees in this eligibility.

The Common Agricultural Policy (CAP) regulations with regard to trees, forests and agroforestry are implemented differently by individual member states. There is an urgent need to ensure that the CAP regulations are revised to allow the use of agroforestry by all member states.

7.4 France - a policy success story for agroforestry

In France, there is much greater recognition of the multiple benefits of an agroforestry approach. France has two agroforestry associations - l'Association Française d'Agroforesterie (AFAF) (www.agroforesterie.fr) and l'Association Française Arbres et Haies Champêtres (AFAHC) - the French association for trees and hedgerows (www.afahc.fr). The focus by the AFAF is on alley cropping as agroforestry likely relates to the important and major initiatives under the Silvoarable Agroforestry For Europe (SAFE) project, which was conducted from 2000 to 2005, building on earlier work by INRA Montpellier and others. In this project, the term "silvoarable agroforestry" was used to denote alley cropping research, which was the focus of the project.

It has been one of the goals of Christian Dupraz (INRA), Fabien Liagre AGROOF) and Alain Cannet (AFAF) to ensure that policymakers were aware of the research work that had been carried out. Formerly, EU policy required agricultural producers to declare their land use as either tree production or agricultural land, but not both, partly because agricultural policy is made by the EU while forestry policies are made by the member countries. Success by the INRA researchers and their supporters has resulted in the current policy that recognises dual cropping of the land. This was achieved as follows:

Between 1998-2000 discussions between stakeholders, farmers and researchers and the French Government were held on the eligibility for CAP support for agroforestry.

Agroforestry has been permitted since 2002 as a standard practice for French landowners and farmers, but it was not always possible to retain Pillar I SPS eligibility.

In 2006 land containing trees was only eligible for Pillar I SPS payments when trees were at a density of less than 50 trees per ha. In 2010 the French government acknowledged agroforestry by providing official agricultural status for agroforestry.

The French ministry of agriculture defines Agroforestry as "an association, on the same plot of land, of crops (or pasture) and trees". It is noted that the technique



“utilises synergies between crops and trees and can reduce inputs and enhance biodiversity”. It is also noted that its increased use requires “clarification of its legal (particularly the ‘Statut du Fermage’) and tax status”, and that uptake “depends on dissemination of technical results, particularly through farmers’ networks”.

Also from 2010 any French agricultural land containing agroforestry trees remained eligible for Pillar I SPS payments when trees are at a density of less than 200 trees per ha.

France is leading other European countries in the implementation of new agroforestry schemes, with policies, funding and technical extension to support adoption. Both silvoarable and silvopastoral agroforestry is now promoted by the French Ministry of Agriculture to French farmers. The extension services serve agroforestry well. In each of the 33 ‘regions’ in France there is at least one specialist agroforestry extension officer. Over 100 farmer agroforestry networks overseen by extension officers operate throughout France. Grants are available for planting the trees, and SPS pillar I support remains available to alley crops, on a “cropped area basis”. The policy operates throughout France, with some provinces adding additional planting grants.

For planting new agroforestry plots, the landowner can access a 40% grant for planting and tree management for the first 3 years. Crops planted in the alleys between the trees remain eligible for CAP SPS payments, however it is not possible to get CAP payments on a silvoarable plot obtained from clearing a forest, or planted on a parcel that was not eligible for CAP payments initially.

Specific agri-environmental schemes (Mesure agro-environnementale agroforestière nationale française) are available to promote agroforestry. Two 5-year agreement options are currently available in France: one for creating new agroforestry plots (€240-360/ha/year during 5 years), and one for managing an existing silvoarable plot (€100-140/ha/year during 5 years).

France did not apply for RDR Article 44 (first establishment of agroforestry on agricultural land) when the RDR was first introduced. Its Rural Development Plan (*Objectif Terres 2020*) includes agroforestry as one measure out of 60 to be applied, and justifies adoption for reasons of biodiversity, improved agronomy, landscape enhancement and soil protection. Unusually for an EU Member State, the French Rural Development Plan runs to 2020 rather than the end of the RDR period in 2013. This provides continuity and assurance for farmers. In 2011 the two French agroforestry associations successfully gained support from the French ministries of agriculture and sustainable development to initiate a dialogue on a European level in order to propose solutions for trees to be considered in the 2014 CAP reforms. This has in turn resulted in the creation of the first European Agroforestry association (see below).

