Agroforestry in Wales

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Climate Smart Woodlands in Wales

Final report

March 2020

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Introduction to the report

This report sets out the findings of the Climate Smart Woodland in Wales project that finished in March 2020. The phrase 'climate smart' denotes production systems that are best suited to respond to the challenges of climate change mitigation and adaptation for specific locations. This report explores what the 'climate smart' options are for two key forms of woodland. The first is the commercial forestry sector, which is likely to be the critical player in meeting future climate change-driven woodland creation targets in Wales. The second is agroforestry, which captures the various forms of system incorporating trees that can be integrated into farming systems, both to deliver benefits to the farm and a wider set of public goods. The report is divided into three sections:

The first section analyses the viability of "land sparing" and "land sharing" strategies for commercial woodland creation within Wales. This research is focused on identifying the opportunity space for productive woodland creation within agricultural land of moderate productivity classified as ALC3b, for both key conifer and broadleaf species to meet climate commitments. We also demonstrated the potential use of modern "app" technology to deliver decision-support for the planning of efficient target-driven woodland creation.

The second section provides an introduction to, and an overview of, agroforestry and discusses opportunities to expand agroforestry systems in Wales. It highlights both the costs and benefits associated with agroforestry (including climate change mitigation benefits) and discusses both how and where to increase agroforestry in Wales.

These two options represent potential adaptation or transformation pathways for agricultural systems in Wales to meet climate change mitigation commitments. Business as usual is no longer a viable option and tree planting, in some form, will be a significant component of any 'climate smart' solution.

The final section explores farmer attitudes to changes in tree cover; including some initial work exploring the role that decision support tools might play.

In developing these outputs, we have sought to be agnostic in relation to which tree-based option might be more or less appropriate in any particular context. The results suggest that there is a degree of overlap in many areas of Wales where both options may be suitable. At the same time, we acknowledge that barriers are also present that may restrict both. As such, this is not a set of proscriptive tools. Instead we wanted to create evidence that can feed into a decision-support framework by identifying areas that had significant potential for both options should the opportunity arise.

Section 2: Agroforestry in Wales

Tim Pagella & John Healey

March 2020

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Section 2: Key Messages:

- Agroforestry is an umbrella term for many different practices (and combinations of practices) ranging from traditional hedgerow systems to much more complex 'modern' agroforestry systems such as alley cropping. There is currently a lack of quantitative information on the extent of (and trends in) agroforestry in Wales.
- All forms of agroforestry have the potential to sequester carbon (C), although the benefits will vary depending on soil type, species, planting density, location and land use intensity.
- Establishing trees on agricultural land can help to mitigate many of the negative impacts of agriculture, for example by regulating soil, water and air quality, supporting biodiversity, reducing inputs by natural regulation of pests and more efficient nutrient cycling, and by modifying local and global climates.
- Farmers are likely to need better decision support to help them design and manage agroforestry systems if they are to provide both *in situ* benefits to farming systems and supply wider public benefits.
- Inclusion of woody species in farming systems should be encouraged, combined with management to provide access to tree and hedgerow fodder.

1.0 Introduction

This working paper aims to provide an overview of agroforestry for Climate Smart Woodlands for Wales.

The rationale for this work was that there was some confusion about what agroforestry was and that the term “agroforestry” meant different things to different people. There is significant potential to expand the area of tree cover outside woodland and this will, most likely, be some form of agroforestry system. As such, there was felt to be a need for a more nuanced, unified definition of the types of tree cover that can be integrated into farming systems. The focus for the Climate Smart Woodlands in Wales project has primarily been on upland systems. It is possible to have forms of agroforestry within an urban context (specifically home garden systems) but these fall out of scope for this work.

The report presented here:

1. Gives a working definition of agroforestry and considers this definition within the context of expanding tree cover in Wales
2. Provides a characterisation of the different benefits associated with different forms of agroforestry system
3. Defines and describes the different types of agroforestry practices available and their likely applicability in different contexts
4. Provides a broad review of current initiatives that are successfully facilitating establishment of trees on farms across the UK (such as the Sheep and Trees Forestry Grant Package provided in Scotland).

1.1 Agroforestry: an overview

A basic definition of agroforestry is that it is a combination of agriculture and forestry, a land use that combines aspects of both, including the agricultural use of trees (van Noordwijk 2019). Agroforestry therefore describes any land-use system, practice, or technology, where woody perennials are integrated with agricultural crops and/or animals in the same land management unit (Marais et al 2019).

World Agroforestry (ICRAF), the institution which has been at the forefront of most of the research associated with agroforestry systems globally for the last five decades, uses the following definition:

"Agroforestry is the interaction of agriculture and trees, including the agricultural use of trees. This includes trees on farms and in agricultural landscapes, farming in forests and along forest margins and tree-crop production, including cocoa, coffee, rubber and oil palm. Interactions between trees and other components of agriculture may be important at a range of scales: in fields (where trees and crops are grown together), on farms (where trees may provide fodder for livestock, fuel, food, shelter or income from products including timber) and landscapes (where agricultural and forest land uses combine in determining the provision of ecosystem services)."

At national and global scales, forestry and agriculture interact ecologically and through policies relating to land use and trade, and both are important with respect to climate change and other environmental concerns. "Agroforestry embraces an agroecological approach, putting emphasis on multi-functionality and the management of complex systems and polycultures rather than focusing exclusively on monoculture" (van Noordwijk et al., 2019).

This definition sets out these basic principles:

1. That agroforestry will normally involve at least two or more species of plants or combinations of plants and animals with at least one plant in any combination being a woody perennial;
2. That an agroforestry system always has two or more outputs (which can be economic and/or ecological). These can be in the form of products that feed directly into the farming system (food, fibre or fuel) or indirect benefits, such as provision of shelter or erosion control;
3. That agroforestry systems are long-term practices – the cycle of an agroforestry system is always longer than one year; and
4. That even the simplest agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a mono-cropping system.
5. Agroforestry is a flexible concept, present to greater or lesser extents on both small and large-sized land holdings.

1.2 Current extent of agroforestry

From the definition, it is clear that agroforestry can take several different forms. Examples of agroforestry systems that can be found in Wales range from simple hedgerow systems, tree shelterbelt systems, various forms of alley cropping, and integrated remnant vegetation (e.g. retaining a tree for shade provision in the middle of a field). The diverse nature of what an agroforestry system comprises can make it challenging to map the extent of agroforestry present (and thus provide detailed inventory data).

At present there is no *de facto* account of the extent of agroforestry in Wales. There have been several broader studies, most importantly a global estimate by Zomer et al. (2017) and a European estimate by den Harder et. al. (2018). Both of these studies used relatively crude metrics to identify agroforestry. These are discussed briefly below.

Zomer et al. (2017) defined agroforestry very broadly, whereby remote sensing data were used to measure tree cover on agricultural land and land with more than 10% tree cover was considered agroforestry. This study found 'agroforestry' on more that 43% of all agricultural land globally. This land-use type represents over 1 billion hectares of land and is utilised by >900 million people. Given the very basic definition, this is undoubtedly an underestimate and would also miss much of the agroforestry present in the UK (as the land area occupied by trees on farm is generally less than 10%).

There has only been a single audit of agroforestry at a European scale (den Herder et al., 2018), which was conducted as part of the AGFORWARD project[1]. This included summary data for the UK land covered by silvopasture and silvoarable systems but did disaggregate the data down to the devolved nations, so there are no specific data for Wales. The audit suggested that 3.3% of farmed land within the UK was under agroforestry compared with an average of 8.8% across Europe. The bulk of this was silvopasture (i.e. agroforestry systems where trees are integrated into pasture), which covered approximately 547,600 ha in the UK. Silvoarable systems (where trees were integrated into cropping systems) accounted for 10,100 ha and boundary planting (i.e. hedgerows systems) contributed a further 239,800 ha. In the study the figures represent the area of land occupied by the trees as opposed to the area of land under the agroforestry system as a whole.

The National Forest Inventory report of tree cover outside woodland in Great Britain (2017) found that there were 742,000 ha of tree cover outside areas classified as woodland in the NFI; 565,000 ha in England, 84,000 ha in Scotland and 93,000 ha in Wales. Whilst some of this tree cover will be present in urban environments, approximately 74% is found in rural environments. Small woods of over 0.1 ha in extent cover 390,000 ha in Great Britain; with 49,000 ha in Wales. It is difficult to capture the extent to which these trees may provide benefit to agricultural practice (and thus fit the definition of agroforestry) but they are a significant component of the UK (and Welsh) land use systems. The inventory found 76 ,000 km length of hedgerows in Wales. Where we have tree cover, the majority is found at altitudes of less than 200 m (accounting for 91% of all tree cover outside woodland).

Agroforestry can occur on urban, peri-urban, agricultural and forest land. As is the case for farm woodlands, it is not restricted to lower quality agricultural land. Agroforestry is possible on almost all of the land in Wales, as it acts as a bridge that both sits between and integrates aspects of agriculture and forestry.

1.3 Remnant agroforestry and novel agroforestry systems

Many agroforestry practices are as old as agriculture itself and have been developed by farmers over many generations. The development of the science of agroforestry has its roots in farmer-focused learning supported by formal science. As such, 'agroforestry' most frequently consists of farmer-designed systems that have been refined through modern science. Whilst agroforestry has begun to enjoy a higher profile over the last couple of years, many people still tend to associate agroforestry

[1] https://www.agforward.eu/index.php/en/

with a range of novel practices, however most farms in the UK have purposively retained trees in a number of different forms, in many cases for long periods of time, to provide on-farm benefits. In some cases, these practices are hundreds, if not thousands, of years old and all meet the definition of agroforestry. So, whilst the umbrella term itself may not be well known, the practices and benefits are a relatively common features in the UK farming landscape. Indeed, many Welsh farmers are currently practising agroforestry (and already recognise many of the benefits) but often do not associate this terminology with the practice. In exploring the concept with farmers, it is often helpful to begin by discussing these remnant agroforestry practices and systems, and frame discussions around expansion of existing practices rather than the introduction of new practices (fig. 1).

