Carbon Sequestration on Farmland

Context

Since declaring a climate emergency in 2019 Wales has legislated to reduce greenhouse gas (GHG) emissions to net zero by 2050.[i] Net zero means balancing the GHG emissions with the amount of gases we're removing from the atmosphere. Agriculture accounted for 14% of Welsh emissions in 2019,[ii] and with over 80% of Wales managed for agriculture the sector has an important role to play in meeting national climate change targets.

Climate change and biodiversity loss have been identified as major contributing factors to food insecurity in the UK and across the world.[iii] Climate change brings with it an increased frequency in extreme weather events[iv] and risk of disease and pest outbreaks,[v] threatening our capacity to produce food[vi, vii] and affecting farm business resilience.[viii] As such, increasing the application of on-farm adaptation and mitigation strategies to manage the impact of climate change and biodiversity loss is of critical importance, with immediate inaction very likely to result in high costs later.[ix]

Carbon Sequestration and Storage

Land can store carbon by locking it up in the soil and in long-lived vegetation. These carbon stores are the result of natural processes balancing between plant sequestration (vegetation taking in carbon dioxide through photosynthesis) and respiration (when carbon dioxide is released back to the atmosphere by plants and microbes). It is the difference between these two processes that lead to the accumulation (net sequestration) or loss (net emission) of these carbon stores over time. Carbon storage refers to the quantity of carbon stored in a reservoir, whilst carbon sequestration refers to the process of removing carbon from the atmosphere and depositing it in a reservoir and refers to the long-term accumulation of carbon in soil.

Grasslands

Soils under grasslands are a major carbon store; storing approximately one third of the global terrestrial carbon stocks.[x] A UK wide survey by ecologists revealed that over 2bn tons of carbon is stored under the UK's grasslands.[xi]

However, the way grasslands are managed influences soil carbon storage.

- Soils under low intensity management with high species diversity are shown to have significantly higher carbon content.[xii,xiii,xiv,xv,xvi]
- Restoration of high plant diversity with deep-rooting species greatly increases carbon capture and storage rates on degraded and abandoned agricultural lands[xvii] whilst findings show that long-term grassland diversity restoration practices can yield significant benefits for soil carbon storage.[xviii]
- Effective grazing management such as rotational and mob grazing (*graze and rest* strategy) can help improve grassland soil carbon, [xix, xx] although the evidence is conflicting.[xxi]
- Meanwhile, intensive grassland management has shown to reduce soil carbon stocks and ecosystem services. [xxii, xxiii, xxiv, xxv]

These nature-friendly practices also deliver multiple benefits beyond carbon sequestration.

- For livestock systems, studies have demonstrated increased yield in grassland because of increasing plant diversity and species richness.[xxvi, xxvii, xxviii]
- Increasing grassland species diversity and adopting effective grazing management via rotational and mob grazing systems can increase productivity and profitability while maintaining or increasing levels of output.[xxix]
- Plant species richness significantly increases water infiltration capacity in grasslands helping to reduce flooding and help with drought resistance. [xxx, xxxi, xxxii]
- From an arable perspective, a large-scale study found that incorporating nature friendly habitats on just 8% of farmland boosted the yield of flowering crops by 25% and resulted in no losses of yield for wind-pollinated crops due to an increase in pollinators and crop pest predators arising from wildflower margins and other habitats.[xxxiii]

With grassland pasture accounting for 75% of land use in Wales, they have an important role to play in tackling climate change. For grasslands, carbon storage will not continue indefinitely as a new equilibrium will be reached through the balance of gains (sequestration) and losses (respiration and decomposition). However, given that grasslands are a large store of carbon, and that it is easier and faster for soils to lose carbon that it is for them to gain carbon, management is essential to maintain these stocks.[xxxiv] Protecting the large carbon stocks in grazing lands is therefore essential to avoid further climate change from additional CO2 release.[xxxv, xxxvi]

Peatland

Peatlands are terrestrial wetland ecosystems in which waterlogged conditions prevent plant material from fully decomposing. Consequently, the production of organic matter exceeds its decomposition, which results in a net accumulation of peat. Other than healthy peatlands, no other habitat will increase carbon content indefinitely.

