Llywodraeth Cymru
Welsh Government

Welsh Soil Evidence Review

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Mae'r ddogfen hon ar gael yn Gymraeg hefyd / This document is also available in Welsh
Rydym yn croesawu gohebiaeth a galwadau ffôn yn Gymraeg / We welcome correspondence and telephone calls in Welsh

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01

Executive Summary

Background

Soil is a vital resource that sustains life and provides crucial ecosystem services to Wales.

These services include food, fibre, water and important contributions to climate regulation, biodiversity and protection from natural disasters. The culture and environment of Wales is distinct, and this translates into the soil and farming of the country, with grassland dominated systems and soils that are often wet and rich in organic matter. Due to slow formation processes, soil is considered a non-renewable resource and thus requires sustainable management. As over 80% of the land in Wales is under agriculture, land use and management are the main factors that influence the condition of soils in Wales. Pressures from climate change, the UK withdrawal from the EU and potential for future land use change, means evidence-based soil policy is necessary to preserve this valuable resource, help tackle the climate and nature emergencies, and enhance the environment for future generations.

Approach and aims

This report synthesises the extensive evidence from the Welsh Government Soil Policy Evidence Programme and beyond to identify:

- the policy framework relevant to agricultural soils in Wales
- current status and threats to agricultural soils in Wales
- future threats and opportunities for agricultural soils in Wales
- gaps in the evidence base.

The full Soil Policy Evidence Programme (SPEP) is available at **gov.wales/soils-policy-evidence-programme**.

This report should be read alongside the Natural Resources Wales (NRW) State of Natural Resources Report (SoNaRR; **www.naturalresources.wales/sonarr2020**).

Policy framework

Recently, the Welsh policy landscape related to soil has been driven by 2 landmark policies and 3 major political events. Briefly, the Environment Act (Wales) 2016 and Well-Being of Future Generations Act 2015 set the regulations and future direction for sustainable land management and beyond. The withdrawal from the European Union triggered the biggest reform in agriculture policy for decades, and the declarations of climate and nature emergencies acknowledge these challenges and set important context and targets for future legislation. However, soil is not explicitly protected by any Welsh policy, leaving a vulnerable gap in the sustainability targets of Wales. With a dedicated soil policy any new legislation or regulations would need to consider and address the sustainability of soils.

Current status and threats

Welsh agricultural soil, especially organo-mineral and peat soils, is high in carbon compared to the European average. This is a valuable national resource. Most Welsh agricultural land is under grassland, which is generally considered to be at a low risk to soil degradation. However, the intensity of management within grassland systems can affect this risk. Grassland soil management can vary significantly across Wales and is dependent on several factors, including farm enterprise, stocking density and the type of grassland.

Future threats and opportunities

Climate Change is predicted to result in sea level rise, wetter winters, warmer and drier summers, and increased intensity and frequency of extreme weather events, like storms and droughts.
There is some evidence that land use and soils are already experiencing the impacts of climate change and it is predicted that soil wetness, carbon, biology, compaction, erosion and agricultural capability will be impacted. The other future soil threat is the risk of inappropriate land use change. In Wales, this is conversion of permanent grassland, as this covers almost two thirds of Wales, to arable cultivation, afforestation, land-based renewable energy such as solar or wind, and housing or employment development. A change in land use can alter the soil properties and functions. Also, the type of soil (e.g. peat) is important to consider as they will have different vulnerabilities to land use change. There are opportunities to maintain and enhance the soil resource with a change in the climate, land management and/or land use. This can improve the future delivery of ecosystem services and related Sustainable Development Goals by soils in Wales.

02 Introduction

Soil is an ecologically and economically valuable resource that sustains life and provides crucial ecosystem services to Wales.

These include food, fibre, water and important contributions to climate regulation, biodiversity and protection from natural disasters. Due to the slow formation process, soil is considered a finite resource. This soil resource is taken care of by farmers, who manage most of the land in Wales. With the increasing pressure of climate change and a need for new Agricultural policy due to the withdrawal from the EU, it is essential that agricultural soils are protected and represented in policy based on current evidence. This synthesis of soil evidence is intended for policy makers, farmers, stakeholders, and the people of Wales to have a clear overview of the current and future needs of agricultural soils in Wales.

2.1 Aims

This report reviews the extensive evidence from the Welsh Government Soil Policy Evidence Programme and beyond to identify:

1. **Current and future policy framework relevant to agricultural soils in Wales.**
2. **Current status and threats to agricultural soils in Wales.**
3. **Future threats and opportunities for agricultural soils in Wales.**
4. **Gaps in the evidence base.**

2.2 Evidence base and limitations

The evidence for this document was drawn from the extensive range of reports in the Soil Policy Evidence Programme (SPEP) and the associated Capability, Suitability and Climate Programme (CSCP). These programmes contain detailed reports that were commissioned by the Welsh Government Soil and Land Use Policy Team over the last 3 years from independent specialists and experts (**www.gov.wales/soils-policy-evidence-programme**). The State of Natural Resources Report (SoNaRR 2020; **www.naturalresources.wales/sonarr2020**) was an additional key evidence source. Where evidence gaps were identified or more information required, the scientific literature was searched for supporting evidence. The key reports and papers supporting each section are identified at the start of each section.

Soils are living systems, they are complex and heterogeneous and measuring them across large ranges is challenging. The evidence used in this document is not all-encompassing and in some cases assumptions inevitably have to be made. In addition, the very nature of predicting future trends by modelling will always contain some level of uncertainty. Further, the majority of the evidence discussed is biophysical only – it does not consider market, infrastructure, storage, skills and labour.

The evidence herein has been synthesised in this context and caveats highlighted where pertinent. Despite this, certain issues, threats, and opportunities are clear and decisions need to be made to protect soils for the future using the best available evidence. If we wait until evidence is all-encompassing it may be too late.

2.3 Agricultural soil definition

Agricultural soils, for the context of this document, are defined as:

'Soils under agricultural management for crops, grasslands and semi-natural habitats'

This definition includes all grasslands; semi-natural habitats (including peat soil under restoration and peat under intensive agriculture); arable, bioenergy and fodder crops; horticulture; agroforestry; silvopasture; paddocks; all nature conservation designated sites (e.g. SSSI, SAC) under agricultural management[1]; and, all areas under agri-environment scheme agreements[2].

1 unless general rules are contradictory to conservation objectives
2 unless general rules are contradictory to scheme objectives

03

Climate, soil and land use in Wales

Figure 1: An overview of Wales by a) land cover [1], b) agricultural land classification land quality (Predictive ALC Version 2) [2], c) elevation [1] and d) major soil groups [3].

MMH is 'mountain, moorland and heath'; BMV stands for 'Best and Most Versatile' land; SW is 'surface water' and GW is 'ground water'.

3.1 Climate and landscape

Key evidence sources [4]

Climate

- Average annual rainfall in Wales varies from <1,000 mm in the border and coastal areas to >3,000 mm in the central uplands of Snowdonia. The wettest months are October to January, while the driest months are late spring to early summer. The annual average temperature varies with altitude, from 9.5 to 11 °C at low altitudes, and 3.5 to 7.5 °C at higher altitudes.
- For most of Wales, soils are at Field Capacity (water remaining in the soil after all gravitational water drained) for over 200 days per year. On much of the land at higher elevation, this figure is 250 – 300 days per year, meaning land work opportunities are strongly limited by climate.

Landscape

- Wales is characterised by an impressive range of landscapes with an estimated 2,700 km of coastline and 28% of land >300 m above sea level (Fig. 1; [5]). Upland areas (>300 m) exceed 800 m in the southern Brecon Beacons and 1,000 m in the northern Snowdonia National Park.
- National Parks and Areas of Outstanding Natural Beauty represent 24.4% of Wales with 40 and 11% of the Welsh landscape nationally or regionally evaluated as having high or outstanding value [5], respectively.
- Data from visual and sensory assessments recognised that 57% of Welsh landscapes have remained unchanged, 34% were identified as declining and 9% were regarded as improving [6]. The main factors (in no particular order) influencing the Welsh landscape (2003-2015) include urban expansion, commercial and industrial development, over-tourism, erosion, forestry, road improvement, onshore windfarms and turbines, and recreational related development [7].

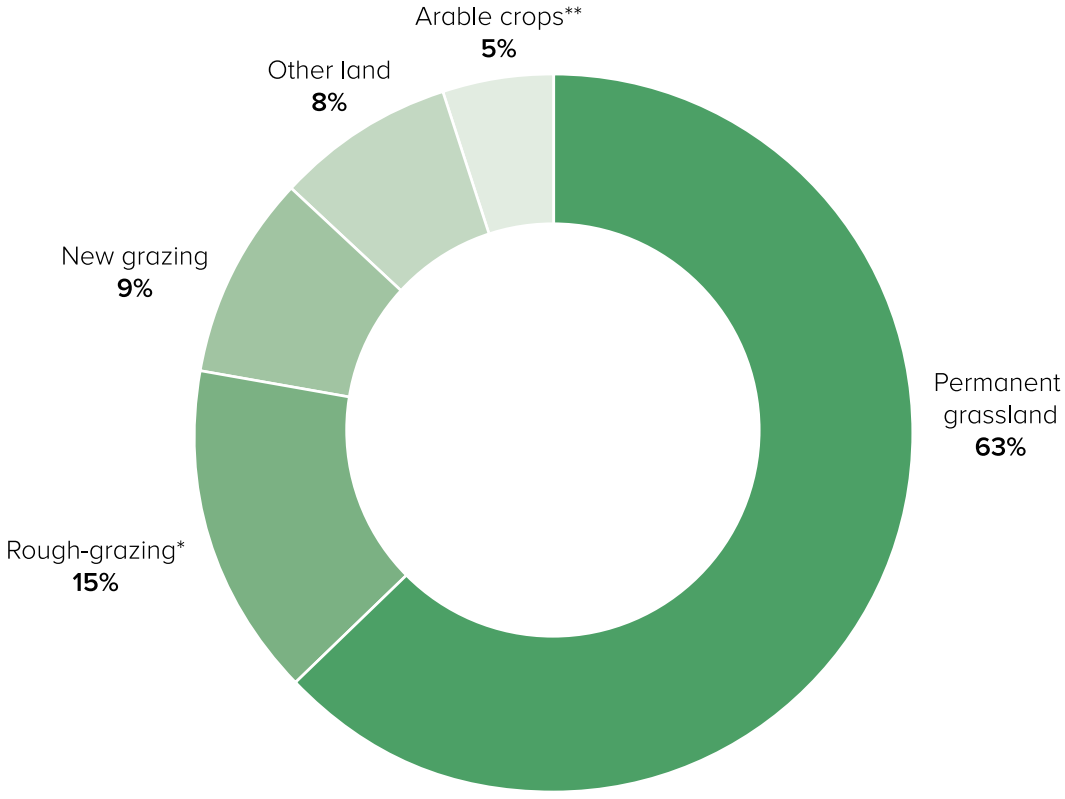
3.2 Land cover and land use history

Key evidence sources [8], [9], [6]

Land use and cover

Agricultural land represents around 90% of total land area of Wales [10]. Therefore, agricultural management is key in the sustainable management of natural resources in Wales. Most of the Welsh agricultural land is dominated by permanent (>5 y) and new (<5 y) grasslands and rough grazing land (Fig. 2).

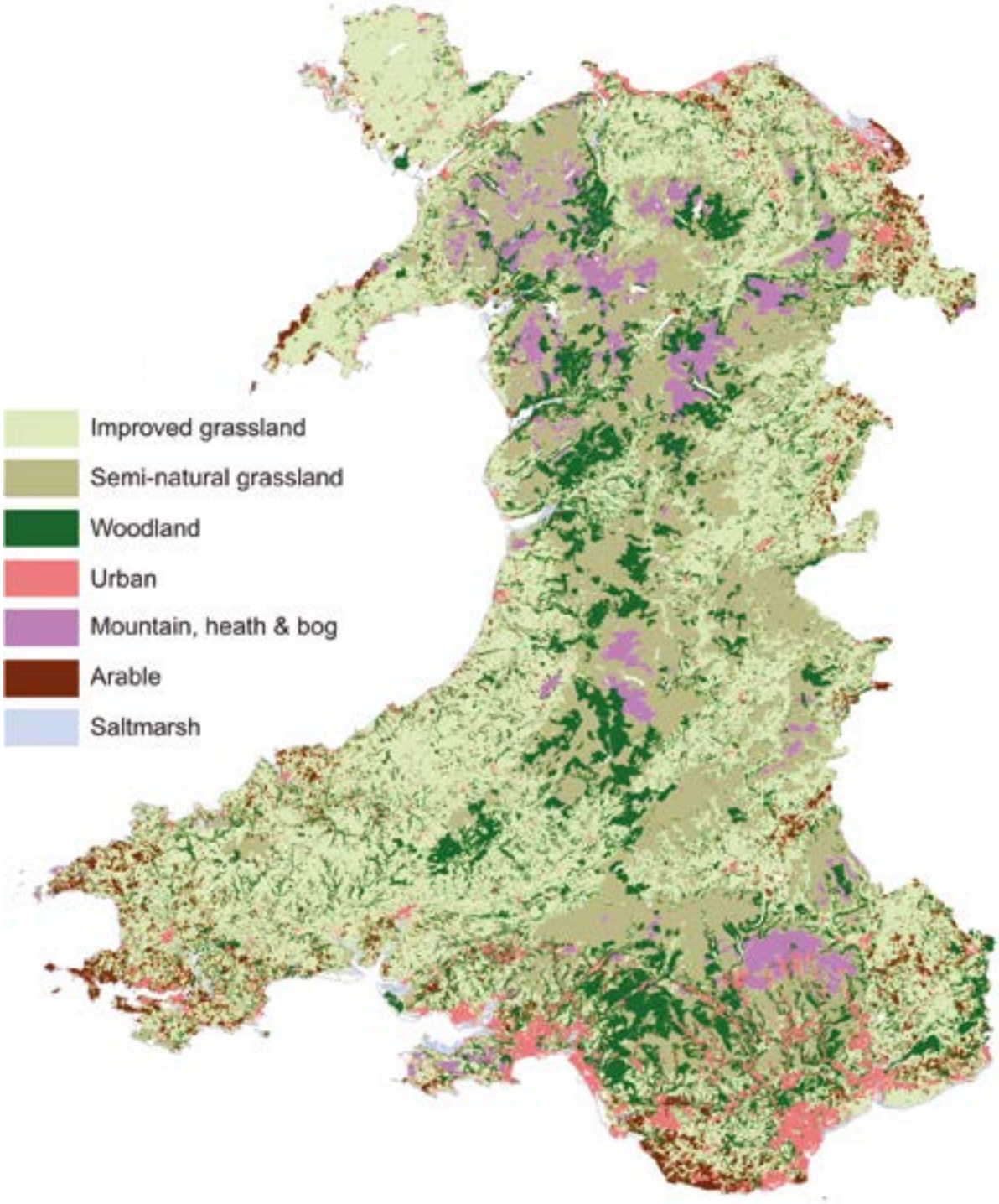
Figure 2: The land use on agricultural holdings in 2020. From [10]



* Rough grazing where holder has sole rights (i.e. excludes common rough grazing which accounts for ca. 180,000 ha).
** Includes horticulture (vegetables and fruit grown in the open, hardy nursery stock and glasshouse).

The cover and use of land in Wales (from 2019) can be classified in 7 categories [1] (Fig. 3):

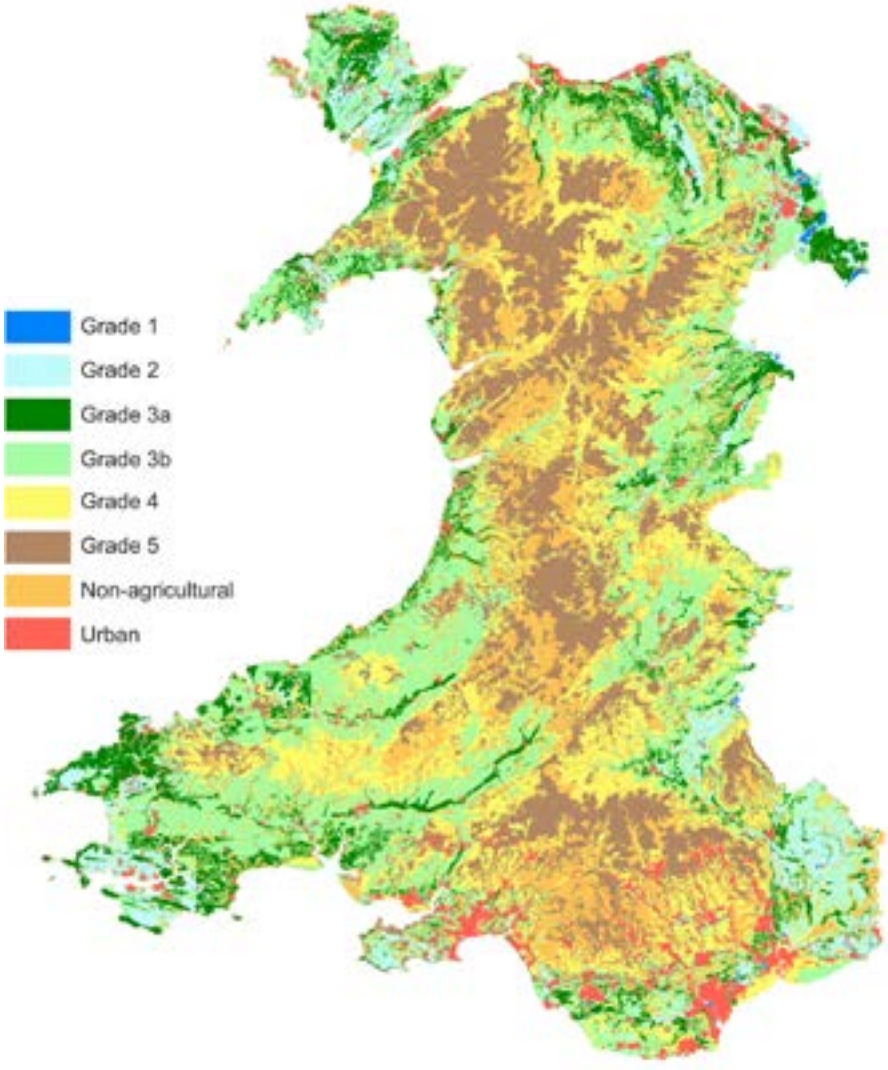
Figure 3: Land cover classes in Wales 2019, [1]



Best and Most Versatile (BMV) land

- Around 10-15% of the land area in Wales is classified as BMV land for agriculture (defined by ALC grade classes 1, 2 and 3a; Fig. 4). This percentage range is based on the Predictive Agricultural Land Classification [2]. This system, while hugely important and useful, does not consider the all the site-specific ALC grading criteria (i.e. flooding, micro-relief, chemical limitations).
- Only 32% of total BMV land (296,897 ha) is used to grow crops (including arable crops, uncropped land, and high value horticultural products; 95,500 ha), the majority of BMV land is under grassland. Most arable production (ca. 60%) occurs in ALC land grades 3a and 3b, with very little occurring in the grade extremes [9]. ALC subgrade 3a represents the core BMV resource. Due to the large extent of agricultural production on subgrade 3b land, future review of the ALC and policy might include or split the 3b subgrade.

