Climateworks Centre

LAND USE FUTURES

# The role of regenerative agriculture in sustainable land use

DISCUSSION PAPER

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## ACKNOWLEDGEMENT OF COUNTRY

We acknowledge and pay respect to the Traditional Custodians and Elders – past and present – of the lands and waters of the Wurundjeri people of the Kulin Nation on which the Climateworks Centre head office is located, and acknowledge that sovereignty has never been ceded. We extend our respect to all Traditional Custodians and Elders of the lands and waters where Climateworks operates. More information.

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**AUTHORS**

Haley Lambert, Jo Sanson, Celina Garcia, Land Use Futures team at Climateworks Centre

**RESEARCH CONTRIBUTORS**

Dr Carla Archibald, Dr Michalis Hadjikakou and Professor Brett Bryan, Deakin University

## ABOUT US

Climateworks Centre bridges the gap between research and climate action, operating as an independent not-for-profit within Monash University. Climateworks develops specialist knowledge to accelerate emissions reduction, in line with the global 1.5°C temperature goal, across Australia, Southeast Asia and the Pacific.

The Land Use Futures program is working to transform Australia's agriculture and land use systems for a sustainable land use future – a future that meets the challenges of climate change, remains within other planetary boundaries and supports the production and consumption of affordable and nutritious food.

The program is a collaboration between Climateworks Centre and Deakin University, with research contributions from CSIRO. We are an affiliate country platform of the global Food and Land Use Coalition, supporting Australia's contribution to meeting global challenges in food and land use systems.

This paper showcases the analysis we have undertaken on a range of solutions to achieve sustainable land use. While these do not represent the full suite of possible solutions to the aforementioned challenges, they include:

- scaling sustainable agricultural practices
- shifts in diets
- reducing food loss and waste
- nature-based solutions e.g. conservation actions to restore biodiversity.

Working with people from across the land use sector, we position climate solutions within the context of the strategic choices that need to inform land use decisions to set us on a path to sustainable land use in Australia.

# Contents

# Executive summary

Food and land use systems are challenged by the significant hurdles of a changing climate, rapid biodiversity loss, and a growing population. Yet achieving sustainable food and land use is also essential to overcome these hurdles. This means finding ways to sustainably produce food, feed and fibre within environmental limits – or planetary boundaries – that set the parameters in which humanity can continue to thrive without compromising the health of the natural environment (Climateworks Centre 2022). In this context, there is a growing need for sustainable agricultural practices to better manage the impacts of agricultural production and achieve outcomes that are better for both people and planet.

Regenerative agriculture is gaining momentum as a solution for providing positive environmental outcomes, while meeting the growing demand for food and fibre. However, there are competing approaches for how to balance the need for and impact of agriculture. One approach, 'sustainable intensification', prioritises technology and other inputs to enhance yield while reducing environmental impacts. By emphasising intensification, this approach aims to reduce the 'extensification' of agriculture, thus sparing land for restoration and conservation. An alternative approach prioritises building on and strengthening natural processes within agricultural systems, and enhancing environmental outcomes through sharing land between agricultural and environmental needs. Regenerative agriculture is generally positioned within this latter approach. There are overlaps between these approaches and debate about whether they are mutually exclusive. However, an important distinguishing characteristic of regenerative agriculture is that it applies nature-based solutions to meeting humanity's needs for food and fibre, by drawing on and strengthening ecological processes.

**Existing models of agricultural practice and food system configuration are failing to meet the full suite of social, environmental, and nutritional needs. Regenerative agriculture, as both a set of practices and social movement, could provide an important lever for change by placing sustainability at the centre of future food production and land use. However, the potential scale of this contribution is uncertain, and the success of sustainable farming methods will also depend on broader shifts within food and agriculture systems.**

In this paper we explore the potential for regenerative agriculture to contribute to five outcomes in Australia: climate change mitigation; health of soils and waterways; biodiversity; land use and productivity; and profitability and resilience.

To assess the potential of regenerative agriculture we must first address two issues: what is meant by regenerative agriculture; and what evidence demonstrates its impacts. This paper explores both, analysing the potential benefits and limitations of regenerative agriculture in an Australian context, based on a review of current academic literature.

Through this analysis we show that regenerative agriculture has the potential to achieve multiple benefits in Australia, including improving resilience, soil health and biodiversity. It also has some potential for contributing to climate change mitigation. However, the extent of these benefits varies, depending on the practice and context, as do implications for productivity and yields. This variation contributes to uncertainty about the potential scope and speed at which regenerative agriculture can be scaled and the specific role it should play in relation to other solutions in the transition to a sustainable land use future.

We conclude that regenerative agriculture does have a role to play in bringing about needed changes to improve the sustainability of Australia's food and agriculture sectors. However, broader, system-wide transformations are also needed, for two main reasons.

First, the success of regenerative agriculture at a large scale depends on its productivity and its other benefits as well as what and how much is required of our land. Second, while holding potential for significant benefits, the limitations and uncertainties around regenerative agriculture mean that it should not be considered a cure-all, particularly for climate change mitigation. A full suite of solutions is needed to balance competing pressures on land to meet climate and other sustainability targets, while still meeting growing demand for agricultural production.

To ensure regenerative agriculture practices are appropriately considered and are scalable to support more sustainable land use in Australia, we propose two main areas for action:

1. Strengthening evidence, knowledge and practice to support more sustainable agriculture, including:
    a. Developing an outcomes-based framework to shift the focus from debates about the definition of regenerative agriculture to measuring the impact of a range of sustainable farming methods
    b. Mainstreaming the measurement and valuation of natural capital in agricultural systems
    c. Continuing to strengthen the evidence base for regenerative agriculture through Australian-specific research
    d. Supporting farmers to innovate and trial new practices and share knowledge.
2. Promoting broader shifts in the food and agricultural system to enable and support more sustainable land use, including:
    a. Reducing demand-side pressures on land by promoting dietary change, particularly reducing livestock-based consumption, promoting alternative proteins, and reducing food loss and waste
    b. Integrating agriculture within coordinated action to align land use with national nature and climate goals to balance competing pressures on land and deliver multiple benefits.

# 1. Introduction

While it is a key export industry, the heart of many rural communities and a source of employment, agriculture is also confronted with, and contributing to, pressing environmental challenges. In Australia, agriculture is the main cause of human-induced land clearing (Climateworks Centre 2022), and a driver of land degradation (Turner et al. 2016). It covers more than half of Australia's land mass (Australian Bureau of Statistics 2022; Department of Agriculture, Fisheries and Forestry n.d.), and agricultural production accounts for 16 per cent of Australia's emissions (Department of Climate Change, Energy, the Environment and Water n.d.); emissions could be even higher when taking into account the full supply chain emissions from food and fibre, which globally are more than double that of on-farm emissions (Intergovernmental Panel on Climate Change 2022). A changing climate, particularly the prospect of increasing future drought intensity, raises the possibility of further land degradation without climate change adaptation across the agricultural sector.

More sustainable land management practices are needed to address the interlinked challenges of biodiversity loss, climate change and food security. Nature-based solutions play a key role in addressing the interconnectedness of these challenges, as they include "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Box 1; Cohen-Shacham et al. 2016). A number of land managers across Australia are already utilising nature-based solutions to contribute to the protection and restoration of the environment while producing healthy food and fibre.

Regenerative agriculture is one approach that is gaining interest. It covers a range of sustainable land management practices that encompass a number of nature-based solutions. A growing number of regenerative agriculture practitioners in Australia and overseas are actively promoting its benefits, including their experiences of improved landscape health, productivity, resilience, profitability and social wellbeing. This has been accompanied by moves from a range of corporations to make commitments or set targets for regenerative agriculture practices within their supply chains. These trends have led many organisations globally to research the potential for regenerative agriculture to meet the multiple goals of feeding the planet, combating climate change and restoring ecosystems.

Agriculture practices and their outcomes are context specific: geography, climate, history, land use pattern and capability (human, capital and infrastructural) all determine outcomes. Assessment of the on-ground impacts of regenerative agriculture in Australia is important to understand its potential as a climate solution, as well as what other environmental and socio-economic benefits, such as biodiversity enhancement, can be realised by its practice.

The potential impacts of regenerative agriculture also need to be considered in the context of broader, strategic choices that inform land use. Agricultural sustainability is determined not just by production methods. It is also influenced by what is expected in terms of production – in other words what we choose to eat and export, and how we provide nutritious food for Australian and global populations. This requires considering both dietary preferences, and the potential productivity, lifecycle impacts and land use benefits of 'off-land' food production. The latter is growing in prominence, as seen with lab-grown and other novel proteins.

Driving sustainable land use in Australia requires an approach at multiple levels. At the national scale, a broad set of land use issues impact how multiple needs can be met, from conservation and biodiversity, carbon sequestration, contributions to the bioeconomy, through to provision of food. At the more local scale sit questions about how to manage land more sustainably, given local contexts and needs. How these questions are addressed is influenced by Australia's broader socioeconomic and political context, and diverse visions of how land and agriculture contribute to social, regional and environmental outcomes.

BOX 1:

### Nature-based solutions

Nature-based solutions involve working with or strengthening natural systems, and using nature's ability to regenerate natural resources (Oke et al. 2021). Nature-based solutions include three main types of actions to address societal challenges for human well-being and biodiversity benefits:

1. Protecting natural ecosystems from loss and degradation
2. Restoring ecosystems that have been degraded
3. Managing working lands such as those used for agriculture or forestry more sustainably (UNEP and IUCN 2021).

Nature-based solutions for climate change mitigation (or 'natural climate solutions') refers to activities that involve conserving or restoring ecosystems and improving land and ocean management to increase carbon storage or avoid greenhouse gas emissions. Nature-based solutions are critical elements for any climate strategy given that natural processes (primarily photosynthesis) are by far the most significant and scalable means of sequestering carbon dioxide.

There is debate about what exactly constitutes a nature-based solution, including in agriculture. However, many of the practices championed by regenerative practitioners are widely accepted to fall under the category of nature-based solutions, as they aim to work with and strengthen natural systems. Understanding how agricultural nature-based solutions support and complement broader nature-based solutions focused on protecting and restoring ecosystems, or compete with them over land use, is an important part of assessing the potential of regenerative agriculture.

This paper presents a review of current Australian-specific and internationally relevant evidence on the benefits and limitations of regenerative agriculture practices, both as a climate solution and for broader sustainability outcomes in Australia. The paper assesses the potential impact of regenerative agriculture on five outcomes:

+ **Outcome 1:** Climate change mitigation
+ **Outcome 2:** The health of soils and waterways
+ **Outcome 3:** Biodiversity
+ **Outcome 4:** Land use and productivity
+ **Outcome 5:** Profitability and resilience.

The paper complements a recent report by the Food and Land Use Coalition (FOLU) – a partner of the Land Use Futures program, titled *Aligning regenerative agricultural practices with outcomes to deliver for people, nature and climate* (FOLU 2023). FOLU's report reviews global evidence linking regenerative agriculture practices to specific outcomes. Their analysis finds that regenerative agriculture creates positive benefits for biodiversity and on-farm biological carbon sequestration, but has mixed impacts on near-term yield and long-term climate change mitigation (FOLU 2023). FOLU's analysis calls for an outcomes-based framework for moving beyond debates about the definition of regenerative agriculture, as well as more robust data collection along with valuing practitioner experiences, calls that are mirrored in this paper.

This paper also discusses the implications of the literature review findings on the need to consider the potential of climate solutions such as regenerative agriculture within the context of the wider agricultural system and the strategic choices that need to inform land use decisions.

# 2. Challenges with assessing regenerative agriculture

There are a number of challenges in assessing the potential benefits and limitations of regenerative agriculture, which make it difficult to quantify impact. Questions around definition and the applicability of the evidence base matter when it comes to assessing regenerative agriculture's potential impacts and scalability. This is especially important as regenerative agriculture grows in prominence internationally, including among large agri-businesses, as a lack of agreed definitions and clarity on practices and outcomes being promoted can contribute to a risk of greenwashing (Giller et al. 2021; FOLU 2023).