- The total soil carbon stock in Wales is 410 Mt. Almost half of this carbon is stored in peat-containing soil despite only covering 20% of the land area of Wales. The 3% of deep peat in Wales stores 30% (121 Mt), while organo-mineral soils store a further 18% of carbon (74.5 Mt). [xxxvii]
- Intensive management of peatland has shown to reduce carbon stocks.[xxxviii]
- Peatlands have been artificially drained over centuries, leading to not only enormous emissions of CO_2 but also mobilization of nutrients, higher flood risks, and loss of biodiversity. These problems can largely be solved by stopping drainage and rewetting the land.[xxxix]
- Peatlands also release methane (CH4) under anaerobic conditions. However, maintaining a water table depth of 5 cm to 13 cm ensures that the cooling effect of CO2 sequestration exceeds the warming impact of CH4 emissions. The key aim is to maintain healthy peatlands and restore degraded peatlands, particularly afforested peatlands or peatlands drained for agriculture, which can greatly reduce greenhouse gas emissions without necessarily halting their productive use.[xl]

Over 95% of the UK land carbon stock is in soils therefore the protection of peatland and other organic soil carbon stocks, and the management of cropland, grassland and forest soils to increase carbon sequestration, will be crucial to the maintenance of the UK carbon balance.[xli]

Trees

The leaves of growing trees absorb atmospheric carbon dioxide though photosynthesis, releasing oxygen. Sequestered carbon is then accumulated in the form of biomass, deadwood, litter and the soils. Forest carbon stocks in Wales in 2020 is broken down as follows.[xlii]

- 19% of the total carbon is stored in tree above-ground tissues
- 9% is stored in surface litter and dead wood
- 7% is stored in roots
- 65% stays in the soil

As a tree grows, it stores more carbon by holding it in its accumulated tissue. The amount of carbon annually sequestered is increased with the size and health of the trees. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere.

Whilst grassland stores relatively little carbon in living vegetation - as plants and the processes acting on them (growth, decomposition, grazing) happen quickly; in comparison woodland, scrub and young trees lock much more carbon in above ground vegetation.[xliii] Around 8% (0.3 billion tonnes) of the total UK forest carbon stock is in Wales.[xliv]

The challenge, and indeed the opportunity, is to integrate trees within the farmed landscape.

Agroforestry

Agroforestry, a land-use system that integrates trees and shrubs with crops and/or livestock production, is identified by many as a 'win–win' 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.[xlv]

It is an appealing option for sequestering carbon on agricultural lands because it can sequester significant amounts of carbon while leaving the bulk of the land in agricultural production. Simultaneously, it can help landowners and society address many other issues facing these lands, such as economic diversification, biodiversity, and water regulation. [xlvi, xlvii, xlviii, xlix, l, li]

Silvo-pasture

Silvo-pasture is the integration of trees and grazing livestock operations on the same land.

- This can play a vital role in sequestering carbon and delivering ecosystem services. [lii, liii, liv]
- In-field trees can improve agricultural productivity and resilience[lv, lvi, lvii]
- Trees also improve animal health and welfare by providing shade to reduce heat stress and shelter from adverse winter weather.[lviiilix, lx, lxi]
- Browsing tree leaves provide nutritional and medicinal benefits for livestock. [lxii, lxiii]
- Research in Ireland with sheep on upland vegetation and sheep and cattle on lowland pastures has shown that silvo-pastoral systems can reduce nutrient leakage, increase invertebrates, birds and flora and create spatial heterogeneity in the canopy and soil.[lxiv]

Silvo-arable

Silvo-arable agroforestry is the integration on a parcel of land of arable crops and trees, where trees are usually grown in rows with wide alleys in-between for cultivating crops.