Figure 4: Predictive agricultural land classification (ALC) grades in Wales, 2011 [2], [11]



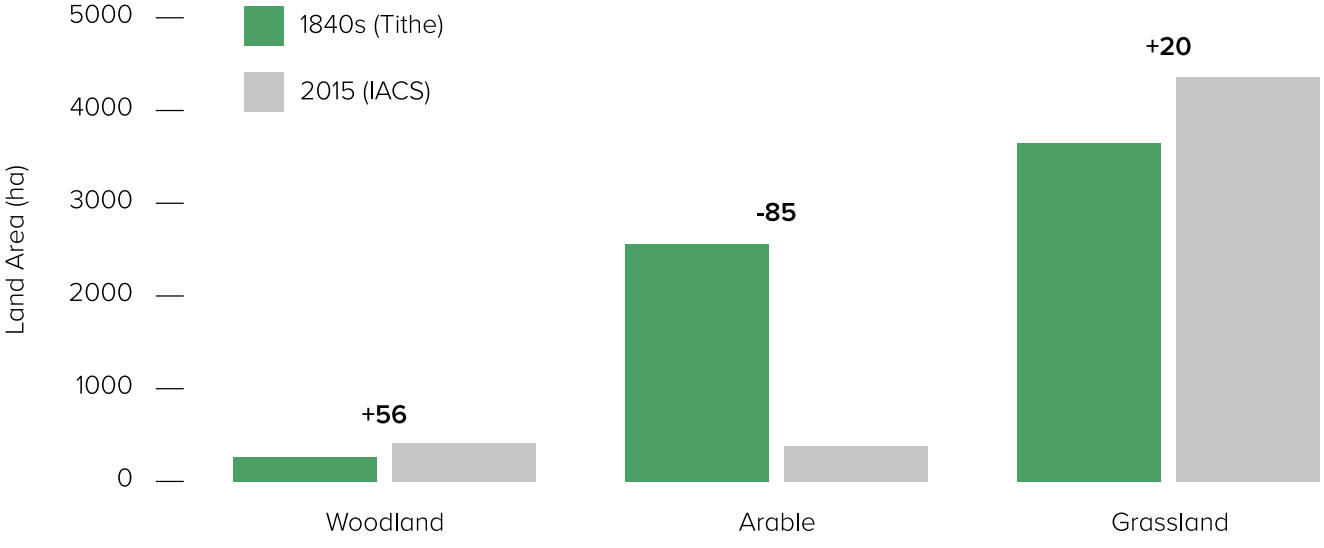
- Around **80% of the agricultural land** in Wales has been designated as **Less Favoured Area** (LFA, European Union). This means land is limited by poor soils and low agricultural income and reflects the mountainous and high rainfall areas in Wales, which are limiting factors for agricultural activity [12].
- 75% of land in Wales is graded by predictive ALC as classes 3b, 4 and 5 (non-BMV), which are less capable of arable cropping (Fig. 4). Grade 3b, although less versatile than 3a, can support good arable utilisation in many areas of Wales. While grade 4 can support some arable production, it is severely limited in supporting long-term intensive arable management as the dominant utilisation. Grade 5 is mostly suited for extensive 'rough' grazing.

Land use history

Historically, land in arable production was more extensive in Wales, while grass and grazing lands, woodlands and the total agricultural area have increased since the 19th Century. While the data in figure 5 does not include a large area of Wales, it is good representation of the changes that occurred.

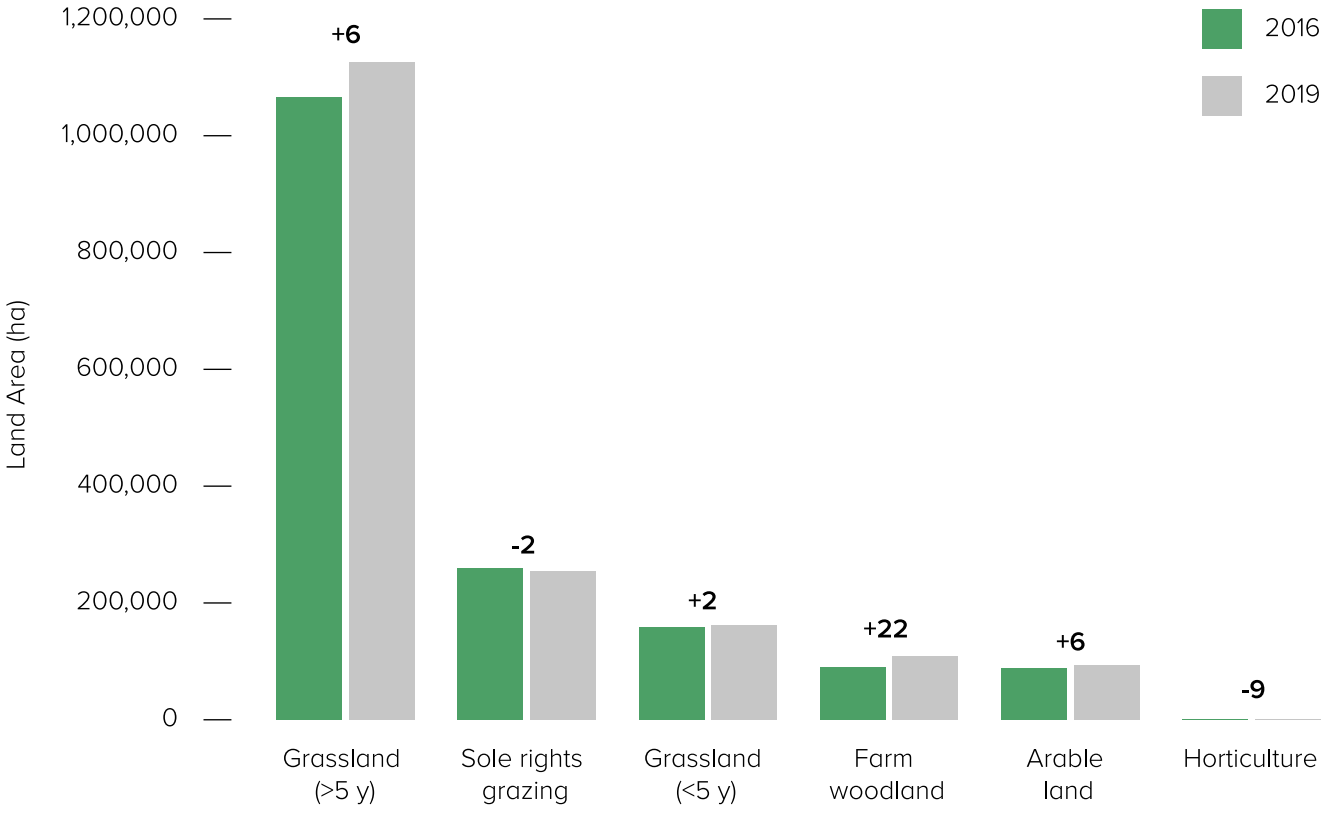
Figure 5: Changes in the areas of different land uses in six parishes across Wales between the 1840s and 2015

Tithe (1838 and 1850) and IACS (Integrated Administration and Control System; 2015) land use data is from non-LFA (Amroth, Pembrokeshire; Llangystennin, (formerly) Caernarfonshire); DA (Llanychaearn, Cardiganshire; Llanfechain, Montgomeryshire); and, SDA (Betws, Carmarthenshire; Dolbenmaen, Caernarfonshire) parishes. These results are not representative of all of Wales and should be treated with some caution [13]. Created by Erik Button.



More recently (2016 to 2019), changes indicate small increases in new and permanent grasslands and arable land (Figure 6). The extent of on-farm woodlands increased the most, while smaller decreases in horticulture and sole rights grazing land areas were observed [6].

Figure 6: Recent (2016 to 2019) changes in land use areas in Wales [6]



3.3 Soils in Wales

Key evidence sources [4], [8]

The climate, altitude and the underlying sediment or rock are key factors influencing the characteristics of Welsh soils. There are 183 different soil series in Wales. These can be generally described by 4 broad groups (Table 1).

Table 1: Soils in Wales can be characterised by 4 broad groups

Mineral Soil	
Description	Mineral soils do not have a peaty surface horizon and are characterised by Brown soils, non-peaty Lithomorphic soils, Pelosols and raw terrestrial soils.
Main Landscape	Lowlands
Example profile	Brown soil (photo: Cranfield University; Richard Hartnup)

Organo-Mineral Soil	
Description	Organo-Mineral soils are represented by Podzols, some surfacewater Gley soils in upland areas that have a peaty topsoil (<40 cm*) and are transitional between peat soil and Gley soils, and shallow Lithomorphic soils in upland areas with shallow peat over rock.
Main Landscape	Uplands (>300 m), steep areas
Example profile	Podzol (photo: John Hollis)

Organic Soils (Peat)	
Description	Organic soils classified as peat soils have >40 cm depth of peat from the surface. They are formed for the most part from partially decomposed plant remains that accumulated under waterlogged conditions and can occur in upland (Blanket bog) and lowland (Fen) areas.
Main Landscape	Uplands (>300 m)
Example profile	Peat soil (photo: Cranfield University; Richard Hartnup)

Gley Soil	
Description	Gley soils have impeded drainage and are characterised by surface and ground water gley, and raw gley soils. They are seasonally waterlogged in the winter due to high groundwater tables or subsurface layers that are slowly permeable.
Main Landscape	Lowlands, uplands and coastal areas
Example profile	Surface water Gley (photo: Ian Rugg)

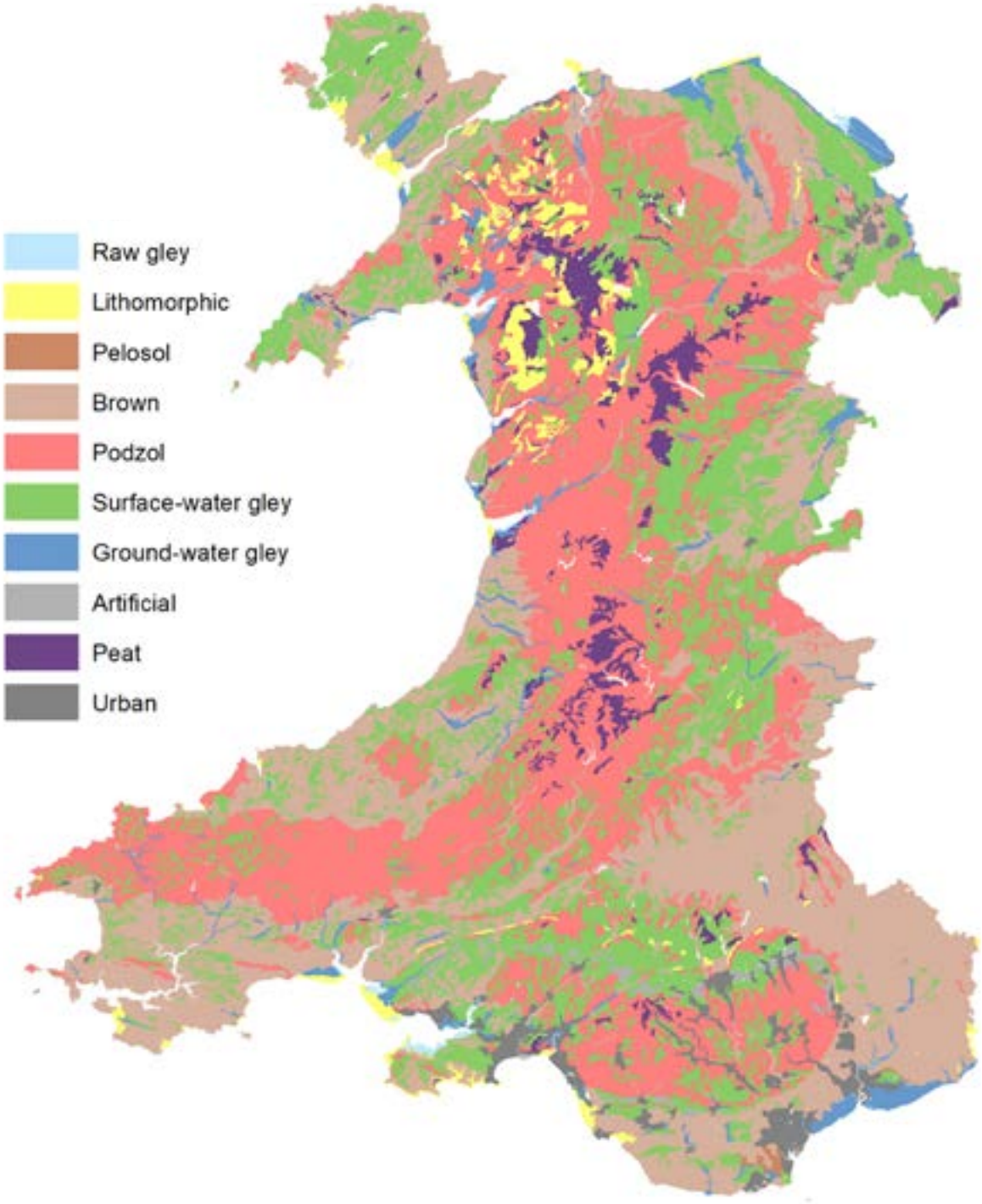
*Descriptive criteria for Welsh Organo-Mineral soils.

The soils in these broad groups are generalised and more insight can be gained when they are further split and described by their major soil groups (Table 2). Figure 7 shows the distribution of these broad soil types across Wales.

Table 2: The described major soil groups and their land cover in Wales [14]

Major soil group	Land cover (%)	Description
Podzol	32.3	Acid soils with brightly coloured iron-enriched subsoil
Brown	30.2	Loamy, permeable soils with weathered subsoil
Surface-water gley	24.7	Loamy and clayey seasonally waterlogged with impermeable subsoil
Ground-water gley	3.4	Soils associated with high seasonal groundwater
Peat	3.4	Soils in deep peat
Urban	3.0	Unclassified land
Lithomorphic	2.2	Shallow soils without weathered subsalt
Artificial	0.4	Restored soils of disturbed ground
Raw gley	0.2	Unripened young soils of saltmarshes
Pelosol	0.1	Clayey ‘cracking’ soils
Terrestrial raw	<0.1	Very young soils with only a superficial organo-mineral layer

Figure 7: Major soil groups in Wales [3]



3.4 Soils and cultural services

- Over 50% of Welsh landscapes are of high or outstanding value [5] and provide aesthetic, mental and physical well-being to the people and visitors of Wales. The provision of these services is underpinned by soil functions which support the landscape.
- These landscapes also provide economic benefits. Wales attracts 11 million overnight visitors annually [15]. Visitors to the three National Parks spend over £1 billion annually on goods and services, supporting the local economy and providing local employment [16].
- The less intensively managed soils in the uplands also support an archaeological resource dating from pre-Mesolithic times to the present [16].
- Soils and their functions support landscapes that are steeped in Welsh heritage, culture and language.

3.5 Distinctiveness of Wales

Wales is different in comparison to much of the UK and other European countries in several ways and this is why policy designed specifically for Welsh agriculture is the best way to protect, maintain and enhance soils for the well-being of future generations in Wales and beyond.

'Our land is different, our communities are different and our sectors are different [to the rest of the UK].'

Excerpt from 'Brexit and our land: Securing the future of Welsh farming' [17].

Wales is dominantly an upland country with a typically high rainfall and restricted versatility in agriculture. For most of Wales, land work opportunities are limited by the climate, which reflects the low extent of high-quality agricultural land in Wales. The extent of woodland in Wales (14.8%) is similar to the rest of the UK, but low compared to the European (38%) and world (31%) averages [18]. This is largely because grazing lands dominate the Welsh landscape. The sheep population in Wales outnumbers the human population almost 3 times over [19] with 27% of the total number of UK sheep found in Wales, despite Wales representing only 9% of the total UK land area. In addition, a greater proportion of the Welsh population are employed by agriculture (4.1%) compared to the UK (1.4%) [17]. Despite this, the total income per hectare from farming is just £102 in Wales compared to £116, £246 and £331 in Scotland, Northern Ireland and England, respectively [17].

The agricultural land use in Wales is deeply linked with the heritage, agricultural and national identity of the land users and managers. Welsh speakers are disproportionately represented in the agricultural sector, with 29.5% of people in agricultural employment being Welsh speakers, almost double the average for the labour market (16.6%) [20]. In addition, Wales has devolved legislative responsibility on agriculture, environment, forestry and land use. With a strong language, cultural, industrial and administrative history, designing policy tailored to meet the specific needs and ambitions of Wales will best serve the land, people and soil resource.

04

Policy framework

4.1 Overview

Three important recent events have driven widespread changes in the soil-related policy landscape in Wales.

These are:

1. The withdrawal from the European Union (EU Exit) in January 2020 following the EU referendum in June 2016

The referendum vote to withdraw from the EU set in motion a reform of agricultural policy that has been in place for decades. The powers provided by the UK Agriculture Act (2020) allow Welsh Ministers the opportunity to develop agriculture policy specifically for Wales. This is especially important given the differences between the devolved nations in land use, agriculture and climate change projections.

2. The declaration of a Climate Emergency in Wales in April 2019

The declaration made by the then Minister for Environment, Energy and Rural Affairs, acknowledges the challenge of climate change and its threats on the health, economy, infrastructure and natural environment of Wales. It sends a clear message that the Welsh Government places climate change as a central priority to the Programme for Government and sets an important context for the emissions targets and future legislation.

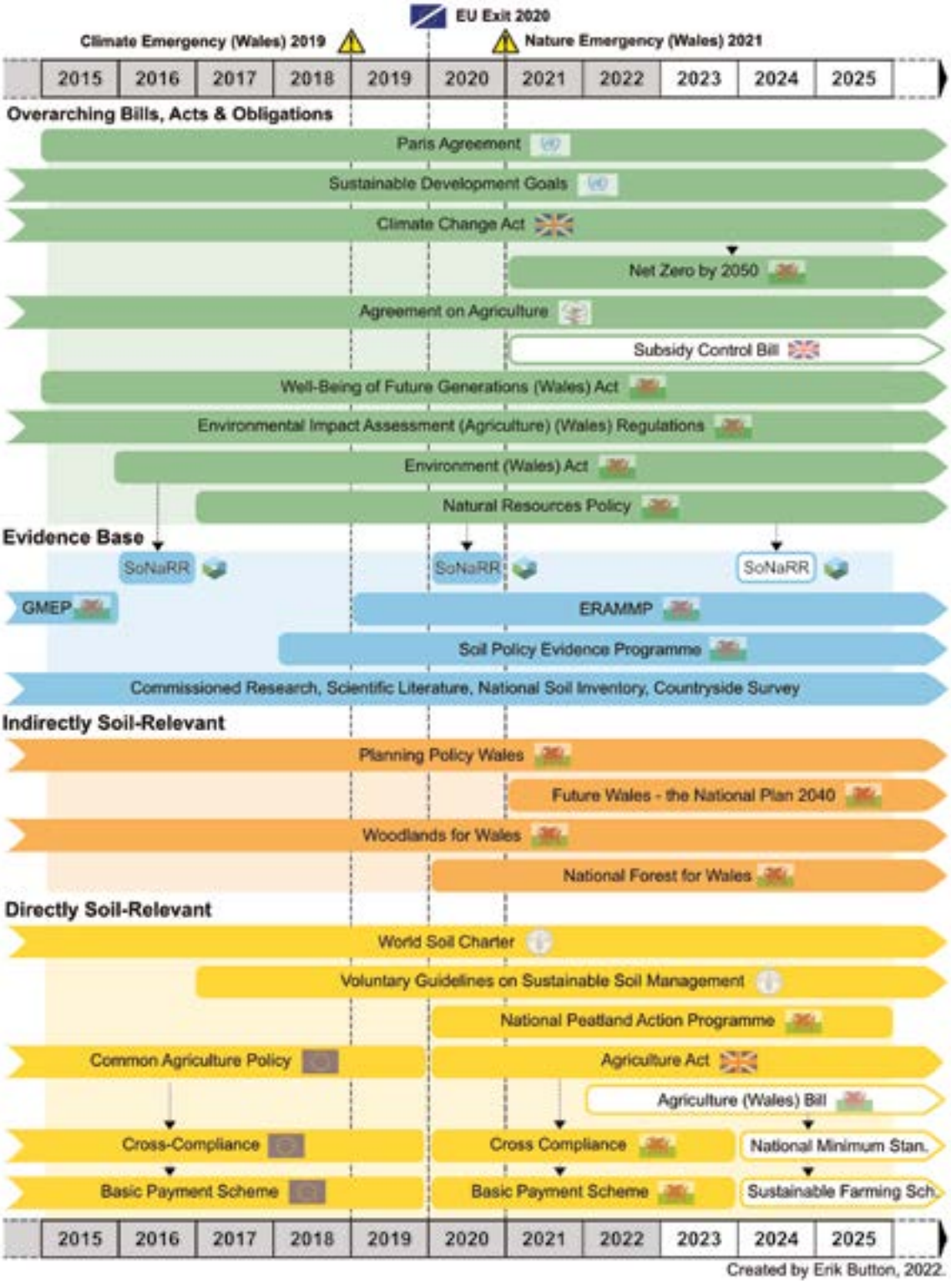
3. The declaration of a Nature Emergency in Wales in June 2021

The landmark Senedd (Welsh Parliament) declaration aims to initiate the halt and reverse of biodiversity decline. Agricultural and woodland management, climate change, urbanisation, hydrological change, invasive species and pollution are the pressures causing loss and threats to native species.