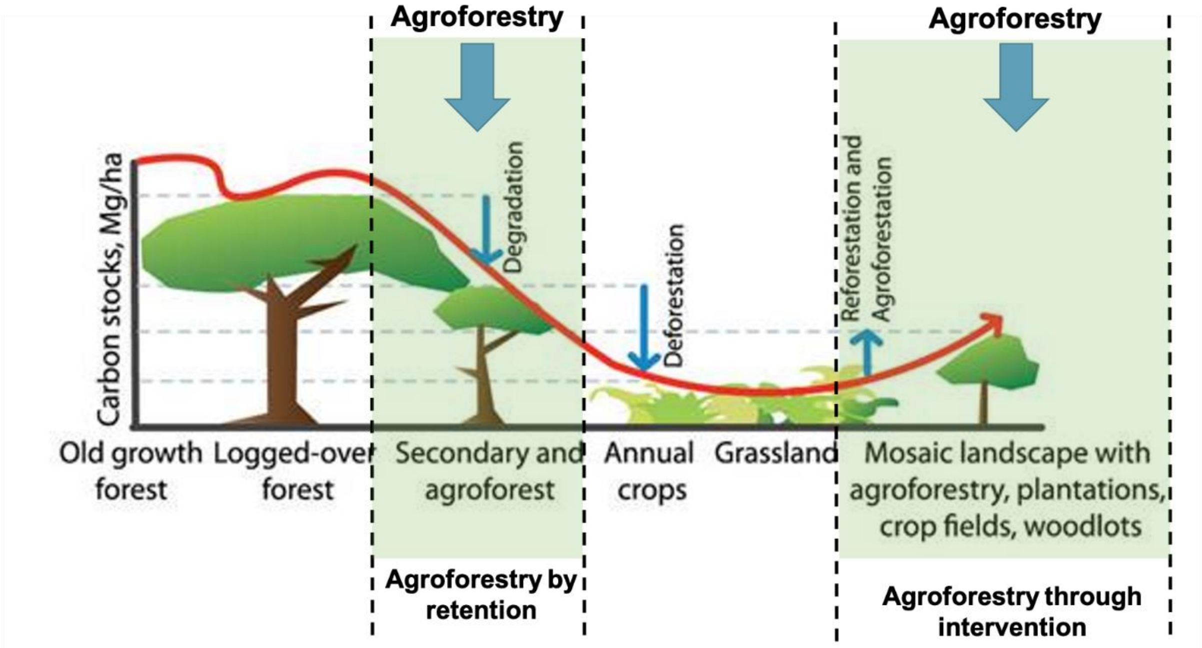

Figure 1: Forest Transition Curve (from van Noordwijk 2019). The figure has been modified to highlight the two pathways by which agroforestry if found in farming systems. In the UK, where silvopastoral systems dominate, almost all farms will have retained tree cover to benefit their livestock (i.e. agroforestry through retention). The current drive is to expand agroforestry systems through interventions but in many cases this will be an expansion of existing practice.

A 'simple' agroforestry system might consist of a single agroforestry practice. For example, a pasture with hedgerow as a boundary, or livestock allowed to graze within a woodland system. More complex agroforestry systems will have combinations of these practices such as a pasture incorporating boundary hedgerows, shelter systems (both for wind and sun) and riparian tree cover (to reduce run-off). A single farm may have a single agroforestry system throughout or be made up of a number of agroforestry systems (for example a Welsh upland farm may integrate shelter systems in exposed higher altitude pastures and retain riparian cover and shade systems in lowland paddocks).

1.4 Global interest in agroforestry

The global case for increasing the amount of agroforestry is compelling. Many farming systems in Europe have successfully increased production with an associated loss of the regulating functions Chatterton et al. (2015). Agricultural expansion is associated with loss of more ecologically complex unmanaged land. In response to this, numerous studies have highlighted the global need to increase food production whilst reducing the environmental costs (e.g. Foresight 2011; FAO 2014).

Globally agroforestry is increasingly recognised as a critically important land use response, and a potentially vital tool, to provide both climate change adaptation and mitigation whilst also addressing land degradation and enhancing food security (recent examples are reported in The Net Zero Report (2019) and the IPCC report on Land use (2019) from which fig. 2 was sourced).

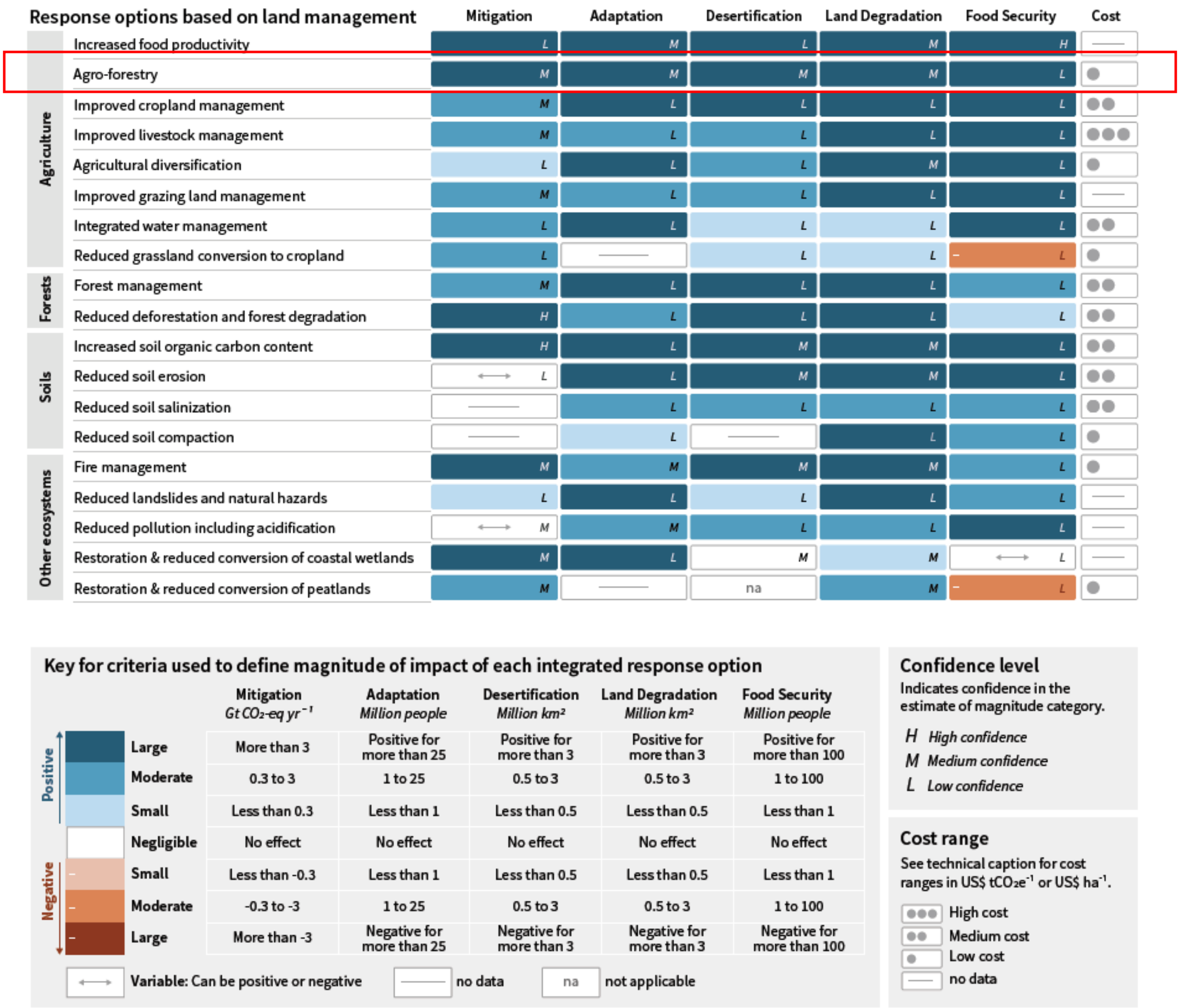

Figure 2: Response options that can be implemented without or with limited competition for land, including some that have the potential to reduce the demand for land. Co-benefits and adverse side effects are shown quantitatively based on the high end of the range of potentials assessed. Magnitudes of contributions are categorised using thresholds for positive or negative impacts. Letters within the cells indicate confidence in the magnitude of the impact relative to the thresholds used (from IPCC, 2019).

Agroforestry increasingly represents a 'win-win' approach, as carefully designed agroforestry systems can maintain or even increase the production of food, fibre, and fuel from agroecosystems whilst restoring natural capital and thereby enhancing the provision of regulating ecosystem services (e.g. erosion control, microclimate regulation). A study looking at ecosystem service provision from agricultural landscapes that incorporated agroforestry systems found that these systems (i) were associated with reduced externalities of pollution from nutrient and soil losses, and (ii) generated additional benefits from carbon capture and storage, and thus generated an overall higher economic gain (Kay et al., 2019).

2.0 Types of agroforestry

There is an important need to distinguish between agroforestry practices and agroforestry systems. In broad terms there are two main categories of agroforestry system; silvopastoral systems and silvoarable systems (and occasionally agrosilvopastoral systems which combine all elements). These can be either trees integrated onto what is predominantly agricultural land or agriculture integrated into woodland.

- Silvopastoral systems are combinations of trees with livestock (and represent the most common forms of agroforestry system encountered in temperate climates, including Wales)
- Silvoarable systems are combinations of trees with arable crops

Both of these agroforestry systems can take multiple forms. These forms are built up through different arrangements or combinations of agroforestry practice. Agroforestry practices are discrete arrangements of trees. These are described and discussed briefly in the following sections.

In Wales, given the nature of our farming systems (fig. 3) the most important form of agroforestry is silvopasture. Cereals, general cropping and horticulture account for only a combined 0.8% of holdings in Wales (National Assembly for Wales, 2018).