- Alley-cropping agroforestry can increase multifunctionality, compared to open croplands, with carbon sequestration, habitat for soil biological activity, and wind erosion resistance improved for cropland agroforestry.[lxv]
- Significant soil organic carbon stocks increases have been reported at various soil horizons and depths in the land-use change from agriculture to silvo-pastoral or silvo-arable pasture. Overall, soil organic carbon stocks increases when land-use changes from less complex systems.[lxvi]
- Agroforestry is suggested to reduce soil erosion and help balance the available nitrogen and phosphorous in soils to the value of £4 - £15 per ha per year in the UK when comparing silvo-arable to arable alone.[lxvii]

The evidence for carbon sequestration benefits from agroforestry appears significant for silvo-arable systems, but less so for silvopastoral systems which already have large carbon stocks in the soil. Furthermore, meta-analyses have shown that tree planting on pasture, at least in the short term, can lead to declines in soil organic carbon.[lxviii]

Hedgerows

Hedgerows are a traditional form of agroforestry in Wales. The establishment of hedgerows can be a promising strategy to promote carbon sinks for climate change mitigation.

- Studies have shown that on average 31% more carbon was stored in soil beneath hedgerows than improved grassland,[lxix] whilst some studies indicate that carbon stocks in hedgerows are on average comparable to estimates for forests.[lxx]
- The length of hedges in Wales in 1984 was 71,800km, but had decreased to 54,000km by 2007. Reinstatement of 17,800 km of hedges with 2m wide hedges would increase carbon stocks by 136,000t C below ground and by 114,500-149,520 t C above ground biomass for hedges between 1.9m and 3.5m high. Doubling the widths to 4m would double the carbon stocks. Doubling the width of the existing

54,000km of hedges from about 2m to 4m may sequester an additional 413,000t C below ground and an additional 347,000-454,000 t C above round biomass in the biomass for hedges 1.9m-3.5m high.[lxxi]

- The UK's goal of planting 193,000 km of hedgerows by 2050 would sequester 13.9–10.1 Tg CO2 in biomass and soil over 40 years, which would offset annually 4.5–6.2 % of UK annual agricultural CO2 emissions. The current planting rate needs to increase fourfold to reach hedgerow planting goal.[lxxii]
- Farm management practices could focus on wider, taller hedges to sequester more carbon.[lxxiii]
- Better hedgerow management can deliver a host of other benefits, including for biodiversity [lxxiv], pollinators [lxxv], climate[lxxvi,lxxvii, lxxviii], natural flood defence[lxxix], pest control[lxxx], soil health[lxxxi, lxxxii], animal health and welfare.[lxxxiii]

Orchards

Orchards are areas of trees and shrubs planted for food, usually fruit and nuts.

- Studies have shown greater carbon sequestration in orchards compared to pastureland.[lxxxiv, lxxxv]
- Integrating food crop trees into a silvo-pasture or silvo-arable system i.e. growing fruit and nut side by side with crops and livestock can deliver multiple benefits.[lxxxvi]
- Consider also that Wales has a huge deficit in fruit and veg production, using 0.1% of land to produce enough to supply only ¼ of a portion per head of population per day. It would only take 2% of land in Wales to grow 5 a day for everyone in Wales.[lxxxvii]

Woodland, Tree lines, Shelter Belts, Riparian Corridors

There is opportunity to integrate larger areas of tree planting within the farmed landscape, such as woodland, shelter belts, rows of trees and riparian buffer zones. In some instances this might mean taking some land out of production, however these approaches can be implemented in a way that addresses both the nature and climate crises whilst simultaneously delivering farm business benefits.