## Defining regenerative agriculture

During the last decade, the term regenerative agriculture has increasingly gained attention as a farming approach with significant potential to regenerate soils, landscapes and ecosystems (Giller et al. 2021). Regenerative agriculture has its origins in the same philosophies motivating other prominent sustainable agriculture approaches. The term 'regenerative' has been associated with farming since the 1970s, and regenerative agriculture as a defined approach was initially promoted in the 1980s by the founder of the Rodale Institute, a prominent organic farming research and advocacy body in the US (Tittonell et al. 2022).

As use of the term regenerative agriculture has grown, it has become clear that there is no single definition of regenerative agriculture, but rather, a diversity of different approaches. The lack of consensus about its meaning has contributed to the challenge of developing an uncontested evidence base regarding its impacts.

Regenerative agriculture is often associated with a set of practices and principles that draw on ecological science to work with and strengthen natural processes. Some stakeholders focus more on intended outcomes when defining regenerative agriculture, with a prominent theme that it goes beyond the 'no harm' principles of sustainable agriculture, and instead aims to repair and improve the broader systemic health of the environment relative to current agriculture (Schreefel et al. 2020; FOLU 2023).

The outcome most strongly used to define regenerative agriculture is improving soil health, though the many components of 'soil health' are often not made explicit. To varying degrees, sequestering carbon, increasing biodiversity, and improving water resources are also outcomes associated with definitions of regenerative agriculture (FOLU 2023).

Process-focused principles associated with regenerative agriculture include supporting living root systems, minimising soil disturbance and promoting plant diversity. These are reflected in regenerative practices for which there is greatest consensus: using no-till practices or reducing soil tillage, minimising bare ground (including utilising cover crops and perennials), crop rotation and diversification, and increasing water percolation. Animal integration, and avoiding or eliminating synthetic inputs are also commonly, but not universally, included (FOLU 2023).

Within both process and outcome-oriented understandings, there is divergence regarding the importance of broader social dimensions of regenerative agriculture. In some cases this includes highlighting the importance of improving livelihoods (for farmers, or through living wages for workers) and other socio-economic benefits. More fundamentally, while most research on regenerative agriculture takes a positivist, scientific approach, focusing on the biophysical elements of ecological improvement, many proponents also highlight the importance of "creating significant shifts in mindset towards more holistic and relational understandings of biological and social ecosystems" (Seymour and Connelly 2022). As such, regenerative agriculture is seen by some to be much more than a set of principles and practices; it constitutes a whole social movement, with the potential for redefining and transforming relationships to land. Though this paper focuses on narrower environmental and economic outcomes, we acknowledge the importance of this perspective, and its potential role in contributing to the broader systemic changes required in food and agricultural systems to enable sustainable land use.

There is overlap between principles and practices described within regenerative agriculture and other terms such as agroecology, biodynamic and organic agriculture, permaculture, climate-smart agriculture and conservation agriculture. However, these overlaps can sometimes be misleading when combined. For example, organic agricultural practices do not necessarily embrace all regenerative principles, even though they do not use synthetic inputs. And the concept of agroecology is arguably broader than that of regenerative agriculture in some respects, encompassing human as well as natural systems. It defines that the "quest for environmental restoration and sustainability is inextricable from the pursuit of social inclusion, equity, or justice" (Cabral et al. 2022). Furthermore, many individual practices deployed in regenerative approaches already sit within the continuum of what are considered more conventional farming and agricultural practices.

It is also important to consider how regenerative agriculture is defined in relation to other solutions which are promoted for enabling greater sustainability in agriculture beyond those that fall within the agroecology–regenerative agriculture continuum. An alternative paradigm is that of 'sustainable intensification', defined as "intensification using natural, social and human capital assets, combined with the use of best available technologies and inputs (best genotypes and best ecological management) that minimise or eliminate harm to the environment" (Pretty 2008).

How environmental harm is best minimised or avoided sits at the core of the difference in paradigms. For sustainable intensification advocates, reducing the amount of land required for agriculture, enabling the 'sparing' of more land for biodiversity and conservation, is paramount (Mockshell and Kamanda 2018). In contrast, regenerative agriculture supports biodiversity and other positive environmental outcomes throughout the production process on agricultural lands. This tends to involve less intensive production techniques but, as discussed below, the extent to which regenerative practices involve a trade-off with productivity, particularly in the long term, is subject to considerable debate. This debate is a product of both evidence limitations and imprecision or divergence regarding what the term 'regenerative agriculture' refers to. In fact, the term's evolving usage has led to the claim that "regenerative agriculture represents a re-framing of what have been considered to be two contrasting approaches to agricultural futures, namely agroecology and sustainable intensification, under the same banner" (Giller et al. 2021).

Sustainable intensification is often presented as a conflicting paradigm to those that underpin regenerative agriculture. Indeed, there are differences, but also a number of synergies. In practice, techniques can overlap and are often combined, particularly those considered widely to be 'good agricultural practices', such as minimal tillage, utilising cover crops and crop rotation. However, sustainable intensification advocates generally have a higher tolerance for genetic engineering and are less concerned with minimising external and chemical inputs – both of which are minimised in agroecology and by many practitioners of regenerative agriculture. They also tend to place greater emphasis on technological innovation such as precision agriculture, although this is not antithetical to regenerative approaches (Mockshell and Kamanda 2018).

## Measuring the impact of regenerative agriculture

### Short- vs long-term measurement affects assessment results

The timeframe over which the impacts of regenerative agriculture practice are assessed is a key factor influencing results. A major criticism of regenerative practices (similar to criticisms of organic agriculture) is that they may result in lower yields than conventional practices, producing less food and fibre in the short term. However, measuring productivity across short time periods does not account for longer term productivity losses which can result from soil and water degradation through unsustainable practices (Turner et al. 2016). A short measurement timeframe also fails to account for potential long-term productivity gains experienced by some regenerative agriculture practices (Delate et al. 2016). Studies have shown the full benefits of regenerative agriculture become apparent after several years and strongly depend on the starting condition of the land (Delate et al. 2016).

## Single practice assessments do not reflect the full impact of regenerative approaches

The focus and scope of analysis is another key factor to consider when assessing the impacts of regenerative agriculture. Many assessments are of single practices, not integrated systems. Regenerative agriculture is based on working with and strengthening natural systems, usually meaning that a variety of different practices are combined in different ways to support the whole system. In addition, some potential outcomes occur beyond the farm, in areas such as biodiversity and hydrology. A further challenge lies in the complexity of natural systems, which can be very difficult to accurately represent in mainstream analytical approaches. Therefore, a more complete analysis across a range of practices and their interactions with each other is required to capture the full impacts of regenerative approaches.

## Physical and socio-economic context is crucial

The highly context-specific nature of the suitability and outcomes of agricultural practices also add to the challenge of measuring their impact. For example, syntropic agriculture is most successful when practised in tropical climates, meaning generalising about its potential for temperate and more arid areas of Australia is problematic. Further, regenerative farmers often adapt management to suit their local context and changes in the environment, so practices can change and evolve over time. Therefore, the importance of local context can make generalisations about impacts and benefits challenging.

The extent to which basic precepts of ecological science can be drawn on to generalise findings across contexts, is itself contested. For example, below ground root growth of perennial grasses is associated with increases in carbon storage, based on models of nutrient cycling and physiology of perennial grasslands. This means that some generalisation across all practices that enhance perennial grasslands (such as ecological grazing) is warranted, by combining evidence from on-ground trials and from physiological/ecological functional models. However, determining exactly what limits should be placed around this generalisation is challenging.

Beyond context-specific physical environments, socio-economic factors must also be taken into account when attempting to generalise about profitability, particularly factors such as relative costs and availability of labour, as well as farmer wellbeing and mental health.

## Measurement methods are evolving

As some aspects of research relating to regenerative agriculture are still emerging, the use of different measurement methods can lead to different results. For example, the soil carbon sequestration associated with soil biota (as opposed to that in above-ground plant biomass) is complex to accurately measure (Kallenbach et al. 2019), and this can lead to varying estimations of soil carbon across the growing season. Enhancing soil biota to drive carbon and other nutrient cycling is a major aim of regenerative agriculture. Therefore, continuing to improve methods of measurement, and empowering agricultural practitioners to measure these on-farm will be important to enable more widespread measurement of soil biota and its associated impacts. Fortunately, new tools are emerging in this field (Buss et al. 2021) and our understanding of carbon cycling by soil biota is developing rapidly.

## On-farm and academic evidence both offer value

All these issues influence the type of evidence appropriate for assessing the potential impacts of regenerative agriculture. Some stakeholders support a focus on expanding academic research on the topic. However, as farmer voices and experiences are often absent in academic literature, others point to the need to value on-ground experimentation and the experience of regenerative practitioners. The lag time required for quality academic research to be undertaken and published means that practitioner case studies can play an important role in the short term to understand the emerging potential of different regenerative approaches. More fundamentally, valuing a more local place-based knowledge system is seen by some proponents as part of the mindset shift that is integral to regenerative agriculture. This has led to varied perspectives on what should be considered as valid evidence and, therefore, where the greatest effort should be focused in developing the evidence base. The availability of academic research is further challenged by the disparity in funding allocated to research on regenerative agriculture as opposed to more conventional, mainstream practices (CIDSE 2020).

In the following sections we bear these issues in mind while reviewing available academic literature, with a focus on the Australian context.

# 3. Methods and scope of literature review

Academic literature documenting the impacts and limitations of regenerative agriculture in the Australian context is an emerging, but growing, field. We therefore relied, where possible, on Australian context literature to conduct a literature review of the impacts and limitations of regenerative agriculture practices on five environmental and economic outcomes. Where Australian studies were limited, we extended the literature review to include peer-reviewed international studies.

Local conditions are important in determining the types of practices most effective and appropriate for a farmer to implement, as well as for measuring the outcomes of these practices. Therefore, we acknowledge that there are risks in generalising findings from studies on regenerative agriculture to other contexts. Furthermore, Australia's agricultural production systems are highly varied across the continent, with a range of commodities produced across unique environmental and economic conditions, meaning that even generalising within Australia is not straightforward. Where possible, our review takes into account the limitations and challenges identified in Section 2, and notes areas for further research and exploration.

Substantial first-hand, farmer-derived evidence and other industry-led publications provide important contributions to the knowledge-base on regenerative agriculture (for example Massey 2020, Farmer's Footprint Australia 2022, Soils for Life 2020). While we acknowledge the value of this literature, this paper focuses on the academic literature.

This research centres on the set of regenerative agriculture approaches outlined in Table 1. As detailed in Section 2, regenerative agriculture can include a wide range of practices – part of the challenge in assessing impact. For this research, we focused on land-based practices that fit under the broad banner of regenerative agriculture and are either common in Australia, or could be applicable to Australia. This does not include off-land practices such as macro- and micro-algae production systems and mushrooms grown on waste. The list in Table 1 includes only the approaches covered in this paper and is not intended to be exhaustive nor definitive regarding all practices that could be considered regenerative.

