Department
for Environment
Food & Rural Affairs

Agroforestry Review (Draft)

January 2017

Contents

Executive summary

Following calls from the agroforestry sector for Defra to review its stance on agroforestry, Defra officials undertook a review into the evidence base and how the agroforestry measure might in practice operate within the Rural Development Programme.

Efforts have been made to estimate the areas of land across Europe where different types of agroforestry systems are practised, reporting that the UK is below average for all types. One estimate is that there is over 500,000 hectares of agroforestry in the UK, but almost all of this is livestock agroforestry. Farmer surveys have highlighted numerous barriers to agroforestry, including economic, a skills shortage, and the disincentives provided under the Common Agricultural Policy. Despite this, farmers who have established agroforestry systems are generally positive about the success of the initiatvies.

There is evidence agroforestry systems can improve the level of ecosystem services, but few studies have made a holistic assessment on the impact across a range of ecosystem services. The evidence on economic performance is mixed – with some enterprises making gains of up to 30%, but some making losses of up to 50% compared to conventional farming.

There is a dedicated agroforestry measure (Article 23) within the Rural Development Regulations[1] and a number of other rural development measures which can be used in conjunction with agroforestry or in support of agroforestry systems. However there are limitations to the level of impact that these measures alone can have on the adoption of agroforestry.

[1] Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD)

Introduction

Following calls from the agroforestry sector in late 2015 and early 2016 for Defra to review its stance on agroforestry the Department recognised the need for a better understanding and full evaluation of the evidence. Defra officials therefore undertook to review the agroforestry evidence base – as explained in correspondence of the 27th February 2016:

> *"Officials have now set up a meeting to explore the evidence base for agroforestry and how the agroforestry measure might in practice operate within the Rural Development Programme. Clearly the way in which agri-environment and agroforestry fit together is not straightforward. It has to be recognised that funding is finite and there would need to be a modification to the Programme if it was decided to take this further."*

The review team, with contributions from industry colleagues, looked at our existing body of evidence relating to agroforestry and also the measures currently available within the Rural Development Programme for England (RDPE).

The EU referendum took place during the review period and therefore the information contained within this report may be used to inform policy development post-exit.

Scope

The review team consisted of representatives from Defra, Natural England and the Forestry Commission. The review aimed to develop a summary of existing agroforestry evidence but did not commission any additional research.

As part of the review process a stakeholder workshop took place on 30 June 2016. Interested parties were invited to comment on the draft report and provided additional evidence which has been considered.

There are a number of proposed definitions of agroforestry, examples of which can be found in

Annex A – definitions of agroforestry including the AGFORWARD[2] research programme definition:

> *"The practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems."*

This definition has also been used in the Land Use Policy Group (LUPG) commissioned study '*The Role of Agroecology in Sustainable Intensification*'[3].

Note, this review covers RDPE only. It does not include an analysis of the Greening of Pillar 1 of the Common Agriculture Policy.

[2] http://www.agforward.eu/index.php/en/

[3] Lampkin, N.H., Pearce, B.D., Leake, A.R., Creissen, H., Gerrard, C.L., Girling, R., Lloyd, S., Padel, S., Smith, J., Smith, L.G., Vieweger, A., Wolfe, M.S., 2015. *The role of agroecology in sustainable intensification.* Land Use Policy Group Commissioned Report, 2015

Types of agroforestry systems

Agroforestry systems vary greatly in complexity, from basic (e.g. occasional trees in pasture and parkland to provide shade and emergency forage for grazing livestock), to more complex systems (e.g. forest gardens which use many different species).

Every agroforestry system on a farm or in a field will be unique, reflecting the specific site location, soil and land capabilities, terrain and topology, climate, choice of species and system components, and the fit with the farm business's management practices and operations. Despite this, attempts at categorisation have been made according to the types of crops and/or livestock used, whether the systems are traditional or more modern versions, whether they are within or between land parcels, and according to the types of trees employed (e.g. timber, fruit crops, etc.).

The sets of criteria for classifying agroforestry systems are the spatial and temporal arrangement of the components, the importance and role of components, the production aims or outputs from the system, and the social and economic features, on a:

- ***Structural basis:*** refers to the composition of the components, including spatial arrangement of the woody component, vertical stratification of all the components, and temporal arrangement of the different components;
- ***Functional basis:*** refers to the major function or role of the system, usually furnished by the woody components (these can be of a service or protective nature, e.g., windbreak, shelterbelt, soil conservation);
- ***Socioeconomic basis:*** refers to the level of inputs of management (low input, high input) or intensity or scale of management and commercial goals (subsistence, commercial, intermediate);
- ***Ecological basis:*** refers to the environmental condition and ecological suitability of systems, based on the assumption that certain types of systems can be more appropriate for certain ecological conditions; i.e., there can be separate sets of agroforestry systems for arid and semiarid lands, tropical highlands, lowland humid tropics, etc.

The Land Parcel Identification System (LPIS)[4] can help identify different types of agroforestry on forest land or agricultural land, or within parcels or on the edges of them. The matrix in the table below, first proposed by Dupraz et al. (in press), identifies 4 'types' or 'systems' (silvoarable, silvopastoral, boundary agroforestry and urban agroforestry) and 12 subtypes. These are used depending on whether trees are within land parcels or between parcels or whether the parcel is classified as forest land or agricultural land.

The typology (
Table 1) was also used in Lawson et al. (2016), reflecting international efforts by the Programme for Endorsement of Forest Certification (PEFC), The Food and Agriculture Organization of the United Nations (FAO), World Agroforestry (ICRAF), and range of other bodies to develop sustainable management standards for Trees Outside the

[4] https://ec.europa.eu/agriculture/direct-support/iacs_en

Forest (TOF). TOF covers those trees which are not formally designated as on forest land, effectively the combination of agroforestry and urban forestry.

Table 1: Typology for Agroforestry in Europe[5] (particularly as implemented within EU agricultural, biodiversity, bio-energy and climate regulations), based on classification of land within the national Land Parcel Identification System.

<table>
<tr><th rowspan="2">Tree Location</th><th rowspan="2">AF System</th><th colspan="3">Official Land Use Classification (Cadastre/LPIS)</th></tr>
<tr><th>Forest Land</th><th>Agricultural Land</th><th>Other Land</th></tr>
<tr><td rowspan="2">Trees within parcels</td><td>Silvopastoral</td><td>Forest Grazing</td><td>Wood pasture
Orchard grazing</td><td rowspan="3">n/a</td></tr>
<tr><td>Silvoarable</td><td>Forest Farming</td><td>Alley Cropping
Alley Coppice
Orchard - Intercropping</td></tr>
<tr><td>Trees between parcels</td><td>Boundary Agroforestry</td><td>Forest Strips</td><td>Shelterbelt Networks
Wooded Hedges
Riparian Tree Strips</td></tr>
<tr><td>Urban trees</td><td>Urban Agroforestry</td><td colspan="2">n/a</td><td>Home Gardens</td></tr>
</table>

Below we briefly describe the main types of agroforestry systems, according to the above typology, and some of the examples in the UK:

1. ***Silvopastoral***
   Silvopastoral systems comprise forest farming on forest land and on agricultural land where trees are introduced into a grasslands or livestock integrated to orchards. ~~The systems are designed to produce a high value tree component, while continuing to produce forage and livestock for a significant time.~~

   Traditional silvopastoral systems are to be found throughout the UK. For example, wood pasture (Fig 1) and under-grazed traditional orchards (Fig 2)

[5] Dupraz C, Lawson GJ, Lamersdorf N, Papanastasis VP, Rosati A, Ruiz-Mirazo J, Temperate Agroforestry: the European Way, *Temperate Agroforestry Systems (in press)*

Figure 1: Parkland at Croft Castle, Fishpool Valley SSSI, Herefordshire. Copyright Natural England/Peter Wakely

Figure 2: Undergrazed orchard at Hole Farm, Chulmleigh Devon. Copyright: Jane Pay of Orchard Live, Devon.

The most recent development of silvopastoral systems in the UK is represented by 'Woodland Eggs', with farmers supplying several of the larger food retailers and manufacturers. Poultry are ranged on pasture with trees provided as shelter and shade. An estimated 200 farms/units participate in the scheme. Minimum tree cover can be as high as 20% for schemes such as that of the Woodland Trust and Sainsbury’s.

Figure 3: Silvopasture system with chickens at FAI farms, Oxfordshire. Copyright: Organic Research Centre.

2. *Silvoarable*

Silvoarable systems are where agricultural or horticultural crops are grown simultaneously with a long-term tree crops. Trees are generally grown in rows with wide alleys in-between for cultivating crops. In the UK, a few examples have tree components consisting of either top fruit trees (apples, pears and plums), short rotation coppice, and/or timber trees, with arable or horticultural crops in the alleys.

Figure 4 : Silvoarable system (Hazel short rotation coppice with alley crops (potatoes)) at Wakelyn's Farm, Suffolk. Copyright: Organic Research Centre.

3. Boundary Agroforestry

Although not strictly a whole 'system', tree plantings at the edges of fields could be considered as a type of agroforestry system where they have an agronomic, silvicultural and/or environmental function. Boundary agroforestry can include buffer strips, shelter belts and hedgerows, with functions of providing shelter and shade to livestock, creating a micro-climate for crops and protection from the wind, forage for livestock, and environmental remediation, such as reducing soil erosion and water run-off.

Figure 1: New hedgerow plantings. Copyright: Natural England.

4. Urban Agroforestry

Urban agroforestry takes place in home gardens (and therefore is not necessarily always in urban settings) close to and sometimes integrated with residential buildings. Recently there has been increasing interest amongst gardeners in 'forest gardening'. This is the design and creation of small-scale, complex agroforestry systems using diversity of trees, shrubs and other plants, and possibly with animals, such as chickens, ducks and geese. In the UK, it is predominantly undertaken as an approach to ensuring household self-sufficiency, rather than on a commercial basis.

Common characteristics

A key aspect of agroforestry are the relationships between the different elements or components within the system. For example, trees providing shade and forage to livestock, whilst the livestock provide fertilisers to the trees, and trees providing nutrients to crops (via leguminous plants) while crop by-products help fertilize and protect trees.

Nair, 1993[6], identifies the following characteristics of agroforestry:

- agroforestry normally involves two or more species of plants (or plants and animals), at least one of which is a woody perennial;
- an agroforestry system always has two or more outputs;
- the cycle of an agroforestry system is always more than one year; and
- even the simplest agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system.

The Association of Temperate Agroforestry states that agroforestry practices and systems have four common characteristics - intentional, intensive, interactive and integrated - which distinguish it from other farming or forestry practices[7].

- ***Intentional:*** Combinations of trees, crops and/or animals are intentionally designed and managed as a whole unit, rather than as individual elements which may occur in close proximity but are controlled separately;
- ***Intensive:*** Agroforestry practices are intensively managed to maintain their productive and protective functions, and often involve annual operations such as cultivation, fertilization and irrigation;
- ***Interactive:*** Agroforestry management seeks to actively manipulate the biological and physical interactions between the tree, crop and animal components. The goal is to enhance the production of more than one harvestable component at a time, while also providing conservation benefits such as non-point source water pollution control or wildlife habitat.
- ***Integrated:*** The tree, crop and/or animal components are structurally and functionally combined into a single, integrated management unit. Integration may be horizontal or vertical, and above- or below-ground. Such integration utilizes more of the productive capacity of the land and helps to balance economic production with resource conservation.

A key characteristic of successful agroforestry is that trees must acquire resources of light, water and nutrients that the crop would not otherwise acquire[8].

---

[6] Nair R. 1993, *op cit*

[7] A US-based NGO, Key Traits of Agroforestry Practices http://www.aftaweb.org/about/what-is-agroforestry.html

[8] Cannell et al. . 1996

Distribution and uptake

Current extent of agroforestry

Recent work within the AgForward programme[9] has sought to estimate the areas of land where different types of AgroForestry systems are practised across Europe. Acknowledging the practical difficulties associated with the use of different datasets, each using different land use definitions which do not always provide a perfect fit with definitions of Agroforestry, they produce the best available estimates of the extent of agroforestry across Europe, summarised in

[9] See work by den Herder et al. at www.agforward.eu. For example: Preliminary stratification and quantification of agroforestry in Europe; and Current extent and trends of agroforestry in the EU27; updated in den Herder, M., Moreno, G., Mosquera-Losada, R.M., Palma, J.H.N., Sidiropoulou, A., Santiago Freijanes, J.J., Crous-Duran, J., Paulo, J.A., Tomé, M., Pantera, A., Papanastasis, V.P., Mantzanas, K., ; Pachana, P., Papadopoulos, A., Tobias Plieninger, T., Burgess, P.J. (2016) . Current extent and stratification of agroforestry in the European Union. Submitted to Agriculture, Ecosystems and Environment.

Table 2.

Whilst these figures are estimates, the authors suggest that the consistent approach used does enable reliable comparison between European countries. According to this analysis, the UK is below average (in terms of percentage of land coverage) across all types of agroforestry.

The vast majority of existing uptake in the UK is agroforestry associated with livestock[10]. Note that the estimates for individual types of agroforestry system, presented by den Herder et al. and cited here include some overlap, notably between high value tree agroforestry and livestock agroforestry.

10 Livestock agroforestry includes grazed woodlands, Wood Pasture and Parkland. High value Tree agroforestry includes grazed orchards. Burgess, P. pers comm.

Table 2: Distribution of types of agroforestry in the UK and EU based on the LUCAS dataset (source den Herder et al. (2016) op cit.

All agroforestry	UK	EU
Arable agroforestry		
Area ('000ha)	2.0	358
% land area[11]	0.0	0.2
Livestock agroforestry		
Area ('000ha)	547.6	15,102
% land area	3.3	8.7
High value tree agroforestry		
Area ('000ha)	14.2	1,050
% land area	0.1	0.6
Total ('000 ha)		
Area ('000ha)	551.7	15,421
% land area	3.3	8.8

Figures do not appear to be available to provide a more detailed breakdown of uptake patterns. In particular:

1. Sub-national data. We have not seen any figures for uptake in relation to sub-national areas or landscape types.
2. Condition. We have not seen any data relating to the condition of established agroforestry systems.
3. Rates of new establishment. It is likely that much of the national uptake reported here are established agroforestry systems, with only a small percentage being the establishment of new systems. Whilst we have some information on potential and new uptake (see below), we are not aware of any authoritative figures on new establishment.

Potential new uptake

Interest in agroforestry appears to be growing across Europe. A recent survey of farmer attitudes to agroforestry in England (51 respondents) found that 22% of respondents were 'very interested with another 33% 'interested''[12]. Overall awareness of agroforestry was found to be higher in this 2012 study than in earlier work conducted in 2003/04[13]. Hence we do not have a robust understanding of the

---

[11] % land area figures calculated by Natural England using Utilised agricultural area data from Eurostat online data sources: Farm structure statistics (2010). Available online: http://ec.europa.eu/eurostat/statistics-explained/index.php/Farm_structure_statistics

[12] C. Meyer (2012) University of Reading MSc Dissertation, unpublished.

[13] Reported by Graves et al. (2009) in A Rigiuerio-Redriquez et al. (eds.), Agroforestry in Europe: Current Status and Future Prospects', but note the small UK survey size (n=15) on this earlier work.

level of interest in agroforestry amongst farmers in England, owing to the small sample size.

There are signs of increasing activity, where farmer interest is supported by available support, suggesting potential to increase the area of agroforestry within the UK. One stakeholder reported significant interest as indicated by farmer visits to a newly-established agroforestry site[14]. The Woodland Trust[15] report that they have supported 42 UK-based farmers to establish new agroforestry systems (alley cropping and other planned use of trees on farms) in the last 3 years and that they have a waiting list of farmers looking to establish (or extend) an agroforestry system.