7.5 Future EU & UK Policy

The recognition of agroforestry in the 2004 European CAP Regulation reforms supporting rural development has allowed some EU member states to adopt agroforestry through Article 44 Measure 222, which makes provision for agroforestry at a member state level. Between 2009-2011 an EU budget of €222 million was available through Article 44 on a co-finance (50% member state match funding basis). Implementation of Article 44 was on a



voluntary basis and the UK chose not to adopt Article 44 or Measure 222. Other member states such as France, Belgium, Bulgaria, Spain, Portugal, Greece, Italy, Germany and Ireland all adopted Article 44, Measure 222 in 2008 allowing them to support agroforestry development.

It has been a major effort and a major victory by French agroforestry researchers like Christian Dupraz (INRA) and policy lobbyists like Fabien Liagre (AGROOF) and Alain Cannet (AFAF) to convince the European policymakers that the use of trees on agricultural land does not constitute a land conversion away from agriculture into forestry, but rather that this form of agroforestry could be a part of sustainable agricultural management.

Proposals currently being considered by the EU include Article 24, which recognises agroforestry as a 'system of land use where trees are grown in conjunction with agricultural production on the same land area'. This is seeking to support agroforestry establishment with an on-going maintenance/management funding for the first 3 years of the tree's life. It is likely that a maximum number of trees per unit area (likely to be 200 trees per ha) will be specified and member states may be required to define species of trees suitable to local climatic conditions. It is proposed that the measure will be available to land owners, legal tenants, municipalities etc.

7.6 European Agroforestry Federation (EURAF) established

Delegates from across Europe supported the foundation of a European Agroforestry Federation (EURAF) to promote agroforestry, lobby for agroforestry policies on the European scale and improve information exchange on agroforestry at an EU level. The inaugural meeting of EURAF, held in December 2011 at the Ministry of Agriculture in Paris, was well attended with over 200 delegates from across Europe participating in person or via an internet broadcast. Representatives from more than 18 EU member states provided an overview of agroforestry systems in their country and it was fascinating to note how diverse these systems were. Going forward the challenges for EURAF are to lobby EU policy makers to ensure that agroforestry is permissible on agricultural land throughout the EU and that policies do not disadvantage, deter or prevent farmers from adopting agroforestry. EURAF also has an important role in improving agroforestry knowledge transfer at an EU level. With the official formation of the federation, I was voted as the first vice chairman of the newly formed EURAF.



8. Global agroforestry research resources and knowledge exchange

When developing innovative farming systems like agroforestry one of the greatest challenges lies in answering questions regarding productivity, economics and physical and biological impacts. These outputs and impacts change with time and it is even more difficult to answer these questions in relation to mature systems.

As part of my Nuffield study tour I have identified that there are a number of excellent, mature, agroforestry research sites around the globe. Most of these were established 17-20 years ago to answer specific research questions. All now contain mature agroforestry and could be used to answer many questions related to the productive potential of agroforestry and its role in climate change mitigation.

The presence of such a valuable mature resource should not be underestimated and I believe that a global research alliance should be formed to co-ordinate research at the sites in different countries. The main mature agroforestry sites are:

- University of Guelph, Ontario, Canada (pine, poplar, maple trees & alley crops 10 & 12 m spacing 18 years old)
- University of Missouri, MO, USA - Ross Jones research site (maple trees and alley crops 40 x 40 ft (18 x 18 m) spacing 18 years old)
- University of Missouri, MO, USA - HARC research site (pine, poplar trees and alley crops 40 x 40ft (18 x 18 m) spacing 18 years old)
- Yenglang University College of Resource & Environmental Sci., Northwest A&F University, Shaanxi China (paulownia, poplar and wheat agroforestry – multiple plots in central China 10-30 years old)
- Restinclières and Vézénobres research sites, INRA, Montpellier, France (poplar and walnut trees and alley cropping 16 m and 32 m spacing 17 years old)
- Royal Agricultural College Glos, England (poplar trees alley cropping 12 m spacing, 18 years old)
- Loughall, Northern Ireland (poplar trees alley cropping 12 m spacing 18 years old)
- Henfaes, Bangor, Wales (poplar trees alley cropping 12 m spacing 18 years old)
- Buckinghamshire, England, (walnut trees alley crops, 12-16 m spacing 20 years old)
- Waklyns agroforestry, Suffolk, England (hardwood, fruit, coppice trees, alley crops 12 m spacings 15+ years old)



9. Study results

Having visited systems on three continents and learnt a great deal about agroforestry, I have found that they are 'loose systems' which are dynamic and change over time.....perhaps it is that they are "Imperfectly perfect".

My original title for my Nuffield study was "*The adoption of commercial Agroforestry and its applicability to UK & temperate farming systems*". I have also been asking the question: "If, as demonstrated in other temperate countries, agroforestry is relevant to the UK, why has adoption of agroforestry been so poor in the UK?"

Agroforestry is used throughout Europe and includes all agroforestry practices like hedgerows and windbreaks, riparian buffers and silvopasture, as well as alley cropping. In European agroforestry and especially in France, there is a major focus on silvoarable systems using alley crops in combination with trees.

In North America, five agroforestry practices (windbreaks, silvopasture, alley cropping, riparian buffers, and forest farming) are the main focus. In North America, there is a greater focus on silvopasture in British Columbia's interior, the US Pacific Northwest and the south-eastern US, while windbreaks are relatively important on the US great plains and Canadian prairies, and alley cropping is a subject of research in Ontario, Quebec, and the US Eastern and Midwestern States.

Despite a regionally different focus, it is important that there is a consistent use of terminology in relation to agroforestry systems so that policymakers, as well as producers, understand the term in its broad context. It is equally important that globally there is an understanding that agroforestry practices deliver wide ranging public goods and ecosystem services.

Engagement of EU policy makers by key lobbyists from France has resulted in a policy/regulatory environment in which farmers wanting to develop agroforestry cropping systems on their farms are not to be penalised under the CAP by having their land reclassified as forest land, and losing SPS eligibility. As a result the area under agroforestry cropping in France is expected to increase significantly because of these policy achievements. Farmer interest in France can be attributed to:

- a) agroforestry alley cropping is an historic practice in France
- b) there is a strong environmental ethic in France and
- c) the high value of walnut and other hardwoods, along with an infrastructure of buyers and woodworkers that generate the demand for it.

The key findings from my Nuffield study tour for successful agroforestry are summarised below:

1. Agroforestry has a long history with its use noted from 206 BC to AD 220 in China and during the 19th century in Europe.
2. Trees have an important role in climate change adaptation, by providing shelter, cooling, shade and controlling rainwater runoff, reducing wind speed and evapotranspiration from crops. Tree planting would (not could) help to reduce greenhouse gas emissions.