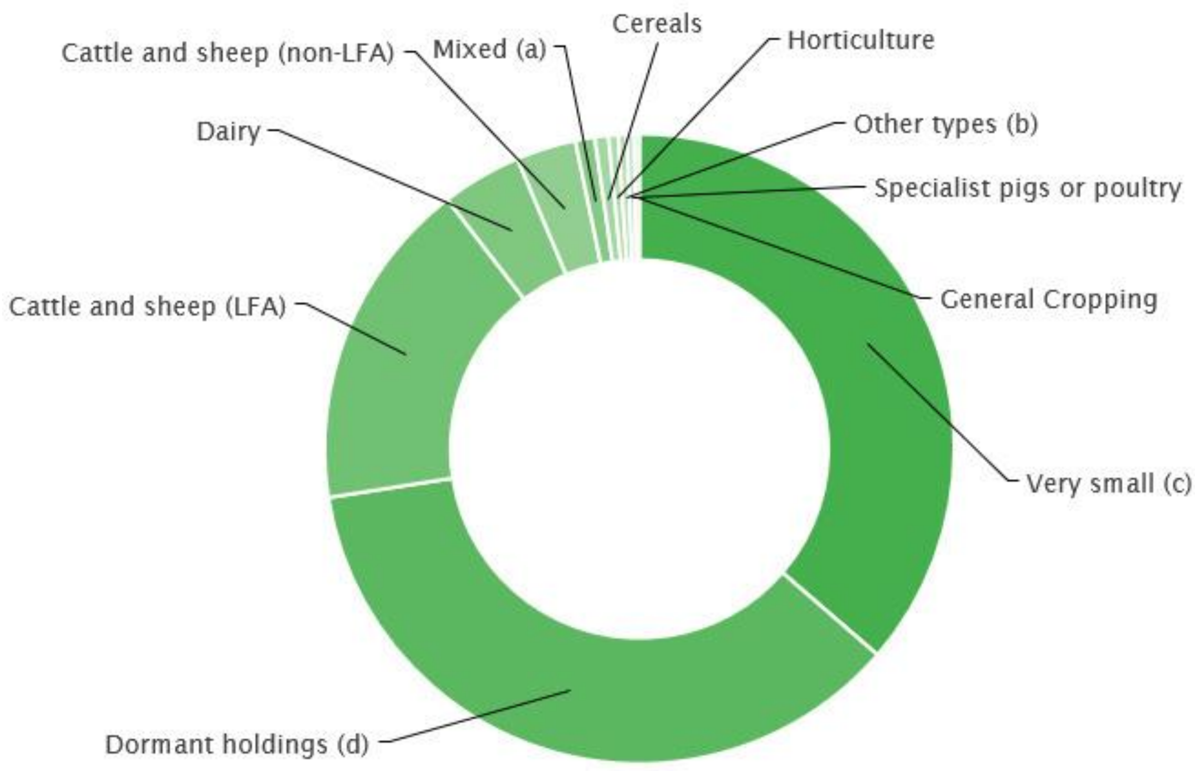

Figure 3: Welsh farm holdings by type (source National Assembly for Wales, 2018).

2.1 Silvopastoral systems

Silvopasture is an ancient practice that integrates trees and pasture into a single system for raising livestock. The potential advantages of silvopasture are considerable. Livestock, trees, and any additional forestry products, such as nuts, fruit and mushrooms, generate income on different time scales. Combining the right trees in the right context can significantly improve the health and productivity of livestock whilst at the same time improving soil health.

In silvopastoral systems there are three primary interactions to consider:

1. Interactions between trees and pasture (*in situ* effects)
2. Interactions between trees and livestock (*in situ* and landscape effects)
3. Interactions between trees and broader ecosystem functions (*in situ* and landscape effects).

All of these interactions can involve trade-offs and outcomes will vary as the tree components mature. Cumulatively in well-designed agroforestry systems these lead to favourable outcomes at both the farm and landscape scale.

In the following section different types of system found in Wales are described and a short list of associated benefits and costs are assigned to each. These benefits and costs also capture whether the benefit is a private good (i.e. the benefit is realised by the owner of the system) or public good (where the benefits also flow off-farm and provide wider societal benefits). Note that these benefits will be very dependent on the condition of the system. Undermanaged hedgerows will produce a very different suite of benefits when compared with highly managed hedgerows. These benefits are then expanded on in Section 3.

Most forms of silvopasture that are potentially viable in a Welsh context involve the integration of trees into pasture systems (sections 2.1.2-2.1.6). There are some systems where livestock are integrated into existing woodland (primarily to benefit the livestock; but with occasional benefits to the woodland (sections 2.1.7-2.1.8).

Note: Grazing animals can damage tree stems, roots and ground vegetation and, as such, cattle, sheep and horses pose dangers to trees. Their natural behaviour is to trample (in the case of cattle) or browse and rub, which means that establishment is impossible in most cases without protection and constant monitoring. This is not a problem in poultry systems.

2.1.1 Hedgerow systems

Hedgerows are the most common form of silvopastoral practice. They are not exclusive to pasture systems (i.e. they are also present in silvoarable systems, but often less extensive, with many hedgerows having been removed as field sizes increased alongside the increased use of mechanised agriculture). Hedgerows can have a variety of forms, dependent on the context, the management objectives and the degree of management. In silvopastoral systems in Wales the primary value of hedgerows will be for their shelter value from wind, rain and snow. Tree standards retained in hedgerows may provide shading benefits as well. Hedgerows are important for marking out farm boundaries and are seen as increasingly important for the delivery of biosecurity, and security benefits. As such, they also have high cultural value, with well-maintained hedgerows acting as an indicator of 'good farming' practice. Hedgerows are important sources of fibre and fuelwood for the farm and may also produce fruits as well as providing an important habitat component for a wide range of species.

Hedgerow systems are generally popular with farmers and contribute significantly to the cultural values associated with farming landscapes across Wales.

Hedgerows are subject to a wide variety of management regimes but are often mechanically flailed in the UK as the main method of restricting their height and width growth, which has the potential to limit recruitment of tree standards, as well as damaging the structure of the hedgerow resulting in a reduction in their value as barriers. Off-farm monitoring of hedgerow condition is generally negligible (fig. 2). Despite their relative importance, there is very little data available on hedgerow extent and condition in Wales.

Figure 4: Upland pasture in the Elwy valley with degraded hedgerows present (i.e. the visible hedgerows have many gaps and are poorly maintained). Note also the presence of historic field boundaries where hedgerows were once present.

2.1.2 Shelterbelts (wind, rain and snow)

Windbreaks and shelterbelts have been used to modify microclimate in agricultural landscapes for centuries (He et al. 2017). Shelter systems, also known as windbreaks, are agroforestry systems that consist of barriers of trees, or trees combined with shrubs, that are planted to reduce wind speed. In silvopasture systems the primary aim is to reduce wind and cold stress in livestock.

Shelterbelts modify microclimate by a combination of slowing the speed of wind travelling through the shelterbelt and increasing air pressure on the windward side whilst decreasing air pressure on the leeward side to create a sheltered zone. The shelter zone is predominantly on the leeward side and encompasses a distance approximately 14 times the height of the shelter. Some shelter (to a distance about twice the height) is also provided on the windward side (Gregory, 1995). Location, height, and wind porosity are stated as the most important factors to consider when parameterising models of shelter to estimate wind speed reduction (Gregory, 1995).

Shelterbelts often contain multiple strata of trees or shrubs, purposively located in exposed locations and can be found at higher altitudes. In the 1970s the favoured type of shelterbelt established in Wales were pure conifer features, but these have limited porosity and this can reduce their effectiveness. Many farmers will still initially seek to plant conifer shelters despite this. The most efficient systems for year-round benefits may be a combination of a lower density of conifers with deciduous broadleaved trees and shrubs.

While hedgerows are also used for shelter, a shelterbelt can be distinguished by including a higher stratum of trees whose crowns form a continuous barrier (fig. 4). This additional structure increases the rate of processes such as carbon sequestration and benefits biodiversity (Mayrinck et al., 2019).

Figure 5: A shelterbelt system at the Pontbren farms in mid Wales. Note the increased width and height. This shelterbelt was about sixteen years old at the time the picture was taken.

Benefits associated with hedgerows and shelterbelts include:

- Enhanced shelter for livestock, particularly against wind, rain and snow (private good)
- Supplementary diet (fodder) (private good)
- Enhanced biosecurity (private good)
- Enhanced carbon sequestration (public good)
- Water regulation (private and public good)
- Enhanced biodiversity, both below and above ground (public and private good)
- Improved soil conservation and health (private good)
- Production of fibre, fuel and food (private good)
- Reduced pest incidence, particularly associated with reduction in damp conditions for livestock (private good)
- Increased pollination (private and public good)
- Potential habitat for the natural enemies of pests (biocontrol agents) (private and public good)
- High cultural value (particularly hedgerows) (private and public good).

Potential detriments associated with hedgerows and shelterbelts include:

- Reduced productivity of the grass forage adjacent to linear tree features (in the later stages of tree development) – private cost
- Potential host of pest species – private cost

2.1.3 Shade systems

Shade systems are where single trees, or small clumps of trees, are purposively located (or retained) in fields or holding areas on farms generally to reduce heat stress in livestock. Sometimes these will be incorporated into hedgerows or they may be trees retained in the middle of fields.

Benefits associated with shade systems include:

- Enhanced shelter for livestock, particularly reductions in heat stress (private good)
- Enhanced carbon sequestration (public good)
- Water and soil regulation (private and public good)
- Enhanced biodiversity, both below and above ground (public and private good)
- Potential habitat for the natural enemies of pests (biocontrol agents) (private and public good)

2.1.4 Regularly-spaced silvopasture systems

Where the primary intention is to provide an alternative crop alongside livestock, this may be achieved by planting trees integrated into fields as regular rows, and these can be classified as regularly-spaced silvopasture systems. These systems often require more silvicultural input to manage the trees, primarily to reduce shading effects and to guard the trees initially from the livestock. For certain systems, such as poultry-based agroforestry systems, these negative interactions are minimal. Open regularly-spaced silvopasture systems offer less shelter than shelterbelt systems designed for this function, though they give more even shade. These systems are more suited to lowland pastoral systems (fig. 6).

Figure 6: Regularly-spaced silvopasture systems at Henfaes, Bangor University's farm.

These systems often incorporate rows, but it is possible to use other structures such as clumps or block designs (examples of these are visible in the right- and left-hand side of fig. 6 respectively). Clumps have several potential advantages over individual tree planting. The cost of tree protection is lower, and it is possible to select high-quality trees, through progressive thinning, to leave a small number of final crop trees in each clump. Furthermore, shading amongst trees within the clump may have silvicultural benefits of enhancing tree height growth and self-pruning, and in exposed conditions the outer trees may shelter inner trees (in addition to the livestock). However, this is at the cost of the very asymmetric crown-form of the edge trees, which is highly detrimental to the quality of harvested wood for structural uses. The shelter benefits are also likely to be enhanced, but significantly lower than for a liner shelterbelt system.