---

[14] S Briggs, pers comm.: 302 visitors (farmers, land owners; agronomists; foresters; researchers; students & NGO staff) in 33 visits over a 4 year period.
[15] Woodland Trust (2016) pers comm.

Barriers to uptake

Some evidence has been generated on the concerns expressed by non-agroforestry farmers in the UK, through surveys of farmer attitudes[16]. European surveys have tended to identify similar barriers amongst non-participants. In the light of Graves et al. (2009) op cit, which found a difference in attitudes between farmers in northern Europe and southern (i.e. Mediterranean) Europe, the findings presented in this section draws on this evidence.

The perceived barriers can be grouped as: economic, policy, farm restructuring, skills & knowledge, agronomic and cultural.

Economic barriers

Economic concerns expressed in the UK–based surveys focus on the establishment costs, potential loss of profits from the pre-existing cropping system, and maintenance costs, such as tree protection and aftercare.

Evidence relating to silvoarable systems with poplar trees suggests that the relative profitability (compared to control systems) depends on quite small variations in factors such as crop prices, financial discounting rates, etc.[17] However, such future variations in these factors cannot be reliably predicted when investing in a long-term system such as agroforestry. Luedeling et al. [18] (2013) note that there is a lack of robust models for projecting the performance of agroforestry systems, limiting our ability address this barrier.

The policy environment

This has been recognised as a barrier in the past where policy rules for farm support payments have restricted eligibility on land with trees, meaning that establishing an agroforestry system has risked the loss of support payments[19], negatively affecting the relative economic performance of agroforestry in comparison to alternative

---

[16] C. Meyer op cit and Gerrard et al. UK 'Organic dairy farmers' perceptions of agroforestry' (via ORC)

[17] Burgess, P.J., Incoll, L.D., Hart, B.J., Beaton, A., Piper, R.W., Seymour, I., Reynolds, F.H., Wright, C., Pilbeam & Graves, A.R. (2003). The Impact of Silvoarable Agroforestry with Poplar on Farm Profitability and Biological Diversity. Final Report to DEFRA. Project Code: AF0105. Silsoe, Bedfordshire: Cranfield University. 63 pp.

[18] Luedeling et al. (2013) 'Agroforestry systems in a changing climate – challenges in projecting future performance' in Current Opinion in Environmental Sustainability 2014, 6; 1-7

[19] Burgess, P.J., Incoll, L.D., Hart, B.J., Beaton, A., Piper, R.W., Seymour, I., Reynolds, F.H., Wright, C., Pilbeam & Graves, A.R. (2003). The Impact of Silvoarable Agroforestry with Poplar on Farm Profitability and Biological Diversity. Final Report to DEFRA. Project Code: AF0105. Silsoe, Bedfordshire: Cranfield University. 63 pp.

systems[20]. In the current system, restrictions have been eased at the EU level but with differing interpretations between UK authorities, there is a concern that uncertainty amongst farmers on the correct interpretation of the rules remains a barrier[21].

Stakeholders also cited the restrictions on the use of agroforestry as a greening measure (where only ‘supported agroforestry’ qualifies), as a further disincentive.

Farm Restructuring

In the UK-based surveys, concerns were raised of the likely need for restructuring of the farm (e.g. investment in new machinery and/or new facilities to store produce from the trees).

There is also a perception that agroforestry systems will be difficult to establish on tenanted land. However, without specifically surveying land ownership and control patterns amongst adopters we have become aware of two recent establishment projects on tenanted land.

Skills & knowledge

In the UK-based surveys, concerns expressed relating to skills and knowledge focussed on agroforestry system design and tree management (e.g. aftercare, wind damage).

Researchers have proposed a variety of mechanisms to address these concerns: demonstration plots, (local to farmers to ensure that they are relevant); collaborative farmer groupings (to identify knowledge gaps and research priorities); knowledge exchange to make better use of existing knowledge[22].

Agronomic barriers

Agronomic concerns expressed by UK survey respondents focussed on perceptions that establishment of agroforestry would increase the arable crop weed burden; pest risk and the practicalities of access to crops with farm machinery.

---

[20] Burgess, P.J., Graves, A.R., Goodall, G.R. & Brierley, E.D.R. (2000). Bedfordshire Farm Woodland Project. Final Project report to the European Commission. ARINCO No95.UK.06.002. Silsoe, Bedfordshire: Cranfield University.

[21] Lawson, G: ‘Options for Agroforestry in the CAP’. Presentation to EURAF Conference. http://www.agroforestry.eu/conferences/III_EURAFConference

[22] Andrianarisoa and Delbende: ‘Understanding the acceptance or refusal of agroforestry systems by farmers in the Nord - Pas-de-Calais region (northern France)’: Presentation to EURAF 3rd Conference. 2016

Earlier work across Europe found that the complexity of work associated with agroforestry systems and the potential conflict with access for machinery were of particular concern to farmers in northern Europe, including the UK[23].

Cultural barriers

Some cultural factors suggest that agroforestry is perceived as outside the norm for the UK. Factors cited include the perception of agriculture and forestry as separate disciplines; a lack of UK based evidence and the absence of policy support.

Whilst agroforestry may be considered outside the norm, a recent conference has noted that it is an ancient practice that was gradually abandoned after World War Two[24]. Hence, the perception of agroforestry as something different may be a recent one.

This cultural attitude is not limited to the UK. Work in Switzerland has sought to understand why agroforestry, traditionally a widespread practice, is currently unpopular amongst farmers there. This work found that farmers under estimated the productivity of agroforestry systems, were resistant to payment for ecosystem services and were uncertain of their ability to manage agroforestry systems. The researchers suggested that these barriers could be addressed by emphasising the marketing opportunities of tree products, by co-production of agroecological knowledge & technologies and by farmer participation in R&D.

Assessment of the impact of barriers

The decision to adopt an agroforestry system is, by definition, a decision that would shape the long-term direction of any individual land holding. It is easy to see how the compound effect of these economic, policy, investment, agronomic, knowledge and cultural barriers will act as a significant deterrent for potential adopters. This observation is supported by evidence from stakeholders who informed us that there is ‘considerable uncertainty’ amongst farmers in many areas, despite agroforestry being ‘the norm in certain parts of Europe’[25].

They advised that, to overcome these barriers would require:

- User friendly methods to access existing results;
- Biophysical and socio-economic models which can predict yields in different locations;
- Use of GIS-based modelling using LPIS land use information and improved soils datasets;

---

[23] Burgess, P.J., Incoll, L.D., Hart, B.J., Beaton, A., Piper, R.W., Seymour, I., Reynolds, F.H., Wright, C., Pilbeam & Graves, A.R. (2003). The Impact of Silvoarable Agroforestry with Poplar on Farm Profitability and Biological Diversity. Final Report to DEFRA. Project Code: AF0105. Silsoe, Bedfordshire: Cranfield University. 63 pp.

[24] ‘EDUCATION IN AGROFORESTRY: Building today’s and tomorrow’s agriculture’. Final conference of the EU project AgroFE. 9 December 2015.

[25] G Lawson, pers comm

- Participative research methods capturing and disseminating the experience of early adopters

Attitudes of adopters

Despite the range of barriers to participation, some UK based farmers have established agroforestry systems. A case study of 4 early adopters in England (silvo-arable with apple trees), found that 3 considered the establishment to be successful, whilst for the remaining one it was too early to tell[26]. The farmers identified economic benefits (product diversification), agronomic benefits (soil protection, control of pathogens, extended cropping season), social benefits (rural employment), and enhanced biodiversity. Whilst concerns were expressed (inefficiencies in field operations, increased weed burden near to tree rows, tree-crop competition, increased labour requirements, restricted access for agrochemical application and the provision of shelter to animal pests), "*in view of the potential benefits, farmers seemed to consider such trade-offs acceptable".*

Recent work by the Innovative Farmers group suggests one method of reducing tree-crop competition in silvo-pasture systems is the use of Shropshire Sheep: where there is evidence that the sheep will graze the grass sward but (unlike other breeds) will not graze the trees[27].

The negative factors identified by these early adopters all relate to the initial design of the agroforestry system (inefficiencies in field operations, tree-crop competition) and the need for new management skills and operations (controlling the weed burden near to tree rows, effective access for agrochemical application, managing shelter for animal pests, increased labour requirements). This may reinforce the concern that access to skills & knowledge is a significant barrier to greater uptake.

[26] Crossland (2015) Novel agroforestry-based apple production systems: An evaluation of management impacts and opportunities. ORC

[27] http://www.farming.co.uk/news/article/12464

Ecosystem benefits

Ecosystem services therefore are the benefits people obtain from ecosystems.. Some ecosystem services involve the direct provision of material and non-material goods to people and depend on the presence of particular species of plants and animals, for example, food, timber, and medicines. Other ecosystem services arise directly or indirectly from the functioning of ecosystem processes. For example, the service of formation of soils and soil fertility that sustains crop and livestock production depends on the ecosystem processes of decomposition and nutrient cycling by soil micro-organisms.

These benefits can be realised on the individual land holding (e.g. where management produces the provisioning service of crop production) and, where there is co-ordinated action across landholdings, at the landscape scale (e.g. improvements in flood risk management).

Ecosystem Services are usually classified into 4 groupings:

- Provisioning services: the products obtained from ecosystems, for example food and water;
- Regulating services: the benefits obtain from the regulation of ecosystem processes, for example climate regulation and disease and pest regulation;
- Supporting services: Ecosystem services that are necessary for the production of all other ecosystem service, for example soil formation and nutrient cycling;
- Cultural Services: the non-material benefits people obtain from ecosystems, for example recreation and aesthetic experience.[28]

The Land Use Policy Group's (LUPG) 2015 report on the role of Agroecology in Sustainable Intensification[29] (see Annex B – LUPG report extract on ecosystem services) summarises the evidence on agroforestry and ecosystem services suggesting that:

- Whilst most evidence focuses on single ecosystem services, one study looking at several Ecosystem Services found improved performance under an agroforestry system.
- Pest problems can be reduced in agroforestry systems compared to monocropping systems, for instance due to the greater diversity of habitat niches in the system increasing the likelihood of hosting natural enemies of pest species. However, there is some evidence of increases in some pest species, notably slugs.
- Improved nutrient capture within agroforestry systems has agronomic benefits and can reduce nutrient leaching from soils.

[28] UK National Ecosystem Assessment

[29] Lampkin et al. (2015) The Role of Agroecology in Sustainable Intensification

- Planned agroforestry can significantly improve soil infiltration rates, impacting on catchment hydrology. There is evidence that agroforestry systems are more resilient to both drought and to flood events.
- Planned agroforestry can intercept ammonia emissions (with experimental results of between 10-45% ammonia abatement).

A recent meta-analysis[30] of the published scientific literature found a bias towards the assessment of regulation, supporting and provisioning services, with cultural services under-represented in the literature. They also found that individual studies typically focussed on just one or two types of service provision and did not fully assess the overall impact on the range of service provision. Overall however, these meta-analyses reinforce the view that agroforestry, both silvoarable and silvopasture systems can enhance biodiversity and ecosystem service provision.

The following section focusses on evidence produced since (or beyond the scope of) the analysis presented by the LUPG.

Regulating services – Carbon

Whilst Arable and Horticultural land is the most widespread Broad Habitat type in Great Britain, it has the lowest carbon density[31]. Agroforestry is recognised as a practice that increases the carbon stock on agricultural land through both the cessation of cultivation (on arable land) under the planted trees enabling soil carbon stocks to increase and the accumulation of carbon in the growing trees. Evidence from the Henfaes experimental plot at Bangor University also indicates increased soil organic carbon levels under silvopastoral systems compared to a pasture control[32].

The Climate Change Committee[33] focussed on agroforestry as one of the main opportunities for increasing carbon sequestration in the Land Use, Land Use Change & Forestry sector during the 5th Carbon budget period (2028-2032). Their 'maximum scenario' assessment suggests, with policy support, agroforestry establishment on 1.1% of UK agricultural land could achieve greenhouse gas (GHG) savings of 1.16MtCO2 by 2030 (not including GHG savings from reduced fertiliser use). In contrast, their 'barriers scenario' in which no policy support is given, achieves 0.2MtCO_2.

[30] Fagerholm et al. : A systematic map of ecosystem services assessments around European agroforestry; Ecological Indicators 62 (2016) 47-65 and
Torralba et al. : Do European agroforestry system enhance biodiversity and ecosystem services? A meta-analysis; in Agriculture, Ecosystems and Environment 230 (2016); 150-161

[31] Ostle et al. (2009): UK Land Use and soil carbon sequestration. Land Use Policy 265. S274-S283

[32] Agroforestry research at Henfaes; paper submitted by Pagella, T.

[33] Climate Change Committee. Sectoral scenarios for the fifth carbon budget.

New work by Garcia de Jalon et al. [34] values the difference in GHG emissions and sequestration between arable and silvoarable (poplars) as €83/ha/year.

Stakeholders also referred to the ability of trees to absorb ammonia, such as that associated with agriculture, thereby reducing the conversion of ammonia into nitrous oxide (a potent GHG).

<u>Regulating Services – Water and flood risk</u>

ThE LUPG report[35] summarised the wide evidence base on the potential for agroforestry to improve water quality and flood risk management. Stakeholders supported this evidence and pointed to the importance of location, layout and density of trees as essential criteria to address in any new system design if these potential benefits are to be realised[36].

The experiences of agroforestry at Pontbren show how societal benefits for flood risk management require coordinated actions across multiple landholdings across individual catchments[37].

<u>Supporting Services – Pest regulation and Disease management</u>

The LUPG report identified mostly positive evidence on the impact of agroforestry on populations of pests (with a negative impact on slugs). They reported a theoretical potential for agroforestry to support disease management in trees but found that little work had been done to investigate this issue.

More recently an MSc project found Carabid beetle distributions were more uniform across silvoarable fields when compared to an arable control (where Carabids were strongly association with field margins). The author postulated that in this way silvoarable farming could therefore enhance biological pest control by carabids[38].

<u>Supporting services - Biodiversity</u>

The LUPG report notes several field studies of biodiversity in existing agroforestry systems in the UK. These have found:

- Higher abundance and species richness of invertebrates (silvo-pasture compared to open grassland in NI and Scotland).

---

[34] Garcia de Jalon et al. (2016): ASSESSING THE ENVIRONMENTAL EXTERNALITIES OF ARABLE, FORESTRY, AND SILVOARABLE SYSTEMS: NEW DEVELOPMENTS IN FARM-SAFE; supplied by Burgess, P.

[35] See Annex 2

[36] Lawson, G. pers comm.

[37] Pagella, T et al. : Pont Bren Case Study. Presentation provided by Briggs, S.

[38] Sharman, J: The Impact of Organic Silvoarable Farming on Ground Beetle Populations and Implications ofr Biological Control. Nottingham Trent University.

- Higher abundance and species richness of airborne arthropods (silvo-arable compared to an arable control in England).
- Mixed results for carabid beetles, with some species more common in the agroforestry system and others more common in an arable control system (silvo-arable compared to an arable control in England).
- Higher abundances of spiders in vegetated understoreys (silvo-arable compared to bare under-storeys).
- Higher numbers of small mammals (silvo-arable compared to arable and forestry control areas).
- Higher abundance and species diversity of butterflies and pollinators (compared to control sites).

The LUPG report also notes some evidence (not UK based) for beneficial impacts at the landscape scale, where scattered trees in an agricultural landscape can provide stepping stones and corridors, enabling the movement of species; and of possible impacts beyond the landscape scale, where agroforestry systems provide a habitat for migratory species, (with the decline in availability of agroforestry habitat in one zone being correlated to a decline in presence of certain migratory bird species at the other end of the migratory range).