3. Monoculture crop production and farm specialisation continues to increase both in the UK and globally. There is increasing separation of production and conservation into 'parks' and 'prairies'. This reduces natural biodiversity and increases production risks in a climate change world.
4. Our increasing reliance on oil based non renewable resources, depleting reserves and increasing costs, makes a high input based approach to agricultural production questionable in the long term.
5. Soil degradation is becoming a major concern both in the UK and globally.
6. As a result of intensification, mechanisation and land consolidation, many traditional European agroforestry systems disappeared during the 20th century. The Common Agriculture Policy (CAP) compounded this with only 'tree free' areas being eligible for Pillar I payments.
7. Policy blockages and CAP regulations are currently the main restraining factors in the UK. These need to be addressed in the CAP reforms and by improving UK policy maker knowledge and understanding of agroforestry.
8. UK tree cover is currently 12%. The UK target of 16% (well below the EU average of 37%) is unlikely to be achieved from woodland planting alone. Agroforestry could make a significant contribution to tree planting in agricultural landscapes.
9. Agroforestry is being used by innovative farmers in Canada, the USA, China and in more than 18 EU member states with these farmers moving away from monoculture to 'managed complexity'.
10. Modern agroforestry systems are compatible with present-day agricultural techniques and lower tree densities of c. 100 trees/ha allowing alley crop productivity to be maintained.
11. Agroforestry can make the farm bigger and more productive if you choose to crop the extra dimension - above and below ground.
12. Agroforestry can be as, or more productive than, monoculture systems, especially in changing climates - the average productivity of silvoarable systems is higher than the combined productivity of separate tree and crop systems, with productivity increases of up to 30% in biomass, and 60% in final products. A Land Equivalent Ratio (LER) of 1.40 (i.e. overall productivity is increased by 40% compared to a monoculture on the same land area) is achievable on-farm, with the LER remaining stable under different climate change scenarios.
13. Agroforestry is as profitable as monoculture, and often more profitable when high value timber trees (such as walnut, poplar or paulownia) are included. Annual crops maintain the annual income for the farmer, while managed low density tree stands provide capital for the future.
14. Most European farmers could develop an agroforestry component on cropland. Adopting 20% of cropped land into agroforestry could increase productive output. If high-value timber species are used, farm profit could double in the long term.



15. Security of land tenure is a big issue for tree crops. Farmers renting land on short term agreement are unlikely to want to adopt agroforestry practice due to the lack of secure tenure.
16. North-south tree row orientation is best suited to the UK to minimise shading of alley crops.
17. Tree row spacings of 12 or 18 m in older agro forestry systems were too close leading to alley crop productivity declining after a decade. Agroforestry systems are now typically planted with 24 or 36 or 48 m row widths.
18. The spacing of trees in the rows is typically 3-9 m depending on tree species, size and desired density of trees.
19. Growth of plants/weeds in the strip under the trees can be managed by cutting twice per year or spraying herbicide. Cutting is with a ride-on mower with a flail deck mid season, and a tractor/topper after harvest. Planting pollen and nectar rich species can enhance pollinator numbers and keep weed levels down. Future tighter legislation on herbicide use at the base of trees may restrict input use.
20. The best bio-physical option is to plant 80-120 trees per ha (130-200 for poplar). The best economic option is to plant a lower density around 60-90 trees per ha (100-130 for poplar) with tree rows spaced 24-36 m.
21. To maintain alley crop productivity the tree height should not exceed the width of the alley.
22. Matching tree and alley crop components to minimise competition for water is an important design component of agroforestry systems.
23. Alley crops can be forage, cereals, legumes, maize, root or vegetable crops or biomass crops for energy.
24. The best combinations of tree : alley crop are short season grain crops i.e. cereals combined with long season tree crops i.e. later leafing trees.
25. Agroforestry changes the way trees root, producing deeper and stronger tree rooting systems which are better able to withstand drought and storm damage. 75%+ of the tree roots are distributed under the cultivated layer of 40-100 cm, with only 12% of roots in the 0-40 cm range. Most alley crops have 80-95% of their roots distributed in the 0-40 cm range; therefore competition for water and nutrients between trees and crops is minimised in agroforestry systems.
26. The roots of trees in agroforestry systems do not interfere with field drainage systems, provided that the drainage systems are operational, well maintained and clear.
27. Agroforestry improves nutrient cycling, with tree roots accessing minerals deeper in the soil profile that would not normally be available to arable crop roots. Through leaf litter incorporation into topsoil, these nutrients are subsequently made available to arable alley crops.