- Tree strips, or rows of trees can offer carbon sequestration potential as large amounts can be accumulated in above-ground biomass in addition to that in soil,[lxxxviii] whilst offering the multiple aforementioned environmental, livestock and farm business benefits.
- Riparian planting (planting trees along watercourses) can help sequester carbon and improve water quality.[lxxxix, xc, xci]
- Studies have shown that farm shelterbelts can serve a role as relevant carbon sinks, as well as improving animal health and welfare.[xcii]
- Planting larger scale woodland can also deliver multiple benefits for farm businesses and have a role to play in the farmed landscape.[xciii]

Clearly, climate change mitigation is a low-hanging fruit of agroforestry; enabling policies and rigorous long-term research are essential for facilitating its timely and sustainable harvests.[xciv] It is an approach that can deliver multiple benefits side by side with food production. Consider also that the public prefer diverse agricultural landscapes with livestock and trees.[xcv]

Conclusions and Policy Recommendations

- Evidence from Wales shows that the agricultural sector can become a net carbon sink via a land sharing approach - where food production, nature, climate and socio-economic outcomes can be delivered together, sometimes on the same land by adopting a holistic approach to land management. This can be achieved through adopting nature friendly farming practices, ambitious afforestation targets (that integrates trees within the farmed landscape), peatland restoration, reducing food waste and moving towards a healthier diet.[xcvi] A business as usual approach will not be sufficient to meet Wales's climate and biodiversity targets.

- Nature-based solutions such as agroforestry, restoring and creating species rich grasslands with deep rooted species and establishing multi species leys, peatland restoration and management, establishing wildflower field margins, wetland and hedgerow creation should be prioritised to deliver twin nature and climate benefits.[xcvii] This approach would also reflect the Environment (Wales) Act 2016 DECCA Approach to ecosystem resilience, which means allowing spaces for nature across the whole farmed landscape.[xcviii] This can be done without compromising agricultural production, and in many instances can even increase yield and profitability.[xcix, c, ci]

- The effectiveness of financial incentives to influence tree planting depends on the pre-existing interest and values of farmers or landowners. Key to future progress will be enabling farmers to choose to plant trees where it best suits local conditions. Tree planting grants co-designed with stakeholders, ensuring barriers are considered are likely to have improved uptake. Policy tools need to be aligned with farmer values and tailored high-quality advice and guidance available.[cii]

- A narrow focus on carbon sequestration could lead to perverse outcomes, such as biodiversity net loss or even carbon losses from the soil.[ciii] These unintentional outcomes highlight some of the complexities of developing an effective climate mitigation strategy at the farm level.

- The wider economic and employment benefits of nature friendly farming must also be considered.[civ,cv, cvi]

- Whilst nature-based solutions can help reduce climate change, we cannot continue emitting greenhouse gases at the same rate: there is not enough land or sea for nature-based solutions to combat current emission levels. Efforts to sequester carbon should be delivered parallel with initiatives to reduce emissions – this includes emission reduction for agriculture as well as other sectors (e.g. energy, transport, industry and business, residential, waste management)

References

[i] Environment (Wales) Act 2016

[ii] Welsh Government Net Zero Wales Carbon Budget 2 (2021-25)

[iii] Impact of climate change and biodiversity loss on food security – *House of Lords Library*, 2022

[iv] Future changes to high impact weather in the UK – *Climatic Change*, June 2021

[v] Pests and Diseases under Climate Change; Its threat to food security - *Food Security and Climate Change,* 2019

[vi] Climate change could wreck traditional sheep farming in Wales – *Aberystwyth University*, 2020

[vii] The effect of Climate Change on Agricultural Land Classification (ALC) in Wales – *ADAS,* 2020

[viii] Extreme weather and its impact on farming viability in Wales – *Farmlytics,* 2024

[ix] The impact of climate change on grass-based agricultural systems - *Aberystwyth University*, 2017

[x] Grassland soil carbon sequestration: Current understanding, challenges, and solutions - *Science*, 2022

[xi] Legacy effects of grassland management on soil carbon to depth - *Global Change Biology*, 2016

[xii] Plant species richness promotes soil carbon and nitrogen stocks in grasslands without legumes - *Journal of Ecology*, 2014

[xiii] Plant diversity drives soil microbial biomass carbon in grasslands irrespective of global environmental change factors – *Global Change Biology*, 2015

[xiv] Plant diversity enhances productivity and soil carbon storage - *Biological Sciences*, 2017

[xv] The effect of no-till farming on the soil functions of water purification and retention in north-western Europe: A literature review - *Soil and Tillage Research*, 2019