As Torralba et al. found in their meta-analysis of existing evidence in relation to European agroforestry:

> *"Our analysis shows a strong positive effect of agroforestry on biodiversity, which is in line with findings from other parts of the world."*

<u>Provisioning Services - Food</u>
The LUPG report summarised the evidence of increased productivity (measured as Land Equivalent Ratios) from agroforestry systems compared against monocropping systems.

Torralba et al.[39], in their meta-analysis of ecosystem service provision found that individual studies tended to focus on individual provisioning service elements (e.g. timber or crops or pasture) and did not consider the full range of provisioning services produced.

<u>Regulating Services – Animal health & welfare</u>
The LUPG report summarises the well-developed evidence base on the value of trees to farm livestock. Benefits accrue from protection against colder and hotter extremes. There is also evidence that the health and welfare benefits of tree cover link through to production benefits (e.g. lower mortality of laying hens and improved egg condition).

---

[39] Torralba et al. (2016) op cit

In the context of silvopasture, on-going work at Harper Adams University suggests that the integration of trees into dairy systems can improve carbon and nitrogen efficiency and provide health benefits to the cattle through the provision of trace elements that might otherwise have to be supplied through mineral concentrates[40].

Cultural Services

The meta-analyses by Fagerholm et al. [41] and Torralba et al. [42], both found that cultural services were under-assessed in the scientific literature.

Evidence from the Pontbren project suggests that valuable cultural services can be derived from actions designed to achieve other ecosystem service benefits. These cultural benefits include both private benefits to the farmer (a sense that the farms had been ‘tidied up’) and societal benefits (through increased social interaction and the unofficial use of the area as an educational resource or demonstration project). Stakeholders also advised of the potential benefits of agroforestry systems for game management[43].

Summary

There is a wide range of evidence relating to ecosystem service provision from agroforestry systems. Much of the evidence base suggests positive benefits for ecosystem service provision.

The meta-analyses by Fagerholm and Torralba concluded that there are gaps in the evidence base, indicating a need for research on socio-cultural aspects and studies addressing a wider range of ecosystem services. They also recommend stronger stakeholder participation and the introduction of spatially explicit mapping.

The evidence base indicates that ecosystem service provision actually achieved by agroforestry in the field depends on choices about system design and the subsequent management. This also suggests the importance of ensuring that adopters have access to the skills and knowledge required to design and manage a system that suits the particular location.

---

[40] Saunders, T: The Nutritional and Medicinal Value of Trees in a Dairy System. Presentation supplied by Briggs, S.

[41] Fagerholm et al. op cit

[42] Torralba et al. op cit

[43] Leake, A. pers comm.

Cost benefits of agroforestry

The AgForward project and other studies are attempting to monetise the ecosystem services which arise from the adoption of agroforestry.

Porter et al. (2009)[44] calculated the values of market and non-market ecosystem services of a novel combined food and energy agroforestry system in Taastrup, Denmark. Belts of fast-growing trees (hazel, willow and alder) for bioenergy production are planted at right angles to fields of cereal and pasture crops, and the system is managed to organic standards that include the prohibition of pesticides and inorganic N. Field-based estimates of ecosystem services including pest control, nitrogen regulation, soil formation, food and forage production, biomass production, soil carbon accumulation, hydrological flow into ground water reserves, landscape aesthetics and pollination by wild pollinators produced a total value of US $1,074 per hectare of which 46% is from market ecosystem services (production of food, forage and biomass crops) and the rest from non-market ecosystem services. Porter et al. (2009) then extrapolated these values to the European scale and calculated that the value of nonmarket ecosystem services from this novel system exceeds current European farm subsidy payments.

Economic performance of agroforestry systems vary. A review by Doyle and Waterhouse (2008)[45] on studies of UK agroforestry systems (Table 3) found a wide range of results, with some studies reporting equivalent or higher returns from agroforestry:

Table 3: Economic returns from different types of agroforestry as compared to conventional agriculture

Comparator farming system	% economic returns
Hill sheep farming in West coast of Scotland	86% - 106%
Hill sheep farming in Scotland	76% - 90%
Lowland cereals	85% - 98%
Cereal-grass system	52% - 65%

The studies showed that the potential profitability of agroforestry depends on a number of issues including tree species, land type, assumptions regarding the

44 Porter et al. . 2009. The Value of Producing Food, Energy, and Ecosystem Services within an Agro-Ecosystem. *AMBIO: A Journal of the Human Environment* 38(4):186-193.

45 C.J. Doyle and T. Waterhouse. 2008. Social and Economic Implications of Agroforestry for Rural Economic Development in Temperate Regions. In: Daizy Rani Batish et al. . ed. *Ecological Basis of Agroforestry*. CRC Press pp.303-318.

impact over time of canopy closure on the production of the understorey crop and the choice of the discount rate (Doyle and Waterhouse, 2008).

Alavalapati et al. (2004)[46] used a 'willingness to pay' approach to identify the economic consequences of internalising nonmarket goods and services from agroforestry to the benefit of landowners. They found that by including payments for environmental services delivered by agroforestry, the profitability of these systems would increase, relative to conventional agricultural systems.

The Land Use Policy Group (LUPG) report on the role of Agroecology in Sustainable Intensification[47] looked at the profitability of agroforestry. An extract from the report can be found in Annex B – LUPG report extract on ecosystem services.

[46] Alavalapati, J.R.R. and E. Mercer. 2004. *Valuing agroforestry systems: Methods and applications*, Kluwer Academic Press, Dordrecht, The Netherlands, pp 1-314

[47] Lampkin et al. (2015) The Role of Agroecology in Sustainable Intensification

Agroforestry and RDPE

There is a dedicated agroforestry measure (Article 23) within the Rural Development Regulation but there are also other rural development measures that can be used in conjunction with agroforestry or in support of agroforestry systems – bearing in mind that the agroforestry system itself comprises two elements: agriculture and forestry.

a) Agri-environment and Climate (AEC) measure Article 28
As implemented under Countryside Stewardship (CS) the AEC measure can be used to support and create specific agroforestry systems – under the options for woodpasture, parkland, and orchards. However, these options are focused on sites where these habitats already exist or where there is a high chance that these habitats can be restored. Under the current CS targeting and option eligibility arrangements these options are unlikely to be implemented in a way that increases the stock of agroforestry outside these parameters.

In addition the woodland element of agroforestry could be supported by the planting of discreet rows of trees in non-forestry situations on grassland or arable. However, planting trees under the AEC measure rather than the Forestry measure (Article 22) is limited to small scale situations where there is little or no impact on agricultural productivity: essentially situations that are below the minimum thresholds set out in the Forestry measures – see below.

CS can also be used to support the management and planting of hedgerows in support of a "bocage" style of agroforestry (the hedgerow systems of Brittany, France, which are an ancient form of **agroforestry).**

In addition, the land management options of CS (grassland and arable) can be used to support enhanced environmental benefits on the land between rows of trees as an alternative to a production focus for the agricultural element of agroforestry). In alley cropping systems it might also be possible to use some of the linear agri-environment options to support the management of the land at the base of the tree strips (e.g. buffer strips, beetle banks, pollen & nectar strips) but this would depend on RPA's view regarding land use and the assurance that CS management and agroforestry management are mutually compatible.

Generally speaking, the impetus for an AEC approach to agroforestry would be to optimise the environmental benefits of the agricultural by making income foregone payments on the farmed area to reflect the degree of extensification required by the system. These payments could be supported by AEC capital works for fencing and water provision etc. to facilitate conservation grazing. This approach would therefore be focused on locations that are priorities for AEC – this would focus the adoption of agroforestry practices (to those areas where environmental benefits could be optimised) and thereby restrict the areas where AEC could be used for agroforestry.

b) Forestry measure (first afforestation) Article 22

This measure is aimed at providing and improving forest rather than simply introducing trees to farmland. However, provided that the planting and management of trees in agroforestry systems could meet the requirements of this measure (see Table 4 below) then these options can be used to support the woodland element of agroforestry. The type of tree that may be planted is limited by scheme rules to those that are:

> *"appropriate to meet the objectives of the woodland planting and be ecologically adapted and resilient to climate change in the bio-geographical area concerned and shall take account of site specific pedologic and hydrologic conditions*" (RDPE 2014-20 section 8.2.6.3.1.6).

In addition there are Regulation requirements that exclude the use of this measure for establishing: short rotation coppice, Christmas trees and fast growing trees for energy production (EU 1305/2013 Article 22. Para 2). In practice the use of this measure would tend to create blocks of trees within agricultural land rather than a fully integrated agroforestry system.

Table 4: Creating or restocking woodland – requirements of the Forestry measure[48]

Dimensions	Create new woodland	Create new woodland to improve water quality or reduce flood risk	Restock after a tree health issue
Minimum agreement size	3ha	1ha	0.5ha
Minimum block size	0.5ha	0.1ha	0.5ha
Minimum width	20m	10m	20m
Minimum stocking density	400 stems per ha (sph)	1,600sph	400sph
Maximum internal open space	20%	20%	20%
Maximum individual glade area (after canopy closure)	0.5ha	0.5ha	0.5ha
Maximum linear open space width (after canopy closure)	20m	20m	

[48] https://www.gov.uk/countryside-stewardship-grants/supply-and-plant-tree-te4

If trees are planted under the Forestry measure to facilitate an agroforestry system then the management of the agricultural land (between the trees) could be either unsupported (i.e. normal production), or supported under AEC for modified practices.

First afforestation is not currently an English Ecological Focus Area (EFA) but is one of the land uses that Member States could select as an EFA.

c) Organic measure Article 29
The organic measure could be used to support the agricultural element of an agroforestry system on organic land (including land under conversion to organic farming) and could be topped up with further modified practices under AEC measures. The wooded area could also be supported as organic provided it met the requirements of the Top Fruit land use. Organic land (including land under conversion to organic) is not subject to the greening measures.

d) Forestry measure (Prevention and restoration of damage) Article 24
Paragraph 1(b) of Article 24 permits the use of *local, small scale prevention activities against fire or other natural hazards; including the use of grazing animals*. The use of grazing animals in this context is clearly limited to the contribution that their grazing can make to controlling vegetation and thereby enhance and maintain firebreaks. It is therefore only applicable to the management of fire risk and in England this aspect of the Regualtionss has not been implemented because this would require “Identification of forest areas classified as being at medium to high risk of forest fire” – and no such classification exists in England (RDPE 2014-2020 p.347)

e) Forestry measure (Agroforestry) Article 23
The agroforestry measure provides support for similar actions to those fostered by the measures set out above. The major difference is that agroforestry merely requires the establishment of an agroforestry system - with little concern as to the intensity or impact of that system. So AEC could be used to support extensive agroforestry whilst this measure would support agroforestry per see (including intensive agroforestry). The measure allows for support for the initial establishment of trees and an annual maintenance payment for up to 5 years. The payments for the initial establishment of trees can include items that are vital to the establishment of an agroforestry system - like fences and watering facilities and the annual maintenance payment can include payments for managing the trees and the protective actions required to maintain the system e.g. relating to fencing and water provision. The rate cannot exceed 80% of these costs (EU 1305/2013 Annex II). There are no provisions for *income foregone* within the Regulations for this measure. Land under agroforestry has not currently been selected in England as eligible for EFA but is one of the land uses that Member States could select as an EFA.

Given the importance of the initial design of a new agroforestry system, it may be beneficial to use a planning capital item (such as a Feasibility Study or

Implementation Plan) to buy in the necessary support for the initial planning stage of a new system.

The current suite of Rural Development measures, adopted in England, are therefore capable of addressing some of the barriers to uptake of agroforestry practices. However, there are limitations to the level of impact that these measures alone can have on the adoption of agroforestry. For example the current measures support the modification of agricultural practice and/or the planting of trees rather than the integration required of an agroforestry system. Whilst the Rural Development agroforestry measure is aimed at filling this gap it is also focused on the elements of agroforestry rather than the system, in as much that it provides support for the planting and post planting management of the tree component but does little to address the wider aspects of the system.

In addition, the agroforestry sector recognises that the Basic Payment Regulation tends to identify agricultural land and woodland as separate and definable categories of land use. The former being eligible for Basic Payments whilst the latter is not. As a consequence land managers may be reluctant to undertake new activities (such as agroforestry) if it would mean a negative impact on their Basic Payment. Even when land is not considered to be woodland, but has trees upon it, there are further concerns within the agroforestry sector that this land does not meet the criteria for eligible agricultural land. These issues can only be resolved within Pillar I (Basic Payment Scheme(BPS)) but have a consequence for Pillar II because the “attractiveness” of a Pillar II scheme, in part, depends on the impact of that scheme on Pillar I payments.

Agroforestry payments

If the agroforestry measure was implemented there are two possibilities for calculating payment rates: either, use the costs and prices that were used for the other elements of CS; or, undertake a new assessment of prices and costs. The former would be challenged for being out-of-date, the latter would probably produce figures that are different (higher) to those currently used in CS – which would bring pressure for a wide ranging payment review. These costs would be converted into an area cost and thereby an annual area payment (based on the number of trees that are required to be planted per hectare). Additional costs may be included but the guidance from the Commission suggests that this is limited to those costs associated with the implementation of an agroforestry system e.g. fencing and water provision when introducing pastoral systems under agroforestry.

The costs of tree planting would be broadly similar to existing CS options but the payments are affected by the limits permitted by the regulations. AEC has a maximum rate of 100% whilst for agroforestry it is 80% (however, AEC tree planting is funded at around 80%). This reflects the more restrictive requirements of AEC and the recognition that agroforestry is concerned with setting up a productive system that generates other benefits rather than an environmental system that can also be used for production.

Table 5 below demonstrates that the cost of tree establishment varies considerably with the size and quality of the planting stock. For agroforestry, a decision would need to be made with regard to this aspect. Planting mature trees is more expensive but reduces the time taken to establish compared to younger stock. The payment per hectare would also be influenced by the planting density (which needs to be determined by the Member State).

Table 5: Cost of tree establishment

	Forestry cost £/tree	Forestry payment £/tree	AEC cost £/tree	AEC payment £/tree
Tree planting	1.60	£1.28[49]		
Orchard tree			28.41	22.50[50]
Standard tree			11.10	8.80[51]
Parkland standard tree			30.66	24.50[52]

49 https://www.gov.uk/countryside-stewardship-grants/supply-and-plant-tree-te4

50 https://www.gov.uk/countryside-stewardship-grants/planting-fruit-trees-te3

51 https://www.gov.uk/countryside-stewardship-grants/planting-standard-hedgerow-tree-te1

52 https://www.gov.uk/countryside-stewardship-grants/planting-standard-parkland-tree-te2

The measure allows for an annual payment to be made in respect of managing the trees established under the measure. In the main this would be the pruning of side branches and possibly mowing of the vegetation under the tree. There are no real equivalents in CS but a possible assumption would be something along the lines of 5 minutes work per tree per year at a rate of say £18/hr = £1.50/tree. 1.50 x 80% = £1.20/tree. If this work is carried out on average once in two years then £0.60/tree.

The agroforestry measure is concerned with the establishment of agroforestry systems. This suggests that there would be some requirement to check not just that trees have been planted but also that a "system" has been established – i.e. that there is some integration between the trees and agriculture. This aspect requires further investigation (the Commission guidance is silent on this matter) which could involve some form of planning by the applicant, an assessment of the plan, and annual assurance that the system has been maintained. If it is necessary to make payments dependent upon evidence that a system is present then further clarification will be required from the Commission as to whether the costs of providing this evidence can be legitimately included within the costs of implementation [of this measure] and thereby may be compensated for within the payment rate.