28. Nutrient utilisation is more efficient in agroforestry systems, with farmland nitrogen losses reduced by 50% in agroforestry compared to monoculture (trees taking up any N not utilised by alley crops), improved nutrient cycling (through leaf litter) and increased soil mychorizal associations, which result in greater phosphate capture and a reduced requirement for phosphate fertilisers.
29. Catchments can be protected by adopting agroforestry with 48% reductions in sediment loss and 50-75% reductions in nitrogen loss recorded from catchments managed under agroforestry.
30. Shade - there are huge variations in crops' ability to cope with shade. Some species and varieties cope well, others reduce photosynthesis and thus their productive potential. There has been very little research in this area and research into alley crop species and different varieties would be very important in further developing agroforestry systems in Europe.
31. Temperature – Agroforestry can increase the relative humidity of the air above the fields by 7-12%, reduce crop air temperature by 1-2^o Celsius and reduce crop thermal stress during critical growing periods.
32. Wind - Agroforestry systems locally reduce wind speed by 30-50 % (depending on the spacing of the trees) having a horizontal effect 10 times the height of the tree.
33. Agroforestry can reduce evapotranspiration from alley crops by 30%, reducing irrigation requirements, and improving the growth and development of crops.
34. Agroforestry systems have more earthworms with 60-70 earthworms per m³ of soil under agroforestry compared to 20 earthworms per m³ of soil under monoculture arable systems.
35. Pest and disease levels are lower in agroforestry systems than in monoculture. With the introduction of trees, precautions must be taken to protect young trees from birds, deer etc.
36. There are significantly more beneficial insects, carabid beetles, syrphid wasps and other insectivores found in agroforestry systems compared to monoculture.
37. There is limited knowledge of paulownia in the UK. It has potential for use in the UK.
38. Agrovoltaic systems have the potential to grow crops and generate electricity simultaneously, especially on smaller farms with high value cropping.
39. There is a strong and increasing demand for wood products throughout the EU and globally.
40. The SAFE project (2001-2005) produced some valuable EU wide research and produced a "Farm SAFE model" for use throughout Europe – its use to date has been mostly in France only.
41. In the UK there is a disconnect between Defra and the Forestry Commission, with neither party taking ownership of agroforestry.



42. Accounting inventory on agroforestry is generally poor throughout the world – better national inventories of agroforestry are needed as part of agricultural census activities.
43. EU CAP and member state policy blockages still exist which provide no incentive for adoption or, worse, prevent adoption of agroforestry at farm level.
44. Agroforestry is being adopted in the 2012 US and Canadian Farm Bills, and China has integrated agroforestry into mainstream agricultural policy. EU Article 44, Measure 222, makes provision for Agroforestry and many EU member states have agroforestry policies. The UK has not adopted Article 44 or Measure 222, makes no provision for Agroforestry, and does not currently have an agroforestry policy.
45. There are a number of mature (18-20 year old) agroforestry research sites in the UK, Canada, the USA, and France – which are currently underutilised and which could, if co-ordinated, provide a valuable research resource to answer questions on productivity, economic viability, resource protection, multi-functional land use, climate change mitigation etc.
46. The French have managed to convince European policymakers that agroforestry can be a part of sustainable agricultural management and have retained Pillar I SPS support for agroforestry land.
47. The formation of the European Agroforestry Federation (EUAFF) with more than 18 participating member states will assist in the promotion of agroforestry and exchange of knowledge throughout Europe and will provide a platform to lobby for agroforestry policies at an EU level.
48. Agroforestry is '*climate smart*' agriculture and provides one of the very few options that has the potential to help reduce greenhouse gas emissions, and help protect natural resources whilst at the same time producing more food and biomass.