2.1.5 Grazed orchards

Traditional orchards are a form of usually regularly-spaced silvopasture systems, where fruit trees are arranged in rows, typically as either open-grown “standard” fruit trees or bush orchards (where trees are pruned to a height of 1-2 m). These orchard types usually have an understory of grass and in some traditional standard orchard systems grazing is practised to manage the grass sward and reduce competition with the fruit trees. In cider system the sheep are removed from the orchard for at least two months before harvest[2]. Historically, chickens were also often kept in fruit orchards, to provide some control of insect pests.

Benefits associated with regularly spaced silvopasture systems include:

- Enhanced shelter for livestock, particularly from heat stress although providing less shelter from cold stress (private good)
- Enhanced carbon sequestration (public good)
- Water regulation (private and public good)
- Enhanced soil health and soil conservation (private and public good)
- Enhanced biodiversity, both below and above ground (public and private good)
- Production of fibre, fuel and/or food (private good)
- Reduced pest incidence, particularly associated with reduction in damp conditions for livestock, as well as providing habitat for natural enemies of pests (private and public good)
- Increased pollination (private and public good)
- Reduced management costs (in orchards) (private good)

Potential detriments associated with regularly spaced silvopasture systems include:

- More complex system requiring higher time inputs (private cost)
- Requirement for more expensive tree guarding or stock management (private cost)
- Reduced productivity of the grass forage adjacent to trees features (particularly in the later stages of tree development) (private cost)

In addition to the integration of trees into pastoral systems, silvopasture also includes the practices of integrating livestock into woodlands. In these systems livestock typically graze within woodlands for short periods of time or for shelter in adverse conditions. Historically, forest grazing tended to focus on cattle, but it can also include sheep, poultry and pigs (for which pannage (of acorns) was an important traditional practice).

The integration of livestock, if managed carefully in terms of grazing pressure, can be an important tool for woodland management and to meet biodiversity conservation objectives. For example, in some conservation systems, pigs are used to help establish new tree seedlings within an established woodland. The action of the pigs on the soil encourages dormant seeds to germinate and may reduce competition from bracken and other dense ground vegetation. However, poor management of the livestock can quickly result in negative outcomes (particularly with pigs, although this isn’t generally an issue in Wales).

[2] https://www.agforward.eu/index.php/en/Grazed_Orchards.html

2.1.6 Farm woodlands

Farm woodlands, in a similar way to hedgerows, are an important but understudied resource. Whilst may of the agroforestry systems above are based on linear tree arrangements, farm woodlands come in all shapes and sizes and are often remnant features where land was deemed unsuitable for cultivation. Traditionally, farm woodlands were planted for shelter, timber production, amenity and game cover or a combination of these. The area of farm woodlands in the Wales is expanding, going from 78,000 Ha in 1915 to 89,200 in 2016 (Forest Research, 2017).

2.1.7 Wood pasture

Wood pasture is a wide encompassing term used to describe systems in which livestock grazing co-occurs with scattered mature (and often ancient) trees and shrubs. These are traditional systems which provide shelter, pasture and fodder for livestock and wood products for local people. Many wood pastures are ancient systems and will have high biodiversity value, many sites have national historic, cultural and landscape significance. Parkland systems are a form of wood pasture, often associated with larger estates and the retention of veteran trees of high cultural and biodiversity value.

Benefits associated with farm woodland and wood pasture systems include:

- Enhanced shelter for livestock, particularly wind and rain (private good)
- Supplementary diet (fodder) (private good)
- Enhanced carbon sequestration (public good)
- Water regulation (private and public good)
- Enhanced and soil health and soil conservation (private and public good)
- Enhanced biodiversity, both below and above ground (public and private good)
- Production of fibre, fuel and/or food (private good)
- Reduced pest incidence, particularly associated with reduction in damp conditions for stock and provision of habitat for the natural enemies of pest species (private and public good)

Potential detriments associated with farm woodland and wood pasture systems include:

- Reduced productivity of the crop adjacent to tree features (particularly in the later stages of tree development) (private cost)
- More complex system requiring higher time inputs (private cost)

Note that the impacts of the livestock component on the objectives and practice of woodland management can be varied and are very dependent on the livestock species, the density of animals, and the duration and seasonal timing of their presence in the woodland. When short of other forms of food horses and cattle can rapidly cause serious damage to the bark of (even semi-mature) trees.

2.2 Silvoarable systems

Silvoarable systems are far less common in the UK generally, and especially in Wales, where the area of arable land is limited (fig. 3).

2.2.1 Row systems

In row systems crops are generally grown between rows of trees and/or shrubs which have been planted at a spacing appropriate for the use of agricultural machinery (Hislop & Claridge, 2000). A specific case is alley cropping, a system in which trees or hedges are planted in closely-spaced rows between the crops.

2.2.2 Boundary systems

Boundary systems are where arable systems have hedgerows or shelter structures. The primary value of the shelter in this context is reduction in wind erosion and microclimate benefits - see also sections 2.1.2 and 2.1.3 above.

Benefits associated with silvoarable systems include:

- Enhanced soil conservation (private good and public good)
- Increased crop production (private good)
- Water regulation (private and public good)
- Enhanced soil health and soil conservation (private and public good)
- Enhanced carbon sequestration (public good)
- Enhanced biodiversity both below and above ground (public and private good)
- Production of fibre, fuel or food (private good)
- Reduced pest incidence, particularly associated with provision of habitat for the natural enemies of pest species (private and public good)
- Increased pollination (private and public good)

Potential detriments associated with silvoarable systems include:

- Reduced productivity of the grass forage adjacent to linear tree features (in the later stages of tree development) – private cost

2.3.3 Home gardens

Multiple layers of vegetation (often referred to as home gardens or kitchen gardens) are typically found in urban areas or on smallholdings and can supply fruits and vegetables at an individual level. These fall out of the scope of this report.

2.3 Non-specific agroforestry practices

There are a number of non-specific agroforestry systems that can occur in both arable and pastoral farming systems, including hedgerows and farm woodlands. Some of these systems, such as contour strips to reduce soil erosion, are very rare to non-existent in the UK whereas others, particularly riparian woodland, are relatively common.

2.3.1 Riparian systems

Riparian systems, or buffer strips, ‘are areas of land maintained in permanent vegetation that helps to control air, soil, and water quality, along with other environmental problems’. These are examples of agroforestry systems that are primarily implemented for their regulating benefits, acting as a buffer to reduce sediment, nutrient and water delivery into freshwater systems. Approximately 15% of water channels in England and Wales have riparian trees (defined as vegetation objects greater than 2.5 m high) but there is need for better data, particularly for upper catchment areas where tree shading may play a critically important role in cooling aquatic habitats for benefits of biodiversity and populations of valuable fish species.

Benefits associated with riparian systems include:

- Water regulation (quality and quantity) (private and public good)
- Enhanced soil conservation (private and public good)

- Enhanced carbon sequestration (public good)
- Enhanced nutrient management (dependent on location) (private and public good)
- Production of fibre, fuel and food (private good)

Potential problems associated with riparian systems include:

- Reduced water quality associated with livestock impacts (private and public cost)
- Reduced land area for farming (private cost)
- Requirement for more expensive tree guarding or stock management in livestock systems (higher establishment costs and labour requirements) (private cost)

3.0 Benefits associated with agroforestry systems

The benefits that agroforestry can provide to farm businesses fall into two broad categories: direct economic benefits through utilisation or sale of products associated with the additional tree component; the indirect economic benefits derived from enhanced agroecological function. These two categories of benefit are not mutually exclusive, trees often can and will provide both, but their relative importance will vary with the management actions (and management priorities) of the landowner and the context in which the agroforestry system is developed.

Context is important, as both the variety and quality of outputs will vary over time and space. For example, with appropriate management more sheltered lowland silvopasture systems sited on better soils will be able to produce significantly higher quality timber or yields of fruit than similar silvopastoral systems in exposed upland locations. In all cases these benefits take time to be realised (and often incur upfront costs at establishment). In addition, the interactions between crop or animal components will change over time, so there will be variation in the nature of benefits over the lifetime of the trees. For example, there may be complementarity between tree and agricultural components in the early stages, which then shifts into competition for resources as the tree component reaches maturity).

3.1 Direct economic benefits

The potential to generate a new income stream by adding an additional tree crop is often the first thing farmers and other landowners consider when thinking of adopting agroforestry. These break down into three basic options: food, fibre and fuel. In principle, maximising the economic value of trees requires careful management (i.e. appropriate tree selection, design, establishment and on-going maintenance) and knowledge (including understanding new markets) to maximise the return on investment. Timber generally requires longer timeframes before these benefits are realised (with many farm trees being invested in as a retirement bonus or as a gift to the next generation of farmers). While trees may also require time to grow to the optimal size for wood fuel production, earlier harvests may be carried out through thinning operations.

3.1.1 Timber production

Depending on context there are opportunities to produce high value timber from agroforestry systems. In lowland systems, particularly silvoarable, there is good potential to produce high quality timber as the trees are less exposed, are sited on good soils and have lower risk of grazing damage, In a pastoral context both the variety and quality of timber will be reduced, although it is still possible to get good timber from high value trees (such as cherry) in well-designed shelter systems and in farm woodlands. Nonetheless, achieving this benefit from open-grown trees generally requires a high labour input for pruning and other tree maintenance operations.

3.1.2 Firewood and other forms of wood fuel

Where timber is harder to grow there is still potential to produce wood fuel and biomass. The economic value of these types of activity are understudied (but see Wong & Walmsley 2013). Destructive harvesting associated with biomass can result in negative environmental outcomes; particularly in riparian areas.

3.1.3 Fruit and nut production

The market for UK-grown fruits, nuts and berries was approximately £769 million in 2018. A comparison in the UK has shown that weighted by area, agroforestry can be more productive than dedicated orchards (Smith et al. 2014).