[xvi] Soil structure and its benefits: An evidence synthesis - *The Royal Society*, 2020

[xvii] Soil carbon sequestration accelerated by restoration of grassland biodiversity - *Nature Communications*, 2019

[xviii] Additional carbon sequestration benefits of grassland diversity restoration - *British Ecological Society*, 2010

[xix] Managing Grazing to Restore Soil Health, Ecosystem Function, and Ecosystem Services - *Frontiers in Sustainable Food Systems*, 2020

[xx] Rotational grazing shown to increase soil organic matter on Welsh farm - *Farming Connect*, 2021

[xxi] Grazed and Confused? Ruminating on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question and what it all means for greenhouse gas emissions – *Food Climate Research Network*, 2017

[xxii] Management of Grazed Landscapes to Increase Soil Carbon Stocks in Temperate, Dryland Grasslands - *Frontiers in Sustainable Food Systems*, 2020

[xxiii] Comparing synthetic and natural grasslands for agricultural production and ecosystem service - *Grassland Science in Europe*, 2014

[xxiv] Impact of agricultural land management practices on soil carbon sequestration – *Indian Journal of Soil Conservation*, 2015

[xxv] Tillage and reseeding effects on soil carbon stocks: evidence from 500 agricultural grasslands in the UK – *Agronomy for Sustainable Development*, 2022

[xxvi] Biodiversity for multifunctional grasslands: equal productivity in high-diversity low-input & low-diversity high-input systems – *Biogeosciences*, 2009

[xxvii] Overyielding in experimental grassland communities – irrespective of species pool or spatial scale - *Ecology Letters*, 2005

[xxviii] Long-term enhancement of agricultural production by restoration of biodiversity – *Journal of Applied Ecology*, 2006

[xxix] Rotational grazing and multispecies herbal leys increase productivity in temperate pastoral systems: A meta-analysis - *Agriculture, Ecosystems and Environment*, 2022.

[xxx] Plant species diversity affects infiltration capacity in an experimental grassland through changes in soil properties – *Plant and Soil*, 2014

[xxxi] Land-use intensity and biodiversity effects on infiltration capacity and hydraulic conductivity of grassland soils in southern Germany – *Ecohydrology*, 2021

[xxxii] Higher species diversity improves soil water infiltration capacity by increasing soil organic matter content in semiarid grasslands - *Land Degradation & Development*, 2019

[xxxiii] Wildlife-friendly farming increases crop yield: evidence for ecological intensification - *Biological Sciences,* 2015

[xxxiv] Do grasslands act as a perpetual sink for carbon? - *Global Change Biology*, 2014

[xxxv] Soil carbon sequestration in grazing systems: managing expectations – *Climate Change*, 2020

[xxxvi] Carbon Sequestration in Soils: The Opportunities and Challenges - *Carbon Capture, Utilization and Sequestration*, 2018

[xxxvii] Welsh Soil Evidence Review – *Welsh Government*, 2022

[xxxviii] Effects of burning and grazing on carbon sequestration in a Pennine blanket bog, UK – *The Holocene*, 2000

[xxxix] The Power of Nature-Based Solutions: How Peatlands Can Help Us to Achieve Key EU Sustainability Objectives – *Advanced Sustainable Systems*, 2020

[xl] Overriding water table control on managed peatland greenhouse gas emissions - *Nature*, 2021

[xli] UK land use and soil carbon sequestration – *Land Use policy*, 2009

[xlii] Forestry Statistics 2020 – Chapter 4: Carbon – *Forest Research*, 2020

[xliii] Carbon in the vegetation and soils of Great Britain - *Journal of Environmental Management,* 1997

[xliv] Forestry Statistics 2022 Chapter 4: Carbon – *Forest Research*, 2022

[xlv] Reconciling productivity with protection of the environment: Is temperate agroforestry the answer? *Renewable Agriculture and Food Systems*, 2012.