The climate and nature emergencies are interlinked and with the withdrawal from the EU an opportunity has arisen to address these with agricultural policy tailored to Wales. In line with the existing landmark polices, the Well-Being of Future Generations Act (2015) and the Environment Act (2016), policies have been created or are under development to create a new policy framework that prioritises sustainability and climate change mitigation. Figure 8 gives an overview of the policy framework from 2015 to 2025 from overarching bills, policies and obligations to those directly relevant to soil. More information can be found in Table 3.

Figure 8: The soil policy framework in Wales over a decade extending to 2025

The colour-coded policy or policy-related areas are the: 1) overarching bills, acts and obligations; 2) evidence base; 3) indirectly soil-relevant; and 4) directly soil-relevant policy, programmes and guidelines. Unfilled boxes represent future outcomes. Flags represent where the policies or other apply and logos represent authorship. More information in Table 3.



Created by Erik Button, 2022.

4.2 Detailed description

Table 3: Details and references to all policies, bills and obligations

Overarching Bills, Acts and Obligations	
Paris Agreement (2015) [21]	The United Nations international treaty on climate change adopted in 2015 and effective from 4 November 2016. Negotiated by 196 countries of which 192 countries are United Nations Framework Convention on Climate Change party members to the agreement (the other 4 are signatories). The Agreement's goal is to limit temperature rise to below 2°C (preferably below 1.5) and to reach net-zero emissions by the middle of the 21st Century.
Sustainable Development Goals [22]	In 2015, the United Nations 2030 Agenda for Sustainable Development with the 17 global goals was adopted. Its predecessor, 'Agenda 21', was signed by >178 countries in 1992.
Climate Change Act 2008 (UK) [23]	Sets out targets for addressing climate change by 2050 for the UK – the duty that the "net UK carbon account for the year 2050 is at least 100% lower than the 1990 baseline".
Net Zero Target by 2050 (Wales) [24]	Approved in 2021. Interim targets by 2020, 2030, 2040. Commitment part of Climate Change Act 2008.
Agreement on Agriculture [25]	The Agreement on Agriculture (1995) is a World Trade Organisation treaty that focuses on reducing the agricultural support and subsidies given to domestic producers by countries. It has 3 pillars: 1. Domestic support – subsidies classified into "boxes" depending on consequences of production and trade: amber (most directly linked to production levels), blue (production-limiting programmes that still distort trade), and green (minimal distortion). 2. Market access – reduction of tariff (or non-tariff) barriers to trade by WTO members. 3. Export subsidies – sets out variable export subsidy reductions by value and volume for developing and developed countries.
Subsidy Control Bill [26]	Introduced to the House of Commons in June 2021 (currently in the House of Lords). The Subsidy Control Bill provides the framework for a new, UK-wide subsidy control regime. This regime will enable the Welsh Government to deliver subsidies that are tailored and bespoke for local needs to deliver government priorities such as levelling up and achieving net zero carbon. Crucial in the development of the Sustainable Farming Scheme.

Overarching Bills, Acts and Obligations	
Well-Being of Future Generations (Wales) Act 2015 [27]	The landmark Act consists of 7 health, environmental, social, economic and cultural goals for the future of Wales. It legally requires public bodies in Wales to think about the long-term impact of their decisions, to work better with people, communities and each other, and to prevent persistent problems such as poverty, health inequalities and climate change. One of these goals is for 'A Resilient Wales', which includes *'Biodiversity and Soil', 'Water and Air Quality'* and *'Using Natural Resources'* target areas, which are all relevant to Welsh soils.
Environmental Impact Assessment (Agriculture) (Wales) Regulations [28]	Established in 2002 and revised in 2017. Regulations for the consideration of the effects (if any) of agricultural projects on the environment (habitats, species, historic features) to be considered. Requirement to comply – breach of which can affect subsidy payments (i.e. Basic Payment Scheme payments).
Environment (Wales) Act 2016 [29]	Landmark 7-part act that sets out: 1. Sustainable Management of Natural Resources (SMNR): • Sets out principles of SMNR • Duty to produce State of Natural Resources Reports (SoNaRRs) every 4-5 years. • Duty to implement National Natural Resources Policy (NNRP) and produce Area Statements to implement NNRP. 2. Powers to WG to put in place climate change targets: • 80% reduction in carbon emissions by 2050 (N.B. Overridden by Net Zero Target [24]). 3. Extends powers to charge for carrier bags. 4. Improves waste management processes (collection and disposal of waste). 5. + 6. Clarifies laws relating to marine licensing and shellfish management; 7. Clarifies the law for environmental regulation regimes, such as flood risk management and land drainage.
Natural Resources Policy (2017) [30]	This policy is a key part of the delivery framework for the SMNR established by the Environment (Wales) Act 2016. It sets out how WG policies can deliver both economic and environmental objectives.

Evidence Base	
State of Natural Resources Report (SoNaRR) [31]	Synthesis of evidence conducted by Natural Resources Wales. Commitment under SMNR of the Environment (Wales) Act 2016 to produce reports every 4-5 years assessing the state of natural resources.
Glastir Monitoring and Evaluation Programme (GMEP) [INACTIVE] [32]	Run by UK Centre of Ecology and Hydrology. Data collected until 2016. The predecessor of the Environment and Rural Affairs Monitoring and Modelling Programme (ERAMMP).
Environment and Rural Affairs Monitoring and Modelling Programme (ERAMMP) [33]	Run by UK Centre of Ecology and Hydrology. Started in 2019 and will provide evidence for future SoNaRRs. Reviewed the evidence for the Welsh National Forest and the Sustainable Farming Scheme, among others.
Soil Policy Evidence Programme (SPEP) [34]	Collection of commissioned reports (2018-2022) written by independent experts and specialists reviewing the evidence on Welsh soils and how agricultural management affect them. The SPEP includes future climate modelling from the Capability, Suitability, and Climate Programme (CSCP).
Countryside Survey [INACTIVE] [35]	Run by UK Centre of Ecology and Hydrology. Surveys were conducted across Great Britain in 1978, 1990 and 2007. Some sites were resampled within the GMEP. From 2019 it has become a NERC-funded research platform that will repeat every 5 years.
National Soil Inventory (NSI) [INACTIVE] [36]	Run by Cranfield University. An extensive soil archive that covers England and Wales across a 5km grid. Sampled in 1980 with partial resampling of sites in the mid-1990s.

Indirectly Soil-Relevant Policies	
Planning Policy Wales [37]	Introduced in 2001, revised in 2018 (Edition 11). Outlines planning policies ensuring that the planning system contributes to the delivery of sustainable development and improves the social, economic, environmental, and cultural well-being of Wales. Contains the BMV (Best and Most Versatile; see Section 3.2) land policy in Section 3 and the Technical Advice Notes 6. Herein, it is stated that *"BMV land [...] should be conserved as a finite resource for the future"*.
Future Wales – the National Plan 2040 [38]	A development plan with a strategy for addressing key national priorities through the planning system. It includes national economic, decarbonisation, climate-resilience, ecosystem strength and community health and well-being priorities. Policy 9, *'A Wales where people live in places that sustainably manage their natural resources and reduce pollution'*, is of greatest soil relevance as it acknowledges the environmental, social and cultural value of the soil resource and states that it is to be managed, maintained and enhanced.
Woodlands for Wales [39]	First published in 2001 and revised in 2018. Sets out how woodlands will be preserved and developed over the next 50 years. Supports the expansion of woodland (>2,000 ha yr^{-1} from 2020) and for appropriate woodland management.
National Forest for Wales [40]	Announced in 2020 with funding available from 2021. It provides financial support (via The Woodland Investment Grants) for the creation of new woodland and the restoration and maintenance of ancient woodlands. The goal is to form a connected network of woodlands throughout Wales. Initially, 14 sites managed by Natural Resources Wales (NRW) were identified to mark the beginning of the commitment.

Directly Soil-Relevant Policies	
World Soil Charter [41]	The 1982 United Nations Food and Agriculture Organisation World Soil Charter (revised in 2015) contains key principles and guidelines to benefit most soil stakeholders to identify the necessary policy and action approaches to guarantee global sustainable soil management.
Voluntary Guidelines for Sustainable Soil Management [42]	The 2017 United Nations Food and Agriculture Organisation Voluntary Guidelines for Sustainable Soil Management are reference guidelines for technical and policy recommendations for sustainable soil management goals for a range of different stakeholders.
National Peatland Action Programme [43]	Landmark national coordinated action programme that runs from 2020-2025. Aims to restore 600-800 ha of peat annually. Progress will be reviewed in 2024. 6 priority themes to restore peat habitat and conditions: 1. Peatland erosion; 2. Peatland drainage; 3., 4. Sustainable management of blanket and lowland peats; 4. Restoration of afforested peatlands; and, 5. Gradual restoration of highest C emitting peatlands.
Common Agriculture Policy EU [WITHDRAWN] [44]	Launched in 1962 and reformed in 2003. The UK withdrew from the Common Agriculture Policy (CAP) as part of the withdrawal from the European Union in January 2021. The CAP supports agriculture via 1) direct payments to support farmers' incomes and to encourage environmentally friendly farming (via the Basic Payment Scheme); 2) rules and measures to regulate and support the marketing of agricultural products; and 3) rural development payments. An updated CAP will be implemented in the EU in 2023.
Cross-Compliance EU [WITHDRAWN] [45]	Introduced in 2000 and developed further in the 2003 CAP reform. Ended in UK January 2021 with EU Exit. To receive financial support, EU farmers must respect a set of basic rules. The interplay between this respect for rules and the support provided to farmers is called cross-compliance. Statutory Management Requirements (SMR) lay rules on animal, public, plant and environment health. In addition, farmers must comply with the EU standards of Good Agricultural and Environmental Condition (GAEC).

Directly Soil-Relevant Policies	
Agriculture Act 2020 (UK) [46]	Introduced in November 2020. The Act provides the legislative framework for replacement agricultural support schemes. It provides Welsh Ministers with powers to continue farming support (i.e. the BPS in England and Wales) until new devolved nation Agriculture Bills are developed. Some of the powers granted to Welsh Ministers through the Act will expire on 31 December 2024 ('sunset clause').
Agriculture (Wales) Bill 2022 [47]	The Bill will be the legislative framework to support Welsh agriculture. A White Paper was published December 2020 for public consultation, which ended March 2021. The Bill is currently under Parliamentary consultation and is due to be released in summer 2022.
Cross Compliance (Wales) [48]	Continuation of the EU cross-compliance rules (SMR and GAEC) post EU withdrawal while a new system is developed. It will be replaced by National Minimum Standards, which is proposed to apply to all farmers regardless of whether they are subscribed to a scheme or not, supported by advice and guidance.
National Minimum Standards [49]	National Minimum Standards (NMS) will be included within the Agriculture (Wales) Bill enabling the Welsh Ministers the power to enforce the Standards. The NMS will not raise the current regulatory baseline but will seek to simplify and streamline existing regulations within cross compliance to provide a clear regulatory baseline which will apply to all farmers in Wales. The National Minimum Standards will become secondary legislation once the Bill receives Royal Assent and are intended to come into force at the same time as the proposed SFS.
Sustainable Farming Scheme [50]	The Sustainable Farming Scheme (SFS) will be the new agricultural support scheme, replacing the Basic Payment Scheme which has been UK funded since the withdrawal from the EU in 2021. BPS will be secured until 2023 where after the transition to the SFS will begin with it officially opening in January 2025. The SFS will be co-designed with farmers and other soil stakeholders. Phase 1 of co-design has been completed and Phase 2 will proceed in summer 2022.

05

Current status and threats to Welsh agricultural soils

Key Messages

- **Land use change and inappropriate management:** The current land use, soil and climate combination in Wales is favourable to minimising widespread risks and threats to soil from degradation processes such as erosion, compaction, and loss of biodiversity. The intensity of management can increase the risks to soil degradation with negative impacts on indicators such as soil biodiversity, nutrients, compaction, and erosion.
- **Climate change:** There is evidence that climate change is affecting agricultural soils currently, but these will become more significant in the future.
- **Soil carbon:** Recent trends indicate soil carbon content is stable in the upper parts of the soil. Stable topsoil carbon contents have been monitored in improved land (grassland and arable).
- **Soil compaction:** Around 40% of Welsh soils are considered potentially vulnerable to compaction although data on the vulnerability or resilience of specific soil or land use types to soil compaction is sparse. The actual state of soil compaction in Wales has not been identified, but in limited grassland surveys livestock poaching and machinery are identified as the most frequent observations of soil damage affecting up to a quarter of grasslands.
- **Soil erosion:** The dominance of grassland systems with permanent vegetation cover in Wales would indicate an overall low risk of soil erosion nationally, however erosion is highly localised and intense resulting in hotspots where significant soil loss can occur. About 7% of land in Wales is susceptible to high erosion rates, and this risk is greatest during high intensity rainfall events. Erosion risk and rates are greatest with bare land but there is no direct evidence for measured erosion rates or the frequency of erosion episodes in Wales.
- **Soil formation:** Soil erosion rates are generally greater than formation rates, meaning that soil is generally considered a finite resource. However, the soil formation rates specific to Wales are estimates and not well known. Whilst soil erosion in grasslands has been estimated to be within the same range as soil production, highly localised, high intensity erosion events can cause significant soil loss.

- **Soil nutrients:** Nitrogen is highest in acid grassland and lower in arable, improved and neutral grasslands. Over the last 5 decades, total soil N has been stable on improved land and (grassland and arable) and semi-natural grassland. National assessments of soil Phosphorus concentration is similar across all land uses and has shown historical declines, although now stable on improved land. However, only 9% of soil samples collected from over 200,000 across the UK were at recommended target levels for both potassium and phosphorus, demonstrating how common under and over application of nutrients is. Further data is needed on nutrient loading to land at sub-national scale in Wales.
- **Soil biodiversity:** Limited evidence currently exists on trends in soil biodiversity in Wales, but changes are most likely related to land use change, loss of organic matter, extreme weather events, and land management and intensity. A major threat to soil biodiversity is the intensification and extensification of agricultural management. A recent decline in the numbers of mesofauna was observed with differences between habitat types; fewer in arable and horticulture compared to neutral or acid grassland. Fungi, bacteria and protists, on the other hand, have been observed to be higher in arable and improved grasslands.

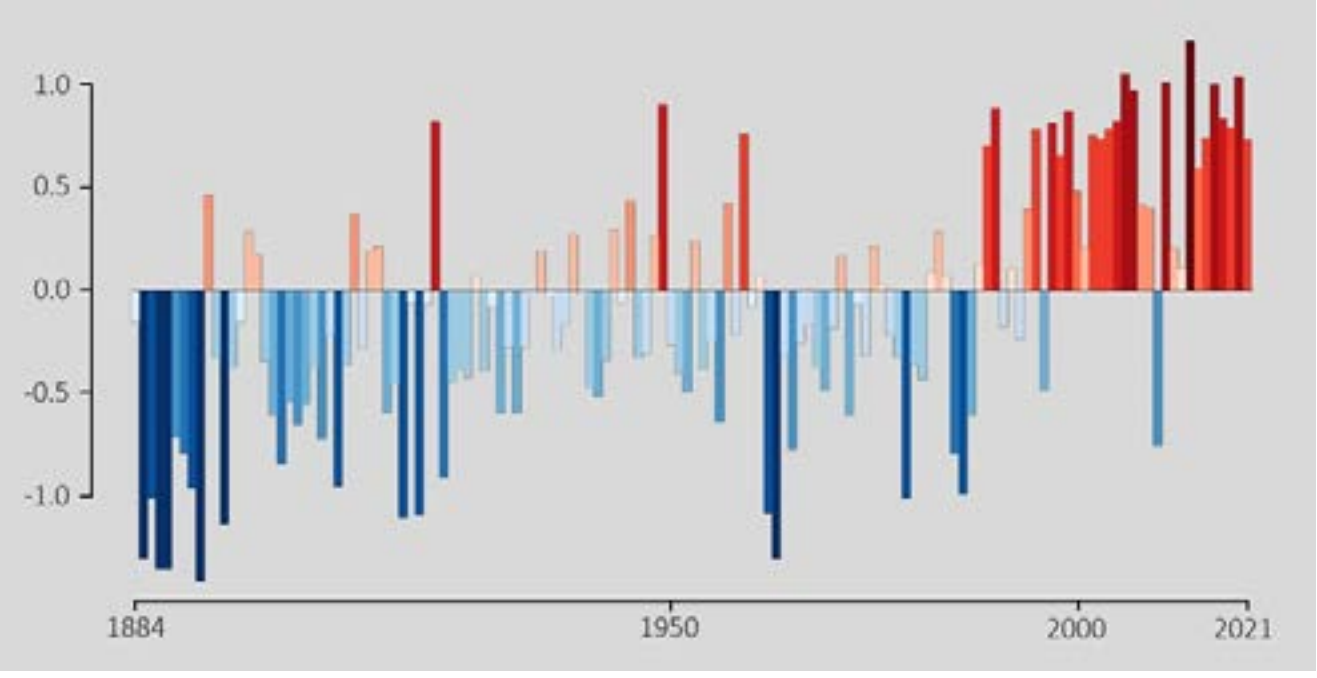
5.1 Climate change

Climate change is the long-term shift in average weather patterns across the world. Since the mid-1800s, humans have released significant amounts of greenhouse gases into the atmosphere. This causes global temperatures to rise, resulting in long-term changes to the climate [50]. In Wales, the last 2 decades have been consistently the warmest since records began in the late 1800s (Fig. 9).

Climate change has already resulted and will further cause sea level rise, wetter winters, warmer summers, and increase the intensity and frequency of extreme weather events, like storms, floods and droughts [51] in Wales. There is some evidence that land use and soils are already experiencing the impacts of climate change through extreme events like floods, fires and droughts [6]. The future climate change predictions for Wales and the related impacts on agricultural soils are described in more detail in section 6.1.