3.1.4 Tree fodder as a feed supplement

Tree fodder can provide an alternative source of nutrition and feed. At present this resource is a highly underutilised source of supplementary feed for livestock with high potential (Kendall et al, 2019). Historically the collection of 'tree hay', could be cut and stored on farm for periods of up to 24 months and then used during dry periods to supplement the livestock diet. Traditionally, many species of deciduous trees were used, in particular wych elm (*Ulmus glabra*), ash (*Fraxinus excelsior*), silver birch (*Betula pendula*), and goat willow (*Salix caprea*). Research has shown that willow and ash can have organic matter digestibility levels similar to hay and grass silage (Musonda et al. 2009; Pitta et al. 2007). As such there is potential for preserved tree fodder to fill the 'spring gap', when the productivity of new season grass is low (Luske et al. 2018). Tree fodder has also been shown to have benefits for livestock mineral nutrition and reduce intestinal parasite loads (Kendall et al. 2019), and also has potential to reduce methanogenesis from ruminants so mitigating climate change (Wiik et al. 2019). These systems have fallen out of practice because of the high labour input required and an increased reliance on inorganic feed supplements and veterinary pharmaceuticals.

3.2 Agroecological benefits

The presence of trees can also provide indirect economic benefits that are realised both at the farm scale and beyond the farm gate (in the form of public goods). These benefits arise where trees either increase the value of other products (for example where the provision of shelter increases the live weight gain of animals) or they reduce costs (for example by drying out wet pastures thereby reducing incidence of disease and thus reducing veterinary costs).

Trees provide a broad range of these agroecological benefits, and this multifunctionality is a key reason why the value of agroforestry is increasingly recognised (van Noordwijk et al., 2019). These benefits may be too imperceptible for many farmers to see (in that it is often harder to measure them in economic terms) but are often critically important for the long-term sustainability of farming systems. The body of evidence associated with the agroecological benefits is growing rapidly (van Noordwijk et al., 2019). An overview of the typical benefits is provided here, but the exact mixture of benefits will vary with farm context and farm objectives.

3.2.1 Increase in soil health

The benefits that trees can provide to agricultural soils are well established (Young, 1997). Trees help to maintain long-term soil fertility. Trees with deeper root systems will capture nutrients leached below the grass or crop rooting zone and return them to surface soil via litter and through root turnover. Trees improve the soil holding capacity for water and nutrients. Trees can limit compaction by animals (poaching) and increase infiltration. Under elevated stress conditions (such as drought), trees invest in their mycorrhizal associations and can scavenge water and nutrients from deeper within the soil. In addition, tree root systems significantly reduce soil loss from erosion, though suppression of perennial grasses by tree shade can increase risks of winter erosion, particularly under the crowns of deciduous tree species. Trees can also encourage beneficial soil organisms. Under most systems where agroforestry is integrated into agricultural land, there are changes in the compositon of fungi and bacteria (George et al., 2019) and increased numbers of earthworms. For most systems this increase is an indicator of a healthier soil.

Trees can also be used to reduce fertiliser costs. Selecting nitrogen-fixing trees (such as alder) can lower the input of nitrogen fertiliser required to achieve the target level of pasture or crop productivity.

3.2.2 Shelter provision

Carefully sited shelterbelt systems and hedgerows can improve livestock welfare and production efficiency by maintaining thermoneutrality and minimising metabolic energy requirements. Lamb mortality in the UK ranges from 10 to 25% (Mellor and Stafford, 2004) and has been reported anecdotally as being as high as 30-40% on individual farms. Exposure-related mortality has been shown to be a major contributor to neonatal deaths in outdoor-lambing systems (Dwyer, 2008; Gascoigne et al., 2017). Effective shelter provision has been shown to reduce lamb mortality rate by up to 50% in inclement weather and offers potential to improve livestock welfare in both summer and winter conditions (Donnelly, 1984; Pent et al. 2020a; Pent et al. 2020b; Pritchard et al., 2020). In the absence of shelter, lamb mortality rates can exceed 70% (especially in wet conditions with wind speed exceeding 5 ms^{-1} (Obst and Ellis, 1977). Opportunities exist to identify tree-species-specific traits that maximise the provision of shelter, and other ecosystem services, to spatially optimise the location of shelter within the agricultural landscape to maximise livestock welfare and production gains.

Summer overheating in livestock can also have a significant impact on livestock productivity. Heat stress contributes to decreased live weight gain (as livestock eat less), which can lower milk production and reduce breeding efficiency. Heat stress costs US dairy farmers $1.2 billion /year in reduced milk production and reduced fertility (Key et al, 2014). Heat stress can reduce conception rates of ewes and lowers the libido and fertility of rams. Similarly, hens show reduced feed intake and egg weight, and lowered immune system as a result of heat stress. Seeking shade or shelter are natural and effective animal behaviours and, in silvopasture where solar radiation can be reduced by as much as 58%, skin temperature has been found to be 4 ^{o}C lower than on open pasture. As a consequence, other normal behaviour patterns such as eating and resting are better maintained under silvopasture. In areas with limited shading opportunities livestock will tend to cluster (increasing the risk of disease, soil compaction and death of vegetation), so provision of more even shade using silvopasture can reduce this effect. Research has shown that, where they have access to natural shade during heat stress periods, cattle can put on an additional >0.5 kg/day of weight gain (Blackshaw and Blackshaw 1994).

3.3 Off-farm benefits: agroforestry and public goods

3.3.1 Agroforestry and climate change

Agroforestry can facilitate climate change mitigation for agricultural land holdings through carbon capture for both sequestration and reductions in net GHG emissions (Beckhert et al. 2016). Planting trees on degraded or treeless agricultural land will increase carbon (C) sequestration in above-ground biomass and in many cases also into the soil. In addition, the capacity of agroforestry systems to improve many on-farm regulating functions (in particular their ability to substantially reduce soil erosion and nutrient leaching) also contributes to maintenance or increase of *in situ* soil carbon stocks (Ford et al., 2019). This has led the IPCC (2019) to advocate agroforestry as a critically important tool for addressing climate change. At global scales silvopasture far outpaces any purely grassland system for counteracting the methane emissions of livestock and sequestering carbon under-hoof. Silvopasture fixes five to ten times as much carbon as treeless pastures of the same size, storing it in both biomass and soil. A recent study by Lal et. al. (2018) estimates a range between 0.55 and 1.90 Mg C ha^{-1} yr^{-1} for the technical potential of C sequestration by silvopasture. Other studies have found similar results. See, for example, Schroeder (1994) who estimated average carbon storage by temperate agroforestry systems at 63 MgC ha^{-1} yr^{-1}. There is also significant literature describing the carbon capture in tropical agroecosystems (van Noordwijk et al., 2019). Temperate agroforestry systems tend to have higher rates of carbon sequestration than tropical systems due to longer rotations and potential for longer-term storage. However, establishing agroforestry systems on previously natural primary or secondary forest sites will reduce C sequestration potential.

According to Nair (2012), silvopastoral systems are able to sequester more carbon in soil in comparison with silvoarable systems due to the accelerated decomposition of soil organic matter following soil tillage done as a soil management practice for crop production in silvoarable systems. Silvopastoral systems generally are expected to offer a low-cost method to sequester carbon because of their increased ability (compared with single-species crop alone or many grass pasture systems) to capture and utilise growth resources (light, nutrients, and water) (Pandey, 2002; Montagnini and Nair, 2004). Nonetheless, it is important to acknowledge that permanent grass pasture systems in environments such as Wales also have the potential to store large quantities of soil carbon stocks (Ford et al., 2019).

Some studies have demonstrated that long-term agroforestry systems tend to store equivalent or higher amounts of soil organic carbon (SOC) than neighbouring natural forests (depending on silt and clay content and soil quality) (Nair et al. 2010). In pastureland in North Wales Ford et al. (2019) found the soil organic carbon stock increased with proximity to hedgerows and above hedgerows on sloping land. This result agrees with some of the findings reported by Follain *et al*. (2007) who provided a comprehensive review of studies that pointed to an increase in SOC content with the presence of hedges.

Agroforestry is also a climate adaptation strategy that can deliver increased resilience in the farmed landscape (van Noordwijk et al., 2019; Smith et al., 2013). This potential depends on a number of factors, including system design (e.g. species composition and age) and environmental factors such as climate, management and how any end products are utilised.

3.3.2 Agroforestry and water

Wales was the site for the only major research conducted on the effects of agroforestry systems (primarily shelter systems and hedgerows) on flood water regulation. This was conducted at the Pontbren experimental catchments between 2004 and 2012 as part of the Flood Risk Management Research Consortium project (Jackson et al., 2008; Woodland Trust, 2013). Small-scale manipulation plots were used to monitor the hydrological effects of de-stocking and native broadleaf tree planting (i.e. agroforestry) under controlled conditions. The 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 due to the trees. 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. Subsequent researcher reported by Webb et al. (2017) and Wiik et al. (2019) has focused on the large variation in impact on soil hydrology of different species of woody plant occurring in hedgerows and shelterbelts in silvopasture systems in North Wales.

3.3.3 Agroforestry and pollution

Research has demonstrated that agroforestry vegetation buffers can reduce pollution from crop fields and grazed pastures (Udawatta et al., 2002; Anderson et al., 2009)). 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). However, if livestock are allowed to graze in riparian systems or to traverse them to gain access to drinking water this can lead to serious problems of soil compaction, erosion and turbidity in the watercourse. Under these circumstances the presence of a dense canopy, especially of deciduous woody plants, can be detrimental if they shade-out perennial grasses leaving bare soil exposed during the winter. Therefore, the benefits of such systems for water quality may be highly dependent on them being fenced to exclude livestock.

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. 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. Permanent pasture systems in Wales can also have high root biomass and efficient nutrient uptake, but these characteristics are compromised by ploughing and reseeding pasture to increase short-term productivity.

3.2.2 Agroforestry and ecosystem services

Agroforestry systems can improve the provision of ecosystem services at the farm scale whilst improving agricultural productivity, thereby playing an important role in the sustainable intensification of agriculture (Kay et al., 2019; Pretty, 2014; Smith et al 2013). Torralba et al. (2016) show through a meta-study that European agroforestry generally enhances the provision of biodiversity and ecosystem services compared with conventional agriculture.

A recent study (Hardaker et al, 2020) evaluated the net ecosystem service benefits of establishing agroforestry systems on grassland and arable land in the Welsh uplands (severely disadvantaged areas (SDA)). The results showed significant increases in the net economic value of ecosystem service benefits from expanding agroforestry systems across some areas of Wales (fig. 7). The net economic value was calculated as the value of ecosystem service benefits less the value ecosystem dis-service costs. In this study the economic value of ecosystem services was based on data of livestock production, arable crops, timber production, carbon sequestration, local flood risk mitigation, livestock shelter and shade, and employment.