Annex A – definitions of agroforestry

The definition in the ***EU RDR Agroforestry Fiche***[53]:
"Agroforestry means land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same land management unit."[54]

"The trees may be single or in groups inside parcels (silvoarable agroforestry, silvopastoralism, grazed or intercropped orchards) or on the limits between parcels (hedges, tree lines). Agroforestry, the integration of trees, crops and/or livestock on the same area of land, has been identified by the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)[55] *as a 'win–win' multifunctional land-use approach that balances the production of commodities (food, feed, fuel, fibre, etc.) with non-commodity outputs such as environmental protection and cultural and landscape amenities".*

The **AGFORWARD**[56] research programme definition:
"The practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems"

The ***Agroforestry Research Trust's***[57] (UK) definition is that:
"Agroforestry is the integration of trees and agriculture to produce a diverse, productive and resilient system for producing food, materials, timber and other products. It can range from planting trees in pastures providing shelter, shade and emergency forage, to forest garden systems incorporating layers of tall and small trees, shrubs and ground layers in a self-sustaining, interconnected and productive system".

And the ***International Centre for Research into Agroforestry (ICRA)*** uses Lundgren & Raintree, 1982[58]:
"Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components."

---

[53] Note that the Agroforestry Measure of the RDR requires the inclusion of (at least some) 'forest tree species', so may preclude support for only fruit/nut tree systems, such as undergrazed or intercropped orchards. Member States are given a high degree of discretion in the choice of tree species by submitting their own lists of allowable tree species;

[54] Agriculture and the Environment IX, Valuing Ecosystems: Policy, Economic and Management Interactions (2012), *Developing modern, multifunctional agroforestry systems for sustainable intensification*: http://orgprints.org/21905/1/2012.Smith%20SACSEPA.pdf

[55] http://www.unep.org/dewa/Assessments/Ecosystems/IAASTD/tabid/105853/Defa

[56] http://www.agforward.eu/index.php/en/

[57] See https://www.agroforestry.co.uk/about-agroforestry/

[58] Lundgren, B.O. and Raintree, J.B. 1982. *Sustained agroforestry*. In: Nestel, B. (ed.), Agricultural Research for Development: Potentials and Challenges in Asia, pp. 37-49. ISNAR, The Hague, The Netherlands

Annex B – LUPG report extract on ecosystem services

Ecosystem Services

The impact of agroforestry on the environment occurs at a range of spatial and temporal scales; externalities from farming systems impact the environment and society at regional or national scales. Agroforestry systems are multifunctional but most research focuses on a single function. One of the few studies to consolidate the multiple services from a single agroforestry system reports on ten years of research on agroforestry strips of hybrid plane (*Platanus hybrida*) and the shrub *Viburnum opulus* in north-east Italy (Borin et al., 2009[59]). The young tree strips reduced total runoff by 33%, Nitrogen (N) losses by 44% and Phosphorus (P) losses by 50% compared to non-buffer controls, while a mature buffer reduced both NO3-N and dissolved phosphorus by almost 100%. Herbicide abatement was between 60 and 90% depending on the chemical and time since application, and it was calculated that the buffer strips sequestered up to 80 t C ha-1 yr-1. The tree strips caused negligible disturbance to maize, soybean and sugarbeet yields, and contributed to increasing the aesthetic value of the landscape based on a visual aesthetic index formulated from people's preferences during interviews (Borin et al., 2009[60]).

Pest regulation

Reduced pest problems in agroforestry systems are predicted and can be observed due to greater niche diversity and complexity than in monocropping systems (Stamps and Linit, 1998[61]). Agroforestry systems can be managed to enhance pest regulation, for example by providing sources of adult parasitoid food (e.g. flowers), and sites for mating, oviposition and resting sites (Young, 1997[62]; Stamps and Linit, op cit. [63]). An example of this is the use of flowering understoreys in orchards. Trees provide greater structural and microclimate diversity, greater temporal stability,

[59] Borin, M., Passoni, M., Thiene, M., Tempesta, T., 2009. Multiple benefits of buffer strips in farming areas. *European Journal of Agronomy*. 32(1)103-111.

[60] Borin, M., et al. , *op cit*.

[61] Stamps, W.T., Linit, M.J., 1998. Plant diversity and arthropod communities: Implications for temperate agroforestry. *Agroforestry Systems* 39, 73-89.

[62] Young, A., 1997. *Agroforestry for Soil Management.* Wallingford: CABI Publishing.

[63] Stamps, W.T., Linit, M.J., 1998. Plant diversity and arthropod communities: Implications for temperate agroforestry. *Agroforestry Systems* 39, 73-89.

greater biomass and surface area, alternative sources of pollen, nectar and prey, alternative hosts and stable refugia. Trees, hedgerows and other permanent non-cropped areas of agroecosystems provide shelter for overwintering natural enemies, as well as alternative food sources when crop pest populations are reduced following harvest (Dix et al., 1995[64]; Schmidt and Tscharntke, 2005[65]).

However, some pest groups such as slugs have been observed in higher numbers in agroforestry systems, and shifts in the relative importance of pest groups may present novel management problems and influence crop choice. Griffiths et al. (1998[66]) observed increased slug populations in agroforestry plots compared to arable controls in a silvoarable experiment in West Yorkshire. Levels of slug damage correlated with slug abundance, with lower numbers of emerging pea plants and higher levels of leaf damage in drill rows next to the tree rows than in the arable control. It was suggested that silvoarable systems can enhance slug populations and activity in two ways. Firstly, slug populations in arable areas are reduced by soil cultivations; permanent, unploughed vegetated areas under the tree rows in agroforestry systems provide refugia for both slugs and their natural enemies. Secondly, the microclimate of the agroforestry system is modified by the presence of the trees and understorey vegetation, with higher levels of soil moisture favouring slug and other populations (Griffiths et al., op cit. [67]).

An alley-cropping system with peas (*Pisum sativa*) and four tree species (*Juglans, Platanus, Fraxinus* and *Prunus*) in Leeds supported higher insect diversities and natural enemy abundance, and lower abundances of pea and bean weevils (*Sitona spp.*) and pea midge (*Contarinia pisi*) compared to a monoculture of peas (Peng et al., 1993[68]). In this same silvoarable system, grain aphid (*Sitobion avenae*)

---

[64] Dix, M.E., Johnson, R.J., Harrell, M.O., Case, R.M., Wright, R.J., Hodges, L., Brandle, J.R., Schoeneberger, M.M., Sunderman, N.J., Fitzmaurice, R.L., Young, L.J., Hubbard, K.G., 1995. Influences of trees on abundance of natural enemies of insect pests: A review. *Agroforestry Systems* 29, 303-311.

[65] Schmidt, M., Tscharntke, T., 2005. The role of perennial habitats for central European farmland spiders. *Agriculture, Ecosystems and Environment* 105 (1-2), 235-242.

[66] Griffiths, J., Phillips, D.S., Compton, S.G., Wright, C., Incoll, L.D., 1998. Responses of slug numbers and slug damage to crops in a silvoarable agroforestry landscape. *Journal of Applied Ecology* 35, 252-260.

[67] Griffiths, J., Phillips, D.S., Compton, S.G., Wright, C., Incoll, L.D., 1998. Responses of slug numbers and slug damage to crops in a silvoarable agroforestry landscape. *Journal of Applied Ecology* 35, 252-260.

[68] Peng, R.K., Incoll, L.D., Sutton, S.L., Wright, C., Chadwick, A., 1993. Diversity of airborne arthropods in a silvoarable agroforestry system. *Journal of Applied Ecology* 30, 551-562.

populations in the winter barley crop were approximately half that of the arable control (Naeem et al., 1994[69]). This was attributed to an increase in cereal aphid predators, primarily hoverflies (*Diptera: Syrphidae*), which used the tree-strips as a refuge (Phillips et al., 1994[70]).

Agroforestry systems have also been shown to support higher bird populations which are likely to contribute to invertebrate pest regulation (Williams et al., 1997[71]). In Iowa and Illinois, USA, Best et al. (1990[72]) recorded seven times as many birds and twice as many breeding bird species in woody edge habitats compared to herbaceous edge habitats.

Disease management

The potential for agroforestry to reduce disease pressure in trees has not been investigated fully, but it is likely that widely-spaced trees could be less susceptible to some tree diseases. A current EU-funded project, CO-Free[73], is investigating the potential of agroforestry as a strategy to replace copper-based products as plant protection products in organic top fruit systems. Integrating top fruit production into an agroforestry system, where woody species are integrated with crop production may have a beneficial effect on the control of plant pathogens such as scab (Venturia inaequalis) due to a number of mechanisms:

- a greater distance between tree rows in agroforestry systems, with crops in the adjoining alleys, is likely to reduce the spread of pathogens - this has been recorded for other crop pathogens (Schroth et al., 1995[74]);

[69] Naeem, M., Compton, S.G., Phillips, D.S., Incoll, L.D., 1994. Factors influencing aphids and their parasitoids in a silvoarable agroforestry system. *Agroforestry Forum* 5(2), 20-23.

[70] Phillips, D.S., Griffiths, J., Naeem, M., Compton, S.G., Incoll, L.D., 1994. Responses of crop pests and their natural enemies to an agroforestry envronment. *Agroforestry Forum* 5(2), 14-20.

[71] Williams, P.A., Gordon, A.M., Garrett, H.E., Buck, L., 1997. Agroforestry in north America and its role in farming systems. In: Gordon, A.M., Newman, S.M., (eds.) *Temperate Agroforestry Systems*. Wallingford: CABI Publishing, 9-84.

[72] Best, L.B., Whitmore, R.C., Booth, G.M., 1990. Use of cornfields by birds during the breeding season: The importance of edge habitat. *American Midland Naturalist* 123, 84-99.

[73] http://www.co-free.eu/

[74] Schroth, G., Balle, P., Peltier, R., 1995. Alley cropping groundnut with *Gliricidia sepium* in Cote d'Ivoire: Effects on yields, microclimate and crop diseases. *Agroforestry Systems* 29, 147-163.

- lower densities of trees favour increased air circulation which has been shown to reduce the severity of scab by reducing leaf wetness duration (Carisse and Dewdney, 2002[75]);
- regular cultivations within the crop alleys will incorporate leaf litter into the soil, thus enhancing decomposition and reducing the risk of re-inoculation from winter-surviving scabbed leaf litter the following Spring.

Soil and nutrient management

Agroforestry systems can promote more sustainable, closed systems with regard to the internal recycling of nutrients. Within agroforestry systems, nutrients are accessed and intercepted from lower soil horizons by tree roots and returned to the soil through leaf fall. Agroforestry systems thereby enhance soil nutrient pools and turnover and reduce reliance on external inputs. For example, leaf fall from 6-year-old poplars in an agroforestry system resulted in mean soil nitrate production rates in the adjacent crop-alley up to double that compared to soils located 8-15 m from the tree row, and nitrogen release from poplar leaf litter was equivalent to 7 kg N ha-1 yr-1 (Thevathasan and Gordon, 2004[76]). Trees can also significantly influence nutrient additions to adjacent alley crops through intercepting rainfall (which contains dissolved, fixed nitrogen, via throughfall (rainwater falling through tree canopies) and stemflow (rainwater falling down branches and stems). Zhang (1999, in Thevathasan and Gordon, 2004[77]), showed that these pathways contributed 11 and 15 kg N ha-1 yr-1 in hybrid poplar and silver maple systems respectively.

Research has demonstrated that agroforestry vegetation buffers can reduce pollution from crop fields and grazed pastures (Udawatta et al., 2002[78]; Lee and Jose, 2003[79];

[75] Carisse, O., Dewdney, M., 2002. A review of non-fungicidal approaches for the control of apple scab. *Phytoprotection* 83, 1-29.

[76] Thevathasan, N.V., Gordon, A.M., 2004. Ecology of tree intercropping systems in the north temperate region: Experiences from southern ontario, canada. *Agroforestry Systems* 61, 257-268.

[77] Thevathasan, N.V., Gordon, A.M., 2004. Op cit.

[78] Udawatta, R.P., Krstansky, J.J., Henderson, G.S., Garrett, H.E., 2002. Agroforestry practices, runoff, and nutrient loss: A paired watershed comparison. *Journal of Environmental Quality* 31, 1214-1225.

[79] Lee, K.H., Jose, S., 2003. Soil respiration and microbial biomass in a pecan-cotton alley cropping system in southern USA. *Agroforestry Systems* 58, 45-54.

Anderson et al., 2009[80]; Dougherty et al., 2009[81]; Udawatta et al., 2010[82]). Riparian buffers in particular, can reduce non-point source water pollution from agricultural land by reducing surface runoff from fields; filtering surface and groundwater runoff and stream water, and reducing bank erosion (Dosskey, 2001[83]).

The 'safety net hypothesis' is based on the belief that the deeper-rooting tree component of an agroforestry system will be able to intercept nutrients leached out of the crop rooting zone, thus reducing pollution and, by recycling nutrients as leaf litter and root decomposition, increasing nutrient use efficiencies (Jose et al., 2004[84]). Greater permanence of tree roots means that nutrients are captured before a field crop has been planted and following harvest, when leaching may be greater from bare soil.

Water and flood management

Buffer strips can significantly decrease pollution run-off, with reductions of 70-90% reported for suspended solids, 60-98% for phosphorus and 70-95% for nitrogen (Borin et al. , 2009[85]). A study in central Iowa, US, found that a switch-grass/woody buffer removed 97% of the sediment, 94% of the total N, 85% of the nitrate-N, 91% of the total P and 80% of the phosphate P in the runoff (Lee et al.., 2003, op cit[86]). Agroforestry systems also have the potential to mitigate movement of harmful

[80] Anderson, S.H., Udawatta, R.P., Seobi, T., Garrett, H.E., 2009. Soil water content and infiltration in agroforestry buffer strips. *Agroforestry Systems* 75, 5-16.

[81] Dougherty, M.C., Thevathasan, N.V., Gordon, A.M., Lee, H., Kort, J., 2009. Nitrate and *escherichia coli* nar analysis in tile drain effluent from a mixed tree intercrop and monocrop system. *Agriculture, Ecosystems and Environment* 131, 77-84.

[82] Udawatta, R.P., Garrett, H.E., Kallenbach, R.L., 2010. Agroforestry and grass buffer effects on water quality in grazed pastures. *Agroforestry Systems* 79(1), 81-87.

[83] Dosskey, M.G., 2001. Toward quantifying water pollution abatement in response to installing buffers on crop land. *Environmental Management* 28(5), 577-598.

[84] Jose, S., Gillespie, A.R., Pallardy, S.G., 2004. Interspecific interactions in temperate agroforestry. *Agroforestry Systems* 61, 237-255.

[85] Borin, M., Passoni, M., Thiene, M., Tempesta, T., 2009. Multiple benefits of buffer strips in farming areas. *European Journal of Agronomy*. 32(1)103-111.

[86] Lee, K.H., Jose, S., 2003. Soil respiration and microbial biomass in a pecan-cotton alley cropping system in southern USA. *Agroforestry Systems* 58, 45-54.

bacteria such as Escherichia coli into water sources (Dougherty et al., 2009[87]) and reduce the transport of veterinary antibiotics from manure-treated agroecosystems to surface water resources (Chu et al., 2010[88]). Agroforestry has been used to address issues of soil salinisation in Australia where a study recorded a lowering of the saline groundwater table by two metres over a seven-year period under a Eucalyptus-pasture system, relative to nearby pasture-only sites (Bari and Schofield, 1991[89]).

During drought periods, tree roots access deeper soil horizons for water, reduce evapotranspiration from the understorey vegetation and provide shade for crops and livestock. Easterling et al. (1997[90]) used a crop modelling approach to look at the effect of climate change on shelterbelt function and found that under several climate change scenarios, windbreaks could help maintain crop production, with sheltered crops performing better than unsheltered crops.