10. What I will do in my own business

- We established 125 acres of Agroforestry at our Whitehall Farm in 2009, combining 4,500 apple trees with combinable and vegetable crops. I designed the system with limited knowledge of agroforestry elsewhere. This is currently the largest agroforestry system in the UK.
- Having subsequently visited similar systems throughout the globe I am now confident that our system will perform well, be profitable and provide improved levels of biodiversity and soil protection.
- We chose apple trees as we wanted to get a commercial return within the period of our farm tenancy. From what I have seen during my Nuffield studies, if I can secure a longer term tenancy I would consider planting nut, coppice or timber trees, which have the potential for an improved financial return.
- In the short term I have learnt a great deal about apple processing during my travels and I will seek to develop some value added activities on our farm using the apples produced by our own agroforestry system.
- I will use the information about agroforestry and experience gained to better inform the wider agricultural industry of the benefits that agroforestry systems can provide and to highlight their contribution to sustainable land management and mitigation against climate change.
- I will continue my involvement as elected vice chairman of the newly formed European Agroforestry Federation (EURAF) to promote agroforestry, lobby for agroforestry policies at the European scale, and improve information exchange on agroforestry at an EU level.



11. Conclusions

1. Agroforestry can make the farm bigger and more productive if you choose to crop the extra dimension - above and below ground.
2. Agroforestry makes better temporal and spatial utilisation of natural resources: sun, air, soil, water, than monoculture.
3. Modern agroforestry systems are compatible with present-day agricultural techniques and tree densities c. 100 trees/ha allow alley crop productivity to be maintained. Successful systems are being used on farms in Canada, the USA, China and in more than 18 EU member states.
4. Agroforestry can be as or more productive and profitable than monoculture systems.
5. Nutrient cycling and utilisation is more efficient in agroforestry systems and nitrogen losses can be reduced by 50% in agroforestry, with improved phosphate availability compared to monoculture.
6. In the UK there is a disconnect between Defra and the Forestry Commission, with neither party taking ownership of agroforestry.
7. EU CAP policy reforms must permit agroforestry and not disadvantage, deter or prevent farmers from adopting agroforestry.
8. Agroforestry is '*climate smart*' agriculture and provides one of the very few options that has the potential to help reduce greenhouse gas emissions and help protect natural resources whilst, at the same time, producing more food and biomass.



12. Recommendations

12.1 Recommendations for farmers

1. Agroforestry can make your farm bigger and more productive, using deeper soil layers and the air space above the farm and make better use of the sun, air, soil and water than monoculture (it's also cheaper than buying more land) - so crop the extra dimension - above and below ground.
2. Agroforestry is a practical, viable form of agriculture which can be as profitable as monoculture, especially when high value timber trees are included. Annual crops maintain the annual farm income, while trees provide capital for the future.
3. Modern systems are compatible with present-day agricultural techniques and machinery and, with tree densities c. 100 trees/ha, allow alley crop productivity to be maintained. Combine short season grain crops i.e. cereals, with long season tree crops i.e. later leafing trees, for best results. Precautions must be taken to protect young trees from birds, deer etc.
4. Agroforestry systems modify local microclimatic conditions (temperature, air, water vapour content, evaporation and wind speed) and provide benefits to crops which are grown with the trees by reducing soil degradation and enhancing biodiversity, pest and disease control.
5. Use agroforestry to locally reduce wind speed by 30-50%, lessen crop thermal stress during critical growing periods, reduce the irrigation requirements of alley crops and protect catchments from sediment and nitrogen loss.
6. Plant 10-20% of cropped land into agroforestry to increase productive output and long term farm profitability.

12.2 Recommendations for landowners

1. Trees as part of an agroforestry system represent a long term asset for landowners, with near term income from rotational harvesting. Annual crops maintain the annual farm income, while trees provide capital for the future.
2. Security of land tenure is a big issue for tree planting. With over 30% of UK land being rented, there is little incentive for many tenants to plant trees. Landowners should consider new shared income options to facilitate agroforestry development – for example : landlord retaining long term asset value combined with shorter term wood, fruit, and nut harvest income shared between landlord and tenant.
3. Agroforestry can improve the aesthetic landscape and sporting value of farmland.