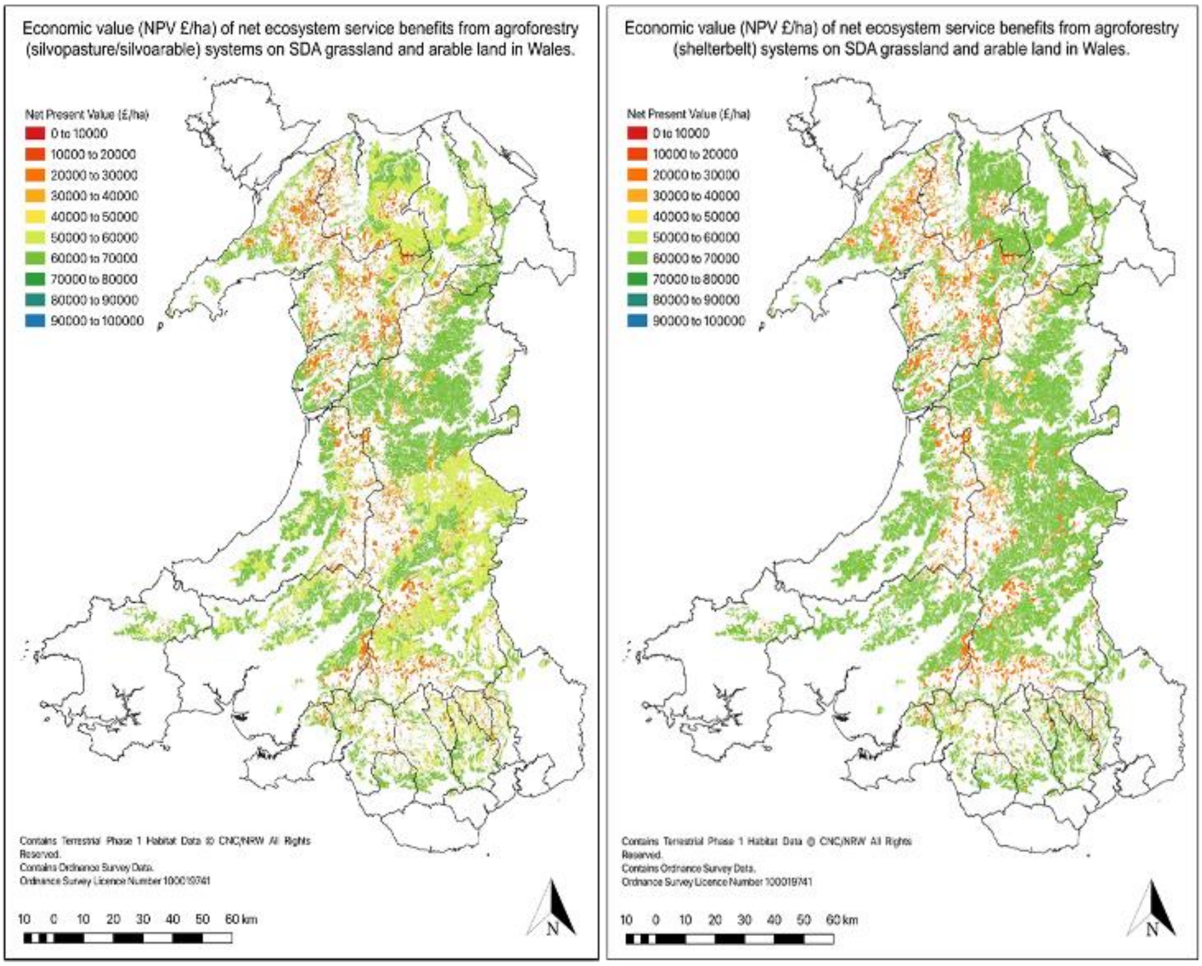

Figure 7: Economic value (NPV ha^{-1}) of net ecosystem service benefits from SDA grassland and arable land in Wales under an agroforestry (silvoarable/silvopasture) system (left panel) and under an agroforestry shelterbelt system(right panel).

These models support the theory that implementing agroforestry systems will deliver different outcomes depending on both design and location. Although the study was restricted to SDA land there are clearly regions where agroforestry will provide substantial benefits such as northern Powys, Ceredigion and northeastern Conwy, and areas where agroforestry results in limited benefit in terms of broader ecosystem service provision such as most of Snowdonia.

4.0 Developing agroforestry in Wales

In this section we will briefly explore the potential for agroforestry expansion in Wales and then review barriers to adoption, suggesting potential mechanisms to overcome these. The section finishes with a review of recent and current research initiatives in the UK.

4.1 Expansion potential for Agroforestry in Wales

The research by Hadaker et al. (in press) suggests that expanding agroforestry, particularly shelterbelt systems, is an economically viable option over the long term and results in both *in situ* and *ex situ* benefits for many parts of Wales.

The study calculated the economic value (NPV ha^{-1}) of net ecosystem service benefits associated with integrating shelterbelt systems under prevailing economic and climatic conditions (fig. 8). These systems were based on modelling where the shelterbelt had approximately 20% canopy coverage of each parcel of improved, semi-improved and unimproved grassland and arable land (primarily on boundaries).

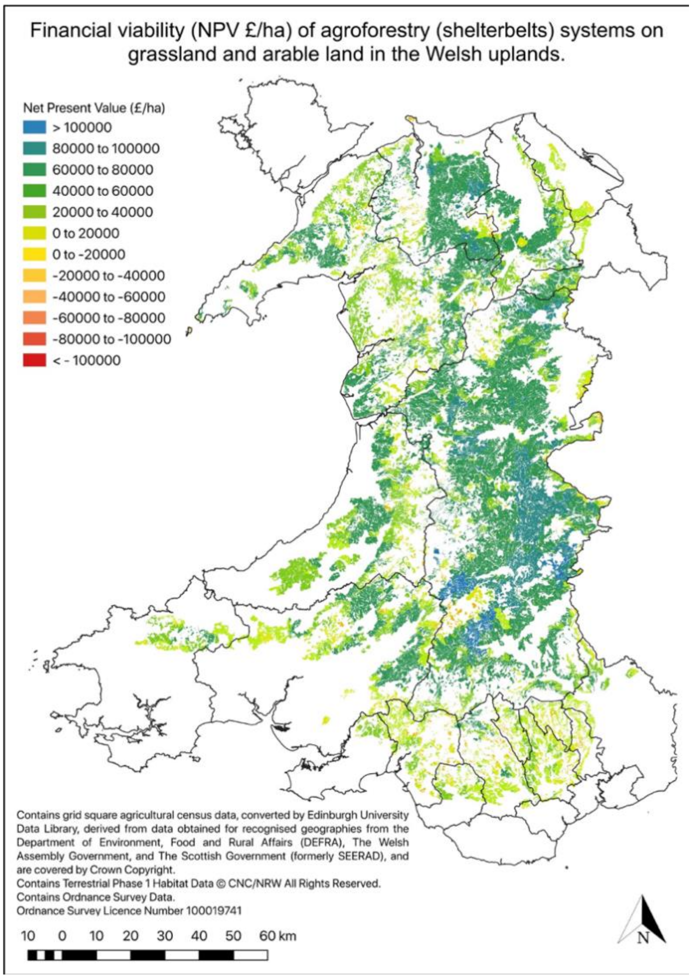

Figure 8: Financial viability (NPV £ ha^{-1}) of agroforestry (shelterbelt) systems on grassland and arable land in the Welsh uplands.

All financial values were based on market prices correct as at 2018 and calculated over 120 years. The agroforestry system presented here was based on shelterbelts planted in blocks 3 m wide of mixed species that are not felled. The economic value of ecosystem services comprised values for livestock production, arable crops, timber production, carbon sequestration, local flood risk mitigation, livestock shelter and shade, and employment. The economic value of ecosystem dis-services comprised GHG emissions and reduction of potable water quality. All net present values (NPV) were correct as at 2018 and calculated over 120 years at a discount rate of 3%.

The study shows many areas where the net present value of shelterbelts was positive but negligible (but not negative) and also areas where implementing this form of agroforestry delivers a clear increase in Net Present Value, particularly in eastern Wales.

When considering where to site agroforestry the most likely land to be viable is land graded as ALC3b in the agricultural land classification, as this is land which has the lowest potential value to farming systems and is where agroforestry benefits are most likely to be realised. There is a case for putting riparian systems both on high-agricultural-value flood plains, particularly in the Clywd catchment where nitrate pollution risks are high. There is a similarly strong case for restoring riparian tree cover in headwater systems to mitigate the warming of freshwater systems.

4.2 Brexit Scenarios

If we look at outputs of current modelling of predicted land use change in Wales under a range of post-Brexit scenarios (fig. 11 and see Cosby et al., 2019) then it is clear that most of the land identified as more likely to stay in some form of agriculture (primarily dairy) under most scenarios is also suitable for agroforestry. It is only under the most extreme form of post-Brexit trade arrangements that economic conditions lead to a large-scale change from farming. Under these circumstances the economic and sustainability benefits of agroforestry could be expected to influence some marginal decisions to retain agricultural production for some current farm enterprises. Areas where this may be particularly likely include southern and eastern Gywnedd (and the eastern end of Pen Llŷn), southwestern Conwy and northwestern Powys, i.e. much of the land around the margins of Snowdonia and the Cambrian Mountains (fig. 11, compare the middle and right-hand panels).