**TABLE 1: REGENERATIVE AGRICULTURE APPROACHES INCLUDED IN THIS PAPER.**

| APPROACH | DEFINITION USED FOR THIS PAPER |
|---|---|
| Low input cropping | Involves sequencing of crops resulting in higher crop diversity over time. Some rotations may include multi-species cover cropping, but more commonly pulse crops and other diverse crops are rotated with grains. Involves minimising tillage and livestock phases for nutrient cycling, often with livestock feeding on cover crops, such as in pasture cropping approaches. Aims to optimise on-farm resources and minimise need for external inputs, and may include organic inputs such as compost or biochar. |
| Low / no-till vegetables | Involves the growing of crops with minimal disturbance to fields and organisms. A range of practices are used depending on soils and other context, such as farm size. Practices include mulch in place, compost addition, tarping and solarisation to manage weeds, complex rotations, as well as bed preparation only at the top few centimetres, to avoid tillage that would disturb fungal networks. |

| APPROACH | DEFINITION USED FOR THIS PAPER |
|---|---|
| Cultural / cool burning | Applies to perennial ecosystems and involves the lighting of low-intensity fires in order to clear underbrush. Generates patchy habitats preferred by small animals and reduces the impact of wildfires. Also ensures that seeds and nutrients in the soil are not lost, and has lower emissions than high-intensity fires. |
| Ecological grazing | Involves the restoration of grasslands and grassy woodlands through managing grazing animals at high densities for brief durations, with long recovery time for pastures between grazing. Also involves management of numbers of stock to the carrying capacity of the land, which avoids reliance on supplementary feed from harvested crops. This form of grazing is described as 'adaptive multi-paddock grazing' in the literature. Care must be taken to avoid confusion with simple rotational or other grazing techniques commonly practised as alternatives to conventional grazing practices. |
| Alley cropping | Involves the planting of rows of trees and/or shrubs between rows of horticultural or fodder crops and aims to create resilience through diversification of production. This is related to intercropping rows of different annual species, and is common in tropical areas. This is not widely practised in Australia, but has potential, particularly in higher rainfall areas, to increase carbon sequestration through incorporating woody perennial vegetation in croplands. |
| Perennial horticulture (single strata orchards) | Consists of a single layer or 'strata' of food trees with a layer of diverse grass and other plants underneath. Sometimes includes the integration of animals, such as poultry, for nutrient cycling. Avoids use of synthetic inputs, and uses residuals from other processes, such as compost and farm waste returned as nutrients. |
| Shelterbelt or riparian plantings | Usually consists of one or more rows of trees or shrubs planted in a specific distribution to provide shelter from the wind and protect soil from erosion. |
| Syntropic agriculture (multi-strata agroforestry) | Provides a harmonious integration of food production and forest regeneration or afforestation, by involving multi-strata agroforestry that mimics the functioning of natural forest systems. This system is most widely practised in tropical and sub-tropical regions but has applicability (with different species and planting patterns) in all climate zones. |
| Silvopasture | Involves the deliberate integration of trees and grazing livestock in the same land, to diversify production and provide shelter for livestock. Recognised as a form of agroforestry where trees and shrubs are integrated with pastures for forage and grazing purposes. |
| Pastured pigs and poultry | Involves growing pigs or poultry/eggs in an agroforestry system, potentially with multi-species cropping for additional forage and/or feed derived from waste streams. Often involves 'non-industrial' breeds of livestock to optimise nutrition from forage. |

# 4. Research findings

Our research focused on the potential for regenerative agriculture to contribute to a set of primarily environmental outcomes, along with productivity outcomes that impact environmental footprints:

- **Outcome 1:** Climate change mitigation
- **Outcome 2:** The health of soils and waterways
- **Outcome 3:** Biodiversity
- **Outcome 4:** Land use and productivity
- **Outcome 5:** Profitability and resilience.

## Outcome 1: Climate change mitigation

**Key finding:** Studies have shown that in some circumstances, farms where regenerative practices have been implemented can deliver emissions reductions and carbon sequestration. However, this is highly context- and practice-specific. More specific research is needed to better assess the potential of regenerative agriculture across different environments and land use contexts to deliver climate change mitigation solutions for Australia.

### Agriculture has a key role to play in climate change mitigation

Australia has committed to the Paris Agreement, which aims to limit temperature increase to 1.5–2˚C globally to avoid the worst impacts of climate change. Australia is predicted to exceed its 1.5˚C carbon budget for achieving this goal by 2026. The country's land-based emissions, which are driven by the agriculture sector, are not currently on track to support a 1.5˚C trajectory (Climateworks Centre 2022). As a dominant user of land in Australia and a driver of greenhouse gas emissions through both production and supply chain emissions, Australian agriculture contributes to climate change, yet it can be an important part of the solution. Sustainable farming practices present an opportunity to both decrease Australia's emissions and sequester carbon in the landscape, as well as improve resilience to the impacts of climate change. Resilience is discussed further in 'Outcome 5'.

### Evidence showing the impact of regenerative agriculture on emissions reduction and carbon sequestration is highly context- and practice-specific

The evidence for the potential positive climate impacts of regenerative agriculture practices falls into two main categories: those that lower emissions from agriculture and land management, and those that store carbon in the landscape.

In terms of emissions reductions, the strongest evidence for the impact of regenerative agriculture practices comes from systems involving livestock farming, such as ecological grazing. International studies have found that adaptive multi-paddock grazing of livestock can improve forage quality and hence digestion, resulting in lower methane emissions (DeRamus et al. 2003; Wang et al. 2015; Thompson and Rowntree 2020). Lower overall greenhouse gas emissions have also been found in Australian free-range poultry systems (as a proxy for pastured poultry) as compared to conventional, higher density poultry systems (Wiedemann et al. 2017). Although current evidence is relatively limited, these findings suggest some regenerative livestock farming practices can have the potential to reduce the emissions footprint of agriculture. Further research investigating the emissions footprint of adaptive multi-paddock grazing across a variety of Australian contexts would be valuable. More research is also needed to compare the full lifecycle emissions of regenerative versus conventional grazing systems, as the avoidance of supplementary feed and synthetic fertilisers as inputs by regenerative practices is likely to have substantial impacts on emissions. Fire management practices for landscapes also present an opportunity to reduce emissions. Cool burning practices are already in use for a large proportion of northern Australia, as part of Indigenous land management practices. This model has been effective at reducing emissions from wildfires (Edwards et al. 2021), and could also be translated to farming land in other parts of the country.

In terms of carbon storage, many regenerative agriculture practices are designed to increase the volume and diversity of vegetation in the landscape. This can, in turn, benefit carbon storage in soil, vegetation, or both. Studies on regenerative agriculture practices report increases in carbon storage, with variations depending on the types of commodities grown and the techniques used to farm them. For example, perennial horticulture crops can store more carbon in soil and vegetation than annual crops (Aguilera et al. 2015; Kreitzman et al. 2020), as they involve the growth of larger tree and shrub species. Adaptive multi-paddock grazing has been found to support improved tree regeneration at rates almost equivalent to ungrazed land in Australia, enabling greater carbon storage than continuously grazed pastures (Fischer et al. 2009). Similarly, regenerative approaches to pasture management can increase soil carbon storage (Conant et al. 2017). Particular low input cropping approaches have also been associated with higher soil organic carbon levels. Overseas examples include cover crops (Franzluebbers 2010; Poeplau and Don 2015; Abdalla et al. 2019) and minimising tillage (Franzluebbers 2010; Jordon et al. 2022). In Australia, studies report that no-till farming (Rogers et al. 2012; Robertson and Nash 2013), and pasture cropping (Badgery et al. 2014) can result in improved soil organic carbon levels.

Regenerative cropping systems are also reported to improve carbon storage according to international studies (e.g. Hobbs et al. 2008; Wolz et al. 2018; Tsonkova et al. 2012; Project Drawdown 2020). Those found to be most pronounced involve tree planting such as alley cropping, silvopasture and syntropic agriculture (Aguilera et al. 2015; De Stefano and Jacobson 2018; Wolz et al. 2018; Kreitzman et al. 2020). In addition, adaptive multi-paddock grazing achieves higher rates of soil carbon sequestration when compared to conventional grazing in a wide range of contexts (Johnson et al. 2022). More generally, studies have shown that conversion of cropping land to pasture has a positive impact on soil organic carbon levels, suggesting shifts away from conventional cropping and towards a practice like pasture cropping (where appropriate) could improve soil carbon (Guo and Gifford 2002; Don et al. 2011).

## There are unresolved questions around the potential of regenerative agriculture as a broad-scale climate solution

While there are some studies which show the potential for emissions reduction through regenerative agriculture approaches, it is difficult to draw conclusions about their potential as a broad-scale climate solution. This is partly because the focus of most studies is on carbon rather than other greenhouse gases such as methane and nitrous oxide. This is important because in Australia, livestock emissions (methane) comprise the majority of total agricultural emissions (Department of Climate Change, Energy, the Environment and Water 2022). There is some evidence to indicate regenerative livestock farming approaches can result in lower emissions per animal, but this evidence is limited. This means the overall emissions reduction potential of regenerative agriculture is currently uncertain and, as with other livestock farming systems, will need to be accompanied by solutions that reduce livestock emissions in order to meet climate goals.

Despite substantial evidence in Australia and overseas showing that a range of regenerative agriculture practices can contribute to carbon storage, this is not necessarily a reliable indicator of broader climate impacts. A key reason for this is because soil organic carbon storage is highly variable through a range of factors such as climate, season, weather, soil type and soil biology (Stockdale et al. 2019). This variability makes it difficult to rely on soil as an opportunity to sequester carbon with consistent impact. For example, there are concerns about the reversibility of carbon in the soil, meaning to what degree carbon stored in the soil could be released back into the atmosphere (Oxford Martin School and University of Oxford 2017). Additionally, practices need to be maintained in order to retain carbon stocks, which complicates prediction of future impacts (Fitch et al. 2022). Soils can also reach a maximum capacity to absorb and store carbon (Smith 2014). Furthermore, there is some concern that increases in soil carbon can, in certain circumstances, lead to increases in nitrous oxide emissions, leading to calls for more research on the relationship between these processes (Fitch et al. 2022).

Measurement is further complicated by the fact that management practices can generally result in small changes in carbon stocks relative to background carbon levels. This means that measurement intervals of at least five years are needed to detect statistically significant changes (Fitch et al. 2022). This factor, combined with the fact that carbon stocks are naturally variable, thus requiring comparison against a control sample to assess impact, complicates efforts to reliably and cost-effectively incentivise carbon sequestration as part of climate strategies.

So although soils can provide significant carbon sequestration potential, there are not clear conclusions about the scale of increases in soil organic carbon that can be achieved, and maintained, through changes in management practices. While not specifically referencing regenerative agriculture, CSIRO reports evidence that management changes can increase soil organic carbon stocks by between 0.18 and 2.9 t CO2-e $ha^{-1}$ $yr^{-1}$. This variation is amplified in estimates of how soil sequestration translates to national sequestration potential, with meta-analyses suggesting a range from below 1 to above 55 Mt CO2-e $ha^{-1}$ $yr^{-1}$ across Australia's cropping and grazing land (Fitch et al. 2022).

Another complicating factor for understanding the climate impacts of regenerative agriculture is that there is limited peer-reviewed Australian evidence detailing the direct climate impact of regenerative practices through lifecycle analyses that compare their climate impacts to conventional agriculture across the entire supply chain. For example, the climate impacts of ecological grazing as compared to conventional grazing systems might be underestimated by studies that do not include the avoidance of upstream production of livestock feed and synthetic fertiliser. This is due to the substantial amount of energy required for their production and transport (Cassidy et al. 2013; Harchaoui and Chatzimpiros 2018; Walling and Vaneeckhaute 2020).

Additional evidence on the potential of regenerative agriculture as a climate solution is needed to scale and accelerate the adoption of regenerative practices. This should include comparisons to alternative approaches that reduce the agricultural footprint on land, noting that conversion of land from native vegetation to agriculture in Australia has typically reduced soil organic carbon stocks from by 20 to 60 per cent below pre-clearing levels (Fitch et al. 2022) (see more on this issue under Outcome 3). Increased evidence should be supported by the development of a framework to enable the consistent measurement of outcomes of regenerative practices, including climate change mitigation. Farmers should be supported to trial new sustainable farming practices and to adopt rigorous measurement of the results. This would enable better prediction and selection of the most impactful opportunities to both reduce agricultural emissions and store carbon in the landscape for land managers, the broader land sector and policy-makers.

## Outcome 2: The health of soils and waterways

**Key finding:** Regenerative agriculture practices can contribute to the health of soils and waterways across Australia. They can create positive outcomes for a range of factors influencing overall soil health, as well as reduce water use and improve water quality, but not consistently across all practices. Further research is required in some areas.