Figure 9: Temperature change in Wales between 1884 and 2021 relative to the average 1971-2000 (°C)

Colours are relative to the positive (reds) or negative (blues) annual average temperature deviations from the 1971-2000 average [52].



5.2 Soil carbon

Key evidence sources [8], [53], [54]

Soil carbon constitutes both organic (biota-derived) and inorganic (mineral-derived) carbon. As a result, different soils and habitats contain varying amounts of carbon. Soil organic carbon (SOC) is the primary constituent of soil organic matter (SOM), which is assumed to make up 58% of SOM by weight [55]. Maintaining and enhancing SOM contents is beneficial to soil fertility and functioning and can aid in climate change mitigation.

Soil carbon in Wales

- The total soil carbon stock in Wales is 410 Mt [5], [56]. 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) [56]. The large extent of peat-containing soil is highlighted by Wales having a high relative carbon stock compared to most European countries (Fig. 10).
- Alonso et al. [57] highlighted the importance of natural and semi-natural habitats as stores of SOC; although this review was for England, these habitats will also be important stores of SOC in Wales (Fig. 11).
- Maintaining the high levels of soil carbon is a major challenge for Welsh soils. However, opportunities exist for increasing SOC stocks by peat restoration and land use changes (See Section 6.3)

Figure 10: The topsoil organic carbon contents of European countries

More than 50% of the EU carbon stock are in peat soils. [58] Modified from JRC, European Commission [59] (Copyright holder 2010).

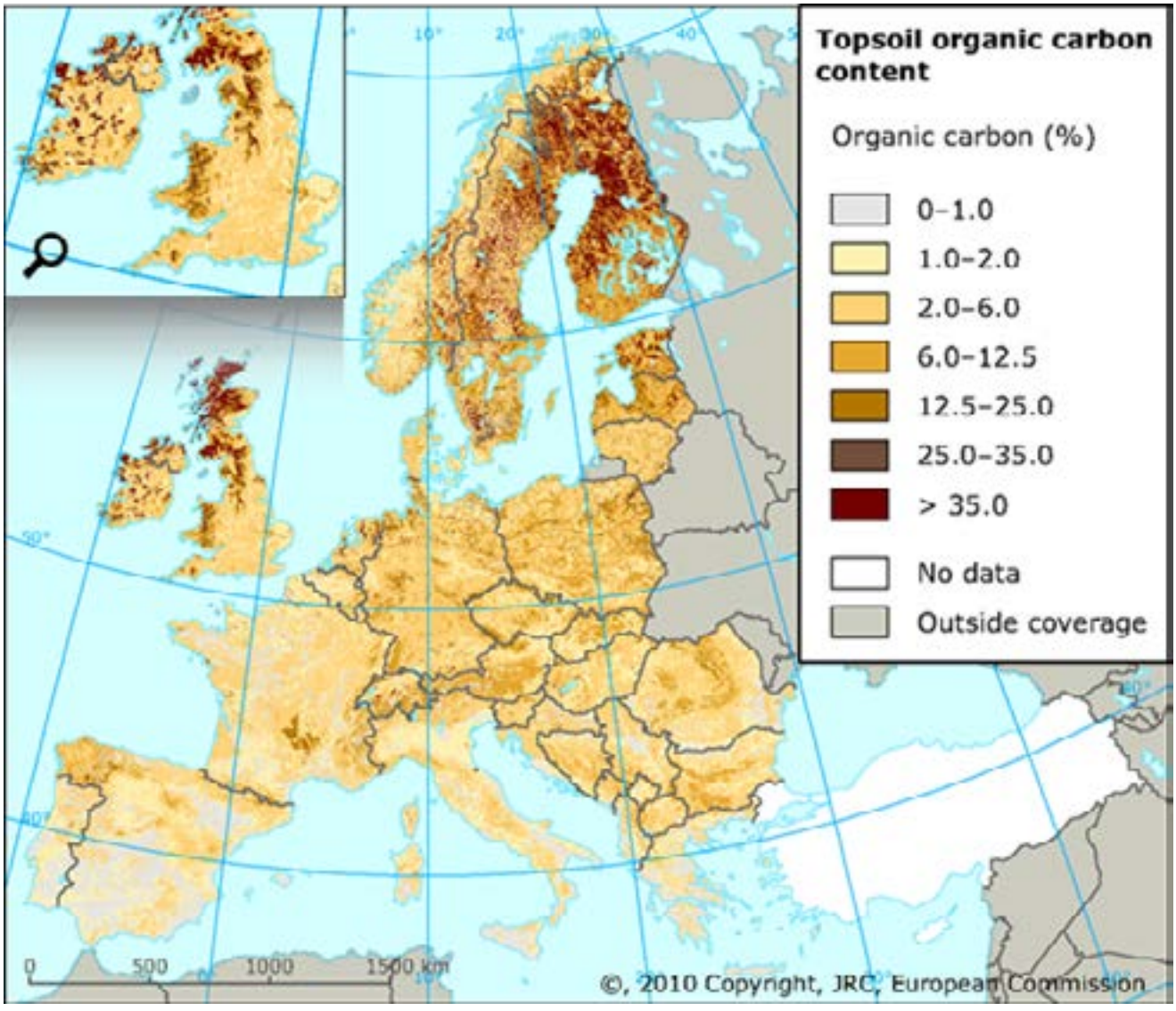
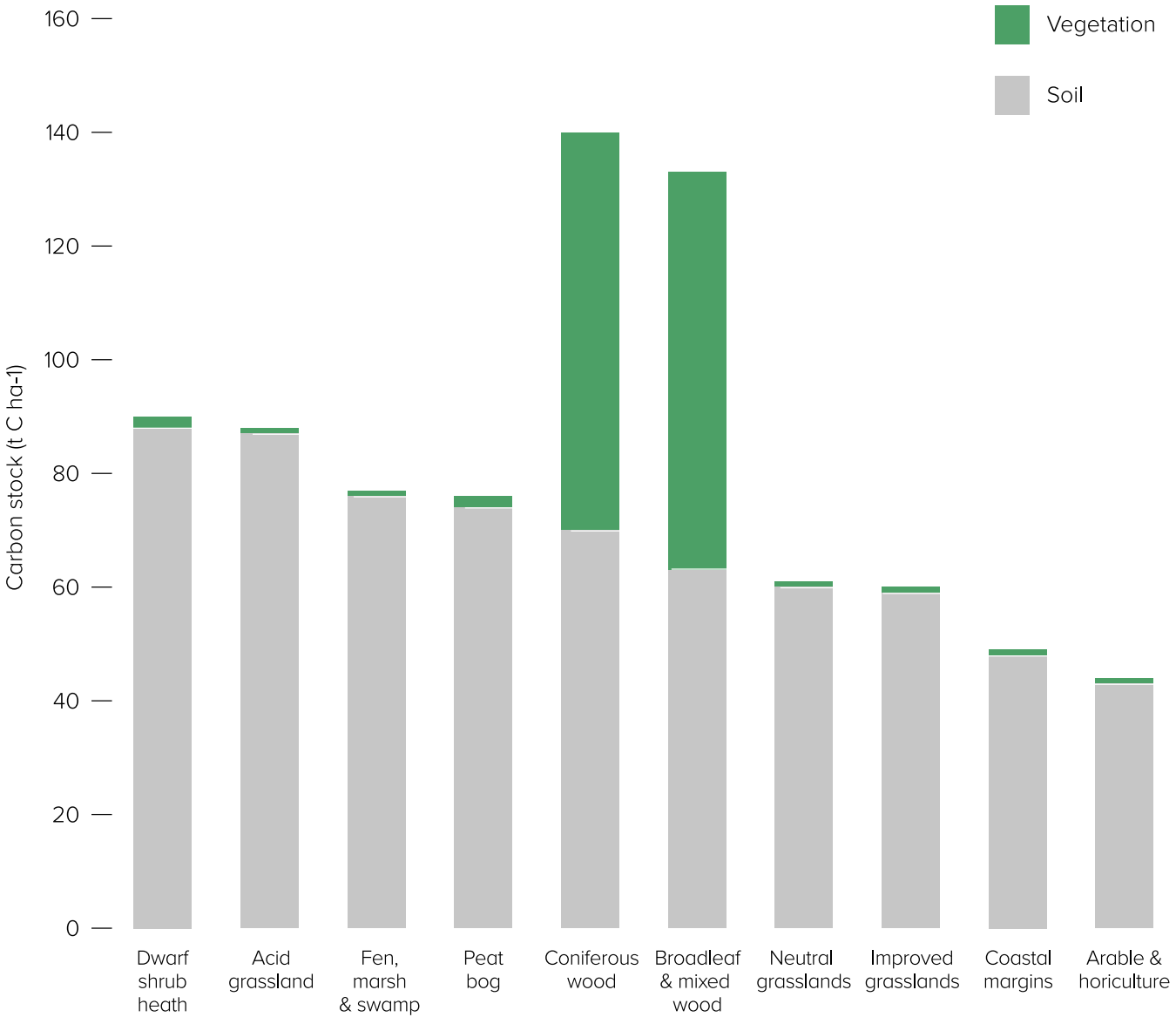


Figure 11: The soil and vegetation carbon stock in different habitats

Data [57] is from 15 cm deep soil samples in England. Woodland vegetation data is from 50-year-old average rotations.



Trends in soil organic carbon

- Topsoil (0-15 cm) carbon has been monitored as part of ERAMMP, however these analyses are based on low sample numbers, particularly for arable land (total of 42 samples). For more information on national monitoring data refer to [60]. ERAMMP data showed a generally stable trend in SOC [60]. More in-depth analysis of GMEP data showed that over the past 30 years topsoil carbon was stable in improved land (arable, horticulture and improved grassland), decreased in habitat land (all habitats except woodland, arable and improved habitats), and increased in woodland (broadleaved, mixed and coniferous). The reason for a topsoil carbon decrease on habitat land is not understood.
- Peats, organo-mineral and shallow soils are the most vulnerable to loss of SOM over time [61] mainly due to mineralization or oxidation driven by drainage, cultivation and conversion to arable land, liming and fertilizer use [62].

Most soils in Wales are at low risk of SOM loss. This reflects the dominance of low disturbance management systems. Permanent and rough grazing grasslands accounts >80% of agricultural land while arable land accounts for 13% of agricultural land. The risk to SOM is greater in more intensively managed land like arable and improved grassland.

Evidence Gaps

- Evidence on soil organic carbon trends in Welsh soils is sparse. Limited data is available for the top 15 cm of the soil profile and no evidence exists on soil carbon dynamics below 15 cm.
- There is no direct evidence of the influence of the interacting factors of land use, soil type and climatic conditions on soil organic carbon in Wales.
- There is no specific data for soil organic matter content in Welsh arable soils.
- Resilience of Welsh soils to loss of organic matter/organic carbon is not reported in the evidence explicitly.

5.3 Soil compaction

Key evidence sources [8], [63]

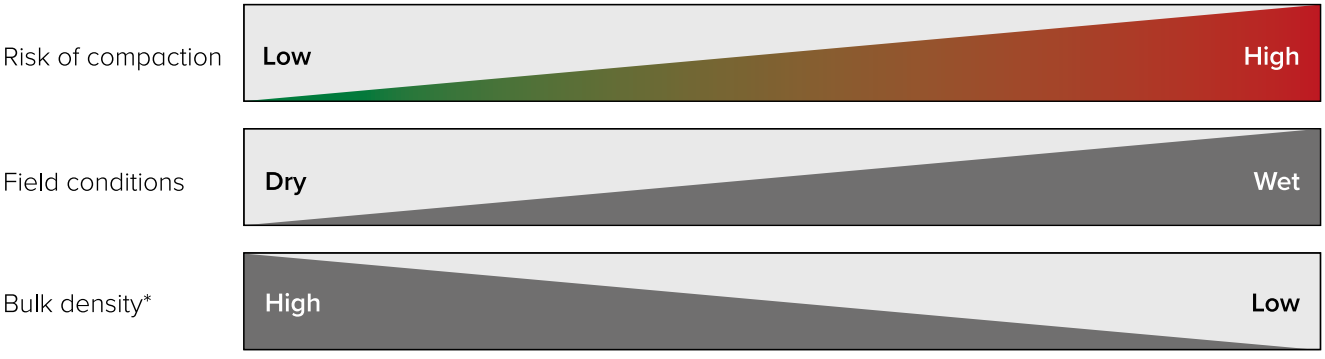
Soil compaction occurs when surface-applied force reduces soil pore space and increases the soil bulk density. Compaction usually occurs when machinery or livestock travel on soils that are not strong enough to withstand their weight. The moisture content, initial bulk density and the texture of the soil are key factors controlling the risk of compaction (Fig. 12). Other important factors related to compaction risk are the stocking densities of livestock; the type and frequency of farming equipment use (including the load size and contact area); and, the vegetation density

on a field.

- **Field conditions:** Wet soils are particularly vulnerable to compaction by machinery and livestock poaching [64].
- **Bulk density:** When soil is at the same initial water content, soil with higher initial bulk density has lower susceptibility to compaction [65].
- **Soil texture:** coarse poorly graded textures (i.e. uniformly sized large particles) can resist compaction well, while fine well-graded textures (i.e. fine or 20% of every particle size) are prone to compaction. Silty and fine sands can also cause surface capping (i.e. a hard impenetrable surface crust formed in the top 1 to 10 mm of soil). Heavy soils with high clay contents are more vulnerable to compaction when wet.

Figure 12: Soil compaction risk

In general, the risk of compaction varies with the field conditions and the bulk density of the soil.



*before compaction

Soil compaction in Wales

As around 40% of Welsh soils are considered wet, slowly permeable or have high groundwater, they are considered potentially vulnerable to compaction from machinery and livestock poaching [4], [64]. At a national level, soils do not appear to show evidence of widespread compaction, however this is based on limited evidence.

- Of 120 surveyed sites [66], 23% of improved grasslands showed evidence of soil damage and 3% of the sampled sites were considered compacted. This suggests a current low level of soil compaction in Wales [64], [66]. However, this may increase with greater reliance on contractors, preventing optimal timings of operations with soil conditions and with increasing size and weight of field machinery [6].
- Grassland compaction in Wales is highly relevant given that >90% of managed agricultural land is under permanent or temporary grassland. An estimated 25% of total grassland areas in Wales are liable to agricultural compaction [4].
- A GMEP survey in 2014 also found that most samples were below the bulk density trigger values (indicator of compaction) suggesting low level of soil compaction [67]. However, these analyses are based on limited topsoil data [60]. Compaction often occurs in the subsoil.

- 600 farmers visually assessed soil damage associated with soil compaction and structural degradation in Wales. Soil compaction due to heavy machinery use and poaching by livestock on grasslands were the most frequent observations of soil damage (19 and 43%, respectively)[66].
- A survey of 300 grassland fields across England and Wales suggested that 10-15% of the fields were in poor structural conditions and 50-60% in moderate condition [68].

The risk of compaction also increases with machine size and number of machinery passes [68], where load sizes >3.5 t can cause serious and permanent compaction [69]. However, not all compaction is permanent as it often can be alleviated.

Soil compaction consequences and opportunities

- Field studies in England, Scotland and Northern Ireland have reported yield reductions that average around 10-15% over multiple years because of soil compaction [68]. Limited data for Wales shows that poor soil structure may reduce the efficiency of nitrogen fertiliser to 40% or less [6].
- Compaction increases the risk of runoff generation. Severe levels of degradation have been visually associated with runoff generation across whole fields, whilst moderate levels of degradation led only to localised patches of enhanced runoff on permanent grassland fields surveyed across south-west England [70].
- Good soil structure and modern grass varieties can increase fertiliser efficiency from less than 40 to 60-75% [6].
- Using herbal lays and diverse swards with variable rooting depths can improve soil structure and break compacted soil layers. These could potentially improve soil structure, water infiltration and provide greater resistance to soil compaction [71].

Evidence Gaps

- There is limited evidence on the level of compaction across Welsh agricultural soils.
- There is no data on the vulnerability or resilience of specific soil or land use types to soil compaction in Wales.
- The extent of damage by compaction from poaching and machinery.
- There is very limited data on the consequences of soil compaction for productivity and/or soil functions in Wales.
- A quantifiable link between improved soil condition and the magnitude of flood events would permit evaluation of the benefits arising from payments to land managers for ecosystem services.
- Compaction risk of different livestock and crop types.
- There is no Welsh data on runoff generation.

5.4 Soil erosion

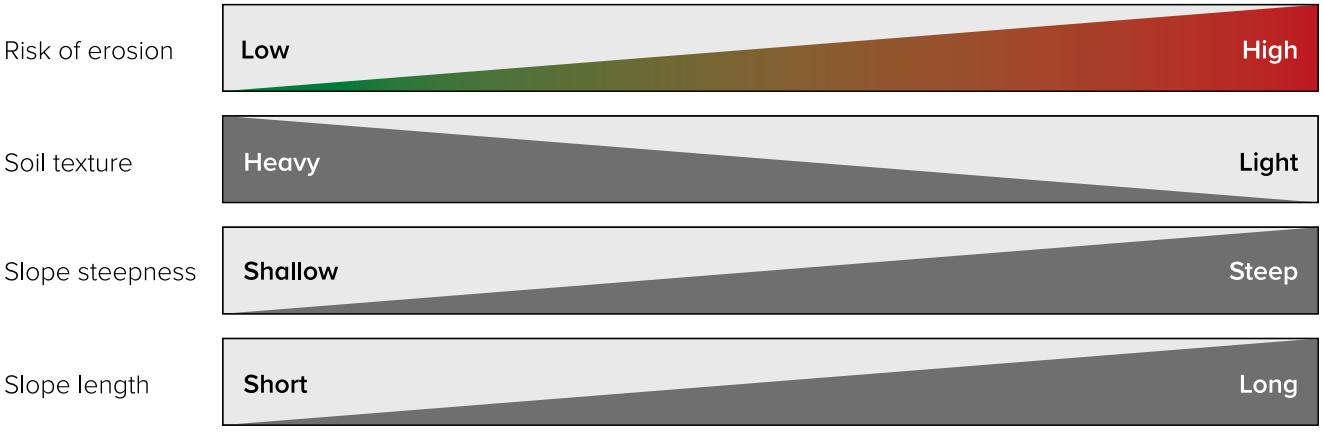
Key evidence sources: [8], [72], [4]

Soil erosion is the displacement of soil by wind or water. Its risk is determined by the intensity, duration and timing of rainfall events; the physical, biological and chemical properties of soils; the length, gradient and form of slope; the type of vegetation or crop on the land and its stage of development; and the type and timing of land management practice [73]. The simplified interaction between physical soil-related factors and their relation to the risk of soil erosion is demonstrated in figure 13.

- **Soil Organic Matter (SOM):** In general soil with <2% soil organic carbon can be considered erodible, however this depends on the origin of SOM [74]. Peat soil, for example, has a very high SOM content but poor aggregate stability meaning it is highly susceptible to water and wind erosion. Soils with farmyard manure-derived SOM have greater aggregate stability.
- **Soil Texture:** Light soils with very fine sand and silt content are more susceptible to erosion compared to heavy clay soils due to a lack of cohesion between particles. Organo-mineral and peat soil are generally at the highest risk as they are the lightest soils.
- **Slope:** The length and steepness of slopes are important factors that impact the vulnerability and severity of soil erosion. Generally, slopes <2° are considered level; 2-3° gently sloping; 3-7° moderate and >7° steep [75]. While any slope >11° are considered very steep and at high risk of erosion, any slope >3° may experience some form of erosion, depending on the soil texture [75]. In addition, the longer an erosion vulnerable slope is the greater the potential for soil erosion, as demonstrated in figure 13.