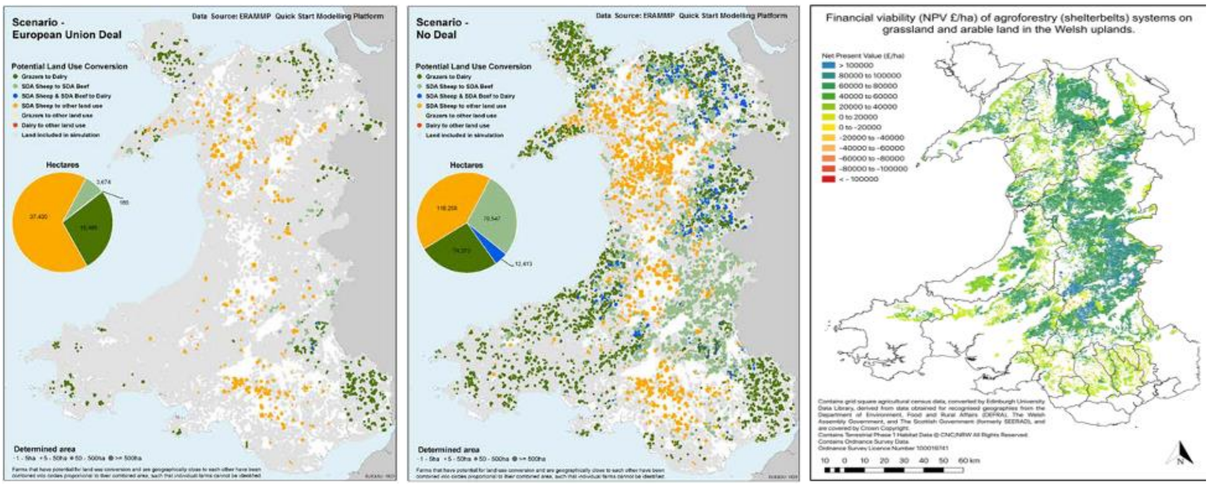

Figure 8: Side-by-side comparison of the output from ERRAMP showing potential land use change of current agricultural land for two Brexit trade scenarios (EU Deal and No deal, left and centre panels respectively) and financial viability (NPV £ ha-1) of agroforestry (shelterbelt) systems (right panel, from fig. 9).

A study evaluating the extent of reliance upon Pillar 1 payments in UK/Welsh farms, however, suggested that approximately 34% of Welsh farm holdings face serious financial difficulties and that

44% of agricultural land in Wales was vulnerable to land use change or abandonment (Arnot et al., 2019). This is a bleaker outlook then that suggested by the ERRAMP work.

"…of those identified as most vulnerable in this study 36% are SDA and DA sheep and cattle farmers. Whilst we cannot accurately predict exit rates of Welsh farmers, we suggest that this group of farmers are most likely to consider an exit strategy, potentially releasing agricultural land to the open market. In some areas, this release of land may lead to an increase in "ranching" as a way of managing land and stock, with control of the land shifting to the control of fewer farmers with larger farms. In other areas, this may result in destocking or land abandonment, a process 'whereby human control over the land (e.g. agriculture, forestry) is given up and the land is left to nature', especially in hill areas if there is little or no viable return from sheep farming."

This article highlighted the need for a more balanced approach to keep farmers on the land and delivering quality 'Public Goods'. However, conversion of larger blocks of land to commercial woodland, where that would have a net economic benefit, is another potential land use change in these areas (See Section 1). There is therefore a need for more sophisticated economic cost-benefit analyses that includes the benefits accruing from timber production or payments for carbon sequestration or other woodland ecosystem services versus those resulting from agroforestry or other farming alternatives, which are likely to show the potential for land use change to either woodland or agroforestry across a wide range of ALC grades under alternative post-BREXIT scenarios.

4.3 Barriers to adoption

As with any form of change or innovation, there are a number of barriers that have limited current adoption of agroforestry systems. A number of studies have highlighted barriers to the adoption of agroforestry in the UK (including the recent Agroforestry Handbook (Raskin & Osborn, 2019); Defra (2017); Perks et al. (2018). These are summarised here.

- If potential agroforestry systems are uneconomic for farmers in comparison with their existing system, this is likely to present a fundamental barrier to the adoption of agroforestry. Economic concerns arise when considering establishment and maintenance costs (such as tree protection and aftercare) and around perceptions of degree of competition between existing grassland or crops and the trees). Establishing trees has historically been associated with loss of government subsidy of land under agricultural use. These concerns vary with the type of enterprise with the biggest concerns coming from farms operating on tighter margins. These risks also increase for agroforestry systems on tenanted land.
- Many farmers lack the skills and knowledge to design, implement and maintain agroforestry systems. This is compounded by a perception of a lack of practitioner support for what is perceived as a more complex system.
- Farmers are often unclear as to how agroforestry systems deliver benefits to the farm enterprise and that where such data exist to inform decision making they are either overly academic or inaccessible.
- A lack of policy support for agroforestry (see 2.2.1 below) combined with increased uncertainty about the economic future of agriculture in a post-Brexit landscape.
- Agroforestry can run counter to farmers' cultural values and norms. This is a complex area and has multiple facets and, again, is an area where there has been little study. A number of potential issues are explored brief below:

1. Most farmers (and policymakers) do not recognise traditional agroforestry practices (such as hedgerows) as forms of agroforestry, and generally reserve the term for more modern forms.
2. Farmers often focus on the ‘core business model’ for farming (i.e. maintenance of the pasture sward) and will often not consider (or have time to consider) other mechanisms to enhance production, such as the provision of shelter (in fact many systems that could provide shelter on the farm are often neglected, fig. 12).
3. Farmers often look at historical solutions to modern problems, so when considering shelter will want to implement conifer belts (which were suggested in the 1970s) rather than considering updated advice on shelterbelt design.

Figure 9: Examples of neglected shelter systems in Wales. A, a hedgerow that has been managed but has no lower foliage and provides limited shelter. B and C, lambs trying to find shelter from the sun. Most farms in Wales have inadequate shelter provision.

In a recent European-level review, Rois-Diaz at al. (2018) suggest that the most important drivers in determining whether a farmer practises agroforestry include whether it was a tradition in the family, the capacity to learn from others, and the benefits of diversifying farm outputs. The study indicated that younger farmers, those with greater income diversity, and holdings with high tourism potential were more likely to implement agroforestry than older farmers, and farmers on specialised farms and holdings with low tourism potential.

4.3.1 Agroforestry and policy

Agroforestry occupies a significant space between ‘agriculture’ and ‘forestry’. At present this space often represents a policy and management void. For example, despite widespread acknowledgement of the importance of hedgerow systems, there is no single agency that takes responsibility for the assessment of the state and condition of hedgerows in the UK. There is very little data available on the extent of hedgerows across the UK nor any plans beyond generic agri-environmental prescriptions to assess future trends.

Of particular relevance to this work, there are currently no consistent government figures available for the amount of carbon that is or could be sequestered by hedgerows. Hedgerows, and indeed most forms of agroforestry, are routinely missed in National Carbon Accounts. In addition, potential benefits associated with changes to maintenance and management regimes are missing.

If we look at the spectrum of tree management in the UK, we see the following groups associated with the management of different forms of tree cover.

Plantation woodlands and, to a lesser degree, managed broadleaved woodland are the domain of traditional forestry institutions and practices. In these systems the management practice ranges from fully production-oriented systems to an increasing, but still nascent, focus on protection forest (where the production of public goods or biodiversity conservation are the primary objectives). Carbon sequestration, interestingly, lies between the two and the relative suitability of different systems to achieve this is highly contested.

- Forestry is a professional discipline and training is widely available to cater for forestry activity at a range of levels.
- There are generally good records kept on the aerial extent and composition of UK woodlands (Forest Research, 2017)

Many of our older, typically broadleaf, woodlands are remnants that persist primarily because their land had limited value for agriculture (for example because they were on steep slopes, thin soils or wet undrainable soils making them inaccessible or unproductive for agriculture), or they were located on large estates and retained primarily for other uses, e.g. hunting/game shooting. Many of these areas are now highly valued (and managed) primarily for their conservation or other amenity value.

- Woodland conservation is a professional discipline and there is extensive training and higher education available on the conservation of woodlands for their biodiversity value.
- We have good data on the conservation status of woodlands across the UK.

Urban woodlands and green infrastructure are an area of increasing importance (and can include various agroforestry practices).

- The management of these systems is primarily the realm of arboriculture.
- We have limited data currently, but increasingly sophisticated methods available (including terrestrial laser scanning), to assist in the characterisation, monitoring and management of urban and peri-urban tree systems.

With respect to agroforestry systems, trees on agricultural land are generally only informally managed by farmers. Some farmers have retained traditional skills associated with elements of agroforestry management (e.g. a good example is the dying art of hedge laying) but there are currently a very limited number of skills providers that can train farmers in how to design and establish new agroforestry practice more generally, and particularly the use of agroforestry at the farm or landscape scale. Agroforestry often falls outside the curricula of both agricultural and forestry courses. However, a growing demand for agroforestry content is being received and met in the forestry programmes at Bangor University.

- There is no professional body with a mandate to provide skills training in agroforestry practice (in Wales or the UK).
    - Coed Cymru and Farming Connect do provide a strong source of advice to farmers in Wales but have limited capacity.
- There is very limited and patchy data available on agroforestry extent and condition in Wales or in the UK as a whole.
- There are no agroforestry specialists in Natural Resources Wales.

Currently, the only capital and revenue support available for farmers to implement agroforestry systems is provided by the Scottish Government, Welsh Government or through the Woodland Trust on a project by project basis. The Scottish[3] and Welsh Governments incentivise the integration of trees with existing upland sheep enterprises by providing both capital and five-year revenue support with little or no claimed impact on Basic Payment Schemes. This will all potentially change post-Brexit but is an area of uncertainty.

[3] https://forestry.gov.scot/support-regulations/sheep-and-trees

4.3.2 Addressing Barriers

Provision of advice to farmers:

1. There needs to be clear identification and communication about what agroforestry is, what the potential benefits are, particularly initially in relation to the farming enterprise and farmers' livelihood systems. The nature of this communication will vary with different types of farming enterprise and different farming contexts and this should be communicated clearly to farmers. Addressing this will require increasing capacity to provide such advice in Wales, drawing on the experience of Coed Cymru and farming Connect.
2. Changing existing practices requires structured engagement. Critically farmers are more receptive to information that is provided regularly and in digestible formats. This is particularly important at times of change. At present the older generation of farmers prefer either verbal communication or the provision of information through leaflets; but this is likely to change with the younger generations of farmers who are more happy working on-line.
3. Successful implementation of agroforestry systems is highly dependent on understanding local context. It is unadvisable to develop fully generic agroforestry prescriptions and it is important to acknowledge the value of local knowledge when designing and implementing systems. This improves farmer 'buy in'.
4. Farmer-to-farmer learning is critically important. 'Agroforestry' most frequently consists of farmer-designed systems that have been refined through modern science. It is important to identify farming systems that have established or are innovating with agroforestry and help monitor outcomes (particularly environmental and economic performance) so that these can then provide platforms for other farmers to learn from.
5. Agroforestry design should be closely aligned to farmer aspirations; which are subject to change. Farmers often see food production as 'core business'.