4. Agroforestry has the potential to reduce greenhouse gas emissions and sequester carbon with the potential to attract carbon trading credits, whilst protecting natural resources at the same time as producing more food and biomass.
5. Plant 10-20% of cropped land into agroforestry under a shared output arrangement with tenants to increase productive output and long term profitability

12.3 Recommendations for UK government and policy makers

1. UK Government departments – Defra and the Forestry Commission - should formally recognise the role and benefits of agroforestry, taking appropriate ownership.
2. Promote agroforestry for use on farmland to enable the UK target of 16% tree cover to be met.
3. The UK SPS rules and guidance with regard to agroforestry are confusing, unclear, conflicting and ambiguous. There is an urgent need to clarify the position of agroforestry with regard to eligibility for SPS as this will be a major blockage for farmers in adopting agroforestry practices.
4. UK SPS implementation policy should be revised to ensure SPS eligibility for agroforestry allowing up to 200 trees per ha, evenly spaced as part of an agroforestry system of production.
5. The UK Government should support EU CAP policy reforms which permit agroforestry and do not disadvantage, deter or prevent farmers from adopting agroforestry.
6. Promote and support the adoption of agroforestry to improve nutrient cycling, phosphate capture and protect catchments from sediment and nitrogen loss from farm land.
7. Promote and support the adoption of agroforestry to regulate wind, reduce crop evapotranspiration and reduce crop irrigation requirements.
8. Promote and support the adoption of agroforestry to stabilise soils, improve soil biological richness and increase beneficial insect populations.
9. Facilitate and support knowledge transfer on agroforestry systems between EU member states and the UK.
10. Government should provide appropriate business, technical and research support to enable UK farmers to be confident about adopting agroforestry practices on their farms.
11. Defra should include Agroforestry as a recordable element in the agricultural census (as is the case in the US and Canadian Farm census).



12. Promote agroforestry as a '*climate smart*' agriculture and one of the very few options that can reduce greenhouse gas emissions and help protect natural resources whilst, at the same time, producing more food and biomass.

12.4 Recommendations for researchers

1. Engage and create a research alliance to utilise the mature 18-20 year old agroforestry research sites in the UK, Canada, USA, France and China to answer questions on productivity potential, resource protection, multi-functional land use, climate change mitigation etc.
2. Shade - There are huge variations in crops' ability to cope with shade. Some species and varieties cope well, others reduce photosynthesis and thus their productive potential. Research is needed to establish which alley crop species and varieties are best suited to UK agroforestry systems.
3. Research is needed to match tree and alley crop components for UK agroforestry systems to minimise competition for water.
4. Research is needed to confirm the best combinations of tree and alley crop under different UK climatic conditions.
5. There is limited knowledge of paulownia in the UK. It has potential for use in UK and its use should be evaluated.
6. Research is required to determine what technical and business information is required by UK farmers for them to be confident about adopting agroforestry practices on their farms



13. End note

My Nuffield Scholarship has been a most fulfilling achievement.

During my Nuffield study I have made some invaluable farming and research contacts around the globe and found that there are many other farmers and professionals who share my inquisitiveness and passion for farming and agroforestry, my concerns for the way farming and land management has travelled plus my worries and optimism for how we will feed the world tomorrow.

During my travels I have also made some very good friends, with whom I now communicate and exchange ideas. Away from the day-to-day activities of farming, running a farming company plus a consultancy business, Nuffield has given me time to reflect and focus. These lessons will now be applied at home and to influencing UK farmers and policy makers as to the merits of agroforestry. I was also very honoured to be involved with the foundation of the European Agroforestry Federation (EURAF) and be voted as the first vice chairman of EURAF.

In my personal life, the level of support I received from my wife, family and farming/consultancy colleagues whilst travelling the globe was paramount to the success of my Nuffield adventure. Without their support it would not have been possible.

When people ask how I managed to fit in a Nuffield Scholarship and take so much time away, I reply: support from family and colleagues and how could I afford not to? Nuffield is a chance in a life time – an opportunity that should not be missed.

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17. Useful websites

European Agroforestry Federation (EURAF) <http://agroforestry.eu/>

World Agroforestry Centre <http://www.worldagroforestrycentre.org/>

Association for Temperate Agroforestry <http://www.aftaweb.org/>

Agroforestry Research Trust <http://www.agroforestry.co.uk/>

International Centre for Research in Agroforestry
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