During flooding events, where trees are present as part of agroforestry systems, the tree roots access deeper soil horizons and a larger area than surface crops. When land is flooded the trees work like 'pumps', removing water from the upper soil layer quicker than from land cropped with monocultures. Research at INRA, France has demonstrated that access to land for agricultural purposes after flooding events can be 7-14 days sooner under agroforestry than for land cropped as a monoculture (Dupraz et al., pers. comm).

Research to investigate the impact of land management changes on soil hydrology and flood risk was carried out at the Pontbren experimental catchments in Wales

[87] Dougherty, M.C., Thevathasan, N.V., Gordon, A.M., Lee, H., Kort, J., 2009. Nitrate and *escherichia coli* nar analysis in tile drain effluent from a mixed tree intercrop and monocrop system. *Agriculture, Ecosystems and Environment* 131, 77-84.

[88] Chu, B., Goyne, K.W., Anderson, S.H., Lin, C.-H., Udawatta, R.P., 2010. Veterinary antibiotic sorption to agroforestry buffer, grass buffer and cropland soils. *Agroforestry Systems* 79(1), 67-80.

[89] Bari, M.A., Schofield, N.J., 1991. Effects of agroforestry-pasture associations on groundwater level and salinity. *Agroforestry Systems* 16, 13-31.

[90] Easterling, W.E., Hays, C.J., Easterling, M.M., Brandle, J.R., 1997. Modeling the effect of shelterbelts on maize productivity under climate change: An application of the Epic model. *Agriculture, Ecosystems and Environment* 61, 163-176.

between 2004 and 2012 (Jackson et al., 2008[91]; Woodland Trust, 2013[92]). Small-scale manipulation plots were used to monitor the hydrological effects of de-stocking and native broadleaf tree planting under controlled conditions. Planting native broadleaved trees significantly improved soil infiltration rates five years after treatment application, with infiltration rates in the tree plots 13 times and 67 times greater than in the ungrazed and grazed plots respectively. This increase in infiltration was attributed to changes in the soil macropore structure and was associated with a reduction in soil bulk density in the upper soil horizons. Associated with increases in soil infiltration were reductions in surface runoff. Land management was also shown to affect stream flow responses with shorter residence times (i.e. flashier stream flow response and increased flood peaks) associated with catchments dominated by improved grassland land use. Using the data from Pontbren, a multidimensional physically-based model has shown how careful placement of small strips of trees within a hillslope can reduce magnitudes of flood peaks by 40% at the field scale (Jackson et al., 2008, op cit[93]).

The Pontbren Project, a farmer-led initiative that used woodland management and tree planting to improve the efficiency of upland livestock farming within one of the wettest areas of the UK, has been a highly successful example of the multiple benefits of integrating trees and woods into farm management (Woodland Trust, 2013, op cit[94]). A group of ten farmers managing a total of 1000 ha within the Pontbren catchment near Welshpool came together in 2001 to make their businesses more sustainable by planting more than 10 miles of hedges and 120,000 trees and shrubs to provide shelter for livestock. It soon became apparent that tree planting not only benefitted the farm business and wildlife habitats but also reduced water run-off during heavy rain, and the project became the focus of scientific research into the effects of land use in catchments prone to flooding (Jackson et al., 2008[95]).

Air quality

Ammonia (NH_3) can result in damage to sensitive plants and soil ecosystems as well as to human health. In the UK, agricultural production accounts for over 80% of NH3

[91] Jackson, B.M., Wheater, H.S., Mcintyre, N.R., Chell, J., Francis, O.J., Frogbrook, Z., Marshall, M., Reynolds, B., Solloway, I., 2008. The impact of upland land management on flooding: Insights from a multiscale experimental and modelling programme. *Journal of Flood Risk Management* 1(2), 71-80.

[92] Woodland Trust, 2013. *The Pontbren project: A farmer-led approach to sustainable land management in the uplands.* Grantham: Woodland Trust.

[93] Jackson, B.M., et al. , 2008, op cit.

[94] Woodland Trust, 2013. Op cit.

[95] Jackson, B.M., et al. , 2008, op cit.

emissions, which come from livestock housing, grazing, and storage and spreading of manure (Misselbrook et al., 2010[96]). Trees are effective scavengers of both gaseous and particulate pollutants from the atmosphere, suggesting that increasing tree cover within agricultural landscapes can remove NH_3 from the atmosphere near the source, thereby reducing impacts on sensitive ecosystems.

A recent project, Agroforestry systems for ammonia abatement (Defra project AC0201) running from 2007-2011, aimed to quantify the emission abatement of agricultural ammonia (NH_3) that is achievable with a range of different on-farm woodland features including downwind shelterbelts, silvopastoral systems and wind breaks, at the UK scale (Bealey et al., 2013[97]). The project included experimental work in a wind tunnel facility and in the field, as well as modelling simulations. Wind tunnel experiments showed that significant ammonia can be recaptured by trees, with the source height the key factor in determining the effectiveness of tree belts as a mitigation measure (Bealey et al., op cit. [98]). Modelling of NH3 capture by shelterbelts and understorey scenarios predicted maximum deposition rates of 28% for shelterbelts around a housing source and 60% for understorey (e.g. woodland chicken) sources. In-field case studies of NH3 concentrations downwind of poultry houses with and without trees on the Food Animal Initiative (FAI, www.faifarms.com) farm near Oxford, concentrations downwind of wooded transects were 10-25% lower than the unwooded transects (Bealey et al. op cit. [99]).

Climate regulation and energy use

Combined food and energy systems, incorporating crops, livestock and energy crops such as willow coppice, can compare favourably in term of energy use to conventional modes of production (Reith and Guidry, 2003[100]; Ghaley and Porter,

---

[96] Misselbrook, T.H., Chadwick, D.R., Gilhespy, S.L., Chambers, B.J., Smith, K.A., Williams, J., Dragosites, U., 2010. *Inventory of ammonia emissions from UK agriculture 2009.* Projects AM0127,AC0112. London: Department for Environment, Food and Rural Affairs.

[97] Bealey, W.J., Braban, C.F., Theobald, M.R., Famulari, D., Tang, Y.S., Wheat, A., Grigorova, E., Leeson, S., Twigg, M.M., Dragosits, U., Dore, A.J., Sutton, M.A., Nemitz, E., Loubet, B., Robertson, A., Quinn, A.D., Williams, A., Sandars, D.L., Valatin, G., Perks, M., Watterson, D., 2013. Agroforestry systems for ammonia abatement. Final report, Project AC0201. London: Department for Environment, Food and Rural Affairs.

[98] Bealey, W.J., et al. , 2013, op cit.

[99] Bealey, W.J., et al. , 2013, op cit.

[100] Reith, C.C., Guidry, M.J., 2003. Eco-efficiency analysis of an agricultural research complex. *Journal of Environmental Management* 68(3), 219-229.

2013[101]). There has also been considerable interest over the last 20 years in investigating the potential of agroforestry as a tool for addressing the issues of climate change through mitigation and adaptation (Adger et al. , 1992[102]; Schroeder, 1994[103]; Albrecht and Kandji, 2003[104]; King et al., 2004[105]; Lal, 2004[106]; Montagnini and Nair, 2004[107]; Peichl et al., 2006[108]; Schoeneberger, 2009[109]).

Agroforestry has the potential to contribute by increasing afforestation of agricultural lands, by reducing resource use pressure on existing forests and by producing both durable wood products and renewable energy resources (Dixon, 1995[110]). Agroforestry can increase the amount of carbon sequestered compared to monocultures of crops or pasture due to the incorporation of trees and shrubs (Jose,

---

[101] Ghaley, B.B., Porter, J.R., 2013. Emergy synthesis of a combined food and energy production system compared to a conventional wheat (*Triticum aestivum*) production system. *Ecological Indicators* 24(0), 534-542.

[102] Adger, W.N., Brown, K., Shiel, R.S., Whitby, M., 1992. Carbon dynamics of land use in Great Britain. *Journal of Environmental Management* 36, 117-133.

[103] Schroeder, P., 1994. Carbon storage benefits of agroforestry systems. *Agroforestry Systems* 27, 89-97.

[104] Albrecht, A., Kandji, S.T., 2003. Carbon sequestration in tropical agroforestry. *Agriculture, Ecosystems and Environment* 99(1-3), 15-27.

[105] King, J.A., Bradley, R.I., Harrison, R., Carter, A.D., 2004. Carbon sequestration and saving potential associated with changes to the management of agricultural soils in england. *Soil Use and Management* 20, 394-402.

[106] Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304, 1623-1627.

[107] Montagnini, F., Nair, P.K.R., 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems* 61, 281-295.

[108] Peichl, M., Thevathasan, N.V., Gordon, A.M., Huss, J., Abohassan, R.A., 2006. Carbon sequestration potentials in temperate tree-based intercropping systems, southern Ontario, Canada. *Agroforestry Systems* 66, 243-257.

[109] Schoeneberger, M.M., 2009. Agroforestry: Working trees for sequestering carbon on agricultural lands. *Agroforestry Systems* 75, 27-37.

[110] Dixon, R.K., 1995. Agroforestry systems: Sources or sinks of greenhouse gases? *Agroforestry Systems* 31, 99-116.

2009[111]). Woody perennials store a significant amount of carbon in above ground biomass and also contribute to below ground carbon sequestration in soils. The potential for agroforestry systems to sequester carbon depends on a number of factors including system design, tree density per unit area, species composition and age, environmental factors such as climate, management and the end product. Schroeder (1994[112]) estimated average carbon storage by agroforestry systems as 9, 21, 50 and 63 Mg C ha-1 in semiarid, subhumid, humid and temperate regions, with higher rates in temperate regions reflecting longer rotations and longer-term storage.

Sharrow and Ismail (2004[113]) found that a Douglas-fir (Pseudotsuga menziesii)/ perennial ryegrass (Lolium perenne)/ subclover (Trifolium subterraneum) silvopastoral system in Oregon, USA, was more efficient at storing C than tree plantations or pasture monocultures. In the 11 years since establishment, the silvopastoral system had accumulated 740 and 520 kg ha-1 year-1 more C than forests and pastures respectively. They suggested that this was a result of higher biomass production and active nutrient cycling patterns within the silvopasture system compared to tree and pasture monocultures. Peichl et al. (2006)[114] also recorded larger total C pools in poplar (Populus)/barley and spruce (Picea)/barley agroforestry systems compared to a barley monocrop (96.5, 75.3 and 68.5 Mg C ha-1 respectively). Gupta et al. (2009)[115] observed increases in soil organic carbon, from 0.36% in monocropped cereals to 0.66% in poplar/cereal agroforestry soils, amounting to 2.9-4.8 Mg ha-1 more soil organic carbon in agroforestry soils.

---

[111] Jose, S., 2009. Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems* 76, 1-10.

[112] Schroeder, P., 1994. Carbon storage benefits of agroforestry systems. *Agroforestry Systems* 27, 89-97.

Schroth, G., Balle, P., Peltier, R., 1995. Alley cropping groundnut with *Gliricidia sepium* in Cote d'Ivoire: Effects on yields, microclimate and crop diseases. *Agroforestry Systems* 29, 147-163.

[113] Sharrow, S.H., Ismail, S., 2004. Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western oregon, USA. *Agroforestry Systems* 60, 123-130.

[114] Peichl, M., Thevathasan, N.V., Gordon, A.M., Huss, J., Abohassan, R.A., 2006. Carbon sequestration potentials in temperate tree-based intercropping systems, southern Ontario, Canada. *Agroforestry Systems* 66, 243-257.

[115] Gupta, N., Kukal, S.S., Bawa, S.S., Dhaliwal, G.S., 2009. Soil organic carbon and aggregation under poplar based agroforestry system in relation to tree age and soil type. *Agroforestry Systems* 76, 27-35.

In a study of carbon sequestration potential in a tree-based intercropping system in Guelph, Ontario, the permanent tree component (13 year old hybrid poplars) sequestered 14 Mg C ha-1 year-1, and C contribution from leaf litter and fine root turnover was estimated at 25 Mg ha-1 year-1; over the 13 year period this amounts to the immobilisation of 156 Mg ha-1 (Thevathasan and Gordon, 2004[116]). Taking into account the release of C back into the atmosphere as leaf litter and fine roots decompose, the net sequestration potential of trees was calculated as 1.65 Mg C ha-1 year-1 or approximately 7 Mg ha-1 year-1 of CO2 (Thevathasan and Gordon, 2004[117]).

Biodiversity

Agroforestry systems, by their nature, are more diverse than monocultures of crops and livestock. This increase in 'planned' biodiversity (the components chosen by the farmer) increases levels of 'associated' biodiversity (the wild plants and animals also occurring on the farmland).

For farmland biodiversity, research has found that scattered trees within agricultural landscapes act as 'keystone species' that facilitate the movement of wildlife through a landscape that may otherwise be too hostile (Manning et al., 2009[118]). By integrating trees within the agricultural matrix, agroforestry can provide corridors that allow movement of species through landscapes. This role will increase in importance under predicted climate change scenarios by allowing species to adapt their distributions in response to the shifting climate.

A study from the Americas suggests that the impact of agroforestry on biodiversity may extend beyond the landscape-scale. Perfecto et al. (2009)[119] consider the correlation between decreasing populations of songbirds in the eastern USA and the elimination of shade trees from coffee agroforests in Latin American countries. Those species in decline were migratory species that overwintered in the southern countries, and were found in the forest-like habitats of traditional coffee farms with a diversity of shade tree species.

---

[116] Thevathasan, N.V., Gordon, A.M., 2004. Op cit.

[117] Thevathasan, N.V., Gordon, A.M., 2004. Op cit.

[118] Manning, A.D., Gibbons, P., Lindenmayer, D.B., 2009. Scattered trees: A complementary strategy for facilitating adaptive responses to climate change in modified landscapes? *Journal of Applied Ecology* 46, 915-919.

[119] Perfecto, I., Vandermeer, J., Wright, A., 2009. *Nature's Matrix: Linking agriculture, conservation and food sovereignty*. London: Earthscan.

The value of agroforestry for UK biodiversity has been assessed in a number of studies on trial sites in the late 1990s (Burgess, 1999[120]; McAdam and McEvoy, 2008[121]; McAdam et al., 2007[122]). Within poplar silvopastoral systems, botanical composition of the understorey changed as the trees matured, with swards dominated by *Agrostis capillaris*, *Holcus lanatus* and *Poa annua* under the tree canopy while *Lolium perenne*, *Poa trivialis*, *Trifolium repens* and *Cirsium arvense* were more common in open pasture (Crowe and McAdam, 1993[123]). Higher abundance and species richness of invertebrates were recorded in silvopastoral systems compared to open grassland in Northern Ireland and Scotland (Cuthbertson and McAdam, 1996[124]; Dennis et al., 1996[125]).

On a silvoarable trial site in Silsoe, Bedfordshire, common arable weeds including barren brome (*Bromus sterilis*), blackgrass (*Alopecurus myosuroides*) and common couch (*Elymus repens*) colonised the area under the trees (Burgess, 1999[126]). Although these species have value as a resource for farmland biodiversity, they can potentially be a nuisance for farmers if they act as a major seed source for reinfestation of the field. With careful and planned management, including sowing with more desirable species and periodic mowing, weed species can be managed in the area under the trees so as not to present a problem for farm production. Peng et al. (1993)[127] recorded higher abundances and species richness of airborne

---

[120] Burgess, P.J., 1999. Effects of agroforestry on farm biodiversity in the UK. *Scottish Forestry* 53(1), 24-27.

[121] McAdam, J., Sibbald, A. R., Teklehaimanot, Z., Eason, W.R., 2007. Developing silvopastoral systems and their effects on diversity of fauna. *Agroforestry Systems* 70, 81-89.