More broadly:

6. Within the context of an adaptive management approach, farmers should be provided with opportunities for experimentation with different arrangements of tree cover (and tree species). It is important for this not to be restricted by excessive regulation. Existing generic prescriptions (such as those currently with the Glastir woodland schemes) potentially constrain adoption by not providing context-appropriate guidance and potentially limited species choice.
7. Farmers will need clear guidance on the economic (and non-economic) values associated with agroforestry. This information is currently being gathered by organisations such as the Soil Association and the Woodland Trust (Raskin & Osborn, 2019). Farmers are unlikely to adopt agroforestry systems that have negative impacts on their livelihood system. This is a perennial issue for agroforestry. As figures 7 and 8 suggest the likely economic outcomes associated with adopting agroforestry vary spatially, so it is important to develop the right system for the right place (or provide policy support through agri-environment type schemes to enable implementation of less economically viable agroforestry systems that deliver public goods so as to minimise economic risk to the farmer).
8. Farmers should also have access to clear guidance on future risks and the potential role that farm trees can play in mitigating these. Agroforestry has a potentially critical role in developing on-farm resilience. As farming changes, the opportunity space for agroforestry

changes. This is critical right now as farmers prepare for the post-Brexit world. Changes to public policy, such as this, will result in potentially highly significant changes to farming systems. These are critical points in time to feed in advice and alternative options.

4.3.2 Key knowledge gaps

- Relatively little evidence on the benefits of agroforestry for larger-scale farming enterprises
- Fodder benefits (including potential inhibition of methanogenic bacteria)
- Points raised by Fagerholm et al. (2016)
- Clear demonstration of the capacity of agroforestry systems to deliver long-term economic benefits to the farm enterprise may therefore improve levels of uptake
- Available evidence for the societal benefits of agroforestry is fragmented and often does not integrate diverse ecosystem services into the assessment (Torralba, 2016).

4.4 Agroforestry Associations in the UK

The Farm Woodland Forum is a registered charity and is effectively the UK 's agroforestry association. It aims to facilitate the generation and exchange of information that supports best practice in, and improves opportunities for, farming with trees. The Forum comprises farmers, foresters and researchers with a common interest in farming with trees in all its aspects. As well as an active email forum, the Forum holds an annual meeting every summer.

The Farm Woodland Forum traces its roots back to the Agroforestry Research UK Discussion Forum, which had its first national meeting in Birmingham. This meeting reached agreement on the general structure of the Silvopastoral National Network Experiment which was originally conceived by the Agroforestry Research Co-ordinating Group (Edinburgh) in 1985 and has a continuing experimental site at Henfaes in North Wales (fig. 6).

Website: https://www.agroforestry.ac.uk/

4.5 Agroforestry research in the UK

There are a number of sources that describe both past and current research activity on agroforestry in the UK. These are described briefly below:

4.5.1. Silvopastoral National Network Experiment

The Silvopastoral National Experimental Network was established late 1980s on 6 sites (3 upland, 3 lowland, sycamore & sheep), including Bangor University's farm at Henfaes (fig. 6). The experimental design is described in Sibbald et al., (2001) and the experimental results for the system in Wales are described in Teklehaimenot et al. (2002). The main results were that there were no reductions in agricultural production (sheep) in the nine years after planting of trees at a density of 400 ha^{-1}. There was increased species diversity of ground insects and birds. Sheep used the trees for shelter but caused soil compaction around the trees. However, this effect was partly ameliorated by the trees compared with open pasture. There was higher water infiltration in the silvopastoral plots (Lunka & Patil 2015) and red alder trees, a nitrogen fixing species used at many of the trial sites, appeared to have had a beneficial effect in terms of nitrogen fixation, as the production in the alder plots was as high as in the pasture control plots with 160 kg N ha 1 yr 1 applied (Teklehaimanot & Mmolotsi, 2007). The broad experiment is described on the Farm Woodland Forum Website:

https://www.agroforestry.ac.uk/agroforestry-research/silvopastoral-national-network

Additional information is available from some of the other sites that participated in the original trial and are still active, most notably in Scotland where the James Hutton Institute is involved with ongoing agroforestry trials at Glensaugh

(https://www.hutton.ac.uk/about/facilities/glensaugh/agroforestry)

and in Northern Ireland where experiments have continued at the AFBI Loughgall

https://www.afbini.gov.uk/news/agroforestry-takes-root-northern-ireland

4.5.2 AGFORWARD

AGFORWARD (Agroforestry that Will Advance Rural Development) was a four-year EU-funded project led by Cranfield University. Its aim was to demonstrate the benefits of integrating trees in a range of farming systems. The project researched a number of different agroforestry practices with the aim of providing data to enable rural development through improved competitiveness and to support social and environmental improvement in farming practice. It worked with more than 800 farmers in 40 separate groups across Europe.

Website: https://www.agforward.eu/index.php/en/

4.5.3 Multiland

The presence of hedgerows and trees in pastures creates a 'multifunctional landscape' that can improve the wellbeing and productivity of livestock through the provision of shelter and foliage. Such a landscape can simultaneously support other landscape services, such as climate and flood regulation, soil health, carbon sequestration and nutrient conservation. Deforestation during the 19th Century, however, reduced UK tree cover to 5% of land area. In Wales, recent policies have increased this to 15%, but the role of trees in sustainable agriculture is not yet fully addressed.

To address this need, the Multi-Land project examined how trees and hedgerows in the landscape affect animal behaviour, improve ecosystem services, and alter nutrient cycling and soil biogeochemistry. Key findings, which are summarised in Wiik et al. (2019) include:

- Strategic integration of trees and hedgerows into farming systems and the wider landscape increases ecological complexity, multi functionality and resilience.
- Tree and hedgerow shelter improve animal energy balance, with the potential to improve farm production efficiency and animal welfare.
- Hedgerows reduce compaction and enhance soil organic carbon storage in livestock grazed pastures, with the potential for climate change mitigation.
- Tree species-specific differences in root morphology substantially alter soil water infiltration. The fastest infiltration rate was found with ash. The loss of ash to disease is likely, therefore, to have an important effect on landscape hydrology and flooding.
- Tree fodder can reduce ruminant methane production compared with grass hay; highlighting the potential to use trees as browse material to mitigate greenhouse gas emissions from grazed pasture.

Website: www.nrn-lcee.ac.uk/multi-land/

4.5.4 AFINET

AFINET (AgroForestry Innovation NETworks) is a consortium of 13 partners from 9 European countries seeking to foster exchange and knowledge transfer between scientists and agroforestry practitioners.

The consortium sought to create "Regional Agroforestry Innovation Networks (RAINs)", in 9 strategic regions of Europe (Spain, UK, Belgium, Portugal, Italy, Hungary, Poland, France and Finland), interconnected and articulated through the figure of the "Innovation Broker". They also sought to creat a European reservoir of scientific and practical knowledge of agroforestry with an end-user friendly access point (the "Knowledge Cloud").

Website: http://www.eurafagroforestry.eu/afinet

4.5.5 Flood Risk Management Research Consortium at Pontbren

The Pontbren farms in Powys, Wales, began experimenting with different forms of silvopasture in 1997 to manage their land in a sustainable way and improve the efficiency of upland livestock farming. They focused on agroforestry; planting tree shelter belts and improving existing woodlands and hedges to help provide shelter.

The farms were the site for a major experimental trial to measure the affect that the trees were having on hydrological processes.as part of the Flood Risk Management Research Consortium project. The findings are reported here:

https://nora.nerc.ac.uk/id/eprint/5890/1/ur16_impacts_upland_land_management_wp2_2_v1_0.pdf

https://www.woodlandtrust.org.uk/media/4808/pontbren-project-sustainable-uplandsmanagement.pdf

4.6 Agroforestry Extension activity in Wales

There are a number of organisations that are promoting agroforestry systems in Wales, most notably Coed Cymru and Farming Connect.

Coed Cymru (Welsh woodlands and timber): http://coed.cymru/index.html

Farming Connect: https://businesswales.gov.wales/farmingconnect/

Both the Woodland Trust and the Soil Association have been running high-profile campaigns to promote agroforestry practice to farmers across the UK. As of December 2019, the Woodland Trust had provided funding for 123,000 trees as part of agroforestry mixes, of which 113,941 were planted by end of December 2019. A further 4,911 trees were planted in January 2020 and there is approved pending planting a further 26,500 in 2020 (Helen Chesshire, Woodland Trust, pers. comm). Both organisations have run a number of conferences and events, culminating in the production of the UK Agroforestry Handbook (2019). Written for farmers and advisors, this free book was designed to help farmers assess the potential business benefits of agroforestry and to understand the possible benefits to the wider environment.

Website: https://www.soilassociation.org/farmers-growers/technicalinformation/agroforestry-handbook/download-the-agroforestry-handbook/

5.0 Conclusions

This section has provided a brief overview of the types of agroforestry system that are suitable for implementation in a Welsh context and points towards many of the potential benefits associated with wider adoption, including significant impacts both for climate mitigation and adaptation. All forms of agroforestry have the potential to sequester carbon (C), although the benefits will vary depending on soil type, species, planting density, location and land use intensity.

Agroforestry is an umbrella term for many different practices (and combinations of practices) ranging from traditional hedgerow systems to much more complex ‘modern’ agroforestry systems such as alley cropping. There is currently a lack of quantitative information on the extent of (and trends in) agroforestry in Wales.

Agroforestry also delivers direct and indirect benefits to farmers, supporting their farming business by increasing the resilience to shocks and providing alternate value chains. These include products derived from tree goods but also potentially marketable public goods. In particular establishing trees on agricultural land can help to mitigate many of the negative impacts of agriculture, for example by regulating soil, water and air quality, supporting biodiversity, reducing inputs by natural regulation of pests and more efficient nutrient cycling, and by modifying local and global climates. As such it offers real value as an agroecological approach to enable sustainable intensification of agriculture.

At present there are a number of barriers that limit uptake. Many of these can be addressed by engaging farmers directly. Farmers are likely to need better decision support to help them design and manage agroforestry systems if they are to provide both in situ benefits to farming systems and supply wider public benefits. Inclusion of woody species in farming systems should be encouraged, combined with management to provide access to tree and hedgerow fodder.

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