Figure 13: Soil erosion risk

In general, the risk of soil erosion varies with the texture of the soil and the steepness and length of the slope of land.



When comparing soil erosion with soil formation it is important to remember that erosion can be highly local and intensive, and this is where erosion rates are likely to outstrip soil production rates in Wales.

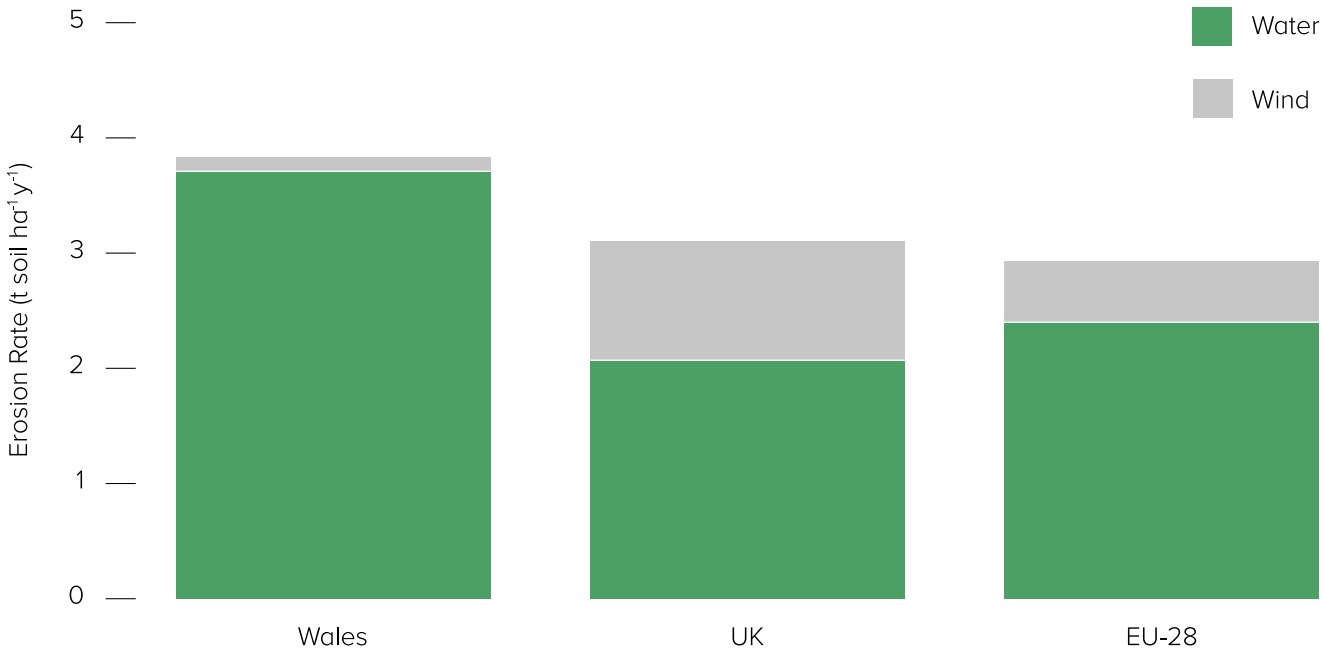
Soil erosion in Wales

About 7% of land in Wales is susceptible to high (>11 t ha^{-1}) erosion rates [8]. In Wales, soil erosion by water is more widespread than erosion by wind, largely due to the dominance of sloping land and high rainfall [8]. The risk of erosion is greatest during high intensity rainfall events. Land use and land use change are important factors affecting the vulnerability of soil to erosive loss.

- The dominance of grassland systems with permanent vegetation cover in Wales would indicate an overall low risk of soil erosion (for medium textured soils) from a national perspective. However, erosion processes are highly local and intense resulting in hotspots where significant soil loss is likely to occur.
- 62% of the total soil lost in water by Wales is from agricultural land and the majority of this is lost via surface runoff (61%) with the remaining 39% from preferential and drain flow [66]. In general, soil erosion in Wales is mainly attributable to upland erosion processes, landslips, stream bank erosion and water erosion along the border with England [6].

Figure 14: The modelled water and wind soil erosion rates for Wales, the UK and the EU-28 in 2012

The wind erosion estimates for the EU-28 are for arable land only. Data from [76], [77]. Data based on the Revised Universal Soil Loss Equation (RULSE).

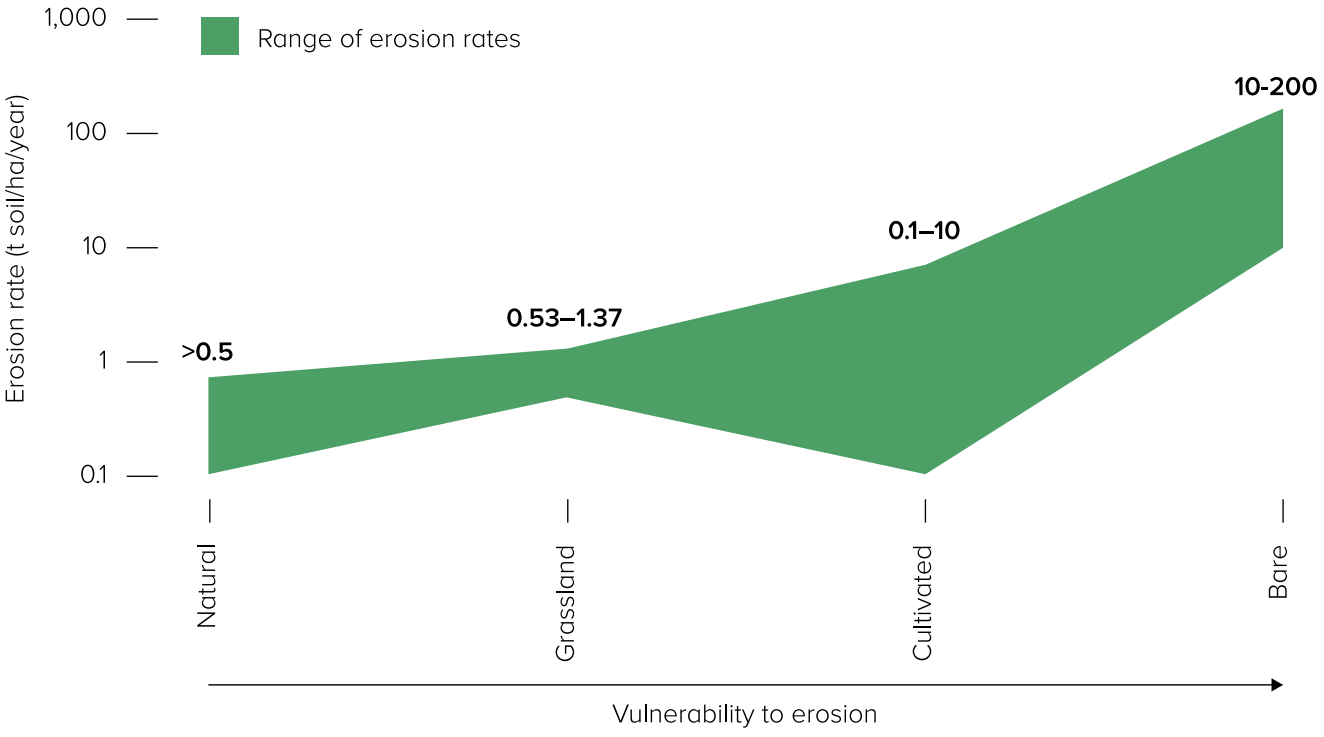


- The modelled soil erosion rates in Wales are high for water (3.71 t ha^{-1} y^{-1}) and low for wind (0.12 t ha^{-1} y^{-1}) erosion (Fig. 14). The Welsh water erosion rate is 79 and 55% higher than the average erosion rate for the UK (2.07 t ha^{-1} y^{-1}) and for the EU-28 (2.40 t ha^{-1} y^{-1}), respectively [77]. However, it is 88 and 77% lower than the average for UK (1.03 t ha^{-1} y^{-1}) and the EU-28 (for arable land; 0.53 t ha^{-1} y^{-1}; [76]), respectively. This is because wind erosion mainly affects sandy and peaty soils in arable production, which are uncommon in Wales.
- Reviews for England and Wales have estimated typical erosion rates for different land uses, however further validation is needed before they can be applied to Wales [6]. Nevertheless, these estimates elucidate the differences in vulnerability to soil erosion of different land uses. ([72]; Fig. 15).
- In Wales, it is estimated that 59% of the estimated sediment loss is from grassland, 29% from rough grazing and 13% from arable land [72].
- In arable systems, the risk of soil erosion is greater than in grassland systems due largely to more frequent and prolonged soil exposure. However, the risk of erosion varies greatly depending on the crop the soils are drilled with, as can be seen in the large ranges in figure 15. For example, 1 in 6 or 7 fields drilled with hops, maize or sugar beet are at risk of erosion, whereas only 1 field in 100 drilled with oilseed rape is at risk [73]. Cultivation practice is also a significant component of erosion risk. Bare soil (i.e. with no vegetative cover) is the land use with the greatest vulnerability to soil erosion (Fig. 15).
- There is no direct evidence of measured erosion rates or the frequency of erosion episodes in arable sites in Wales [4]. Although cultivated (5%) and bare arable land (6%) currently represents a small area of the total agricultural land in Wales, there is potential that this area might increase in the future [78].

Figure 15: Ranges of soil erosion rates

The logged ranges of soil erosion rates for different land uses ordered from least ('natural' land) to most vulnerable (bare soil) to erosion.

The erosion rates are plotted on a logarithmic scale. Ranges are estimates for England and Wales. Data from [72].



Evidence Gaps

- Soil erosion risk in grasslands may be lower than arable but it does not mean that it is always low.
- Typical soil erosion rates specifically in Wales have not been directly measured and quantified. The available estimates are for England and Wales combined.
- The extent and condition of soil drainage in Welsh agricultural soils is not known.
- The Glastir Scheme had limited impact on reducing sediment loads [79].
- Models, such as the Revised Universal Soil Loss Equation (RUSLE), tend to overestimate soil losses as they do not account for soil conservation measures. However, they do provide an indication of relative risk.
- There is a lack of erosion data for different systems (e.g. min-till, no till, plough, undersowing).

5.5 Soil formation

Key evidence sources [80]

Assessment of soil formation has largely been based on the soil parent material where many of the properties involved with soil formation and development, such as texture and mineralogy, are derived. Precipitation, relief and climate are also fundamental to the development of soils. It is important to note that the soil formation rates presented below assume favourable climatic conditions for soil formation and do not take soil loss by erosion into account.

For England and Wales soil erosion in grasslands has been estimated to be within the same range of soil production (i.e. 0.02 – 0.03 mm yr^{-1}, assuming bulk density of 1 g cm^{-3}) [81]. However, it is worth remembering that soil erosion can be highly local and intense and may have high within-field variation, with mid-slopes being more susceptible to soil erosion than other areas. As soil erosion rates are generally greater than formation rates, soil is considered a finite resource [80].

Soil formation rates for mineral soils

- For consolidated hard rocks covering around 54% of Wales, no specific soil 'production' rates are available for Wales. However, based on current available information of England and beyond, the soil formation range for Welsh hard to soft rock soils is 0.004 – 0.193 mm y^{-1} [80].
- For unconsolidated rocks, where the soil parent materials are eroded (such as glacial till, alluvium, colluvium), covering around 37% of Wales the development of soil horizons may be in the order of around 100 y, and in the 1000s of years for full soil profile maturity. This is based on data from the Baltic region for Podzol development, which provide an indication of the rates of formations in climatic regions closest to those of Wales [80].

Soil formation rates for organo-mineral and peat soils

- Organic soils build up by accumulating organic matter. The formation rates specific to Wales are not well known but organic matter accumulation for peat, organo-mineral soils and peaty topsoils is suggested to be in the range of 0.5 – 1 mm y^{-1}, the same as measured in Scotland [80].

Evidence Gaps

- The soil formation rates specific to Wales are not well known. There is also a lack of measured data on soil erosion rates, so the soil formation and loss balance has not been directly measured.

5.6 Soil nutrients

Key evidence sources [66], [78]

Current status of major soil nutrients in Welsh habitats

- Total topsoil nitrogen is highest in acid grassland, woodland, bracken and heath and bog habitats, followed by arable land, and improved and neutral grasslands [82]. Historically, nitrogen concentrations were stable on improved land (grassland and arable), semi natural grassland and woodland (1970s – 2019). However, there was a significant decline in topsoil nitrogen on mountain moor and heath [54].
- Total topsoil phosphorus concentrations were similar across all habitats (acid grassland, woodland, bracken and heath and bog habitats, arable land, improved and neutral grassland) [82]. Since the 1970s, total topsoil phosphorus concentrations have decreased across all habitats [54]. Yet, since recent declines, levels in improved land are stable.

- Extractable phosphorus (Olsen-P), available for plant uptake, was lower in neutral grassland compared with improved grassland and arable sites. However, the value for extractable Phosphorus in 75% of the improved and neutral grassland sites (with moderate soil quality) were above a trigger value for habitat support, meaning the concentration of nutrients in these sites was too high to support plant species to maintain this habitat.

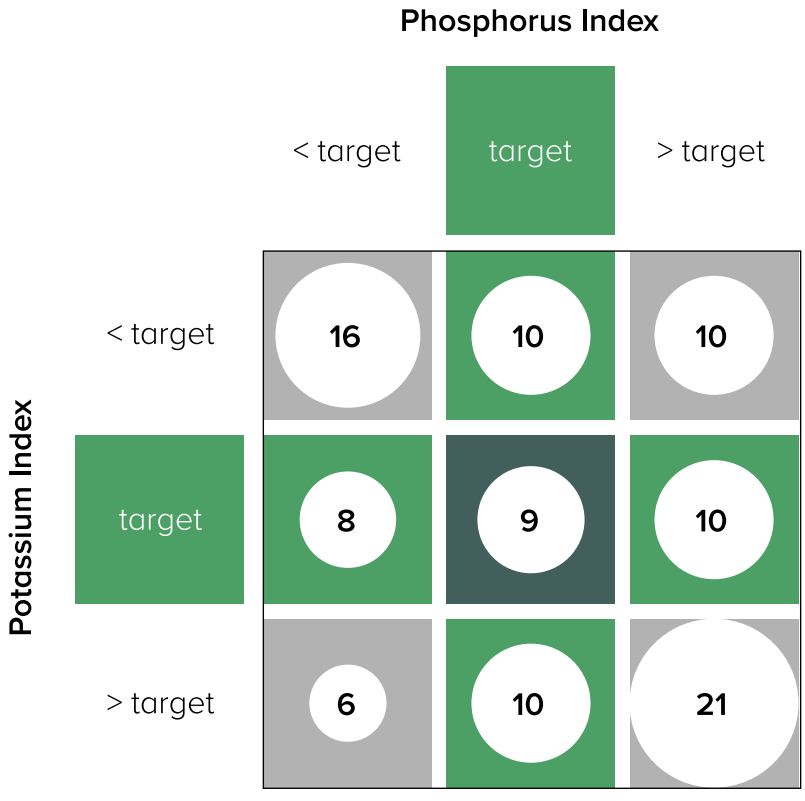
Trends in nutrient application and losses from soil

Managing nutrient application to land to optimise supply for crop growth is important to minimise losses and impacts to the environment.

- Recent data from over 200,000 samples for phosphate (P) and potassium (K) application across the UK showed that only 9% of samples were at target levels for both P and K (Fig. 16) and this has remained almost unchanged for a decade. In addition, 16% were below targets and 21% were above targets for both P and K, demonstrating most applications were below or in excess of plant uptake [83].

Figure 16: Potassium and Phosphorus index of soil samples from PAAG

Matrix of percentages of all soil samples (total of 206,959) from the Professional Agricultural Analysis Group (PAAG) in relation to target P and K Indices [83]. Circle sizes are relative to percentages.



- Annual nutrient losses from Welsh agriculture are estimated at around 37,000 t of nitrate-N and 700 t of phosphorus to water, and 20,000 t of ammonia and 8,000 t of nitrous oxide to air [66], [84]. In Wales, agriculture accounts for around 60% of nitrates in rivers and it is a major source of phosphorous.
- Recent analysis of Welsh rivers with Special Area of Conservation (SAC) status revealed that 61% failed the target for phosphorus, demonstrating a significant problem of phosphorus pollution in SAC Welsh rivers [85]. In addition, Welsh Water Framework Directive (WFD) waterbodies are predominantly in 'Moderate' condition due to pollution and a low biodiversity [86].
- In general, the impact of nutrients to the environment increases with land management intensification, and typically phosphate loads are higher under arable than grassland systems. However, phosphate losses can still be high in more intensively managed grasslands due to the strong influence of site-specific pathways and land management intensity on phosphate movement [78].

The role of pH in nutrient availability

The availability of soil nutrients to plants is affected by soil pH. The soil pH should be within optimum ranges for certain crops (pH 6.5 for arable crops and pH 6 for permanent grassland on mineral soils) for effective nutrient uptake. Soil pH outside these optimum ranges can result in the build-up of nutrients in the soil and an increased risk of loss to surface waters. The range of soil pH is also an important determinant for supporting plant species in specific habitats.

- Recent data (GMEP 2016 to 2019) showed arable, improved grassland and neutral grassland tend to have the highest pH, although some sites are below the optimum pH thresholds for arable crops and grassland [87].
- Other habitat sites (acid grassland, woodland, heath, fen and bog) have lower pH. Most sites are within the pH limits that would offer good support for the ecological habitat and biodiversity within specific habitat types.
- Longer term trends showed a reduction in soil acidity across improved land (grassland and arable), semi natural grassland, mountain moor and heath and woodland. Although recent increases in acidity have been observed in improved land and woodland [54].

Evidence Gaps

- Apart from nitrogen, phosphate and potassium, there are no national level data available for other essential nutrients such as sulphur.
- Lack of spatial data for phosphate indices in Welsh soils, the data that is available is old.
- There is no data for Wales for nutrient loading to land from organic and inorganic sources. This is particularly important in land managed at high intensities with high stocking densities of livestock dairy (Southwest) and poultry (Mid Wales).