[122] McAdam, J., Burgess, P.J., Graves, A.R., Rigueiro-Rodríguez, A., Mosquera-Losada, M.R., 2008. Classifications and functions of agroforestry systems in Europe. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada, M.R., Rosa, M., (eds.) *Agroforestry in Europe: Current Status and Future Prospects*. Belfast: Springer, 21-42.

[123] Crowe, S.R., McAdam, J., 1993. Factors affecting herbage biomass production in a mature tree silvopastoral system. *Agroforestry Forum* 4(3), 14-18.

[124] Cuthbertson, A., McAdam, J., 1996. The effect of tree density and species in carabid beetles in a range of pasture-tree agroforestry systems on a lowland site. *Agroforestry Forum* 7(3), 17-20.

[125] Dennis, P., Shellard, L.J.F., Agnew, R.D.M., 1996. Shifts in arthropod species assemblages in relation to silvopastoral establishment in upland pastures. *Agroforestry Forum* 7(3), 14-17.

[126] Burgess, P.J., 1999. Effects of agroforestry on farm biodiversity in the UK. *Scottish Forestry* 53(1), 24-27.

[127] Peng, R.K., Incoll, L.D., Sutton, S.L., Wright, C., Chadwick, A., 1993. Diversity of airborne arthropods in a silvoarable agroforestry system. *Journal of Applied Ecology* 30, 551-562.

arthropods in a silvoarable system compared to an arable control in northern England, probably in response to a greater diversity of plants along the tree rows. Some taxa have more species-specific responses. Phillips et al. (1994)[128] found that some species of carabid beetles were more common in the agroforestry system, while others were more common in the arable control. This is likely to reflect the narrow habitat requirements of many carabids. Some species prefer open habitats found in arable fields, others prefer damp, shaded conditions associated with tree cover.

Vegetated understoreys within the tree rows were shown to have higher abundances of spiders than bare understoreys in a silvoarable system in Yorkshire (Burgess et al. 2003[129]), reflecting the association of this taxon with habitats with greater structural diversity. The number of bank voles (*Clethrionomys glareolus*), wood mice (*Apodemus sylvaticus*), field voles (*Microtus agrestis*) and common shrews (*Sorex araneus*) were higher in the silvoarable system than in the arable and forest control areas, possibly reflecting an edge effect (Klaa et al., 2005[130]; Wright, 1994[131]). Even at an early stage of development, the silvopastoral systems were shown also to have a positive impact on birds, and attracted both woodland and grassland species, thus creating a unique assemblage of species (McAdam et al., 2007[132]). More recently, preliminary results from a PhD research project investigating ecosystem services in six organic agroforestry systems in England indicated significantly higher abundance and species diversity of butterflies in agroforestry sites compared to the monocropping controls (Varah et al., 2013[133]).

---

[128] Phillips, D.S., Griffiths, J., Naeem, M., Compton, S.G., Incoll, L.D., 1994. Responses of crop pests and their natural enemies to an agroforestry envronment. *Agroforestry Forum* 5(2), 14-20.

[129] Burgess, P.J., Incoll, L.D., Hart, B.J., Beaton, A., Piper, R.W., Seymour, I., Reynolds, F.H., Wright, C., Pilbeam, D.J., Graves, A.R., 2003. The impact of silvoarable agroforestry with poplar on farm profitability and biological diversity: Final report to Defra Project AF0105. Silsoe, Beds; Leeds; Cirencester: Cranfield University; University of Leeds; Royal Agricultural College.

[130] Klaa, K., Mill, P.J., Incoll, L.D., 2005. Distribution of small mammals in a silvoarable agroforestry in Northern England. *Agroforestry Systems* 63, 101-110.

[131] Wright, C., 1994. The distribution and abundance of small mammals in a silvoarable agroforestry system. *Agroforestry Forum* 5(2), 26-28.

[132] McAdam, J., Sibbald, A.R., Teklehaimanot, Z., Eason, W.R., 2007. Developing silvopastoral systems and their effects on diversity of fauna. *Agroforestry Systems* 70, 81-89.

[133] Varah, A., Jones, H., Smith, J., Potts, S.G., 2013. Enhanced biodiversity and pollination in UK agroforestry systems. *Journal of the Science of Food and Agriculture* 93(9), 2073-2075.

Using pollinator abundance and species diversity as a proxy for pollination services, Varah et al. (op cit. [134]) recorded significantly higher pollinator abundance in silvoarable systems. This was attributed to the development of understorey vegetation within the rows of trees. The silvoarable understorey of grasses and forbs remains largely undisturbed in these organic agroforestry systems, allowing greater structural diversity and flowering plants to reach maturity, thus providing nesting habitat and foraging resources for many pollinator species (Varah et al. 2013[135]).

Animal health and welfare

Trees in animal production systems can also contribute to animal welfare. In addition to a diversity of foraging resources, they provide shelter from rain and wind, shade from the sun and cover from predators. Cattle in both tropical and temperate climates are particularly sensitive to heat stress. Evaporative cooling is the primary mechanism by which cattle reduce their temperature, and this is affected by humidity, wind speed, and physiological factors such as respiration and sweat gland density. By providing shade, trees can reduce the energy needed for regulating body temperatures, and so result in higher feed conversion and weight gain. Research in the southern United States found that cattle that had been provided with shade reached their target weight 20 days before those with no shade (Mitlohner et al. , 2001[136]). Higher respiration rates and lower activity rates of those cattle without shade were thought to reduce productivity. Evidence of benefits of shade for lactating dairy cows in temperate climates has also been found (Kendall et al. , 2006[137]).

During cooler months, windbreaks and shelterbelts provide valuable protection from the wind for livestock, particularly for new-born lambs and freshly shorn sheep. When livestock have been protected from winter storms by windbreaks, significant savings in feed costs and improved survival and milk production have been reported

[134] Varah, A., Jones, H., Smith, J., Potts, S.G., 2013. Enhanced biodiversity and pollination in UK agroforestry systems. *Journal of the Science of Food and Agriculture* 93(9), 2073-2075.

[135] Varah, A., Jones, H., Smith, J., Potts, S.G., 2013. Enhanced biodiversity and pollination in UK agroforestry systems. *Journal of the Science of Food and Agriculture* 93(9), 2073-2075.

[136] Mitlöhner, F.M., Morrow, J.L., Dailey, J.W., Wilson, S.C., Galyean, M.L., Miller, M.F., McGlone, J.J., 2001. Shade and water misting effects on behaviour, physiology, performance and carcass traits of heat-stressed feedlot cattle. *Journal of Animal Science* 79, 2327-2335.

[137] Kendall, P.E., Nielsen, P.P., Webster, J.R., Verkerk, G.A., Littlejojn, R.P., Matthews, L.R., 2006. The effects of providing shade to lactating dairy cows in a temperate climate. *Livestock Science* 103, 148-157.

by producers in Dakota, US (Brandle et al. , 2004[138]). European research on the benefits of shade and shelter for the animal appears more limited (see for example Sibbald, 2006[139]). One Finnish study observing behaviour at calving indicates some preference for using places that do provide shelter (Lidfors et al., 1994[140]).

Ranging behaviour in chickens is affected by the type of outdoor environment provided. Dawkins et al. (2003)141 observed ranging behaviour in commercial free-range broiler systems and recorded a maximum of only 15% of the total flock outside the house at any one time. The number of birds ranging outside was correlated with the percentage tree cover on the range, and behavioural studies showed that trees and bushes were the preferred habitat (Dawkins et al., op cit. [142]). Descended from the forest-dwelling red junglefowl (Gallans gallans) of India, China and south-east Asia, it is unsurprising that chickens prefer to range in tree and thicket cover. Trees offer protection from aerial predators in particular, and can provide an escape from aggressive behaviour within the flock as well as reducing visual stimulation that can provoke aggression (Yates et al. , 2007[143]). The trees also benefit from the interaction with the animal and higher leaf nitrogen concentrations and increased total height was recorded for three-year-old black walnut trees (Juglans nigra) fertilised with a chicken manure compared to a non-fertiliser control (Ponder et al., 2005[144]).

In the UK, all laying-hen producers within the McDonald's Restaurants Ltd egg-supply base are required to plant at least 5% of the range area with trees (Bright et

---

[138] Brandle, J.R., Hodges, L., Zhou, X.H., 2004. Windbreaks in North American agricultural systems. *Agroforestry Systems* 61, 65-78.

[139] Sibbald, A., 2006. Silvopastoral agroforestry: a land use for the future. *Scottish Forestry* 60, 4-7.

[140] Lidfors, L.M., Moran, D., Jung, J., Jensen, P., Castren, H., 1994. Behaviour at calving and choice of calving place in cattle kept in different environments. *Applied Animal Behaviour Science* 42(1), 11-28.

[141] Dawkins, M.S., Cook, P.A., Whittingham, M.J., Mansell, K.A., Harper, A.E., 2003. What makes free-range broiler chickens range? *In situ* measurement of habitat preferences. *Animal Behaviour* 66, 151-160.

[142] Dawkins, M.S., Cook, P.A., Whittingham, M.J., Mansell, K.A., Harper, A.E., 2003. What makes free-range broiler chickens range? *In situ* measurement of habitat preferences. *Animal Behaviour* 66, 151-160.

[143] Yates, C., Dorward, P., Hemery, G., Cook, P., 2007. The economic viability and potential of a novel poultry agroforestry system. *Agroforestry Systems* 69, 13-28.

[144] Ponder, F., Jones, J.E., Mueller, R., 2005. Using poultry litter in black walnut management. *Journal of Plant Nutrition* 28, 1355-1364.

al. , 2011[145]; Bright and Joret, 2012[146]). Multiple retailers such as Sainsbury's also promote the Woodland Egg initiative in partnership with the Woodland Trust. Research has shown that the tree cover has benefits for animal welfare. Plumage damage, a key animal-welfare indicator for laying hens in non-cage systems, was found to be negatively correlated with the percentage of canopy cover within tree-planted areas (Bright et al. , op cit. [147]). In another study of the same producers, researchers investigated whether there was a difference between two production traits – egg seconds (grade-out at the packing station indicating shell quality which is influenced by nutrition, stress and bird health) and mortality – in matched free-range laying flocks with and without tree cover on the range (Bright and Joret, op cit. [148]). They found that in flocks with tree cover, there were fewer total egg seconds and significantly fewer ≥45 week egg seconds (when egg seconds are a particular problem) and lower mortality ($p=0.1$) than in flocks without tree cover.

Like chickens, pigs have a forest-dwelling ancestor, the Eurasian wild boar (Sus scrofa) which is found primarily in mixed, predominantly deciduous woodland. Behavioural studies of domestic pigs have shown that trees encourage expression of normal behavioural patterns (Stolba and Woodgush, 1989[149]). Domestic pigs are particularly susceptible to heat stress, heat stroke, porcine stress syndrome and even death at temperatures above 22°C, and can suffer from sunburn and dermatitis in direct sunlight (Brownlow, 1994[150]). Conversely, low temperatures increase the prevalence and transmission of disease. Reproductive success of domestic pigs is also influenced by temperature, with a reduction in live litter sizes with decreasing

[145] Bright, A., Brass, D., Clachan, J., Drake, K.A., Joret, A.D., 2011. Canopy cover is correlated with reduced injurious feather pecking in commercial flocks of free-range laying hens. *Animal Welfare* 20, 329-338

[146] Bright, A., Joret, A.D., 2012. Laying hens go undercover to improve production. *Veterinary Record* 170(9), 228-229.

[147] Bright, A., Brass, D., Clachan, J., Drake, K.A., Joret, A.D., 2011. Canopy cover is correlated with reduced injurious feather pecking in commercial flocks of free-range laying hens. *Animal Welfare* 20, 329-338

[148] Bright, A., Joret, A.D., 2012. Laying hens go undercover to improve production. *Veterinary Record* 170(9), 228-229.

[149] Stolba, A., Woodgush, D.G.M., 1989. The behaviour of pigs in a semi-natural environment. *Animal Production* 48(2), 419-425.

[150] Brownlow, M.J.C., 1994. The characteristics and viability of land-use systems which integrate pig or poultry production with forestry in the UK. *Department of Agriculture*. Reading: University of Reading.

temperatures, and reduced interactions between sows and boars in poor weather lowering fertility (Brownlow, op cit. [151]).

Social and cultural services

Cultural aspects of agroforestry systems, particularly in temperate regions, are often overlooked, despite the long tradition of systems such as woodland and orchard grazing, alpine wooded pastures, pannage, the dehesa and parklands (McAdam et al., 2008[152]). Lifestyles such as nomadism, transhumance (seasonal movement of people with their livestock), and traditional techniques such as pollarding and hedge-laying, are integrated within such systems and the symbolic and cultural perception of these landscapes are shaped by local practices, laws and customs (Ispikoudis and Sioliou, 2005[153]). While only remnants of these traditional landscapes exist today, the significance and value of these cultural landscapes have been recognised at the international level by UNESCO[154] and at the European level by the European Landscape Convention[155]. Within the UK, national park status was awarded in 2005 to the New Forest, to protect one of the largest remaining areas of wood-pasture in temperate Europe.

Public attitudes to agroforestry reflect society's view of the non-market benefits connected with amenity, habitat, landscape and animal welfare. The visual impact of monocultures of crops in large scale arable fields or mono-species forest plantations is unappealing for many people; integrating trees into agricultural landscapes can increase the diversity and attractiveness of the landscape (McAdam et al., 2008[156]).

However, as with all forms of tree plantings, modern agroforestry, characterised by rows of trees and alleys, may not be appropriate for all landscapes, particularly open landscapes such as downlands and fens, or historic landscapes such as parkland,

---

[151] Brownlow, M.J.C., 1994. The characteristics and viability of land-use systems which integrate pig or poultry production with forestry in the UK. *Department of Agriculture*. Reading: University of Reading.

[152] McAdam, J., Burgess, P.J., Graves, A.R., Rigueiro-Rodríguez, A., Mosquera-Losada, M.R., 2008. Classifications and functions of agroforestry systems in Europe. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada,

[153] Ispikoudis, I., Sioliou, K.M., 2005. Cultural aspects of silvopastoral systems. *In*: Mosquera-Losada, M.R.,

[154] http://whc.unesco.org/en/culturallandscape

[155] http://www.coe.int/t/dg4/cultureheritage%20/heritage/landscape%20/default_EN.asp

[156] McAdam, J., Burgess, P.J., Graves, A.R., Rigueiro-Rodríguez, A., Mosquera-Losada, M.R., 2008. Classifications and functions of agroforestry systems in Europe. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada,

moorlands and lowland heathlands. Agroforestry systems can provide recreational opportunities that can benefit the general public as well as the landowner (McAdam et al., op cit[157.]). Cultural landscapes such as the dehesas of Spain and Portugal, and the wood pastures of the Alps, can provide opportunities for eco-tourism.

Productivity

A central hypothesis in agroforestry is that productivity is higher in agroforestry systems compared to monocropping systems due to complementarity in resource-capture; i.e. trees acquire resources in space and time that the crops alone would not (Cannell et al., 1996[158]). This is based on the ecological theory of niche differentiation; different species obtain resources from different parts of the environment. Tree roots generally extend deeper than crop roots and so access soil nutrients and water unavailable to crops, as well as absorbing nutrients leached from the crop rhizosphere. These nutrients are then recycled via leaf fall onto the soil surface or fine root turnover. This should lead to greater nutrient capture and higher yields by the integrated tree-crop system compared to tree or crop monocultures (Sinclair et al., 2000[159]). Equally, the tree canopy occupies space above surface crops, making better use of above ground space for interception of sunlight and photosynthesis, with tree leaves continuing to harvest solar energy for longer periods than most annual crops.