### The health of soils and waterways is critical for achieving positive outcomes for nature, climate mitigation and people

Soil health and water quality are key determinants of functioning ecosystems, and directly impact the land's ability to support biodiversity and produce food and fibre. For example, soils with higher carbon content also have a higher water holding capacity, so there is the potential to improve agricultural water use efficiency, although this can be highly variable and in some cases overestimated (Minasny and McBratney 2018). Australia is approaching the safe limit of its freshwater use, and water quality in some catchments is being significantly impacted by surplus nitrogen and phosphorus, primarily due to the application of fertilisers to agricultural soils (Climateworks Centre 2022). We also know that conventional agricultural practices are resulting in soil loss (Turner et al. 2016). It is therefore vital to explore the potential of sustainable agriculture practices to help mitigate these impacts, and improve the ability of the environment to support biodiversity, sequester carbon and produce food.

## There is some evidence that regenerative agriculture can improve soil health and waterways

Australia's soils are ancient and generally nutrient-poor, and have experienced continued degradation and erosion since European colonisation (Koch et al. 2015). There is substantial evidence demonstrating the positive impact regenerative agriculture can have on soil organic carbon. Soil organic carbon is an important determinant of overall soil health and, as a result, gains in soil organic carbon may be accompanied by a range of benefits such as improved plant productivity and biodiversity (Rowntree et al. 2020). In addition to the improvements in soil organic carbon described for 'Outcome 1', regenerative agriculture practices have also been found to improve soil health. For example, international studies have found improved soil health indicators associated with multi-paddock grazing, including improved soil structure, strengthened ecological function and reduced soil loss (Rowntree et al. 2020). Practices within low input cropping approaches have also been associated with positive soil health outcomes, such as reduced nitrogen leaching from cover cropping (Abdalla et al. 2019). However, Australian-specific literature in this area is limited. Better soil benchmarking across all agricultural systems is needed. Additionally, long-term studies measuring the interactions of regenerative practices with a range of Australian soils would be valuable to guide adoption of these practices and the development of policy to support this.

A number of regenerative practices have also been found to positively impact water use and water quality. There is evidence that some practices can reduce run-off of nutrients into water systems. Continuous ground cover is associated with many regenerative agriculture practices, and can reduce the erosion of soil into waterways (e.g. syntropic agriculture in South America, (Andrade et al. 2020)). In the US, multi-paddock grazing has been associated with reduced levels of surface run-off and sediment losses, as well as risk reduction for droughts and floods, as compared to continuous stocking (Park et al. 2017; Kim et al. 2022). International studies have also shown improvements in water-use and nutrient-use efficiency associated with alley cropping, pasture cropping and no-till cropping (Soane et al. 2012; Tsonkova et al. 2012; Wolz et al. 2018; Luna et al. 2020). In contrast, some regenerative practices in particular contexts may have higher water demands than conventional farming systems, such as some alley cropping systems that require more water for trees (Tsonkova et al. 2012).

## More Australian research could guide investment in particular practices or regions to improve soil health and waterways

Australian peer-reviewed literature in this area is very limited. Given the highly context-specific nature of soil and waterway health and how this is impacted by agricultural practices, further Australian research is needed to assess the potential impacts of regenerative agriculture practices on this country's soils and waterways. In addition, the link between soil health and ecosystem functioning is currently an emerging field of science, and the nature of these interactions is critical but also highly variable and complex (Guerra et al. 2020). More research into these questions will be particularly important for assessing the potential for regenerative agriculture to support agricultural and natural environment resilience to the increasing impacts of climate change in Australia, such as changes in temperature and rainfall patterns. The implementation of the Australian Government's National Soil Strategy will support the development of this evidence base (Commonwealth of Australia 2021).

Despite the need for further research on these issues, current evidence suggests that regenerative agriculture can make a positive contribution overall to the health of soils and waterways.

## Outcome 3: Biodiversity

**Key finding:** There are examples demonstrating positive impacts of regenerative agriculture for Australian biodiversity. Regenerative agriculture has a role to play in the conservation of biodiversity, but is insufficient in isolation to address current declines in biodiversity. This needs to be addressed by a broader strategy to achieve habitat protection and restoration on both agricultural and natural landscapes across Australia.

### Australia's biodiversity is under significant pressure

Australia's biodiversity is in decline, increasingly being impacted by climate change, land clearing, and the degradation and destruction of suitable habitat (Murphy and van Leeuwen 2021), to which agricultural expansion has contributed (Climateworks Centre 2022). The rate at which Australian species are becoming extinct is as much as 430 times higher than would be expected without intensive human activity (Climateworks Centre 2022). Responding to these pressures will require an approach that simultaneously considers the restoration of vegetation, soil, carbon and biodiversity (Cresswell et al. 2021).

### Regenerative agriculture can play an important role in the creation of habitat to support biodiversity on farms

Regenerative agriculture offers an opportunity to positively contribute to biodiversity outcomes. It can result in improved habitat for biodiversity on Australian farms through newly planted or maintained vegetation such as trees and shrubs, which can be utilised by species as core habitat areas or habitat corridors. For example, ecological grazing has been associated with improved tree regeneration, which can provide valuable habitat for native fauna (Fischer et al. 2009; Ogilvy et al. 2018). Similarly, shelterbelts can improve habitat connectivity, as well as providing sources of food and shelter for a range of species (Agriculture Victoria 2020a). These improvements in habitat features for biodiversity are examples of nature-based solutions that create mutually reinforcing benefits for climate and ecosystem health.

There is global evidence that aligns with these findings. Alley cropping systems can provide habitat for species, and have been associated with higher bird, mammal, invertebrate and fungi diversity (Tsonkova et al. 2012; Wolz et al. 2018). Alley cropping can also support higher plant diversity by providing different ecological niches through the planting of new trees (Tsonkova et al. 2012). No-till farming is associated with improved soil fauna diversity (Hobbs et al. 2008), which in turn can have important benefits for soil health. This practice also promotes higher diversity above-ground, supporting higher numbers of beneficial insects due to ground cover and mulching (Hobbs et al. 2008).

### More is needed to address declines in biodiversity

Although regenerative agriculture practices can result in positive outcomes for biodiversity, its scope is limited to agricultural land. Land which is farmed using regenerative agriculture practices doesn't replicate fully intact habitat for biodiversity, so its impacts may be more difficult to scale up. To address continuing declines in biodiversity in Australia, large-scale land protection and restoration is needed across public and private land. This needs to include a range of actions that improve ecosystem functioning, restore habitat quality and connectivity more broadly, and alleviate pressures on biodiversity, such as invasive species, disease and land clearing (Geary et al. 2019). Regenerative agriculture can contribute to these actions, but needs to be part of a much larger, more comprehensive strategy to reverse biodiversity decline.

Current evidence suggests regenerative agriculture can contribute to tackling pressures on biodiversity through balancing production with ecological outcomes on agricultural land; that is, enabling land sharing between agriculture and nature. However, policy-makers need to assess the potential of regenerative agriculture against other biodiversity conservation solutions, particularly sparing land from agriculture (Box 2). These other solutions are very likely to remain necessary even if regenerative agricultural practices become the norm.

BOX 2:

### Land sharing and land sparing

Questions about the benefits of regenerative agriculture reflect broader debates about the merits of agricultural practices that share versus spare land for nature.

'Land sharing' refers to agricultural approaches that support climate, nature and other environmental outcomes on the same land that is used to produce food or fibre. Regenerative agriculture tends to be a land sharing approach.

'Land sparing' refers to the intensification of agriculture to produce food using less land. This frees up land to achieve environmental outcomes, including biodiversity and carbon storage through reforestation or avoided deforestation.

Critics of land sharing approaches argue that it leads to extensification, with negative impacts for biodiversity loss and climate change. Critics of land sparing argue that the deployment of agrochemicals and other technology to increase productivity damage the environment and soil biota (Mockshell and Kamanda 2018).

However, these approaches are not necessarily mutually exclusive. Some proponents of regenerative agriculture argue that this dichotomy itself is a product of the sustainable intensification paradigm, by positing that land sparing trade-offs are inevitable in approaches that prioritise land sharing. Intensification-oriented approaches can also integrate some regenerative principles. However, it is important to take into account the land use requirements of practices, and in so doing weigh the co-benefits and trade-offs in relation to broader sustainability goals. This requires us to understand outcomes for biodiversity in unison with productivity potential.

The success of regenerative agriculture at a large scale is dependent on its productivity and its other benefits, but also, what, and how much, is required of our land. Both land sharing and sparing are likely to be needed to reduce the environmental impacts of agriculture while meeting humanity's needs.

## Outcome 4: Land use and productivity

**Key finding:** The productivity of regenerative agriculture practices varies, as compared to conventional practices. In some cases, regenerative agriculture can have lower yields, while in other cases, the opposite is true. A limitation to understanding comparative productivity is the lack of evidence on the land area required by regenerative versus conventional practices to produce equivalent food and fibre. In addition, demands on land and agricultural production need to be considered alongside other system-wide shifts required to achieve sustainable land use.

## Australia's land is under pressure from competing demands

Agriculture has and continues to be a key driver of land use change in Australia, and many of Australia's ecosystems are under pressure as a result (Climateworks Centre 2022). Agriculture currently occupies around half of Australia's landmass (Australian Bureau of Statistics 2022). However, much of this is extensive grazing on areas of native vegetation, which is relatively low intensity despite occupying large areas of land (Department of Agriculture, Fisheries and Forestry n.d.). Australia's intensive agriculture zone represents a much smaller area along Australia's eastern and south-western coasts. These are the main production regions for Australia's broadacre crops, horticulture and where livestock is grazed intensively on modified pastures (Department of Agriculture, Fisheries and Forestry n.d.). The intensive agriculture zone also overlaps with areas where Australia's population is concentrated, meaning there are a range of competing demands on land for urban, industrial, agricultural, cultural and environmental uses.

## Regenerative agriculture can have highly variable impacts on productivity

With regard to land use, there are questions about whether regenerative agriculture requires more land to produce equivalent food and fibre. There is very little research assessing the land area requirements of regenerative agriculture approaches as compared to conventional agriculture. This is an important issue for further investigation, especially given the need to determine the potential land use impacts of reduced reliance on external feed and synthetic fertiliser across the full lifecycle of regenerative versus conventional livestock production.

Current evidence on the comparative yields of regenerative versus conventional farming practices is mixed. It is important to consider this in the context that regenerative agriculture is often performed to restore land that has lost productivity.

A number of studies show improved yields in regenerative agriculture systems. Ecological grazing and pasture cropping systems report higher pasture biomass in Australia and the US (Millar and Badgery 2009; Hillenbrand et al. 2019), implying these practices result in improved forage for livestock. Although planting of shelterbelts removes some, often marginal, agricultural land from production (Agriculture Victoria 2020b; ANU 2021), this can be compensated by higher yields due to improved protection of crops, pasture and grazing livestock from the negative effects of wind (Bird et al. 1992; Johnston n.d.), and support for biodiversity. Similar results have been found more recently in South African vineyards, with shelterbelts significantly lowering wind speeds, leading to reduced evapotranspiration in grape crops (Veste et al. 2020). Internationally, syntropic agriculture and silvopasture have been associated with higher yields due to the ability to grow multiple commodities on one area of land (Andrade et al. 2020; Pent 2020). Lower stocking densities for laying hens have been associated with improved egg production and egg quality in Australia (Campbell et al. 2017), indicating that pastured poultry may have some productivity benefits compared to cage or barn-laying systems.

In contrast to the examples above, higher productivity was not a uniform trend across practices and contexts. Some Australian and European pasture cropping studies report lower yields than conventional cropping only systems (Finlayson et al. 2012; Luna et al. 2020), although these systems do have the benefit of producing both pasture and crops rather than crops alone. Alley cropping yields were also found to be lower over time than conventional field grain cropping in Australia (Unkovich et al. 2003), although this wasn't the case in a European study (Tsonkova et al. 2012). International studies have also documented lower yields in no-till cropping and low input cropping (Seufert and Ramankutty 2017; LaCanne and Lundgren 2018), or no impact on yields (Jordon et al. 2022). However, Australian cropping systems are vulnerable to decreasing yields with the impacts of climate change and land degradation (Turner et al. 2016), meaning the long-term yield trends of conventional cropping systems are unlikely to be sustained into the future.