5.7 Soil biodiversity

Key evidence sources [8], [64], [88]

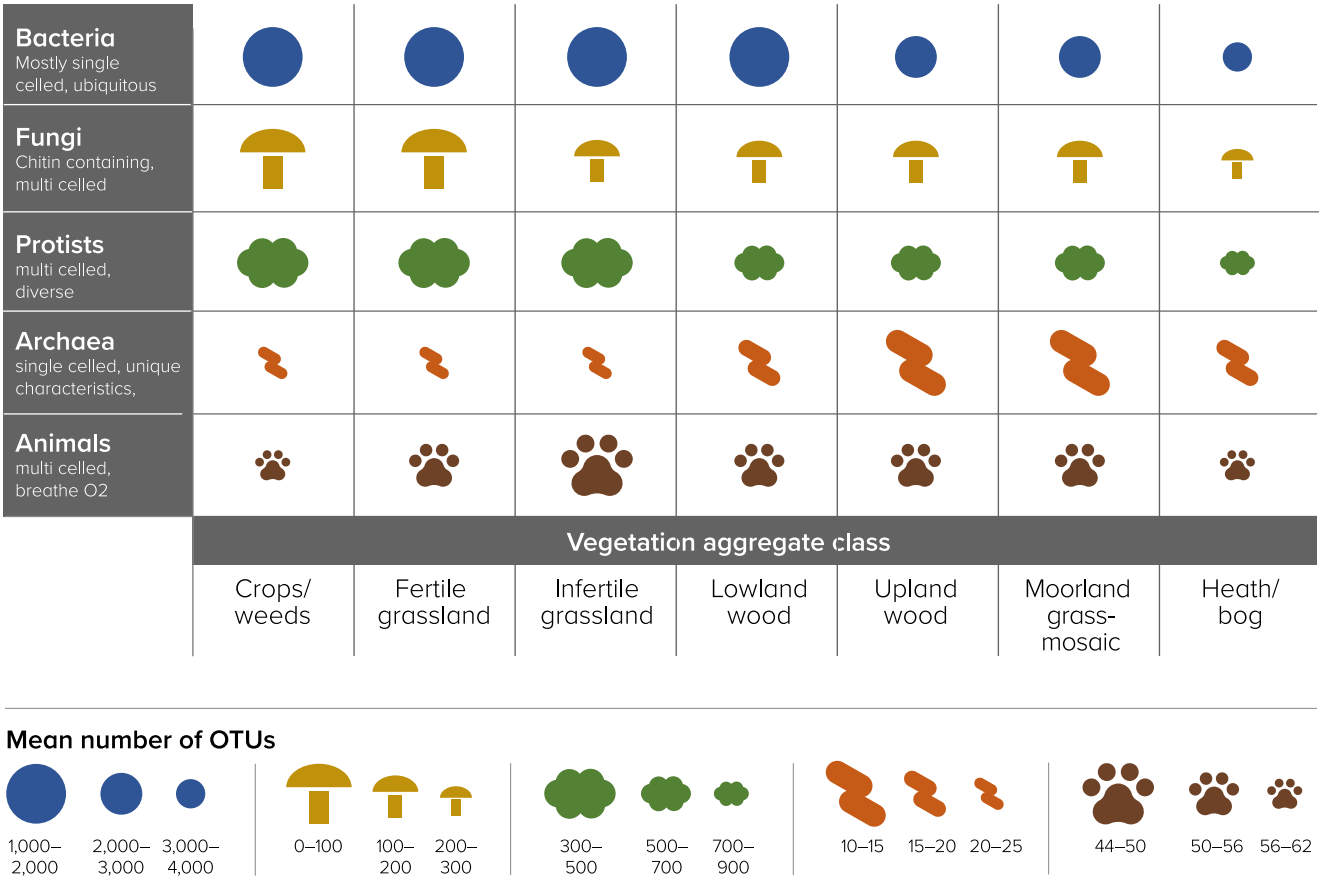
Soil biota accounts for around a quarter of global biodiversity and is essential for nutrient cycling, soil formation, plant growth and other ecosystem services [89]. Soils provide a variety of habitats for a multitude of organisms of different sizes, physiological behaviours, and ecosystem functions. This ranges from bacteria and fungi for which the species richness and functional diversity is yet to be fully established, to larger species, such as earthworms, whose role has been more clearly defined.

Soil biodiversity in Wales

- Of the 557 species included on the Section 7 list of the living organisms of principal importance for the purpose of maintaining and enhancing biodiversity in relation to Wales, more than two thirds are partly or directly reliant on the functioning of the soil.
- Limited evidence currently exists on trends in soil biodiversity in Wales but changes are most likely related to i) land use change, ii) loss of organic matter, iii) extreme weather events, and iv) land management and intensity.
- The threat of soil biodiversity loss is generally lower in low intensity systems compared to highly intensive ones. Changes in land management practices and land use can have large effects on soil biodiversity over relatively short-time scales. A major threat to soil biodiversity is the intensification and extensification of agricultural management [4].
- Most soils in Wales are currently at low risk of biodiversity loss. Areas at risk of biodiversity loss in Wales are confined to southwest Wales and areas bordering England, reflecting the higher proportion of highly intensive management (i.e. arable production) in these areas. Large areas of the Welsh uplands are mapped as having extremely low or no threats to soil biodiversity [90].
- Analysis from GMEP data (2013-2016) reported a decline in total topsoil mesofauna (invertebrates between 0.1 and 2 mm in size) abundance to similar levels to those in 1998 numbers across all land uses [64]. The total number of mesofauna was lowest in the land under arable and horticultural management, and also heath and bog. Improved grasslands had lower mesofauna numbers than neutral or acid grasslands. While abundance data is not the same as a measure of biodiversity, it is a good indicator of the biological condition of the soil.
- A further GMEP analysis using environmental DNA methods found bacterial and fungal diversity to be greatest in arable and horticultural soils, where nutrients were also higher, and that the diversity declines across the land productivity gradient (Fig. 17) [88]. This was linked to the same trend in soil pH.

Figure 17: Soil organism groups (mean OTU) under different vegetation classes

The mean Operational Taxonomic Units (OTU; measure of biodiversity) of different soil organism groups in soil of 436 sites across Wales from different vegetation classes. Each aggregate vegetation class is ordered from most (crops/weeds) to least (heath/bog) productive. Data from [88].



Evidence Gaps

- There is no quantitative data on the vulnerability and resilience of Welsh agricultural soils to losses in soil biodiversity.
- Monitoring of soil biodiversity has not been taken forward in the Environment and Rural Affairs Monitoring and Modelling Programme (ERAMMP) – the successor of GMEP – therefore, there is no evidence of the state and trends in soil biodiversity in Welsh soils beyond 2016.

5.8 Loss of soil to development

Key evidence sources [8]

- Development on soil seals the surface or causes irreversible changes to the soil. Less than 5% of land area of Wales is developed, but there remains a need to build houses, employment developments and associated infrastructure. All soil types are equally vulnerable to sealing or land take because the main driver of site selection is location rather than any soil related factor. However, loss of high-quality agricultural land represents the greatest potential impact of development.
- Sealing of soil surfaces limit the capability for soils to regulate water, which cause greater risk of flooding [91].
- Development is also most likely to affect food, fodder and fibre production, as agricultural land represents the vast majority of land cover in Wales [4].
- The BMV resource is the best agricultural land in Wales and is finite. Between 1939 and 2011, BMV land decreased by 21,275 ha (around 21,000 rugby fields) [9]. This loss was mainly driven by land conversion for urban development. Development on BMV land should be carefully controlled. Since 2001, BMV land is protected under Planning Policy Wales from loss to development, which includes renewable energy development.

Evidence Gaps

- There is a need to monitor the type, extent and location of soil sealing and land take in Wales and the impact of loss on soil functions and agricultural capability.

06

Future drivers and opportunities for Welsh agricultural soils

Climate change and land use change individually impact the soil and land and it is important to understand the details of these changes, which have been outlined in Sections 6.1 and 6.2.

However, it is also important to consider that they can interact and influence each other. This is especially significant with climate change driving land use change. For example, higher temperatures and longer growing seasons can make conversion of land to intensive land uses more profitable.

These interactions are poorly understood, and research is limited partly due to limited data availability and analytical issues in addressing the interaction effects. Not acknowledging or understanding these interaction effects can risk ineffective management, but also may provide opportunities, whereby the impacts from climate change can be mitigated by land use or management change [92].

6.1 Climate change

Changes in climate threaten ecosystem resilience and ecosystem services through shifting species ranges, localised extinctions, changes to life-cycle events and other impacts on ecosystem function [93]. Climate change interacts and exacerbates other environmental stressors, such as the increase in invasive species and disease vectors. It is also projected to increase the frequency and intensity of droughts, fluvial and coastal floods and heatwaves, which are projected to further reduce ecosystem resilience. Globally and within Wales, some of the impacts of climate change including sea level rise and coastal erosion will be irreversible [93].

Key Messages

- **Soil wetness:** The predicted changes in climate are anticipated to cause changes in soil wetness. This will impact the stability of the current soil carbon stock and potential for carbon sequestration; change the structure and function of soil biological communities, and affect agricultural productivity.
- **Soil carbon stock:** Higher rainfall may increase carbon content in mineral soils, where organic matter can accumulate, whereas higher temperatures may reduce carbon in more sensitive organic soils. As predictions are of both temperature increases and seasonal concentration of rainfall, it is difficult to know exactly how carbon stocks will change with climate in Wales.
- **Agricultural capability:** The extent of the Best and Most Versatile land is predicted to increase by 2050 offering greater opportunity to deliver future crops for food and non-food uses. However, after 2050, drought limitations are predicted to cause declines in land quality and increased irrigation may be necessary to meet crop water demands.
- **Soil biology:** Droughts and warmer temperatures can impact soil microbial communities, especially when climatic conditions are prolonged. There is a lack of evidence for accurate predictions.
- **Compaction and erosion:** Longer growing and grazing seasons could result in greater soil compaction and erosion from livestock and machinery.

A change in climate also has repercussions for the soil environment and the functions it provides. The capability of agricultural land for production is strongly influenced by climate.

The soil and land also have potential to aid in the mitigation of the impacts of climate change through different management approaches. In addition, changes in climate may provide new opportunities for cultivation.

6.1.1 Climate projections

Key evidence sources [8], [94], [95]

The following climate projections are based on the application of the Agricultural Land Classification (ALC) climate interpolation routine to three of the UKCP18 representative concentration pathways (RCP) scenarios [8]:

- 'Low' emissions scenario – RCP4.5 (warming of 2.4 °C)
- 'Medium' emissions scenario – RCP6.0 (warming of 2.6 °C)
- 'High' emissions scenario – RCP8.5 (warming of 4.3 °C).

Temperature

- By 2050, an increase in accumulated annual mean temperature above 0 °C for all three UKCP18 representative concentration pathways (RCP) is predicted (Fig. 18), particularly in southwest Wales. Further increase by 2080 – 2099 of 1-2 to 3-4 °C higher than the baseline (1981 – 2000) is predicted and will limit large areas of the Borders and the north and southern coastal areas. Spatial variation in annual temperature within Wales is only predicted for the highest concentration pathway scenario (RCP8.5) where greatest temperature increases are predicted for southeast Wales.
- Winter and summer temperature is predicted to increase by 2080 – 2099: 1-2 to 4-5 °C and 5-6 °C in winter and summer respectively.

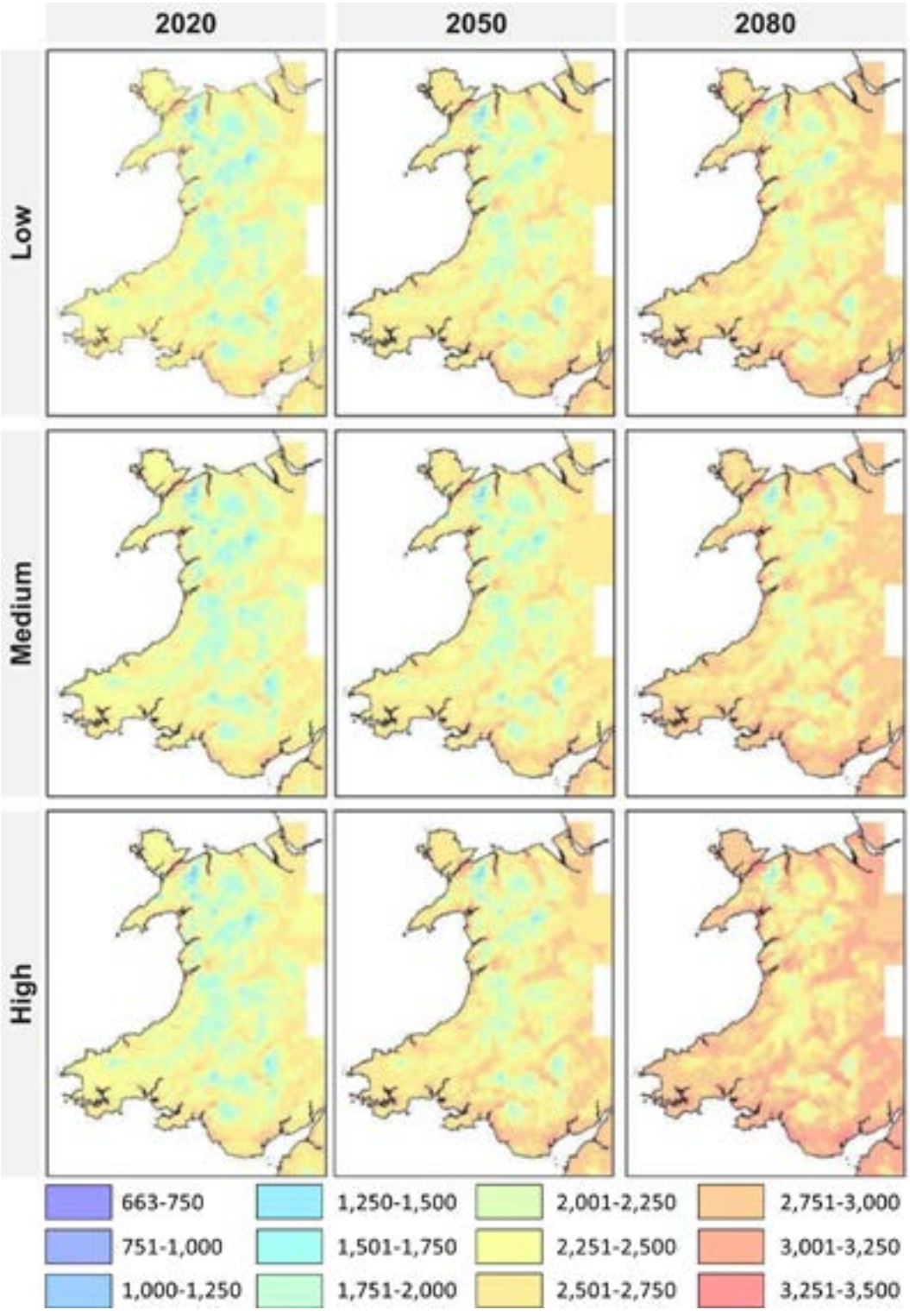
Rainfall

- Annual average rainfall is suggested to increase slightly in west Wales and remain at baseline levels in east Wales (all concentration pathways and time scenarios).
- Change in the seasonality of rainfall is predicted resulting in increasingly wetter winters and drier summers [51]. Winter rainfall is predicted to increase compared to the baseline (1981 – 2000). Summer rainfall is expected to decrease (the decrease is particularly marked in south and east Wales) by approx. 20-40% compared to baseline levels by 2080 – 2099.

Drought

- Drought arises from insufficient rainfall and its impact on plant or crop development depends on several factors. These include the climate (temperature and rainfall), soil texture, structure, stoniness and depth, the rooting depth of the plants, the photosynthesis pathway and the regional origin of the plant variety.
- UKCP18 predictions for 2020, 2050 and 2080 demonstrate a consistent decrease in grass growth class over time and with increasing concentration pathway scenarios (low, medium and high). By 2080 under the high concentration pathway scenario, more than 15% of grasslands could be in the poor or very poor grass growth class and good and very good classes could decrease from 77 to 50% cover due to more drought conditions [96].

Figure 18: Accumulated Summer Temperature above 0°C (April to September) under Low, Medium and High UKCP18 Scenarios. Modified from [97]



Flooding

- According to the UK Climate Change Risk Assessment 2021 evidence report, approximately 52,413 hectares of Best and Most Versatile (BMV) land in Wales is at 1 in 75 year or greater risk from fluvial flooding. A further 10,726 hectares is at a 1 in 75 year or greater risk of surface coastal flooding assuming no further adaptation.

Seal level rise

- Agricultural land and soil will be threatened and potentially lost to a rise in the sea level driven by climate change. This applies to a range of agricultural land quality grades.
- Sea level rise of different heights is predicted to affect certain coastal areas in Wales more than others with a range of ALC graded land predicted to be lost.

Evidence Gaps

- Climate change impacts should be based on most current data. Compare projections to actual trends on an ongoing basis. More localised agricultural and metrological data are needed to support modelling, trends and data refinement.
- Current sea level rise evidence in Wales does not take shoreline and defence management into account, so predictions represent the maximum extent of risk and not likely the reality.
- Monitoring changes in crops grown as a response to a changing climate.

6.1.2 Climate change impacts on soil

Key evidence sources [8]

The predicted changing climatic conditions are expected to impact the soil functionality and the agricultural potential of Welsh agricultural soils.

Soil physical and chemical properties

- Climate change is a key driver for soil degradation. The dominant effect of climate change in Wales is changes to soil wetness, particularly shifts in the period of waterlogging which is expected to decrease after 2080. This will impact soil carbon, soil biodiversity, grassland productivity, and compaction and erosion risks. Climate change scenarios in Wales that may result in extended grazing seasons might create opportunities for longer outdoor grazing, which might increase the risk of compaction by livestock. This in turn could reduce reliance on high risk fodder crops such as maize and result in less requirement for slurry spreading – less machinery on the land.
- The duration of field capacity days (FCD) is not expected to change significantly across Wales until 2050, with the two highest categories (223-279 days and >280 days) predicted for all time and concentration pathway scenario combination. However, the timing of FCD might change, even if the number of FCD stays similar. Soils may enter field capacity later in the year and exit field capacity later in the spring, this may have potential impacts for timing of seeding for crops [98] and extended grazing seasons might create opportunities for longer outdoor grazing, which might increase the risk of compaction by livestock. There could be a reduction in field capacity days in 2050 and 2080 in some areas of Wales (e.g. southeast) compared to 2020 because of the predicted reduction in summer rainfall.

- Soil type influences the impact of climate change on soil carbon content. Organo-mineral and mineral soils behave differently to organic soils [99]:
  - Higher rainfall might increase carbon content in mineral soils.
  - Increased temperatures might result in a reduction in carbon in organic soils while minerals soils are less sensitive to changes in temperature.

Soil biology and biodiversity

Soil biodiversity supports the multifunctionality of land ecosystems to produce food, store carbon and support habitats. Climate warming and increases in extremes such as drought and floods can cause major changes in the structure and functioning of ecosystems. These extreme events can cause a shift in the abundance and diversity of soil organisms and their interactions between each other and with plants. These changes in the soil biological community are likely to impact on the key functions these organisms perform such as nutrient cycling, carbon storage and habitat provision. It is currently uncertain exactly how a shift in the soil community in response to climate change will affect soil functions, which is further complicated by the complexity and diversity of soil type and land use.

- Ecological networks describe interactions between species, the underlying structure of communities and the function and stability of ecosystems. Analysis of the response of networks of soil bacteria found they were more strongly affected by short term drought than fungal networks in mesotrophic grasslands [100].
- Long term experimental warming and drought of an organo-mineral heathland soil showed significant changes in bacterial and fungal communities in response to drought and warming. The changes in the microbial communities were more distinct after a longer period of climate manipulation [87].

Evidence Gaps

- Continue – and increase refinement – of modelling to show the projected impact of climate change on Welsh soils, especially soil biodiversity.
- Better understand soil and climate relationships and the impact on Welsh soils and their potential for food production and habitat sustainability.
- Map and better quantify the carbon contents of soils across Wales.
- How the interaction between climate change and land use change can impact soil is poorly understood.

6.1.3 Climate change impacts on land

Key evidence source [101], [102]

The changing climate is predicted to impact BMV land and the suitability of land for different land uses.

- There may be an increase in land quality (determined by ALC grading) across certain parts of the country in 2020 and 2050 (22-24% coverage) compared with the baseline UKCP18 (20%). Greater expansion of Grade 2 land is predicted. This means that agricultural potential for cultivation is predicted to improve in some areas, predominantly by a single grade or subgrade class increase.
- These land quality changes are mainly due to the ALC climate criteria becoming less limiting (Fig. 19).
- However, between 2050 and 2080 a tipping point is predicted where climatic conditions become limiting and BMV land area decreases (i.e. a decrease in agricultural potential) to 18,

16 and 9% coverage in the Low, Medium and High UKCP18 representative concentration pathway scenarios (Fig. 18). These decreases in land quality are due to limitations to the ALC grades (wetness, droughtiness, climate and other physical limitations). Practically, this translates to:

- **Summer:** less precipitation and higher temperatures (increased risk of droughtiness).
- **Winter:** more precipitation (increased risk of flooding and soil erosion).