[xlvi] Quantifying Regulating Ecosystem Services with Increased Tree Densities on European Farmland – *Sustainability*, 2020

[xlvii] Agroforestry: an opportunity for sustainable intensification of farmland to improve productivity and reduce environmental impact - *Farming Connect Technical Article*

[xlviii] Agroforestry for soil health – *Agroforestry Systems*, 2018

[xlix] Agroforestry: working trees for sequestering carbon on agricultural lands - *Agroforestry Systems*, 2008

[l] Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe – *Land Use Policy,* 2019

[li] Co-benefits from tree planting in a typical English agricultural landscape: Comparing the relative effectiveness of hedgerows, agroforestry and woodland creation for improving crop pollination services – *Land Use Policy* 2023

[lii] Temperate silvopastures provide greater ecosystem services than conventional pasture systems – *Scientific Reports*, 2023

[liii] Agroforestry options - *Dr David Cutress: IBERS, Aberystwyth University*, 2022

[liv] Soil Carbon Storage in Silvopastoral Systems and a Treeless Pasture in Northwestern Spain – Journal of Environmental Quality, 2011

[lv] Tree and livestock productivity in relation to tree planting configuration in a silvopastoral system in North Wales, UK – *Agroforestry Systems*, 2002

[lvi] Trees on farms to support natural capital: An evidence-based review for grazed dairy systems – *Science of the Total Environment*, 2020

[lvii] Over-yielding in temperate silvopastures: a meta-analysis - *Agroforestry Systems*, 2020

[lviii] Lamb performance in hardwood silvopastures: animal gains and forage measures in summer. *Translational Animal Science*, 2020.

[lix] Sustainable, efficient livestock production with high biodiversity and good welfare for animals – *Biological Sciences*, 2013

[lx] Heifer performance and body temperatures in open pasture versus silvopasture in mid-Atlantic USA – *Agroforestry Systems*, 2023

[lxi] Effects of tree arrangements of silvopasture system on behaviour and performance of cattle – a systematic review – *Annals of Animal Science*, 2023

[lxii] Components of sustainable animal production and the use of silvopastoral systems – *Brazilian Journal of Animal Science*, 2017

[lxiii] Tree leaves as supplementary feed for ruminant livestock - *Woodland Trust Research Briefing*, 2019

[lxiv] The Potential for Silvopastoralism to Enhance Biodiversity on Grassland Farms in Ireland - *Agroforestry in Europe*, 2009.

[lxv] Multifunctionality of temperate alley-cropping agroforestry outperforms open cropland and grassland – *Communications Earth and Environment*, 2023

[lxvi] Soil carbon sequestration in agroforestry systems: a meta-analysis – *Agroforestry Systems*, 2017

[lxvii] Whole system valuation of arable, agroforestry and tree-only systems at three case study sites in Europe – *Journal of Cleaner Production*, 2020

[lxviii] A synthesis of change in deep soil organic carbon stores with afforestation of agricultural soils – *Forest Ecology and Management, 2013*

[lxix] Soil carbon sequestration potential of planting hedgerows in agricultural landscapes – *Journal of Environmental Management*, 2022

[lxx] Carbon sequestration in hedgerow biomass and soil in the temperate climate zone – *Regional Environmental Change*, 2021

[lxxi] ERAMMP Report-68: Review of GHG Emission Reduction and Carbon Sequestration in Agriculture to Inform Agriculture and Land Use Policy - *Harvard Prosser*, 2022

[lxxii] Planting hedgerows: Biomass carbon sequestration and contribution towards net-zero targets - *Science of the Total Environment*, 2023

[lxxiii] Carbon storage in hedge biomass—A case study of actively managed hedges in England - *Agriculture, Ecosystems and Environment*, 2017

[lxxiv] Long-term effects of hedgerow management policies on resource provision for wildlife – *Biological Conservation*, 2012

[lxxv] The benefits of hedgerows for pollinators and natural enemies depends on hedge quality and landscape context - *Agriculture, Ecosystems & Environment*, 2017.