### Context matters when assessing land use and productivity of regenerative practices

The high variability in land use and productivity trends found in this literature review demonstrates the importance of context when considering the impacts of specific regenerative agriculture practices. There is evidence to suggest that some practices can use land more efficiently and deliver higher productivity than conventional practices, but there is also evidence of the opposite trend. It is important to consider the relative costs and benefits of freeing up (or sparing) agricultural land through higher intensity agriculture to be prioritised for environmental outcomes, along with supporting soil and water health and improving biodiversity through regenerative practices that share land (Box 2). Thinking about productivity therefore requires a consideration of local conditions and what level of productivity might be supported by regenerative agriculture, along with the broader context of what is needed across a landscape to feed people, protect nature and manage impacts on the environment.

## Outcome 5: Profitability and resilience

**Key finding:** Some regenerative agriculture practices have lower input requirements, creating cost savings that can offset higher costs often associated with labour. Price premiums are also an opportunity for regenerative farms to improve profitability. Further evidence is needed to directly measure the financial impact of sustainable farming practices that achieve positive environmental outcomes, as evidence remains inconclusive about the relative profitability of regenerative agriculture.

### Profitability is a factor in assessing the viability of regenerative agriculture

It is important to understand the relative profitability and resilience of regenerative agriculture compared to other agricultural practices, to test its viability. While some practitioners report improved profitability and economic resilience, others point to startup costs or ongoing impacts on profit as a barrier to adopting regenerative practices (Gosnell et al. 2019). These questions have implications for farmers' decisions about the viability of regenerative agriculture for their own farms, as well as its viability as a scalable solution for sustainable agriculture.

### The profitability of regenerative agriculture is variable and depends on a range of factors

A principle of all regenerative practices is to minimise or eliminate the inputs required to be brought in from outside the farm, such as fertiliser and pesticides. This is achieved by maximising factors such as soil health and natural pest control. Successful examples of this have been found in alley cropping and shelterbelts, with habitat provision enabling higher populations of natural pest predators resulting in lower incidence or risk of pest outbreaks (Wolz et al. 2018; Agriculture Victoria 2020a). Higher crop diversity in some regenerative systems can also result in reduced pressure from weeds (Finlayson et al. 2012). The resulting lower reliance on agricultural inputs can result in cost savings for producers, which can help offset yield reductions or higher costs in other areas, such as potentially higher labour costs (LaCanne and Lundgren 2018).

A number of regenerative practices are associated with higher labour costs. Global evidence suggests that this is the case for no-till farming, free-range pig production, syntropic agriculture and some organic systems (Bornett et al. 2003; Crowder and Reganold 2015; Seufert and Ramankutty 2017; Andrade et al. 2020). There is also evidence in some systems that production costs can be lower overall, with evidence from South America suggesting that the integration of crops, forests and livestock (such as in perennial horticulture) can reduce overall production costs (Costa et al. 2018). However, peer-reviewed evidence is currently lacking for labour costs of regenerative versus conventional farming in the Australian context.

Regeneratively grown products can also attract a price premium, leading to higher revenue for producers (LaCanne and Lundgren 2018). This was found to be the case for some Australian pasture cropping systems, as compared to conventional cropping (Finlayson et al. 2012). There is also international evidence for this in organic cropping systems (Crowder and Reganold 2015). For example, market research conducted for Beef and Lamb New Zealand found some evidence for consumer willingness to pay more for regenerative products (Beef + Lamb New Zealand 2021).

## Regenerative agriculture practices contribute to resilience in a range of ways

A key benefit of regenerative agriculture highlighted by its proponents is improved resilience of farm businesses and farmers themselves. In terms of economic resilience, reduced reliance on inputs can reduce the vulnerability of regenerative farmers to price shocks related to inputs. The diversity of commodities produced in some regenerative systems such as alley cropping can also result in greater economic resilience compared to monoculture farming (Wolz et al. 2018).

Regenerative agriculture practices can also offer greater resilience to environmental stressors, including climate change-related shocks and trends. In some cases, when environmental conditions are poor or challenging, the profitability of regenerative agriculture can be more favourable than conventional practices. For example, a study of grazing practices in New South Wales grassy woodlands found that regenerative graziers tended to be more profitable in dry years compared to more conventional graziers, while productivity was comparable in other years (Ogilvy et al. 2018). Evidence from the US also suggests that organic agriculture can result in 40 per cent higher yields in times of drought compared to conventional practices (Rodale Institute 2011). Higher plant diversity, as seen in many regenerative agriculture approaches, can enable greater resilience of crops in response to stresses such as disease and weather variability (Reiss and Drinkwater 2018). Reduced vulnerability to environmental stressors can, in turn, lead to greater income stability for farmers (Ogilvy et al. 2018). Building resilience to climatic extremes will become increasingly important as the impacts of climate change increase in frequency and severity. Therefore, the potential of regenerative agriculture to support climate adaptation deserves attention.

Regenerative agriculture can also have social benefits that can contribute to the resilience of land managers. Conventional farming has been associated with poor physical and mental health outcomes as compared to other professions. This is likely due to a range of factors, including economic pressures such as volatile commodity prices and rising input costs, as well as other stressors such as drought and pest outbreaks. Social isolation and low uptake of mental health support services can also contribute to poorer health outcomes for farmers (Schirmer et al. 2013). Although there has been limited academic research on the relationship between regenerative agriculture and farmer wellbeing (Brown et al. 2021; Ogilvy et al. 2018), there is some Australian evidence demonstrating positive outcomes. For example, regenerative graziers were found to have improved wellbeing as compared to conventional graziers (Brown et al. 2021, 2022), including improved 'self-efficacy'. This relates to confidence in being able to successfully manage different aspects of their farm, and is directly linked to wellbeing (Brown et al. 2022; Ogilvy et al. 2018). These benefits can extend beyond the farmer themselves, to the resilience of the farm business as a whole. Australian studies have shown links between improved wellbeing of regenerative farmers and their abilities to adapt to changing and adverse conditions, such as climate change (Sherren et al. 2012; Brown et al. 2022).

## More research is needed on the impacts of regenerative agriculture on profitability

Further evidence is needed to directly measure the financial impact of sustainable farming practices that achieve positive environmental outcomes, as the evidence is still inconclusive about the relative profitability of regenerative agriculture compared to conventional agriculture. There are a small number of initiatives in Australia to collect and disseminate data on the productivity, cost and profitability of regenerative agriculture practices, which can be compared to equivalent metrics for conventional practices. For example, the Farming for the Future program is currently working to build the evidence base linking on-farm natural capital, productivity and business resilience (Farming for the Future 2022). Climateworks Centre's Natural Capital Investment Initiative is also contributing to this field by creating tools and resources to support banks, land managers and food retailers to consistently measure the natural capital in their customer folios and supply chains.

# 5. Implications from the literature review: What's needed to shift from on-farm to broader scale impact

To fully realise the potential of regenerative agriculture, significant shifts in current agricultural practices are needed. Debates about regenerative agriculture's limitations and potential need to be taken seriously, including broadening the evidence base to deepen understanding of trade-offs in relation to alternative paradigms for enhancing sustainability in agriculture. Such evidence can help add nuance to understanding which practices and combinations thereof, and in what contexts, are most beneficial. Deepening understanding of regenerative agriculture's limitations and trade-offs can also help further inform what broader shifts in food and agricultural systems are needed to enable more sustainable land use, including but not limited to strengthening the enabling environment for regenerative agriculture.

A number of opportunities to scale the impact of regenerative agriculture are outlined in this section. These include continued efforts to: develop an outcomes-based framework to move beyond definitional debates and enable context-specific adaptation; build the evidence base; support on-farm experimentation; and mainstream the measurement and valuation of natural capital in agricultural systems. Simultaneous effort is needed to address systemic issues, including reducing demand-side pressures on land from food systems and strengthening strategic decision-making around land use to more effectively consider broader co-benefits and trade-offs.

## Develop an outcomes-based framework

As detailed in Section 2, there is a lack of consensus about which practices define regenerative agriculture and how it differs from other agricultural approaches, as well as what is important to measure to assess sustainability and environmental impact across the agricultural supply chain. An outcomes-based framework for regenerative agriculture could help to move beyond these debates by building consensus on key outcomes and appropriate benchmarks (related to factors such as climate, biodiversity, water use, productivity and profitability), and how they should be measured, while allowing context-specific practices and innovation (FOLU 2023). It is likely that different frameworks may emerge to meet the needs of different parts of the life cycle of agricultural goods, or particular commodities or geographic areas. This is appropriate to account for variation across contexts, but it will still allow for convergence around overarching sustainability outcomes. At a global level, Regen10 is a program of work that is developing principles, metrics and frameworks for regenerative agriculture. Harmonising outcomes, and metrics can help accelerate the uptake of promising practices by enabling supportive policy and unlocking finance.

At a farm scale, an outcomes-based framework for on-farm sustainability could include principles, outcomes and metrics. The development of a framework and the farm-level metrics within it would need to involve farmers as well as First Nations peoples and other land managers who are custodians of, and working on Australia's lands and waters. This would build a shared understanding of the outcomes being sought and how best to measure them. Drawing on experience and lessons from these groups is particularly important given the context-specific nature of regenerative agricultural impacts. To measure these experiences, farm-level metrics need to be practical to implement and include flexibility to suit different agricultural contexts. This flexibility can inform choices around which practices can operate at scale to support national and global goals. Climateworks Centre's Natural Capital Investment Initiative is working to create consistency for on-farm measurement of natural capital (Climateworks Centre 2021).

In addition to developing consistency around outcomes and on-farm metrics, there are other barriers that impact on-farm decisions, including capacity and capabilities. These barriers must be overcome if we are to scale up agricultural practices that can achieve regenerative outcomes. Building upon farmer and producer experiences to identify and work through additional barriers is vital, particularly given increasing interest from businesses and governments seeking to address impacts on nature in their supply chains.

## Strengthen the evidence base

As previous sections demonstrate, there are areas where additional research could be undertaken to offer studies specific to the Australian context. Creating a robust, deeper evidence base of regenerative agriculture benefits will mean that practices, and combinations of practices, with the greatest impact can be prioritised on-farm and implemented at scale. This will be critical to addressing the complex challenges facing global food systems. It is also important that these studies involve and give back to the agricultural practitioners, land managers and First Nations peoples.

On-farm studies should be complemented by broader landscape and national scale studies that can contextualise regenerative agriculture alongside other solutions and address strategic land use choices, such as those around land sparing or sharing. This is the focus of the Land Use Futures program, which is looking at a variety of solutions to support climate goals along with other environmental and socio-economic outcomes. This perspective is crucial to identifying potential trade-offs in land use and maximising the potential for co-benefits. For example, where might nature-based solutions offer the greatest opportunity for biodiversity and climate outcomes without compromising food security?

## Support on-farm experimentation and learning

As land managers and farmers search for more sustainable farming methods, experimenting and sharing lessons learned is an important part of shifting from on-farm to landscape and broader scale impacts. Academic research is critical but can also be a slow process, and there is value in simultaneously building farmers' capacity to test and trial regenerative practices on Australian farms and valuing their contributions.

There are already many successful examples of regenerative agriculture in Australia, but more can be done to remove barriers for trialling different practices and to enable a wider range of farmers to build capacity. For example, farmers need to be supported to test and trial the practices that best suit their farm's specific conditions. This can involve access to specialists to assist farmers with decision-making, including the design of trials and measurement of outcomes. As noted above, adopting an outcomes-based framework to create consistency about which on-farm data is measured is an important element of this.

The strong emphasis on on-farm experimentation and local knowledge within the regenerative agriculture movement can be empowering while also leading to place-specific solutions. However, such experiments can lack generality. Connecting the findings from local experimentation with a supportive network of modelling and knowledge infrastructure can help contextualise and interpret results from on implementation at a particular location and time.