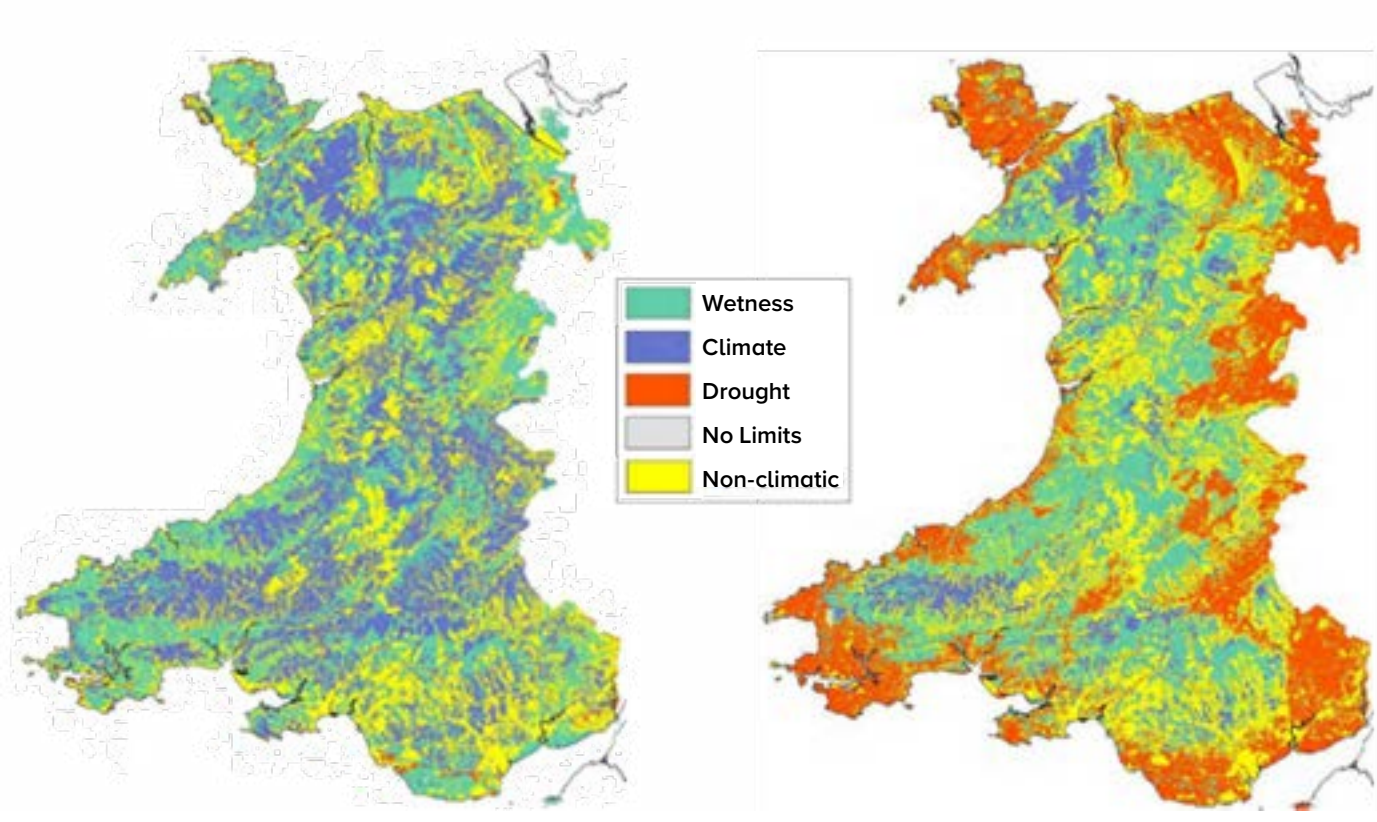
- According to the UK Climate Change Risk Assessment 2021 evidence report, approximately 52,413 hectares of Best and Most Versatile (BMV) land in Wales is at 1 in 75 year or greater risk from fluvial flooding. A further 10,726 hectares is at a 1 in 75 year or greater risk of surface coastal flooding assuming no further adaptation.

Figure 19: Main limitations to Agricultural Land Classification

Main limitations to Agricultural Land Classification (prioritised by Climate, Drought, Wetness, Other factors) for the Predictive ALC Map (version 2) for a) the baseline, and b) the medium emission scenario in 2080. Other limitations include all other non-climatic ALC criteria such as soil depth, topsoil stone content and gradient. Modified from [101].

a) Baseline

b) Medium emission scenario



Evidence Gaps

- It is important to continue to review the Agricultural Land Classification system, especially considering the predicted impacts to soil highlighted in section 5.1.2 and 5.1.3.
- Modelling identifies the climatic potential of shifting cropping under climate change, but it does not take into account other constraints (e.g. suitability or limitations of the soil or topography)
- Modelling tends to focus on specific aspects and should seek to consider the interactions of these potential effects and constraints.

6.2 Land use change

Land use change can alter soil properties and functions. This is demonstrated by empirical evidence of changes in soil organic matter, soil biodiversity and pH after land use change, with some properties such as soil carbon showing a time lag to adjust to different soil processes under the new land use.

Changing from less intensive (e.g. semi natural grassland) to more intensive (e.g. arable) land use results in negative effects on fundamental soil properties such as soil organic matter and soil biodiversity. The probability of soil degradation is high across all soil types in urban, horticulture and intensive arable land use and low in unimproved or rough grassland, woodlands and wildscapes [8].

Key Messages

- **Soil carbon loss:** Conversion of land from less intensive (e.g. semi natural grassland) to more intensive (e.g. tilled arable) land use will result in a loss of soil carbon and a reduction in soil biodiversity. Certain soil types, such as peat and organo-mineral soils, may be particularly vulnerable to land use change as these often occur in areas of unimproved grassland or heathland. Organo-mineral soils also hold considerable stores of carbon that are at risk of loss during land use change or agricultural intensification.
- **Development on agricultural land:** Land demand from urban, mineral and land-based renewables (solar and wind) development, place additional pressures on land use conversion, especially when on high quality agricultural land. The longer-term impacts of development on soils and ecosystems needs to be better understood considering initial disturbance, active site management and decommissioning.
- **Best and Most Versatile land loss:** Predicted loss of BMV to housing and development uses over next five decades is expected to be minimal compared to historical losses, assuming continued protection under planning policy. Increased demands and competition between land uses are predicted between sectors, such as forestry, renewable energy and urban development, for which agricultural land will be required.

In Wales, key areas under risk of land use change are permanent grassland, as this covers almost two thirds of the land area of Wales. The main land use changes from permanent grassland are conversion to arable land, afforestation, land-based renewable energy such as solar or wind and housing or employment development. The type of soil within these areas is also important to consider as they will have different vulnerabilities to land use change. Many permanent grassland areas are supported by organo-mineral soils, which have shallow organic layers that are highly vulnerable to land use change [103].

Current policies and guidelines that take into consideration the effects of land use change on soil are 1) the assessment of Best and Most Versatile Land in the planning system to limit development on good grade agricultural land (Planning Policy Wales, Section 3) and 2) avoiding establishing new forests on soils with peat exceeding 40 cm in depth and on sites that would compromise the hydrology of adjacent bog or wetland habitats in the UK Forestry Standard Guidelines (UKFS, 2017).

Any future direction in land use change will be determined by several, sometimes competing factors such as climate change, the impact of Brexit and trade deals, agricultural commodity prices, and current and future policy around agriculture, food security, net zero (tree planting and renewables), sustainable management of natural resources, well-being and national growth plans.

6.2.1 Drivers for increases in arable land

Key evidence source [104], [97], [6]

Several factors are predicted to increase the potential for arable cultivation in Wales in the future. Converting permanent grassland to arable land has the potential to significantly affect soil properties and functions.

Changing climate

- Greater carbon dioxide concentrations, higher temperatures and longer growing seasons mean more land will become viable for effective arable production.
- The demand for cereals to be grown in Wales might be greater as climate change is likely to impact cereal production in England more severely.

Demand for food and population growth

- With the population of Wales projected to increase by 2.7% between 2018 and 2028 [105] and a shift towards a more plant-based diet (i.e. lower animal product consumption), the demand for food and plant-derived food is likely to increase [24], [78].
- Arable agriculture can produce more calories per unit area than livestock with substantially fewer resources (e.g. water) and lower GHG emissions.
- Increased future droughtiness in the east of England could make the BMV land in Wales more important for food production.

EU Exit and self-sufficiency

- In 2019, 45% of UK food consumed is imported and this proportion is rising [106]. The vast majority of Welsh agricultural products are exported to the EU. With an uncertain trade future, there is a risk that the Welsh red meat sector may not be viable or profitable.

Plant (protein) demand

- The majority of livestock feed (i.e. plant protein) is imported and the food market for human consumption is growing.
- There is a growing market for cultivation for biofuel, fibre, and medicines. Currently, most biofuel is imported.

6.2.2 Impact of development on agricultural land

Key evidence source [107], [11]

BMV land is a strategic national asset. Retaining BMV land is crucial to ensure the most flexible agricultural resource remains for future generations. While the physical nature of the soil and the climate determine the quality of agricultural land via the predictive Agricultural Land Classification, development on BMV land is practically irreversible and represents a major risk to Welsh BMV land.

Urban development

- The predicted loss of BMV land over the next 50 years is expected to be minimal when compared to historical losses (see 4.8).
- Under a high urban scenario (i.e. a high future need for housing), the predicted decline of BMV by 2065 is 0.4% [11]. This represents an £11.2 million cumulative loss of agricultural production (Gross Margin Value) [11].
- Loss of ALC grade 2 land has the greatest impact on agricultural Gross Margin Value loss (48%) closely followed by ALC grade 3a (44%). This is partly because grades 2 and 3a are predicted to suffer most of the lost under high growth scenario.

Photovoltaic (PV) site development

- An increase in solar energy in the electricity mix will require more land for PV installation. A suitable grid connection is a major factor determining the proposed location of a site, which can be on or in the proximity of BMV land.
- The benefits of PV sites to ecosystem services and natural capital are recognised, but the longer-term impacts of solar PV sites on ecosystems need to be better understood. It is suggested that recovery after solar PV sites is likely to occur more quickly than mineral site restoration, but this requires further evidence.
- Non-standardised guidelines exist for good management practice; however, these are rarely backed by evidence.
- There is an emphasis that PV sites on agricultural land be 'reversible' (low disturbance, no concrete, minimal foundation), but there is little detail on how this could or should be delivered. An agreed definition of reversibility in the context of guidance and monitoring of sites is required.
- Decommissioning (i.e. solar PV site installation in reverse), is a current issue which is expected to become significant in the next couple of decades. The aim is to leave the site as if it has never had a solar PV installation.
- In the UK, plans are usually prepared near (within 6 months) the end of life for the site (up to 40 y). The requirements for a successful outcome of a decommissioning plan need to be identified at an early stage.

Evidence Gaps

- There is a need to regularly monitor and report the type, extent and location of soil sealing / land take in Wales.
- There is a general lack of evidence on the impact of PV site development on soil and land quality.
- 'Reversible' PV installation lacks detail on how this could be achieved.

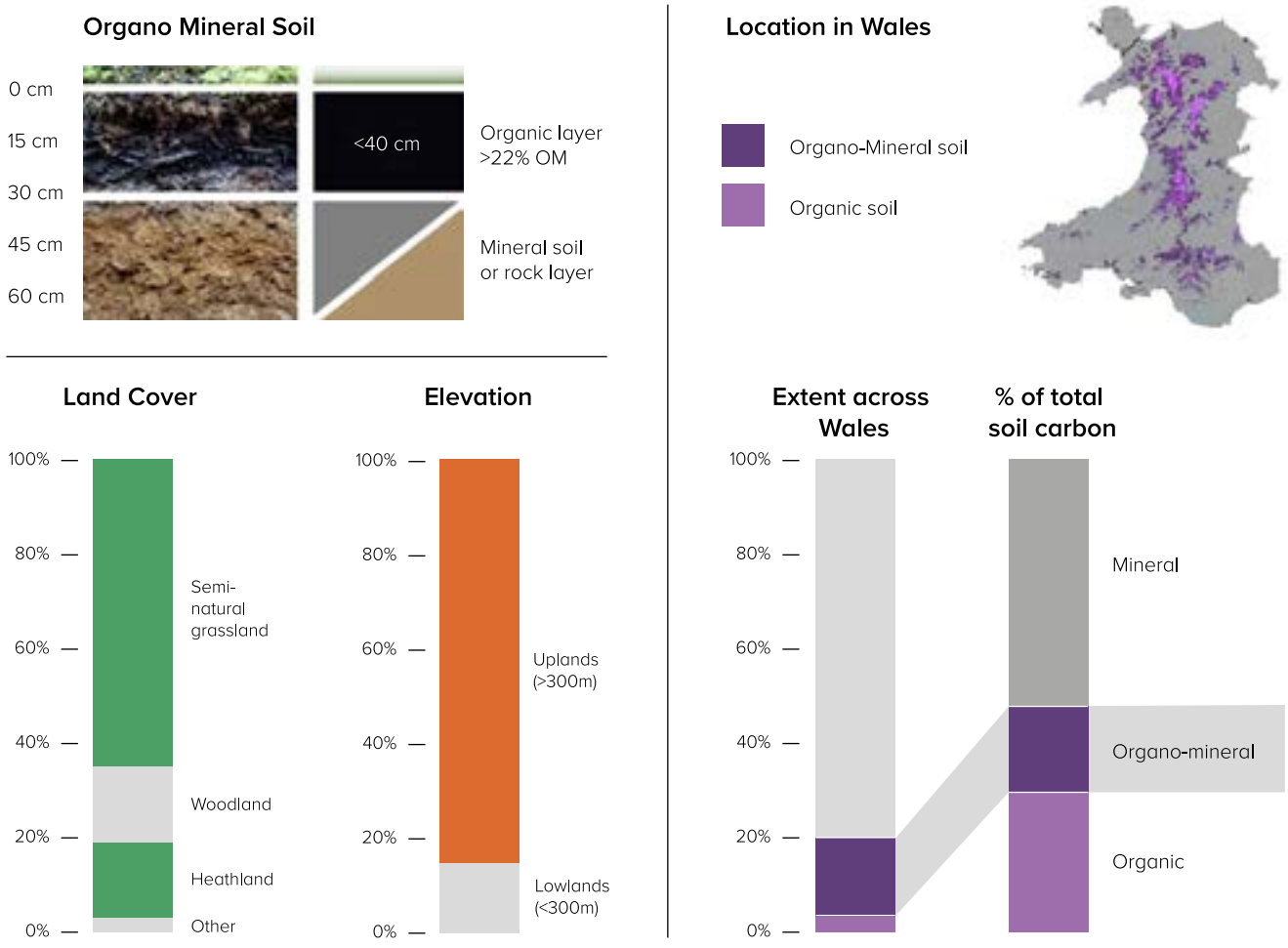
6.2.3 Impact of land use on organo-mineral soil

Key evidence source [108], [109]

Organo-mineral soils cover around 17% of Wales and are a nationally important carbon stock containing around 18% of the carbon stored in Welsh soils (74.5 Mt C to a depth >1 m) [56]. However, over half of the total carbon stock of Welsh organo-mineral soils is estimated to be stored at a depth of 0-15 cm, meaning it is more vulnerable to management practices and environmental changes.

Figure 20: An overview of organo-mineral soils in Wales

The description, location, extent, proportion of total soil carbon, land cover and elevation of organo-mineral soils are shown. Data and map (modified) from [103]; soil profile example photo from John Hollis.



Due to climatic constraints, topography and soil characteristics, agricultural productivity is restricted on much of the organo-mineral soil area in Wales. This is reflected by the predominance of organo-mineral soils present in the uplands (Fig. 20). A substantial proportion of the total organo-mineral soil land in Wales is occupied by semi-natural grasslands (65%), while 16% is occupied by woodland and 16% is underlying heathland. The remainder (3%) occupied by cropland, wetland and coastal habitats [103].

Conflicting pressures on land use in Wales, including the need for supporting food production, mineral extraction, energy provision, commercial development, conservation and climate change mitigation (tree-planting), have highlighted the need to understand the impact of land use change on Welsh organo-mineral soils. Overall, more intensive management practices increase the risk of degradation of organo-mineral soils.

Impact of agricultural management

- Agricultural management, including stocking rate, grazing regime, frequency of re-seeding and the use of fertilisers and lime are likely to influence soil carbon storage and organo-mineral soil functioning.
- Conversion of organo-mineral soil under grassland to arable land use has the potential to cause major loss of soil carbon.

Impact of commercial forestry

- While woodlands can support a range of ecosystem services, the effects of land use change on ecosystems services are site specific and should be carefully considered on a site-by-site basis. There is uncertainty regarding the impact of organo-mineral soil afforestation on the carbon stocks and full greenhouse gas budgets (carbon dioxide, methane and nitrous oxide) [110].
- Research by Forest Research suggest that when moderate and high productivity trees are planted using low soil disturbance methods it is possible that afforestation may result in little or no net change in soil carbon when the full cycle of forest growth is considered over two forest rotations [110], [111]. However, this is based on limited evidence and there is no data to show the longer (>100 year) effects of afforestation upon organo-mineral soil carbon stocks.
- Activities associated with afforestation such as planting, management and harvesting disturb soil and can cause soil carbon loss during first rotation forestry [108]. Afforested organo-mineral soils may lose carbon at a much faster rate than carbon can be sequestered. Therefore, if the aim of woodland creation is to provide a net carbon sequestration benefit preventing soil carbon loss is a priority.
- Soil hydrology will likely be impacted by afforestation and a reduction in water yields from catchments due to increased canopy interception of rainfall and evapotranspiration compared with grassland is expected [108].
- Many areas of the Welsh uplands organo-mineral soils are similar in peat depth to soils defined as peat soils (>40 cm deep). Due to hydrological connection between these soils, afforestation of organo-mineral soils in these locations is likely to impact the hydrology of the deep peat. At these sites afforestation could also adversely affect deep peat vegetation communities and associated biodiversity.

Impact of mineral extraction and development

- Soil disturbance and the removal of vegetation from organo-mineral soils for development and mineral extraction purposes is likely to cause carbon loss by increasing rates of organic matter decomposition and soil vulnerability to erosion. This will likely also influence soil structure and, in turn, soil hydrological functions, including infiltration rates and water holding capacity.

Evidence Gaps

- The capacity and timescale over which soil functions (including carbon storage) of organo-mineral soils may be restored following land use change is not well known.
- The long-term effects of forestry upon organo-mineral soil carbon stocks are uncertain. There are currently no long-term studies (over 100 years) of carbon change resulting from the afforestation of organo-mineral soils.
- Many of the long-term forestry studies are partly based on outdated management practices and are less relevant for understanding impacts of modern forestry on soil.
- No evidence in the literature of studies investigating changes in organo-mineral soil carbon stocks under broadleaf forest.
- There is a knowledge gap regarding understanding of the different stabilisation mechanisms of organic carbon within peat and mineral soil layers and the effect of forest management upon carbon stability.
- Further work is required to improve understanding of the impact of forestry on full greenhouse gas budgets as all of these gases are impacted by land use change. Not all current models investigating these emissions from forestry consider methane and nitrous oxide emissions.