[lxxvi] Using hedgerow biodiversity to enhance the carbon storage of farmland in the Fraser River delta of British Columbia – *Journal of Soil and Water Conservation*, 2015

[lxxvii] Chapter Five - Carbon Sequestration in Agroforestry Systems – *Advances in Agronomy*, 2010

[lxxviii] Biomass increment and carbon sequestration in hedgerow-grown trees – *Dendrochronologia*, 2021

[lxxix] The potential of tree and hedgerow planting to reduce the frequency and impact of flood events in the UK - *Dr William Stiles: IBERS, Aberystwyth University*.

[lxxx] Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control – *Biological Sciences* 2006

[lxxxi] Hedgerows as Ecosystems: Service Delivery, Management, and Restoration - *Annual Review of Ecology, Evolution, And Systematics,* 2006

[lxxxii] The role of hedgerows in soil functioning within agricultural landscapes - *Agriculture, Ecosystems & Environment*, 2019

[lxxxiii] Effects of heat stress on the welfare of extensively managed domestic ruminants – *Livestock Production Science*, 2000

[lxxxiv] Carbon sequestration of hazelnut orchards in central Italy - *Agriculture, Ecosystems & Environment*, 2022,

[lxxxv] Carbon storage in kiwifruit orchards to mitigate and adapt to climate change – *Communications in Soil Science and Plant Analysis*, 2012

[lxxxvi] Does money grow on trees? 'A case study on the long-term financial and socio-economic performance of silvopastoral agroforestry practices in the Netherlands.' – Utrecht University, 2021

[lxxxvii] Welsh Fruit and Veg Production - *Baseline study for Tyfu Cymru by Dr. Amber Wheeler*, 2020

[lxxxviii] Soil Use and Management Soil Use and Management Managing field margins for biodiversity and carbon sequestration: a Great Britain case study – *Soil Use and Management*, 2006

[lxxxix] Managing riparian buffer strips to optimise ecosystem services: A review - *Agriculture, Ecosystems and Environment*, 2020

[xc] Nutrient accumulation and carbon sequestration in 6-year-old hybrid poplars in multiclonal agricultural riparian buffer strips – *Agriculture, Ecosystems and Environment*, 2010

[xci] Soil organic carbon enhancement in diverse temperate riparian buffer systems in comparison with adjacent agricultural soils – *Agroforestry Systems*, 2021

[xcii] Quantification and comparison of shelterbelt carbon stocks within and between an organic mixed-cropping farm and a conventional dairy farm – *New Zealand Natural Sciences*, 2016

[xciii] Welsh woodland demonstrates how trees can be a viable option for farmers – *Farming Connect*, 2023

[xciv] Climate Change Mitigation: A Low-Hanging Fruit of Agroforestry - *Agroforestry - The Future of Global Land Use*, 2012

[xcv] What does the UK public want farmland to look like? – *Land Use Policy*, 2021

[xcvi] Pathways to achieving nature-positive and carbon–neutral land use and food systems in Wales – *Regional Environmental Change*, 2023

[xcvii] Sustainable climate change mitigation in UK agriculture - *Report to the RSPB by Ellie Crane*, 2020

[xcviii] Ecosystem Resilience in a Nutshell 1: What is ecosystem resilience? – *Natural Resources Wales*

[xcix] Long-term evidence for ecological intensification as a pathway to sustainable agriculture - *Nature Sustainability*, 2022

[c] Nature Means Business: how regenerative farming in Wales is making farms more financially resilient and improving the environment – *NFFN Cymru*, 2023

[ci] Stability of farm income: The role of agricultural diversity and agri-environment scheme payments – *Agricultural Systems*, 2021

[cii] Meeting tree planting targets on the UK's path to net-zero: A review of lessons learnt from 100 years of land use policies – *Land Use* Policy, 2023

[ciii] Avoiding bio-perversity from carbon sequestration solutions – *Conservation Letters*, 2011

[civ] The impact of green economy measures on rural employment: Green jobs in farms - *Journal of Cleaner Production*, 2019

[cv] Investing in hedgerows for climate, nature and the economy - *Agricology*, 2021

[cvi] Jobs for a green recovery Levelling up through nature - *Green Alliance policy insight,* May 2021