Sharing knowledge is also key for building capacity and scaling up the adoption of sustainable farming practices. Successful examples of regenerative farms can act as demonstration farms, driving outreach that shares lessons learned and expertise to enable practice change among other land managers. There are already several successful initiatives that are working to support knowledge sharing and capacity building for regenerative agriculture in Australia, and further support for these and similar programs will continue to strengthen the evidence base.

## Mainstream the measurement and valuation of natural capital in agricultural systems

How data and evidence is used determines how measurement is incentivised and how results are acted upon. To support outcomes-based approaches, it is critical to track and monitor progress towards 'best practice' benchmarks.

Most landholders recognise the need to protect the natural capital that underpins their production systems and provides wider benefits to society. However, the market-based system that landholders participate in does not assign a monetary value to natural assets and the various services provided by the environment. Recognising and rewarding landholders for the wide range of benefits that their land provides has the potential to drive improved stewardship of nature among and alongside productive land activities.

Mainstreaming the valuation of natural capital throughout agricultural supply chains can help incentivise and reward farmers for measuring the outcomes of their practices, and for prioritising practices that support long-term sustainability over short-term productivity. Such efforts involve businesses, financial institutions and government taking into account the risks (e.g. reputational or financial) and benefits (e.g. consumer competitiveness) of better managing nature in relation to their long-term organisational goals.

A number of efforts are underway to mainstream the measurement and valuation of natural capital. Globally, the Taskforce on Nature-related Financial Disclosures (TNFD) is a framework to enable companies and financial institutions to integrate nature into decision-making. In Australia the Natural Capital Investment Initiative (NCII) seeks to create an enabling social and institutional environment for consistent natural capital measurement at scale. Several pilot projects, including with National Australia Bank (NAB) and a major Australian food retailer, are underway through the NCII to trial incentive programs for measurement of natural capital. The program is also developing an open-source, independent Natural Capital Measurement Catalogue that seeks to align consistent measures and methodologies of natural capital at the property scale. Creating this enabling environment for consistent and incentivised natural capital measurement will help Australia to be well positioned when the TNFD becomes a part of global regulatory frameworks.

In order to drive uptake of measurement and valuation of natural capital at scale, industry, business, retailers and financial institutions need to incentivise and support their value chain stakeholders to undertake measurement, and the government needs to play an enabling role in supporting the private sector to do so. The cost of investing in measurement is expected to be minimal in comparison to the risks associated with the degradation of nature. On the flipside, a modest investment now can result in long-term benefits, including pre-empting changes in consumer preference and preparedness for regulation and risk reporting.

## Take a whole-of-system approach

Achieving sustainable land use will require balancing competing demands for land. Land management must ensure we both reduce the direct environmental impact of agricultural practices, and also spare land for nature and biodiversity, in order to support climate and other environmental goals. By working with nature, regenerative agriculture is an important pathway to more sustainable agriculture. However, the levels of uncertainty and limitations in impacts, along with concerns about yield and hence land sparing implications, must be acknowledged. These point to the need for a full suite of solutions to balance competing pressures on land to meet climate and other sustainability targets, while still meeting growing demands for agricultural production. A number of organisations are engaged in efforts to transform Australia's food system, including CSIRO's *Food and Agribusiness Roadmap* (CSIRO 2022).

## Reduce demand-side pressures on land

What is produced, at what scale, and by whom, has implications for how it can be produced. This influences the viability of regenerative agriculture at scale. Exploring opportunities for synergies with more intensive approaches, supported by technological innovation, may help address this to some extent. Such innovations should be considered as complementary to regenerative agriculture, by reducing pressures on land for highly intensive processes that are more difficult to reconcile with regenerative outcomes.

However, no supply-side solutions are likely to sustainably meet current patterns of demand, especially as populations continue to grow. So changing consumer preferences, particularly reducing demand for animal protein, is also crucial for reducing pressures on land. Innovations in and scaling of alternative proteins can be a key enabler to shift demand. Reducing food loss and waste is also important for easing demand-side pressures on land. As part of the Land Use Futures program, Climateworks is collaborating with Deakin University to model the impacts of a range of demand and supply-side factors on the environmental impacts of agricultural production.

## Coordinate action to align land use with national nature and climate goals

An interrelated set of implications relates to the way decisions are made about how land is used and managed to be aligned with climate and nature goals, while balancing co-benefits and trade-offs. Achieving the needed scale of action in the land sector requires taking into account the complexity surrounding decisions about how land is used, and the opportunity cost associated with that use. This may indeed be supported by elements within the regenerative agriculture movement that promote a redefinition and transformation of relationships to land, but action is also required from beyond the agricultural sector.

Coordinated action to align land use planning with national nature and climate goals can help balance the pressures and demands on land to deliver multiple benefits. This includes enabling and supporting nature-based solutions within agricultural systems, while sparing land for nature-based solutions outside of agriculture. A nation-wide, strategic approach to land use decision-making can also support informed decisions about how to manage trade-offs, enabling a more equitable and just transition for farmers, consumers and other landholders including First Nations peoples.

It is also worth noting that the proponents of the differing paradigms for achieving more sustainable agriculture tend themselves to differ in their composition. Sustainable intensification relies more on external inputs and expert knowledge, with high capital requirements, thus favouring large scale farmers and agribusinesses. Regenerative agriculture proponents often stress the importance of reducing external inputs, and valuing local knowledge and experimentation. While these principles can align more with smaller or independent farmers (Mockshell and Kamanda 2018), regenerative agriculture now features strongly in the narratives of large agrifood corporations as part of their target setting related to environmental footprints (as opposed to the concept of agroecology with broader focus on social impacts) (Cabral et al. 2022). How sustainability itself is defined is partially at stake here, particularly the relative value assigned to economic or productivity gains compared to the ecological and social dimensions of sustainable agriculture, but also, who stands to win and lose from gains and trade-offs. These factors also need to be taken into account to promote a just transition in the land use sector.

# 6. Conclusions

This paper investigates the potential benefits and limitations of regenerative agriculture for Australia across a set of environmental and economic outcomes and draws out implications for what might be needed to move from on-farm to broader scale solutions.

Regenerative agriculture is growing in prominence globally (Giller et al. 2021) and there is increasing momentum behind its potential as a sustainable agriculture practice that can achieve climate and other environmental outcomes while producing healthy food and fibre.

Regenerative agriculture has the potential to deliver a range of benefits, including improved soil health and biodiversity. While there is emerging evidence that, in some situations, regenerative agriculture can reduce emissions and sequester carbon, more research is required to better understand the contribution it can make to broader climate change mitigation and land use strategies. There is also growing evidence to suggest regenerative agriculture can support adaptation and resilience to climate change through reducing fluctuations in productivity in the face of weather variability, and improving farmer wellbeing in the face of these shocks and pressures. A number of these findings mirror research into the global experience, which found regenerative agriculture can create benefits for a number of environmental outcomes, but also showed there are gaps in evidence, and advocated for an outcomes-based framework to measure impacts (FOLU 2023).

Improving agricultural production is critical to addressing challenges in the food and land use sector. This includes a role for practices that achieve regenerative outcomes. To support the scaling up of regenerative agricultural practices we suggest:

+ Developing an outcomes-based framework to help move beyond debates about the definition of regenerative agriculture, and instead shift the focus to measuring the impact of a range of sustainable farming methods
+ Continuing to strengthen the evidence base for regenerative agriculture through Australian-specific research
+ Supporting farmers to trial new practices and share knowledge
+ Mainstreaming the measurement and valuation of natural capital in agricultural systems.

However, support for sustainable agriculture practices needs to be considered as part of a broader suite of solutions that include major shifts across other aspects of the food and land use system, such as changing diet and reducing food waste and loss, and strategic approaches to land use planning that balance climate, nature, economic and cultural objectives. Ultimately, the role of regenerative agriculture should be approached as one part of the broader system shifts required in the food and agricultural sector to support climate and other sustainability goals, shifts which in turn could support the scalability of regenerative agricultural practices.

Climateworks Centre is working to support these areas through its Land Use Futures program and the Natural Capital Investment Initiative. These programs aim to identify how decision-makers in Australia can support the pursuit of net zero emissions and broader sustainability goals in the land use sector.

# References


Abdalla M, Hastings A, Cheng K, Yue Q, Chadwick D, Espenberg M, Truu J, Rees RM and Smith P (2019) 'A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity', *Global change biology*, 25(8):2530–2543, doi:10.1111/gcb.14644.

Agriculture Victoria (2020a) *Shelterbelts to protect wildlife*, https://agriculture.vic.gov.au/farm-management/soil/erosion/shelterbelts-to-protect-wildlife, accessed 27 October 2022.

Agriculture Victoria (2020b) *Effective shelterbelt design*, https://agriculture.vic.gov.au/farm-management/soil/erosion/effective-shelterbelt-design, accessed 27 October 2022.

Aguilera E, Guzmán G and Alonso A (2015) 'Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards', *Agronomy for Sustainable Development*, 35(2):725–737, doi:10.1007/s13593-014-0265-y.

Andrade D, Pasini F and Scarano FR (2020) 'Syntropy and innovation in agriculture', *Current Opinion in Environmental Sustainability*, 45:20–24, doi:10.1016/j.cosust.2020.08.003.

ANU (2021) *Establish shelterbelts with multiple benefits –, ANU Sustainable Farms*, https://www.sustainablefarms.org.au/on-the-farm/shelterbelts/, accessed 27 October 2022.

Australian Bureau of Statistics (2022) *Agricultural commodities, Australia*, https://www.abs.gov.au/statistics/industry/agriculture/agricultural-commodities-australia/2020-21, accessed 27 October 2022.

Badgery WB, Simmons AT, Murphy BW, Rawson A, Andersson KO and Lonergan VE (2014) 'The influence of land use and management on soil carbon levels for crop-pasture systems in Central New South Wales, Australia', *Agriculture, ecosystems & environment*, 196:147–157, doi:10.1016/j.agee.2014.06.026.

Beef + Lamb New Zealand (2021) 'Regenerative Agriculture: Market Scan and Consumer Insights. Summary of research findings, the New Zealand context and what the findings mean for New Zealand sheep and beef farmers', https://www.mpi.govt.nz/dmsdocument/48412-Regenerative-Agriculture-Market-Scan-and-Consumer-Insights-.

Bird PR, Bicknell D, Bulman PA, Burke SJA, Leys JF, Parker JN, Van Der Sommen FJ and Voller P (1992) 'The role of shelter in Australia for protecting soils, plants and livestock', *Agroforestry Systems*, 20(1):59–86, doi:10.1007/BF00055305.

Bornett HLI, Guy JH and Cain PJ (2003) 'Impact of Animal Welfare on Costs and Viability of Pig Production in the UK', *Journal of Agricultural and Environmental Ethics; Dordrecht*, 16(2):163, https://www.proquest.com/scholarly-journals/impact-animal-welfare-on-costs-viability-pig/docview/196561601/se-2.

Brown K, Schirmer J and Upton P (2021) 'Regenerative farming and human wellbeing: Are subjective wellbeing measures useful indicators for sustainable farming systems?', *Environmental and Sustainability Indicators*, 11:100132, doi:10.1016/j.indic.2021.100132.

Brown K, Schirmer J and Upton P (2022) 'Can regenerative agriculture support successful adaptation to climate change and improved landscape health through building farmer self-efficacy and wellbeing?', *Current Research in Environmental Sustainability*, 4:100170, doi:10.1016/j.crsust.2022.100170.

Buss W, Sharma R, Ferguson S and Borevitz J (2021) 'Soil organic carbon fractionation and metagenomics pipeline to link carbon content and stability with microbial composition – First results investigating fungal endophytes', *bioRxiv*2021.12.19.473394, doi:10.1101/2021.12.19.473394.