6.2.4 Impacts to Priority Habitats

Key evidence source [112], [16]

The Environment (Wales) Act 2016 Section 7 sets out a list of the habitats of principal importance for the purpose of maintaining and enhancing biodiversity in relation to Wales. These habitats provide key benefits including carbon storage, flood mitigation, food, fibre and some of Wales's most iconic species and landscapes.

- It is important to appreciate the historical context of natural and semi-natural habitats to avoid 'shifting baselines', where each new generation accepts the losses of the past and looks only at recent changes [16].
- There are specific soil, topographical and climatic conditions required to support the principal terrestrial priority habitats [112]. Therefore, any change in soil or climate conditions could alter the current and future suitability to maintain, restore or establish a priority habitat.

- Any potentially suitable site is not protected and therefore it might be under threat from land use change. Thus, habitat suitability should be considered when land use change from agriculture to development is proposed, so that a potential to restore or establish a priority habitat is protected.

Evidence Gaps

- There is a need to model and monitor the potential impact of climate change on soil for habitat suitability and resilience.

6.2.5 Sustainable BMV land use

Key evidence source [11]

BMV land is the best land for sustainable agricultural management due to soil and climatic conditions allowing for efficient, cost-effective and productive workable land. Using this land will be important for future food production and its use needs to be sustainable.

- Around 76% of Wales is being utilised for agriculture at a high or very high production level, including areas of BMV land, according to GMEP modelling work on land cover, soil and slope conditions (accuracy and resolution of maps not validated; [11]).
- The current predominance of grassland on BMV land (70% of total BMV land) means that any change in land use will likely impact soil quality (soil carbon, water quality and soil biodiversity). This refers to both changes in management and changes to a land use other than grasslands.
- As BMV land often contains lighter and more easily workable soils, it requires fewer "passes" by agricultural machinery to establish seedbeds. The reduction in the amount of time machinery spends on the land helps reduce fuel, labour and maintenance costs. It also reduces the potential for damage to SOM. Horticultural and root crops grown on BMV land can also be harvested in a cleaner condition reducing loss of soil, water usage and crop wastage. Therefore, BMV land will be important for future sustainability at both small area and national levels.
- How climate change will affect the services BMV land provides, particularly if land use patterns also change, is not well understood. The main challenge and potential opportunity is to view a soil system from a multifunctional perspective rather than a single narrow focus (food production, development potential or carbon storage) [11].

Evidence Gaps

- Further research and analysis should determine the total economic value of BMV land resource in Wales. This will help identify whether preserving BMV land is the best option for WG policy or whether efforts should be focused toward the potential for ALC grade 3a or other grades to provide goods and services that meet future societal demands.

6.3 Opportunities

Key Messages

- **Restoration of peatlands:** 75% of peatlands have in some way been impacted, turning them from carbon sinks to carbon sources. Restoration of peatlands can improve the condition and increase carbon storage of peatlands. Peatland restoration also has significant co-benefits of improving habitat condition, biodiversity, and water regulation.
- **Greater arable and horticultural cultivation potential:** With predictions of higher temperatures, reductions in field capacity days and an increase in growing season length; the opportunity for arable and horticultural cultivation of land is likely to increase in extent. This may become increasingly important for becoming more self-sufficent in food production and for food security.
- **Afforestation and Woodland creation:** To address the climate emergency and meet Net Zero targets, the Welsh Government aims to plant significant amounts of new woodland. Afforestation can enhance the soil carbon content, especially when using techniques that minimise disturbance and when planted in the appropriate soil. Increases in soil carbon are shown after inclusion of trees on arable land or conversion to woodland. There is a risk of carbon loss when planting on high carbon soils, such as peat and organo-mineral soils, as evidence suggests it takes several rotations before there is a gain in soil carbon.
- **Grassland carbon sequestration:** Wales is predominantly covered by grasslands which store a large proportion of the national carbon stock, but grasslands are generally thought to be in equilibrium (i.e. no loss or gain in carbon) and not sequestering additional carbon. Improving grazing management by a reduction of stocking rates and grazing season has been found to increase soil carbon. 'Light' grazing is the most beneficial for soil carbon in grasslands. Organic inputs, liming, fertilisation and sowing of legumes and other grass varieties are other ways to enhance soil carbon in grasslands.
- **Reduction of greenhouse gases:** A variety of agricultural practices have been identified to reduce greenhouse gas emissions from agricultural soils. These include: improved nitrogen management, the use of perennial crops, increasing organic matter inputs and reduced or zero tillage.

There are opportunities to maintain and enhance soil resources that benefit from future changes in land use and/or management and climate. This can improve the future delivery of ecosystem services and related Sustainable Development Goals by soils in Wales.

Converting land use to less intensive land uses, reducing land management intensity and improving and restoring semi natural and natural habitats can result in beneficial improvements to soil resources and their capacity to deliver ecosystem services.

6.3.1 Carbon sequestration and retention

Key evidence source [104]

The greatest increases in soil carbon can be achieved through land use change or through habitat restoration. The greatest opportunity for increasing soil carbon is in areas where there has been historical depletion such as on arable land, whereby converting it to grassland or woodland will increase the soil carbon stock. The carbon stock after converting to the new land use does not normally increase continually and will reach saturation (i.e. not sequester any further carbon) after a few decades [113].

Where there are currently large stocks of soil organic carbon, such as in areas of peatland and organo-mineral soils, these should be retained and preserved. Any proposed land use changes should be carefully considered so that any substantial net loss of soil carbon or reduction in soil to deliver other ecosystem services over the long term is avoided.

Restoration of peatlands

- Despite their small land area, peatlands represent the largest terrestrial store of carbon in Wales.
- 75% of peatlands have in some way been impacted, turning them from carbon sinks to carbon sources. Restoration of peatlands by reducing drainage, burning and reduction or exclusion of livestock grazing can increase the condition and carbon storage of peatlands. Peatland restoration also has significant co-benefits to habitat condition, supporting biodiversity and regulating water.
- The National Peatland Action Programme [43] is a 5-year peatland restoration plan in Wales with key objectives to tackle the biodiversity crisis through habitat restoration and meeting Net Zero targets by safeguarding and enhancing carbon storage in peatlands. The programme will target peatlands that need the most restoration, aiming to restore 600-800 ha of land every year. The programme restored over 650 ha in the first year of the project (2020-21) [114].

Afforestation and Woodland creation

- To address the climate emergency and meet Net Zero targets the Welsh Government aims to plant 43,000 ha of new woodland by 2030, and 180,000 ha by 2050.
- Afforestation can enhance the soil carbon content as seen in figure 8, especially when using ground preparation and cultivation techniques that minimise disturbance. The greatest increases in soil carbon are shown after woodland creation on arable land [115], [116]. Overall, the rate of soil carbon accumulation, or loss, (in the soil surface and at depth) after woodland creation depends on the soil type, previous land use, tree species and woodland or forest management. Also, it is important that the right species of tree are planted in the right place to avoid detrimental environmental impacts or unsuitability with changing climatic conditions.

- Modelling (using CARBINE) has demonstrated carbon stock in mineral soil decreases after woodland establishment for the first 30 years but steadily increases as the forest matures, where a woodland is created as a 'carbon reserve' (i.e. not managed for timber and felled) [117]. The model is based on the assumption that carbon in soil can continue to accumulate for many decades (possibly centuries) before saturation is reached [117]. In forests managed for timber, soil carbon in mineral soils decreases after initial planting and again after felling, but the net effect after several rotations is an increase in soil organic carbon stock [117]. There is a similar effect on organo-mineral soils (representing a Humic Surface Water Gley) but a net increase in soil organic carbon is not observed until the second and third rotations.

- The inclusion of trees on arable land and grasslands by increasing agroforestry, hedgerows and trees outside woodlands can increase the soil organic carbon content in the soil due to extensive litter, rooting and carbon inputs [118]. Other studies have shown a decrease in topsoil carbon 14 years after planting trees in pasture in England [119] or no change in SOC or soil N 26 years after converting permanent grassland to silvopasture or woodland in Northern Ireland [120].

- A study of sites in England under woodland creation on mineral soils (surface water gleys) showed soil carbon stocks under secondary woodland were similar to ancient woodland sites, indicating rapid accumulation rates under initial woodland establishment, that slowed over time [116]. However, adjacent grassland had a total SOC stock comparable to ancient woodland, which indicated that, for these sites, woodland creation on pasture had little benefit for soil carbon sequestration compared to woodland creation on former arable land [116].

- A study on 10 farms in Wales of SOC contents of grassland pasture adjacent to hedgerows, found a 15% increase in SOC stock within 2m of a hedgerow compared with further into the grassland field. It did not show any difference in the average soil carbon stock overall in fields with hedgerows, compared to the other boundary features [121].

- An analysis of 427 soil carbon data pairs found the mean SOC contents in agroforestry to be 19% higher than in arable lands or pastures [122]. This data was from varied countries spanning temperate and tropical climate zones, there is no specific data for Wales.

- In Agroforestry, crop yields have been found to increase due to complementarity in resource-capture and generation of more favourable conditions (reduced wind stress, moderation of temperature extremes and greater soil moisture) [123].

- There are co-benefits to increasing trees and woody vegetation on farm for improved soil structure, reduction in compaction and soil erosion, increased infiltration of water and reduced run off.

- Tree crops are long-lived, so land which presents good growing conditions at the time of planting may no longer be favourable at the time of harvest, affecting the crop return value. A study by [124] showed that only 32% of land currently suitable for Sitka spruce will remain by 2080 under the medium concentration pathway scenario. Considering climate change predictions and appropriate species choices are a requirement by the UK Forestry Standard (UKFS) [125].

Grassland carbon sequestration

Wales is predominantly covered by grasslands which store a large proportion of the national carbon stock, but grasslands are generally thought to be in equilibrium (i.e. no loss or gain in carbon) and not sequestering additional carbon. It is of national and global importance that this carbon is retained, but there may also be scope to enhance this carbon store through management practices that could enable the sequestration of additional carbon in grasslands. Soil carbon sequestration is a potential aide to reducing atmospheric carbon dioxide concentrations and mitigating the effects of climate change.

Modelled rates of carbon sequestration for temperate grasslands are between 0 and >8 t C ha-1 y-1[126]. However, in some cases negative rates (i.e. carbon loss) has been measured in temperate grasslands (New Zealand) [127]. Considering the potential for both carbon gain and loss, improving management practices to increase the C sequestration rate of grasslands.

- A global analysis of 341 datasets found SOC to decrease with increasing grazing intensity[128]. Another global analysis of 126 studies found improvement of grazing management (reduction of stocking rates and grazing season) increased SOC contents. However, the relationship between grazing and SOC dynamics is complex and no one management approach will work universally. Overall, the evidence suggests that in most conditions 'light' grazing can be beneficial to increasing soil carbon contents on grassland soils.
- Organic inputs, liming and fertilisation can increase plant growth and SOC stock. Liming can also increase SOC but the effect is highly context dependent [128].
- Sowing of legumes and other grass varieties as well as irrigation can improve productivity and, therefore, a greater amount of carbon to be fixed from the atmosphere into the grass and soil [129].

Evidence Gaps

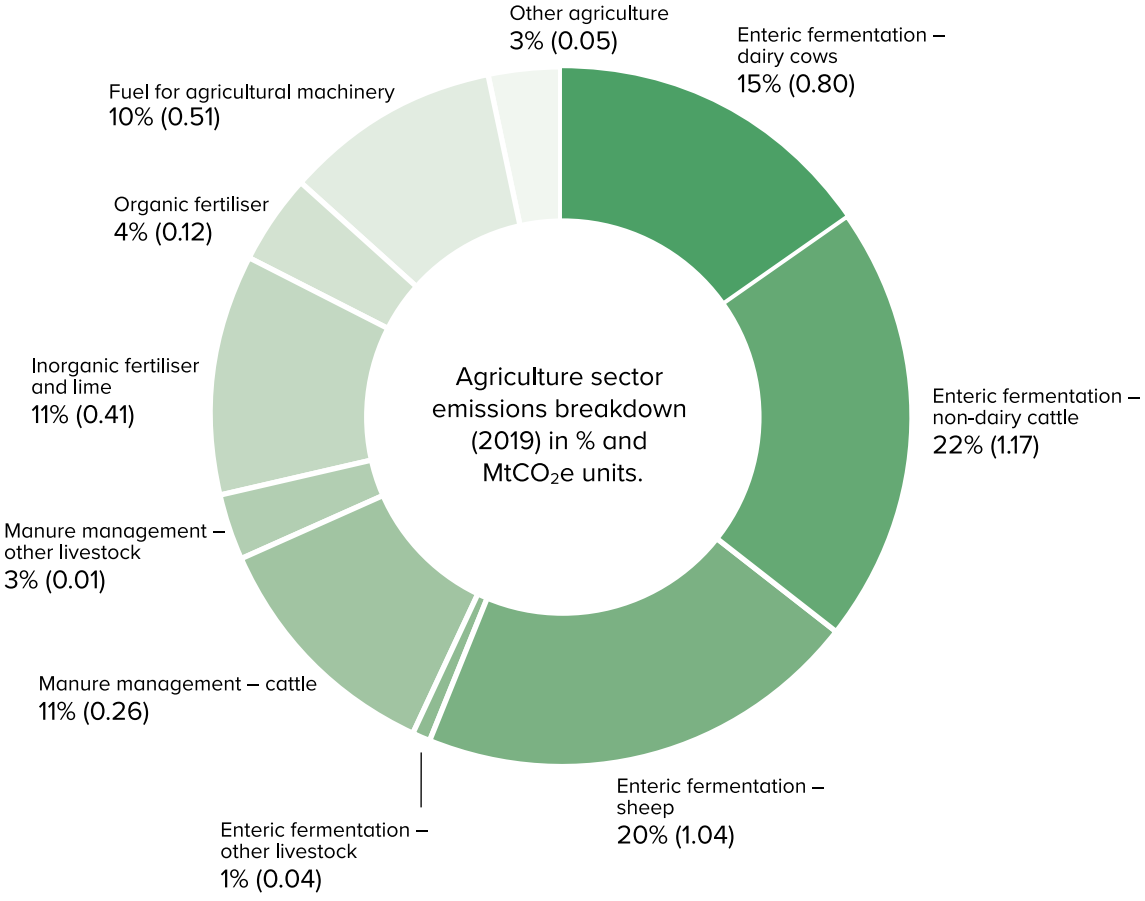
- A baseline for Wales is needed to track trends and changes in soil carbon, specifically the impact of soil type, previous land use, tree species and woodland or forest management on the rate of soil carbon accumulation, or loss, following woodland creation.
- There are mixed effects on the short to long term effects on soil carbon when planting trees in grassland.
- A better understanding of the dynamics of soil carbon and soil GHG balances, for highly organic and organo-mineral soils, particularly during the periods immediately after woodland establishment and after major harvesting events (particularly clearfelling) is needed to reduce uncertainties in modelling. A soil carbon map for Wales would highlight where there are opportunities to sequester more carbon or to retain existing large carbon stores.
- More Welsh-specific evidence is needed to understand the context of specific management scenarios on soil carbon, especially in grasslands.

6.3.2 Reduction of GHG emissions

Key evidence source [104]

The agricultural sector accounts for 14% of Welsh greenhouse gas (GHG) emissions [24]. The challenge for Welsh agriculture is to reduce GHG emissions whilst considering the balance between food production, food security, land use and carbon leakage (i.e. exporting emissions via imports). Whilst the majority of the emissions (Fig. 21) are not directly soil related, they can in some cases be addressed indirectly via soil and land management.

Figure 21: Welsh Agriculture sector emissions in 2019 ($MtCO_2e$). Sourced from [24]



Livestock management

- Livestock enteric fermentation emissions account for 58% of GHG emissions from the agricultural sector in Wales and manure management represents a further 16% [24]. Mitigation of these emissions can be achieved to varying extents by use of high genetic merit livestock, improved grazing, animal nutrition and health and planting of high sugar grasses.

Nutrient use efficiency

- Nitrous oxide emissions contribute 20% to agricultural emissions in Wales from nitrogen cycling processes linked to fertiliser and manure application. Increased nitrogen application accuracy, timing and incorporation techniques as well as use of nitrification and urease inhibitors can reduce the emissions of nitrous oxide.
- The majority of the most cost-effective methods for reducing N2O emissions from soils relate to nutrient management planning. Information from the Wales Farm Practice Survey in 2012 suggest that 43% of farmers have a soil nutrient plan [66].

Agroforestry

- The inclusion of trees on arable land and grasslands can increase the soil organic carbon content in the soil due to extensive rooting and carbon inputs [118]. Crop yields have been found to increase due to complementarity in resource-capture and generation of more favourable conditions (reduced wind stress, moderation of temperature extremes and greater soil moisture) [123].
- An analysis of 427 soil carbon data pairs found the mean SOC contents in agroforestry to be 19% higher than in arable lands or pastures [122].

Perennial crops use

- The majority of food produced for human consumption is provided by annual cereal crops that require annual cultivations, which can increase the risks of soil erosion, nutrient runoff or leaching, and loss of biodiversity and organic matter [130].
- Perennial crops increase soil organic carbon by greater root architecture and lower soil disturbance.

Organic matter inputs

- Use of cover crops (with clover), green manure crops, perennial forage crops, animal manure, compost, straw, and other crop residues maintain and enhance carbon input into the soil [131].
- The mechanisms for SOC increase are mainly from direct C inputs but also from increased biomass production resulting from nutrient additions and improvements in soil bio-physical properties. Nutrient loading from organic matter inputs needs to be considered.

Tillage

- Conventional tillage, characterised by inversion of the topsoil layer through ploughing, leads to exposure and mineralisation of SOC, releasing carbon dioxide into the atmosphere and degrading soil structure.
- Reduced or zero tillage reduces soil disturbance and organic matter oxidation with topsoil carbon increasing compared to conventional tillage. Increases in SOC due to reduced tillage vary, as carbon deeper in the soil may not change resulting in limited overall carbon stock gains [132]–[134].

Evidence Gaps

- Much of the work investigating the management of perennial arable crops has been carried out overseas and further work is required to assess their relevance for Welsh (and UK) agriculture.
- Few studies have assessed the impact of agroforestry systems on carbon storage in soils in temperate climates, as most have been undertaken in tropical regions.

6.3.3 Changes in land quality and cropping opportunities

Key evidence source [101], [135], [102]

- There may be an increase in land quality (determined by ALC grading) across certain parts of the country in 2020 and 2050 (22-24% coverage) compared with the baseline UKCP18 (20%). Greater expansion of Grade 2 land is predicted. This means that agricultural potential for cultivation is predicted to improve in some areas, predominantly by a single grade or subgrade class increase.
- These land quality changes are mainly due to the ALC climate criteria becoming less limiting.
- By 2080, large parts of Wales are expected to become too dry during the summer for the types of crops grown at present (Fig. 18b), unless interventions are made to mitigate the drought effects (e.g. irrigation) or drought tolerant crop varieties are used. Rainfall is increasingly expected to fall during intense weather events, with longer dry periods between rainfall episodes.
- Irrigation is likely to become more important for rain-fed crops that are susceptible to drought through increasingly dry summers (e.g. spring barley, winter wheat, maize, rape, winter rye, oat potato and hay). Competition for water from different users (agricultural, domestic, industrial) is likely to increase. Although the future demand for irrigation water will grow, by 2080 irrigation of crops is predicted to increase to 14 million m^3 [136]. This is, however, less than half the water currently consumed by livestock in Wales (30.6 million m^3) [137].
- Longer growing seasons are likely to favour continental crops such as sunflowers, navy beans, soya, lupins and grapevines.

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