The Land Equivalent Ratio (LER), first proposed by Mead and Willey (1980[160]), is a means of comparing productivity of polycultures and monocropping systems. It is calculated as the ratio of the area needed under sole cropping to the area of intercropping at the same management level to obtain a particular yield:

LER = (Tree agroforestry yield) + (Crop or livestock agroforestry yield)
(Tree monoculture yield) (Crop or livestock monoculture yield)

[157] McAdam, J., Burgess, P.J., Graves, A.R., Rigueiro-Rodríguez, A., Mosquera-Losada, M.R., 2008. Classifications and functions of agroforestry systems in Europe. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada,

[158] Cannell, M.G.R., Van Noordwijk, M., Ong, C.K., 1996. The central agroforestry hypothesis: The trees must acquire resources that the crop would not otherwise acquire. *Agroforestry Systems* 34, 27-31.

[159] Sinclair, F.L., Eason, W.R., Hooker, J., 2000. Understanding and management of interactions. In: Hislop, A.M., Claridge, J., (eds.) *Agroforestry in the UK*. Bulletin 122. Edinburgh: Forestry Commission.

[160] Mead, D.J., Willey, R.W., 1980. The concept of a 'land equivalent ratio' and advantages in yields from intercropping. *Experimental Agriculture* 16, 217-228.

If a rotation includes more than one crop, a weighted ratio for each crop can be used, based on its proportion in the rotation. A LER of 1 indicates that there is no yield advantage of the intercrop compared to the monocrop, while, for example, a LER of 1.1 would indicate a 10% yield advantage. Under monocultures, 10% more land would be needed to match yields from intercropping (Dupraz and Newman, 1997[161]). Yields can be expressed in physical units so that the LER refers to the biological efficiency of the mixture, or monetary units where the LER indicates the economic efficiency of the mixture. As a ratio, the result is independent of the yield units used. The LER reflects the ability of crops to partition resources in space and time, so that lower (physical) values of LER are recorded from mixtures of grasses in pasture, intermediate values from dissimilar vegetables, cereals and legumes, and highest values in agroforestry systems (Dupraz and Newman, 1997[162]).

Werf et al. (2007)[163] calculated Land Equivalent Ratios (LER) for two lowland poplar silvoarable trial systems in lowland England and found that LER values stayed above one for the 12 years after establishment. Newman (1986, in Dupraz and Newman, 1997)[164] calculated LER values of 1.65 and 2.01 relating to economic and biomass yield respectively for a pear orchard/radish (Raphanus sativus) system. Dupraz (1994, in Dupraz and Newman, op cit.)[165] modelled LERs for a Prunus avium/Festuca arundinacea system in France and estimated annual LERs of 1.6 in the early years after establishment, declining to 1.0 later in the rotation, with an average of 1.2 over the 60 year rotation.

---

[161] Dupraz, C., Newman, S.M., 1997. Chapter 6. Temperate agroforestry: The European way. *In*: Gordon, A.M., Newman, S.M. (Eds.), *Temperate agroforestry systems*. Wallingford: CABI Publishing, 181-236.

[162] Dupraz, C., Newman, S.M., 1997. Chapter 6. Temperate agroforestry: The European way. *In*: Gordon, A.M., Newman, S.M. (Eds.), *Temperate agroforestry systems*. Wallingford: CABI Publishing, 181-236.

[163] Werf, W.v.d., Keesman, K., Burgess, P.J., Graves, A.R., Pilbeam, D.J., Incoll, L.D., Metselaar, K., Stappers, R., Keulen, H.v., Palma, J., Dupraz, C., 2007. Yield-safe: A parameter-sparse process-based dynamic model for predicting resource capture, growth and production in agroforestry systems. *Ecological Engineering* 29, 419-433.

[164] Dupraz, C., Newman, S.M., 1997. Chapter 6. Temperate agroforestry: The European way. *In*: Gordon, A.M., Newman, S.M. (Eds.), *Temperate agroforestry systems*. Wallingford: CABI Publishing, 181-236.

[165] Dupraz, C., Newman, S.M., 1997. Chapter 6. Temperate agroforestry: The European way. *In*: Gordon, A.M., Newman, S.M. (Eds.), *Temperate agroforestry systems*. Wallingford: CABI Publishing, 181-236.

Biophysical modelling of hypothetical silvoarable systems in Spain, France and the Netherlands using the YieldSAFE model predicted LERs of between 1 and 1.4, indicating higher productivity where crops and trees were integrated on the same land area compared to separate monocultures (Graves et al., 2007[166]).

In addition to higher yield potentials of agroforestry, product diversification may increase the potential for financial returns, by providing annual and periodic revenues from multiple outputs throughout the rotation and reducing the risks associated with farming single commodities (Benjamin et al. 2000[167]). Tree products can be used on the farm (e.g. for fence posts, fodder or bioenergy) and this, combined with greater resource-use efficiency (e.g. nutrient use), should reduce inputs and increase the 'eco-efficiency' of the farming system. However, the potential financial benefits may not be realised if suitable markets are unavailable, or if they are outweighed by additional labour and machinery costs. The establishment costs, as well as the time before the agroforestry component becomes productive, will also affect overall financial performance.

Agroforestry illustrates the dual character of labour becoming an obstacle to adoption as well as an opportunity for creating additional employment, although this is significantly influenced by the design of the system and the potential for mechanisation. Successful tropical agroforestry systems show that management of intercropped systems is often intensive with high manual labour input required. The high cost of manual labour in Europe is thought likely to lead to greater reliance on agrochemical and mechanical input, especially when unfavourable combinations of trees and crops are used (Eichhorn et al. , 2006[168]). Within the UK and across parts of Northern Europe, there has been a decline in opportunities for manual employment in rural areas over the last 20 years. Doyle and Thomas (2000)[169] suggest that even where agroforestry displaces traditional, grass-based livestock systems, job gains from the 'forestry' component of the system will compensate for any job losses from a reduction in livestock. Where the trees used in agroforestry produce annual products such as fruit and nuts, additional pruning and harvest

---

[166] Graves, A.R., Burgess, P.J., Palma, J.H.N., Herzog, F., Moreno, G., Bertomeu, M., Dupraz, C., Liagre, F., Keesman, K., van der Wert, W., Koeffeman de Nooy, A., van den Briel, J.P., 2007. Development and application of bio-economic modelling to compare silvoarable, arable and forestry systems in three European countries. *Ecological Economics* 29, 434-449.

[167] Benjamin, T.J., Hoover, W.L., Seifert, J.R., Gillespie, A.R., 2000. Defining competition vectors in a temperate alley cropping system in the midwestern USA 4. The economic return of ecological knowledge. *Agroforestry Systems* 48, 79-93.

[168] Eichhorn, M.P., Paris, P., Herzog, F., Incoll, L.D., Liagre, F., Mantzanas, K., Mayus, M., Moreno, G., Papanastasis, V.P., Pilbeam, D.J., Pisanelli, A., Dupraz, C., 2006. Silvoarable systems in Europe - past, present and future prospects. Agroforestry Systems 67, 29-50.

[169] Doyle, C., Thomas, T., 2000. Chapter 10: The social implications of agroforestry. *In*: Hislop, A.M., Claridge, J. (eds.), *Agroforestry in the UK. Bulletin 122*. Edinburgh: Forestry Commission, 99-106.

employment may be created, although this may be casual and insecure rather than permanent employment. There may also be positive implications for local industries supplying inputs and processing outputs from both the agricultural and forestry components of the system.

Profitability

Economic studies of agroforestry systems have shown that financial benefits are a consequence of increasing the diversity and productivity of the systems, influenced by market and price fluctuations of timber, livestock and crops. Where agroforestry is introduced into agriculture-dominated regions, there may be issues with access to or development of suitable markets for the tree projects. The costs of establishment, and time delay before returns from the tree components can be realised, may also act as a barrier to the adoption of agroforestry, at least in the absence of support such as that potentially available under EU Rural Development programmes (Smith et al., 2013b)[170].

A New Zealand study comparing the economics of grazing sheep and beef in open pasture with three silvopastoral systems involving *Pinus radiata*, *Eucalyptus fastigata* or *Acacia melanoxylon*, demonstrated that the silvopastoral systems produced higher long-term returns than the open pasture system (Thorrold et al. , 1997, in Benavides et al., 2009[171]). A bioeconomic model (MAST: Modelled Assessment of Swine and Trees) of a theoretical integrated domestic pig/woodland edge enterprise in the UK suggested that the financial performance of this agroforestry system could be superior to that of a pasture-based enterprise (Brownlow, 1994[172]; Brownlow et al. , 2005[173]). The authors identified key factors influencing the profitability of the system: premium prices for 'forest-reared' pig carcasses; the effect of shelter on feed conversion rates; and the availability of cheaper land rents.

---

[170] Smith, J., Westaway, S., Pearce, B., Lampkin, N., Briggs, S., 2013b. *Can agroforestry deliver production and environmental benefits in the next rural development programme?* Report to Natural England. Newbury: Organic Research Centre.

[171] Benavides, R., Douglas, G.B., Osoro, K., 2009. Silvopastoralism in New Zealand: Review of effects of evergreen and deciduous trees on pasture dynamics. *Agroforestry Systems* 76, 327-350.

[172] Brownlow, M.J.C., 1994. The characteristics and viability of land-use systems which integrate pig or poultry production with forestry in the UK. *Department of Agriculture*. Reading: University of Reading.

[173] Brownlow, M.J.C., Dorward, P.T., Carruthers, S.P., 2005. Integrating natural woodland with pig production in the United Kingdom: An investigation of potential performance and interactions. *Agroforestry Systems* 64, 251-263.

Bruggen, A.H.C.v., Semenov, A.M., 2000. In search of biological indicators for soil health and disease suppression. *Applied Soil Ecology* 15, 13–24.

Compared with exclusively forestry land use, agroforestry practices are able to recoup initial costs more quickly due to the income generated from the agricultural component (Rigueiro-Rodríguez et al. , 2008[174]). Fernández-Núnez et al. (2007, in Rigueiro-Rodríguez et al. , 2008[175]) carried out an assessment of initial investments and establishment costs of forestry, agriculture and agroforestry in the Atlantic area of Spain. They found that establishing agroforestry required higher initial investment than the agricultural and forestry systems due to higher initial inputs, but over a 30 year period, profitability per hectare was higher in the agroforestry system than in the exclusively livestock (17%) or forestry (53%) systems. When environmental and ecological benefits were included in the evaluation, the performance of the agroforestry system was even higher.

In silvoarable systems, annual returns from crops produced between tree rows can offset plantation establishment costs. Similarly, providing saplings are protected from livestock damage, integrating chickens into newly established plantings enables farmers to receive income well before any income from tree products is realised (Yates et al., 2007[176]). Valuable timber trees such as black walnut (*Juglans nigra*) were once raised as a retirement crop; farmers would sell a mature timber stand to fund their retirement (Scott and Sullivan, 2007[177]). High value timber trees such as black walnut are not ready for harvest until decades after establishment; integrating crops and/or livestock into the system can produce economic value for at least the first twenty years after establishment.

Modelling of economic returns from a black walnut alley cropping system in Midwestern USA highlighted the importance of system design and management for

---

[174] Rigueiro-Rodríguez, A., Fernández-Núnez, E., Gonzalez-Hernandez, M.P., McAdam, J., Mosquera-Losada, M.R., 2008. Agroforestry systems in Europe: Productive, ecological and social perspectives. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada, M.R., Rosa, M., (eds.) *Agroforestry in Europe: Current Status and Future Prospects*. Belfast: Springer, 43-65.

[175] Rigueiro-Rodríguez, A., Fernández-Núnez, E., Gonzalez-Hernandez, M.P., McAdam, J., Mosquera-Losada, M.R., 2008. Agroforestry systems in Europe: Productive, ecological and social perspectives. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada, M.R., Rosa, M., (eds.) *Agroforestry in Europe: Current Status and Future Prospects*. Belfast: Springer, 43-65.

[176] Yates, C., Dorward, P., Hemery, G., Cook, P., 2007. The economic viability and potential of a novel poultry agroforestry system. *Agroforestry Systems* 69, 13-28.

[177] Scott, R., Sullivan, W.C., 2007. A review of suitable companion crops for black walnut. *Agroforestry Systems* 71, 185-193.

maximising productivity (Benjamin et al., 2000[178]). Systems with widely-spaced tree rows (12.2m between tree rows) were predicted to be more profitable than both closely-spaced (8.5m between tree rows) designs and walnut plantations, while root-pruning increased economic returns by extending the period of profitable crop production within the rotation. All agroforestry systems were modelled as having higher returns than monocropping systems (Benjamin et al., 2000[179]).

The effect of grants on profitability and feasibility of agroforestry systems in Europe was explored in a bio-economic model 'FarmSAFE' developed by Graves et al. (2007)[180]. While silvoarable systems were often the most profitable system (compared to arable and forestry systems) at landscape test sites in France, Spain and the Netherlands under a 'no grants' scenario, a pre-2005 grant regime based on direct area payments, and a post-2005 grant regime associated with the single farm payment scheme changed the profitability of silvoarable systems compared to arable and forestry systems, with some agroforestry systems becoming less profitable (Graves et al., 2007[181]). For example, in the Netherlands, losing arable land for slurry manure application made changing land use to agroforestry uncompetitive.

Recently, there has been considerable interest in placing a monetary value on the delivery of ecosystem services such as soil protection and carbon sequestration. Based on information on biophysical changes caused by shelterbelts, Kulshreshtha and Kort (2009)[182] estimated the value of external environmental benefits provided by shelterbelt systems in the Canadian prairie provinces as over CDN$140 million.

---

[178] Benjamin, T.J., Hoover, W.L., Seifert, J.R., Gillespie, A.R., 2000. Defining competition vectors in a temperate alley cropping system in the midwestern USA 4. The economic return of ecological knowledge. *Agroforestry Systems* 48, 79-93.

[179] Benjamin, T.J., Hoover, W.L., Seifert, J.R., Gillespie, A.R., 2000. Defining competition vectors in a temperate alley cropping system in the midwestern USA 4. The economic return of ecological knowledge. *Agroforestry Systems* 48, 79-93.

[180] Graves, A.R., Burgess, P.J., Palma, J.H.N., Herzog, F., Moreno, G., Bertomeu, M., Dupraz, C., Liagre, F., Keesman, K., van der Wert, W., Koeffeman de Nooy, A., van den Briel, J.P., 2007. Development and application of bio-economic modelling to compare silvoarable, arable and forestry systems in three European countries. *Ecological Economics* 29, 434-449.

[181] Graves, A.R., Burgess, P.J., Palma, J.H.N., Herzog, F., Moreno, G., Bertomeu, M., Dupraz, C., Liagre, F., Keesman, K., van der Wert, W., Koeffeman de Nooy, A., van den Briel, J.P., 2007. Development and application of bio-economic modelling to compare silvoarable, arable and forestry systems in three European countries. *Ecological Economics* 29, 434-449.

[182] Kulshreshtha, S., Kort, J., 2009. External economic benefits and social goods from prairie shelterbelts. *Agroforestry Systems* 75, 39-47.

Carbon sequestration accounted for the majority of this (CDN$73 million) and reduced soil erosion also provided significant economic benefits (CDN$15 million).

Alavalapati et al. (2004)[183] used a 'willingness to pay' approach to identify the economic consequences of internalising non-market goods and services from agroforestry to the benefit of landowners. They found that by including payments for environmental services delivered by agroforestry, the profitability of these systems would increase, relative to conventional agricultural systems.