Cabral L, Rainey E and Glover D (2022) *Agroecology, regenerative agriculture, and nature-based solutions: Competing framings of food system sustainability in global policy and funding spaces*, IPES.

Campbell DLM, Lee C, Hinch GN and Roberts JR (2017) 'Egg production and egg quality in free-range laying hens housed at different outdoor stocking densities', *Poultry science*, 96(9):3128–3137, doi:10.3382/ps/pex107.

Cassidy ES, West PC, Gerber JS and Foley JA (2013) 'Redefining agricultural yields: from tonnes to people nourished per hectare', *Environmental research letters: ERL [Web site]*, 8(3):034015, doi:10.1088/1748-9326/8/3/034015.

CIDSE (2020) *Finance for Agroecology: More than just a dream?*, https://www.cidse.org/2020/09/30/new-data-reveals-massive-gap-in-public-funds-towards-agroecology/, accessed 27 October 2022.

Climateworks Centre (2021) *Natural capital measurement catalogue*, https://www.climateworkscentre.org/resource/natural-capital-measurement-catalogue/, accessed 27 October 2022.

Climateworks Centre (2022) *Living within limits: Adapting the planetary boundaries to understand Australia's contribution to planetary health*, *Climateworks Centre*, https://www.climateworkscentre.org/resource/living-within-limits-adapting-the-planetary-boundaries-to-understand-australias-contribution-to-planetary-health/, accessed 27 October 2022.

Cohen-Shacham E, Walters G and Janzen C (2016) 'Nature-based solutions to address global societal challenges', *IUCN: Gland*, https://serval.unil.ch/resource/serval:BIB_93FD38C8836B.P001/REF.

Commonwealth of Australia (2021) *National Soil Strategy*, agriculture.gov.au/sites/default/files/documents/national-soil-strategy.pdf.

Conant RT, Cerri CEP, Osborne BB and Paustian K (2017) 'Grassland management impacts on soil carbon stocks: a new synthesis', *Ecological applications: a publication of the Ecological Society of America*, 27(2):662–668, doi:10.1002/eap.1473.

Costa MP, Schoeneboom JC, Oliveira SA, Viñas RS and de Medeiros GA (2018) 'A socio-eco-efficiency analysis of integrated and non-integrated crop-livestock-forestry systems in the Brazilian Cerrado based on LCA', *Journal of cleaner production*, 171:1460–1471, doi:10.1016/j.jclepro.2017.10.063.

Cresswell ID, Janke T and Johnston EL (2021) *Overview: Management approaches. In: Australia State of the environment 2021*, Australian Government Department of Agriculture, Water and the Environment, https://soe.dcceew.gov.au/overview/management/management-approaches, accessed 27 October 2022.

Crowder DW and Reganold JP (2015) 'Financial competitiveness of organic agriculture on a global scale', *Proceedings of the National Academy of Sciences of the United States of America*, 112(24):7611–7616, doi:10.1073/pnas.1423674112.

CSIRO (2022) *Food and Agribusiness Roadmap: unlocking value-adding growth opportunities for Australia*, CSIRO, Viewed 23 March 2023, https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/agriculture-and-food/agribusiness-roadmap .

Delate K, Cambardella C, Chase C and Turnbull R (2016) ‘A review of long-term organic comparison trials in the US’, in K Etingoff (ed) *Sustainable Development of Organic Agriculture : Historical Perspectives*, Apple Academic Press.

Department of Agriculture, Fisheries and Forestry (n.d.) *Land use*, https://www.agriculture.gov.au/abares/aclump/land-use, accessed 21 December 2022a.

Department of Agriculture, Fisheries and Forestry (n.d.) *Snapshot of Australian Agriculture 2022*, https://www.agriculture.gov.au/abares/products/insights/snapshot-of-australian-agriculture-2022, accessed 27 October 2022b.

Department of Climate Change, Energy, the Environment and Water (2022) *National Inventory Report 2020*, https://www.dcceew.gov.au/sites/default/files/documents/national-inventory-report-2020-volume-1.pdf.

Department of Climate Change, Energy, the Environment and Water (n.d.) *National Greenhouse Gas Inventory Quarterly Update: March 2022*, https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-gas-inventory-quarterly-update-march-2022, accessed 21 December 2022.

DeRamus HA, Clement TC, Giampola DD and Dickison PC (2003) ‘Methane emissions of beef cattle on forages: efficiency of grazing management systems’, *Journal of environmental quality*, 32(1):269–277, doi:10.2134/jeq2003.2690.

De Stefano A and Jacobson MG (2018) ‘Soil carbon sequestration in agroforestry systems: a meta-analysis’, *Agroforestry Systems; The Hague*, 92(2):285–299, doi:10.1007/s10457-017-0147-9.

Don A, Schumacher J and Freibauer A (2011) ‘Impact of tropical land-use change on soil organic carbon stocks - a meta-analysis’, *Global change biology*, 17(4):1658–1670, doi:10.1111/j.1365-2486.2010.02336.x.

Edwards A, Archer R, De Bruyn P, Evans J, Lewis B, Vigilante T, Whyte S and Russell-Smith J (2021) ‘Transforming fire management in northern Australia through successful implementation of savanna burning emissions reductions projects’, *Journal of environmental management*, 290:112568, doi:10.1016/j.jenvman.2021.112568.

Farming for the Future (2022) *Farming for the Future – Evolving Farm Business*, https://farmingforthefuture.org.au/, accessed 27 October 2022.

Finlayson JD, Lawes RA, Metcalf T, Robertson MJ, Ferris D and Ewing MA (2012) ‘A bio-economic evaluation of the profitability of adopting subtropical grasses and pasture-cropping on crop–livestock farms’, *Agricultural systems*, 106(1):102–112, doi:10.1016/j.agsy.2011.10.012.

Fischer J, Stott J, Zerger A, Warren G, Sherren K and Forrester RI (2009) ‘Reversing a tree regeneration crisis in an endangered ecoregion’, *Proceedings of the National Academy of Sciences of the United States of America*, 106(25):10386–10391, doi:10.1073/pnas.0900110106.

Fitch P, Battaglia M, Lenton A, Feron P, Gao L MY, Hortle A, Macdonald L, Pearce M, Occhipinti S, Roxburgh S and Steven A (2022) *Australia’s carbon sequestration potential: a stocktake and analysis of sequestration technologies*, CSIRO.

FOLU (2023) *Aligning regenerative agricultural practices with outcomes to deliver for people, nature and climate* (2023), https://www.foodandlandusecoalition.org/knowledge-hub/regenag-people-nature-climate/, accessed 20 February 2023.

Franzluebbers AJ (2010) ‘Achieving Soil Organic Carbon Sequestration with Conservation Agricultural Systems in the Southeastern United States’, *Soil Science Society of America Journal; Madison*, 74(2):347–357, https://www.proquest.com/scholarly-journals/achieving-soil-organic-carbon-sequestration-with/docview/346559432/se-2.

Geary WL, Nimmo DG, Doherty TS, Ritchie EG and Tulloch AIT (2019) 'Threat webs: Reframing the co-occurrence and interactions of threats to biodiversity', *The Journal of applied ecology*, (1365-2664.13427), doi:10.1111/1365-2664.13427.

Giller KE, Hijbeek R, Andersson JA and Sumberg J (2021) 'Regenerative Agriculture: An agronomic perspective', *Outlook on agriculture*, 50(1):13–25, doi:10.1177/0030727021998063.

Gosnell H, Gill N and Voyer M (2019) 'Transformational adaptation on the farm: Processes of change and persistence in transitions to "climate-smart" regenerative agriculture', *Global environmental change: human and policy dimensions*, 59:101965, doi:10.1016/j.gloenvcha.2019.101965.

Guerra CA, Heintz-Buschart A, Sikorski J, Chatzinotas A, Guerrero-Ramírez N, Cesarz S, Beaumelle L, Rillig MC, Maestre FT, Delgado-Baquerizo M, Buscot F, Overmann J, Patoine G, Phillips HRP, Winter M, Wubet T, Küsel K, Bardgett RD, Cameron EK, Cowan D, Grebenc T, Marín C, Orgiazzi A, Singh BK, Wall DH and Eisenhauer N (2020) 'Blind spots in global soil biodiversity and ecosystem function research', *Nature communications*, 11(1):3870, doi:10.1038/s41467-020-17688-2.

Guo LB and Gifford RM (2002) 'Soil carbon stocks and land use change: a meta analysis', *Global change biology*, 8(4):345–360, doi:10.1046/j.1354-1013.2002.00486.x.

Harchaoui S and Chatzimpiros P (2018) 'Can Agriculture Balance Its Energy Consumption and Continue to Produce Food? A Framework for Assessing Energy Neutrality Applied to French Agriculture', *Sustainability: Science Practice and Policy*, 10(12):4624, doi:10.3390/su10124624.

Hillenbrand M, Thompson R, Wang F, Apfelbaum S and Teague R (2019) 'Impacts of holistic planned grazing with bison compared to continuous grazing with cattle in South Dakota shortgrass prairie', *Agriculture, ecosystems & environment*, 279:156–168, doi:10.1016/j.agee.2019.02.005.

Hobbs PR, Sayre K and Gupta R (2008) 'The role of conservation agriculture in sustainable agriculture', *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 363(1491):543–555, doi:10.1098/rstb.2007.2169.

Intergovernmental Panel on Climate Change (2022) *Climate change 2022: Mitigation of climate change*.

Johnson DC, Teague R, Apfelbaum S, Thompson R and Byck P (2022) 'Adaptive multi-paddock grazing management's influence on soil food web community structure for: increasing pasture forage production, soil organic carbon, and reducing soil respiration rates in southeastern USA ranches', *PeerJ*, 10:e13750, doi:10.7717/peerj.13750.

Johnston J (n.d.) *Permaculture Shelterbelts*, https://www.life.ca/naturallife/9710/organics.htm, accessed 21 December 2022.

Jordon MW, Willis KJ, Bürkner P-C, Haddaway NR, Smith P and Petrokofsky G (2022) 'Temperate Regenerative Agriculture practices increase soil carbon but not crop yield—a meta-analysis', *Environmental research letters: ERL [Web site]*, 17(9):093001, doi:10.1088/1748-9326/ac8609.

Kallenbach CM, Wallenstein MD, Schipanksi ME and Grandy AS (2019) 'Managing Agroecosystems for Soil Microbial Carbon Use Efficiency: Ecological Unknowns, Potential Outcomes, and a Path Forward', *Frontiers in microbiology*, 10:1146, doi:10.3389/fmicb.2019.01146.

Kim J, Ale S, Teague WR and Wang T (2022) 'Evaluating hydrological components and streamflow characteristics under conventional and adaptive multi-paddock grazing management', *River research and applications*, 38(4):776–787, doi:10.1002/rra.3948.

Koch A, Chappell A, Eyres M and Scott E (2015) 'Monitor Soil Degradation or Triage for Soil Security? An Australian Challenge', *Sustainability: Science Practice and Policy*, 7(5):4870–4892, doi:10.3390/su7054870.

Kreitzman M, Toensmeier E, Chan KMA, Smukler S and Ramankutty N (2020) ‘Perennial staple crops: Yields, distribution, and nutrition in the global food system’, *Frontiers in sustainable food systems*, 4, doi:10.3389/fsufs.2020.588988.

LaCanne CE and Lundgren JG (2018) ‘Regenerative agriculture: merging farming and natural resource conservation profitably’, *PeerJ*, 6:e4428, doi:10.7717/peerj.4428.

Luna IM, Fernández-Quintanilla C and Dorado J (2020) ‘Is Pasture Cropping a Valid Weed Management Tool’, *Plants*, 9(2), doi:10.3390/plants9020135.

Massy, C (2020) *Call of the Reed Warbler: A New Agriculture : a New Earth*, University of Queensland Press.

Millar GD and Badgery WB (2009) ‘Pasture cropping: a new approach to integrate crop and livestock farming systems’, *Animal Production Science*, 49(10):777–787, doi:10.1071/AN09017.

Minasny B and McBratney AB (2018) ‘Limited effect of organic matter on soil available water capacity’, *European journal of soil science*, 69(1):39–47, doi:10.1111/ejss.12475.

Mockshell J and Kamanda J (2018) ‘Beyond the agroecological and sustainable agricultural intensification debate: Is blended sustainability the way forward?’, *International Journal of Agricultural Sustainability*, 16(2):127–149, doi:10.1080/14735903.2018.1448047.

Project Drawdown (2020) ‘Multistrata agrofoestry’, https://drawdown.org/solutions/multistrata-agroforestry/technical-summary, accessed 27 October 2022.

Murphy HT and van Leeuwen S (2021) *Biodiversity: Key findings. In: Australia State of the environment 2021*, Australian Government Department of Agriculture, Water and the Environment, https://soe.dcceew.gov.au/biodiversity/key-findings, accessed 27 October 2022.

Ogilvy S, Gardner M, Mallawaarachchi T, Schirmer J, Brown K and Heagney E (2018) *Report: Graziers with better profitability, biodiversity and wellbeing*.

Oxford Martin School and University of Oxford (2017) ‘Grazed and confused?’, *Oxford Martin School*, https://www.oxfordmartin.ox.ac.uk/publications/grazed-and-confused/, accessed 27 October 2022.

Park J-Y, Ale S, Teague WR and Jeong J (2017) ‘Evaluating the ranch and watershed scale impacts of using traditional and adaptive multi-paddock grazing on runoff, sediment and nutrient losses in North Texas, USA’, *Agriculture, ecosystems & environment*, 240:32–44, doi:10.1016/j.agee.2017.02.004.

Pent GJ (2020) ‘Over-yielding in temperate silvopastures: a meta-analysis’, *Agroforestry Systems*, 94(5):1741–1758, doi:10.1007/s10457-020-00494-6.

Poeplau C and Don A (2015) ‘Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis’, *Agriculture, ecosystems & environment*, 200:33–41, doi:10.1016/j.agee.2014.10.024.

Pretty J (2008) ‘Agricultural sustainability: concepts, principles and evidence’, *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 363(1491):447–465, doi:10.1098/rstb.2007.2163.

Project Biome Australia (2022) ‘Farmer’s Footprint Australia’, viewed 23 March 2023, https://farmersfootprint.org.au/.

Reiss ER and Drinkwater LE (2018) ‘Cultivar mixtures: a meta-analysis of the effect of intraspecific diversity on crop yield’, *Ecological applications: a publication of the Ecological Society of America*, 28(1):62–77, doi:10.1002/eap.1629.

Robertson F and Nash D (2013) 'Limited potential for soil carbon accumulation using current cropping practices in Victoria, Australia', *Agriculture, ecosystems & environment*, 165:130–140, doi:10.1016/j.agee.2012.11.004.

Rodale Institute (2011) *The Farming Systems Trial: Celebrating 30 years*.

Rogers G, Hall M and Simpson R (2012) *Quantifying the effects of no till vegetable farming and organic mulch on greenhouse*, Horticulture Australia Ltd.

Rowntree JE, Stanley PL, Maciel ICF, Thorbecke M, Rosenzweig ST, Hancock DW, Guzman A and Raven MR (2020) 'Ecosystem impacts and productive capacity of a multi-species pastured livestock system', *Frontiers in sustainable food systems*, 4, doi:10.3389/fsufs.2020.544984.

Schirmer J, Berry HL and O'Brien LV (2013) 'Healthier land, healthier farmers: considering the potential of natural resource management as a place-focused farmer health intervention', *Health & place*, 24:97–109, doi:10.1016/j.healthplace.2013.08.007.

Schreefel L, Schulte RPO, de Boer IJM, Schrijver AP and van Zanten HHE (2020) 'Regenerative agriculture – the soil is the base', *Global Food Security*, 26:100404, doi:10.1016/j.gfs.2020.100404.

Seufert V and Ramankutty N (2017) 'Many shades of gray-The context-dependent performance of organic agriculture', *Science advances*, 3(3):e1602638, doi:10.1126/sciadv.1602638.

Seymour M and Connelly S (2022) 'Regenerative agriculture and a more-than-human ethic of care: a relational approach to understanding transformation', *Agriculture and human values*, doi:10.1007/s10460-022-10350-1.

Sherren K, Fischer J and Fazey I (2012) 'Managing the grazing landscape: Insights for agricultural adaptation from a mid-drought photo-elicitation study in the Australian sheep-wheat belt', *Agricultural systems*, 106(1):72–83, doi:10.1016/j.agsy.2011.11.001.

Smith P (2014) 'Do grasslands act as a perpetual sink for carbon?', *Global change biology*, 20(9):2708–2711, doi:10.1111/gcb.12561.

Soane BD, Ball BC, Arvidsson J, Basch G, Moreno F and Roger-Estrade J (2012) 'No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment', *Soil and Tillage Research*, 118:66–87, doi:10.1016/j.still.2011.10.015.

Soils for Life (2020) 'Case Studies', Soils For Life, viewed 23 March 2023, https://soilsforlife.org.au/case-studies/.

Stockdale EA, Griffiths BS, Hargreaves PR, Bhogal A, Crotty FV and Watson CA (2019) 'Conceptual framework underpinning management of soil health—supporting site-specific delivery of sustainable agro-ecosystems', *Food and energy security*, 8(2):e00158, doi:10.1002/fes3.158.

Thompson LR and Rowntree JE (2020) 'Invited Review: Methane sources, quantification, and mitigation in grazing beef systems', *Applied Animal Science*, 36(4):556–573, doi:10.15232/aas.2019-01951.

Tittonell P, El Mujtar V, Felix G, Kebede Y, Laborda L, Luján Soto R and de Vente J (2022) 'Regenerative agriculture—agroecology without politics?', *Frontiers in sustainable food systems*, 6, doi:10.3389/fsufs.2022.844261.

Tsonkova P, Böhm C, Quinkenstein A and Freese D (2012) 'Ecological benefits provided by alley cropping systems for production of woody biomass in the temperate region: a review', *Agroforestry Systems*, 85(1):133–152, doi:10.1007/s10457-012-9494-8.

Turner GM, Dunlop M and Candy S (2016) 'The impacts of expansion and degradation on Australian cropping yields—An integrated historical perspective', *Agricultural systems*, 143:22–37, doi:10.1016/j.agsy.2015.11.006.

Unkovich M, Blott K, Knight A, Mock I and Portelli M (2003) ‘Water use, competition, and crop production in low rainfall, alley farming systems of south-eastern Australia’, *Australian journal of agricultural research*, 54(8):751–762, doi:10.1071/AR03049.

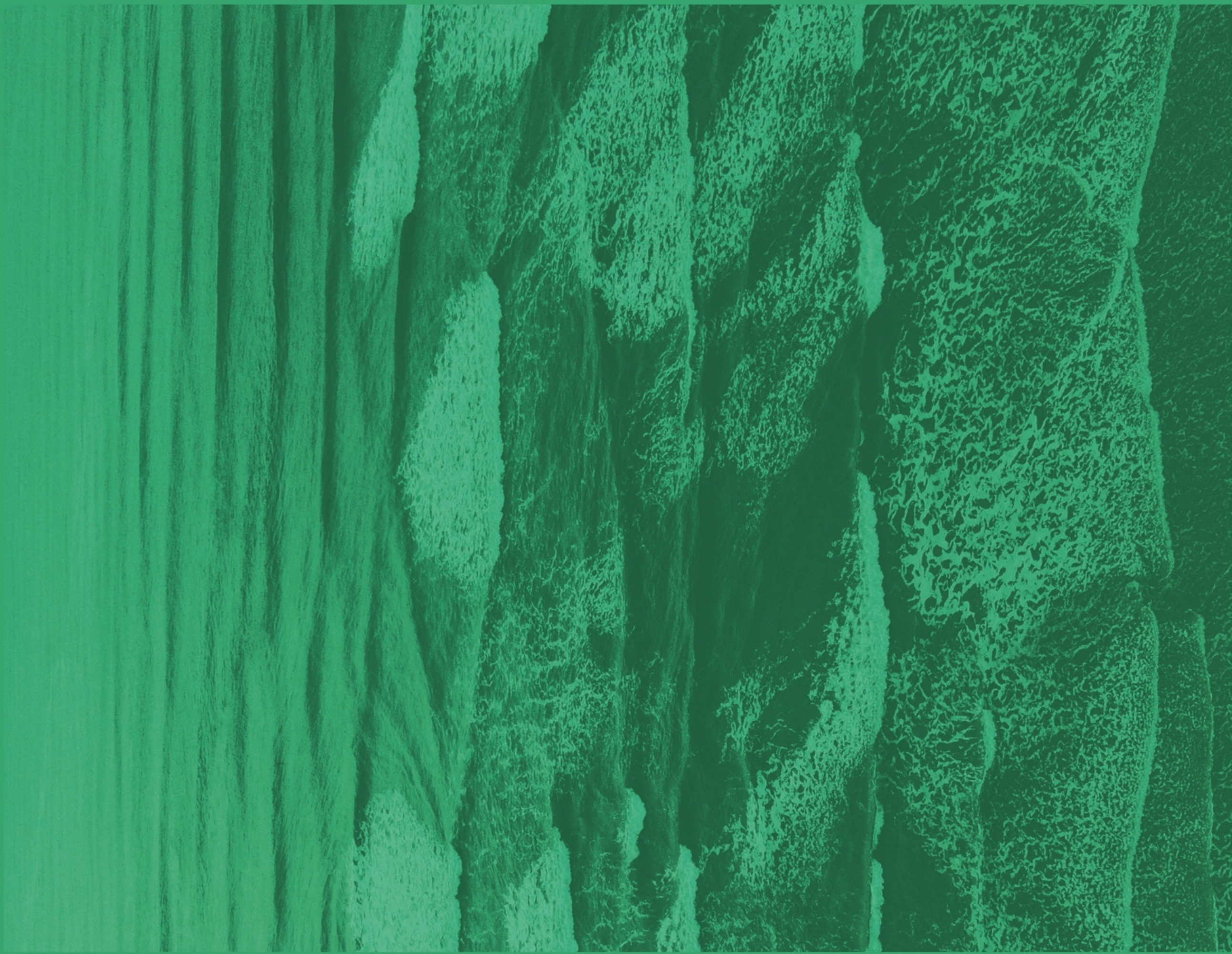
Veste M, Littmann T, Kunneke A, du Toit B and Seifert T (2020) ‘Windbreaks as part of climate-smart landscapes reduce evapotranspiration in vineyards, Western Cape Province, South Africa’, *Plant, Soil and Environment; Prague*, 66(3):119–127, doi:10.17221/616/2019-PSE.

Walling E and Vaneeckhaute C (2020) ‘Greenhouse gas emissions from inorganic and organic fertilizer production and use: A review of emission factors and their variability’, *Journal of environmental management*, 276:111211, doi:10.1016/j.jenvman.2020.111211.

Wang T, Teague WR, Park SC and Bevers S (2015) ‘GHG Mitigation Potential of Different Grazing Strategies in the United States Southern Great Plains’, *Sustainability: Science Practice and Policy*, 7(10):13500–13521, doi:10.3390/su71013500.

Wiedemann SG, McGahan EJ and Murphy CM (2017) ‘Resource use and environmental impacts from Australian chicken meat production’, *Journal of cleaner production*, 140:675–684, doi:10.1016/j.jclepro.2016.06.086.

Wolz KJ, Lovell ST, Branham BE, Eddy WC, Keeley K, Revord RS, Wander MM, Yang WH and DeLucia EH (2018) ‘Frontiers in alley cropping: Transformative solutions for temperate agriculture’, *Global change biology*, 24(3):883–894, doi:10.1111/gcb.13986.




**For further information please contact the authors:**

**Jo Sanson**
Land Use Futures program
Climateworks Centre
jo.sanson@climateworkscentre.org

Climateworks Centre
Level 27, 35 Collins Street
Melbourne Victoria 3000
Wurundjeri Country



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