Palma et al. (2007a)[184] used multi-criteria decision analyses to integrate quantitative environmental and economic outputs of agroforestry and allow comparison with conventional agriculture in three European countries. The profitability of the systems varied from country to country depending either on policy or biophysical conditions. In France, analysis indicated that with equal weighting between environmental and economic performance, silvoarable agroforestry was preferable to conventional arable farming, while in Spain and the Netherlands, the overall performance of agroforestry systems depended on the proportion of the farm planted, tree density and land quality used (Palma et al., 2007a[185]).

Porter et al. (2009)[186] calculated the values of market and non-market ecosystem services of a novel combined food and energy agroforestry system in Taastrup, Denmark. Belts of fast-growing trees (hazel, willow and alder) for bioenergy production are planted at right angles to fields of cereal and pasture crops, and the system is managed organically with no inputs of pesticides or inorganic N.

Field-based estimates of ecosystem services including pest control, nitrogen regulation, soil formation, food and forage production, biomass production, soil carbon accumulation, hydrological flow into ground water reserves, landscape aesthetics and pollination by wild pollinators produced a total value of US $1074 ha-

---

[183] Alavalapati, J.R.R., Shrestha, G.A., Stainback, G.A., Matta, J.R., 2004. Agroforestry development: an environmental economic perspective. *Agroforestry Systems* 61, 299-310.

[184] Palma, J., Graves, A.R., Burgess, P.J., Werf, W.v.d., Herzog, F., 2007a. Integrating environmental and economic performance to assess modern silvoarable agroforestry in Europe. *Ecological Economics* 63, 759-767.

[185] Palma, J., Graves, A.R., Burgess, P.J., Werf, W.v.d., Herzog, F., 2007a. Integrating environmental and economic performance to assess modern silvoarable agroforestry in Europe. *Ecological Economics* 63, 759-767.

[186] Porter, J., Costanza, R., Sandhu, H., Sigsgaard, L., Wratten, S., 2009. The value of producing food, energy and ecosystem services within an agro-ecosystem. *Ambio* 38(4), 186-193.

1, of which 46% is from market ecosystem services (production of food, forage and biomass crops) and the rest from non-market ecosystem services.

There has been considerable interest in the potential of an agroforestry approach to conserve and sequester C while maintaining land for food production and reducing deforestation and degradation of remaining natural forests. The 1997 Kyoto Protocol calls on participating countries to reduce the rising levels of CO_2 and other greenhouse gases by decreasing fossil fuel emissions and accumulating C in soils and vegetation of terrestrial ecosystems. It provides a mechanism by which countries that emit carbon in excess of agreed limits can purchase carbon credits from countries that manage carbon sinks. Leading the way with establishing tradable securities of carbon sinks to off-set emissions, Costa Rica invested $14 million in 1997 for the Payment for Environmental Services (PES), with 80% of funding coming from a tax on fossil fuels and 20% from international sales of carbon permits from public protected areas. This scheme led to the reforestation of 6,500 ha, the sustainable management of 10,000 ha of public natural forests and the preservation of 79,000 ha of private natural forests (Montagnini and Nair, 2004[187]). In 2003, the scheme was expanded to include agroforestry systems, and the Costa Rican government budgeted $400,000 for the integration of agroforestry management into carbon trading schemes with payments depending on the number of trees present on the farm (Oelbermann et al., 2004[188]). Introducing carbon payments to landowners and managers of agroforestry systems in temperate regions opens the way to obtaining additional income from these systems and may increase the attractiveness of establishing an agroforestry system, as well as adding value to established systems such as riparian buffers, shelterbelts, and silvopastoral and silvoarable systems.

---

[187] Montagnini, F., Nair, P.K.R., 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems* 61, 281-295.

[188] Oelbermann, M., Voroney, R.P., Gordon, A.M., 2004. Carbon sequestration in tropical and temperate agroforestry systems: A review with examples from costa rica and southern canada. *Agriculture, Ecosystems and Environment* 104, 359-377.

Annex C – LUPG report extract on profitability

Economic studies of agroforestry systems have shown that financial benefits are a consequence of increasing the diversity and productivity of the systems, influenced by market and price fluctuations of timber, livestock and crops. Where agroforestry is introduced into agriculture-dominated regions, there may be issues with access to or development of suitable markets for the tree projects. The costs of establishment, and time delay before returns from the tree components can be realised, may also act as a barrier to the adoption of agroforestry, at least in the absence of support such as that potentially available under EU Rural Development programmes (Smith et al., 2013b)[189].

A New Zealand study comparing the economics of grazing sheep and beef in open pasture with three silvopastoral systems involving Pinus radiata, Eucalyptus fastigata or Acacia melanoxylon, demonstrated that the silvopastoral systems produced higher long-term returns than the open pasture system (Thorrold et al., 1997, in Benavides et al., 2009[190]). A bioeconomic model (MAST: Modelled Assessment of Swine and Trees) of a theoretical integrated domestic pig/woodland edge enterprise in the UK suggested that the financial performance of this agroforestry system could be superior to that of a pasture-based enterprise (Brownlow, 1994[191]; Brownlow et al. , 2005[192]). The authors identified key factors influencing the profitability of the system: premium prices for 'forest-reared' pig carcasses; the effect of shelter on feed conversion rates; and the availability of cheaper land rents.

---

[189] Smith, J., Westaway, S., Pearce, B., Lampkin, N., Briggs, S., 2013b. *Can agroforestry deliver production and environmental benefits in the next rural development programme?* Report to Natural England. Newbury: Organic Research Centre.

[190] Benavides, R., Douglas, G.B., Osoro, K., 2009. Silvopastoralism in New Zealand: Review of effects of evergreen and deciduous trees on pasture dynamics. *Agroforestry Systems* 76, 327-350.

[191] Brownlow, M.J.C., 1994. The characteristics and viability of land-use systems which integrate pig or poultry production with forestry in the UK. *Department of Agriculture*. Reading: University of Reading.

[192] Brownlow, M.J.C., Dorward, P.T., Carruthers, S.P., 2005. Integrating natural woodland with pig production in the United Kingdom: An investigation of potential performance and interactions. *Agroforestry Systems* 64, 251-263.

Bruggen, A.H.C.v., Semenov, A.M., 2000. In search of biological indicators for soil health and disease suppression. *Applied Soil Ecology* 15, 13–24.

Compared with exclusively forestry land use, agroforestry practices are able to recoup initial costs more quickly due to the income generated from the agricultural component (Rigueiro-Rodríguez et al., 2008[193]). Fernández-Núnez et al. (2007, in Rigueiro-Rodríguez et al., 2008[194]) carried out an assessment of initial investments and establishment costs of forestry, agriculture and agroforestry in the Atlantic area of Spain. They found that establishing agroforestry required higher initial investment than the agricultural and forestry systems due to higher initial inputs, but over a 30 year period, profitability per hectare was higher in the agroforestry system than in the exclusively livestock (17%) or forestry (53%) systems. When environmental and ecological benefits were included in the evaluation, the performance of the agroforestry system was even higher.

In silvoarable systems, annual returns from crops produced between tree rows can offset plantation establishment costs. Similarly, providing saplings are protected from livestock damage, integrating chickens into newly established plantings enables farmers to receive income well before any income from tree products is realised (Yates et al., 2007[195]). Valuable timber trees such as black walnut (*Juglans nigra*) were once raised as a retirement crop; farmers would sell a mature timber stand to fund their retirement (Scott and Sullivan, 2007[196]). High value timber trees such as black walnut are not ready for harvest until decades after establishment; integrating crops and/or livestock into the system can produce economic value for at least the first twenty years after establishment.

Modelling of economic returns from a black walnut alley cropping system in Midwestern USA highlighted the importance of system design and management for

[193] Rigueiro-Rodríguez, A., Fernández-Núnez, E., Gonzalez-Hernandez, M.P., McAdam, J., Mosquera-Losada, M.R., 2008. Agroforestry systems in Europe: Productive, ecological and social perspectives. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada, M.R., Rosa, M., (eds.) *Agroforestry in Europe: Current Status and Future Prospects*. Belfast: Springer, 43-65.

[194] Rigueiro-Rodríguez, A., Fernández-Núnez, E., Gonzalez-Hernandez, M.P., McAdam, J., Mosquera-Losada, M.R., 2008. Agroforestry systems in Europe: Productive, ecological and social perspectives. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losada, M.R., Rosa, M., (eds.) *Agroforestry in Europe: Current Status and Future Prospects*. Belfast: Springer, 43-65.

[195] Yates, C., Dorward, P., Hemery, G., Cook, P., 2007. The economic viability and potential of a novel poultry agroforestry system. *Agroforestry Systems* 69, 13-28.

[196] Scott, R., Sullivan, W.C., 2007. A review of suitable companion crops for black walnut. *Agroforestry Systems* 71, 185-193.

maximising productivity (Benjamin et al., 2000[197]). Systems with widely-spaced tree rows (12.2m between tree rows) were predicted to be more profitable than both closely-spaced (8.5m between tree rows) designs and walnut plantations, while root-pruning increased economic returns by extending the period of profitable crop production within the rotation. All agroforestry systems were modelled as having higher returns than monocropping systems (Benjamin et al., 2000[198]).

The effect of grants on profitability and feasibility of agroforestry systems in Europe was explored in a bio-economic model 'FarmSAFE' developed by Graves et al. (2007)[199]. While silvoarable systems were often the most profitable system (compared to arable and forestry systems) at landscape test sites in France, Spain and the Netherlands under a 'no grants' scenario, a pre-2005 grant regime based on direct area payments, and a post-2005 grant regime associated with the single farm payment scheme changed the profitability of silvoarable systems compared to arable and forestry systems, with some agroforestry systems becoming less profitable (Graves et al., 2007[200]). For example, in the Netherlands, losing arable land for slurry manure application made changing land use to agroforestry uncompetitive.

Recently, there has been considerable interest in placing a monetary value on the delivery of ecosystem services such as soil protection and carbon sequestration. Based on information on biophysical changes caused by shelterbelts, Kulshreshtha and Kort (2009)[201] estimated the value of external environmental benefits provided by shelterbelt systems in the Canadian prairie provinces as over CDN$140 million.

---

[197] Benjamin, T.J., Hoover, W.L., Seifert, J.R., Gillespie, A.R., 2000. Defining competition vectors in a temperate alley cropping system in the midwestern USA 4. The economic return of ecological knowledge. *Agroforestry Systems* 48, 79-93.

[198] Benjamin, T.J., Hoover, W.L., Seifert, J.R., Gillespie, A.R., 2000. Defining competition vectors in a temperate alley cropping system in the midwestern USA 4. The economic return of ecological knowledge. *Agroforestry Systems* 48, 79-93.

[199] Graves, A.R., Burgess, P.J., Palma, J.H.N., Herzog, F., Moreno, G., Bertomeu, M., Dupraz, C., Liagre, F., Keesman, K., van der Wert, W., Koeffeman de Nooy, A., van den Briel, J.P., 2007. Development and application of bio-economic modelling to compare silvoarable, arable and forestry systems in three European countries. *Ecological Economics* 29, 434-449.

[200] Graves, A.R., Burgess, P.J., Palma, J.H.N., Herzog, F., Moreno, G., Bertomeu, M., Dupraz, C., Liagre, F., Keesman, K., van der Wert, W., Koeffeman de Nooy, A., van den Briel, J.P., 2007. Development and application of bio-economic modelling to compare silvoarable, arable and forestry systems in three European countries. *Ecological Economics* 29, 434-449.

[201] Kulshreshtha, S., Kort, J., 2009. External economic benefits and social goods from prairie shelterbelts. *Agroforestry Systems* 75, 39-47.

Carbon sequestration accounted for the majority of this (CDN$73 million) and reduced soil erosion also provided significant economic benefits (CDN$15 million).

Alavalapati et al. (2004)[202] used a 'willingness to pay' approach to identify the economic consequences of internalising non-market goods and services from agroforestry to the benefit of landowners. They found that by including payments for environmental services delivered by agroforestry, the profitability of these systems would increase, relative to conventional agricultural systems.

Palma et al. (2007a)[203] used multi-criteria decision analyses to integrate quantitative environmental and economic outputs of agroforestry and allow comparison with conventional agriculture in three European countries. The profitability of the systems varied from country to country depending either on policy or biophysical conditions. In France, analysis indicated that with equal weighting between environmental and economic performance, silvoarable agroforestry was preferable to conventional arable farming, while in Spain and the Netherlands, the overall performance of agroforestry systems depended on the proportion of the farm planted, tree density and land quality used (Palma et al., 2007a[204]).

Porter et al. (2009)[205] calculated the values of market and non-market ecosystem services of a novel combined food and energy agroforestry system in Taastrup, Denmark. Belts of fast-growing trees (hazel, willow and alder) for bioenergy production are planted at right angles to fields of cereal and pasture crops, and the system is managed organically with no inputs of pesticides or inorganic N.

Field-based estimates of ecosystem services including pest control, nitrogen regulation, soil formation, food and forage production, biomass production, soil carbon accumulation, hydrological flow into ground water reserves, landscape aesthetics and pollination by wild pollinators produced a total value of US $1074 ha-

---

[202] Alavalapati, J.R.R., Shrestha, G.A., Stainback, G.A., Matta, J.R., 2004. Agroforestry development: an environmental economic perspective. *Agroforestry Systems* 61, 299-310.

[203] Palma, J., Graves, A.R., Burgess, P.J., Werf, W.v.d., Herzog, F., 2007a. Integrating environmental and economic performance to assess modern silvoarable agroforestry in Europe. *Ecological Economics* 63, 759-767.

[204] Palma, J., Graves, A.R., Burgess, P.J., Werf, W.v.d., Herzog, F., 2007a. Integrating environmental and economic performance to assess modern silvoarable agroforestry in Europe. *Ecological Economics* 63, 759-767.

[205] Porter, J., Costanza, R., Sandhu, H., Sigsgaard, L., Wratten, S., 2009. The value of producing food, energy and ecosystem services within an agro-ecosystem. *Ambio* 38(4), 186-193.

1, of which 46% is from market ecosystem services (production of food, forage and biomass crops) and the rest from non-market ecosystem services.

There has been considerable interest in the potential of an agroforestry approach to conserve and sequester C while maintaining land for food production and reducing deforestation and degradation of remaining natural forests. The 1997 Kyoto Protocol calls on participating countries to reduce the rising levels of CO_2 and other greenhouse gases by decreasing fossil fuel emissions and accumulating C in soils and vegetation of terrestrial ecosystems. It provides a mechanism by which countries that emit carbon in excess of agreed limits can purchase carbon credits from countries that manage carbon sinks. Leading the way with establishing tradable securities of carbon sinks to off-set emissions, Costa Rica invested $14 million in 1997 for the Payment for Environmental Services (PES), with 80% of funding coming from a tax on fossil fuels and 20% from international sales of carbon permits from public protected areas. This scheme led to the reforestation of 6,500 ha, the sustainable management of 10,000 ha of public natural forests and the preservation of 79,000 ha of private natural forests (Montagnini and Nair, 2004[206]). In 2003, the scheme was expanded to include agroforestry systems, and the Costa Rican government budgeted $400,000 for the integration of agroforestry management into carbon trading schemes with payments depending on the number of trees present on the farm (Oelbermann et al., 2004[207]). Introducing carbon payments to landowners and managers of agroforestry systems in temperate regions opens the way to obtaining additional income from these systems and may increase the attractiveness of establishing an agroforestry system, as well as adding value to established systems such as riparian buffers, shelterbelts, and silvopastoral and silvoarable systems.

---

[206] Montagnini, F., Nair, P.K.R., 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems* 61, 281-295.

[207] Oelbermann, M., Voroney, R.P., Gordon, A.M., 2004. Carbon sequestration in tropical and temperate agroforestry systems: A review with examples from costa rica and southern canada. *Agriculture, Ecosystems and Environment* 104, 359-377.