REGENERATIVE OPPORTUNITIES FOR INCREASING RESILIENCE IN LOW RAINFALL FARMING SYSTEMS

MALLEE REGIONS OF SOUTH AUSTRALIA AND VICTORIA

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Purpose of the Discussion Paper

The relatively new appeal for use of 'Regenerative Agriculture' on farms across the world has the interest of many people; some changing paths in their farming practices, some continuing to do what they know and do well, and others still scratching their heads trying to understand what it is.

Regenerative, agricultural practices are not new, but the term 'regenerative agriculture' or 'regenerative farming' was coined by the US based, organic farming Rodale Institute in the early 1980s. Use of the term faded as emphasis turned to sustainable agriculture, organic farming and agroecology, until 2014 when the institute released a white paper titled 'Regenerative Organic Agriculture and Climate Change'[1]. Since 2016, there has been a resurgence with references to regenerative agriculture rising dramatically in conversation across the globe in all corners; producers, researchers, retailers, and consumers, as well as politicians, policy makers and the mainstream media, spanning the public, private, and non-profit sectors. Governments from local to international levels, are exploring the possibilities for regenerative agriculture to contribute to climate action plans[2].

Academic literature referring to regenerative agriculture is limited but growing, although few address agronomic matters (Giller, Hijbeek, Andersson, & Sumberg, 2021). As more public and private organisations make commitments to regenerative agriculture, more funding is entering agronomic research, but Giller points out that 'navigating the rhetoric and potential for greenwash will be a major challenge for research agronomists'.

Practitioners of the regenerative agriculture movement usually come from outside of Mallee demographics with respect to enterprises, climate and business structure, and can be from a range of stages in life. Sometimes even celebrities become spokespeople. Being told how to farm in general messages without local relevance, is something lower rainfall growers can quickly become cautious and dismissive of - particularly if told they are doing it wrong and implied bad land managers that need to change to be good land managers[3].

Regenerative agriculture is not well-defined system, and consensus differs whether it needs to be organic or certifiable, but nonetheless, most definitions share a suite of similar aims, principles, and potential practices to achieve them. To apply these principles to different landscapes and farming systems, they often need to be modified to suit that environment, and in some instances may not be suitable at all.

Low rainfall growers already implement a range of soil health and diversity practices. More recently, as growers meet with practitioners of regenerative agriculture and try introducing novel practices to their local environment with successes and failures, there has been a shift in the narrative about how prescriptive practices need to be, to a more 'trial and see what works on your farm' approach. Simply using suggested practices, biological or otherwise, does not mean that a system becomes regenerative, just like using practices regarded as the 'bad boys' of industrial agriculture does not mean a system is regressive. Field evaluation of any practice is needed to substantiate soil and plant health benefits, and economic analysis required to understand business sustainability over time.

Now is an ideal opportunity to localise the relevance of what it means to be regenerative and understand suitable approaches to achieve the 'most-regenerative' low rainfall agriculture. This will enable low rainfall Mallee growers to make their own informed farming method decisions, that can either continue to sustain the best possible soil health on their farms or make soil health improvements without making costly mistakes.

This discussion paper explores what science and practitioners understand about managing soil health and reversing biodiversity loss under agricultural production, with supporting evidence (using peer reviewed papers, published reports and farmer experiences), highlighting current practices and opportunities, and recognising gaps in knowledge for the low rainfall Mallee regions of South Australia and Victoria.

What are we Trying to Improve or Regenerate?

Why do we need agricultural systems to be regenerative?

Agriculture has a significant environmental footprint around the world, accounting for about one third of global land use, is a key driver of land use change[4], and is associated with ~15% of global greenhouse gas emissions. At the same time, global food needs are anticipated to grow with increases in both population and per capita demand[5].

The change from native ecosystems to agricultural production areas has modified the landscape in most agricultural systems across Australia. Stocks of soil organic carbon have declined for more than 40 years, with carbon loss off about 51% in the top 10cm of soil (Luo, Wang, & Jianxin Sun, 2010), along with a subsequent reduction in nutrient stocks, particularly nitrogen (Farrell, Vadakattu, & Macdonald, 2021).

Conservation agriculture has reduced erosion in cropping systems immensely compared with previous practice of multiple tillage passes. However, with it has often come a loss of diversity in the system; rotations of monocultures have intensified and longer-term mixed pasture phases incorporating legumes have decreased. This has also led to increased reliance on pre-emergent and selective herbicides, insecticides and fungicides, with an associated rise in input costs and development of resistance to pesticides.

In response to these pressures, along with climate variability and climate change, and ever-growing consumer and trade demands for ethical production and stewardship of farmland, there is a need for more sustainable and regenerative agricultural systems that build and protect soil carbon and biodiversity.

Historical agricultural management of Mallee soils

Mallee landscapes have been farmed for over 100 years. In north-west Victoria, agricultural development began in the South in the 1880's, spreading to the north by the early 1920's[6]. At a similar time in the early 1900's, land was opening-up throughout the South Australia Mallee region.

After land was cleared, foreign European farming practices were introduced, but due to a lack of understanding about the environment and soils, wind erosion quickly became a problem on an extensive scale across the Mallee in the 1920's and 1930's.

Over the past century, government agencies, farmers and more recently advisors, have worked together, continually modifying farming practices to protect and manage soil health to keep agricultural lands productive and farm businesses viable across seasons.

In the Mallee, adoption of no-till cropping systems with stubble retention has been widespread for 20 years, with the presumption that soil organic carbon stocks will increase. Over time research is suggesting this outcome is very climate and soil specific [7,8], but fortunately there are other agronomic benefits that come with those practices such as improved groundcover, reduced wind erosion and better water use efficiency by crops.

Bringing context to the Mallee with a focus on agronomy

To date, much of the pioneering work into broadacre regenerative farming practices, including Australian practitioners of regenerative agriculture, occurs in higher rainfall regions with >500 mm rainfall per annum. These areas often have rainfall events spread across most months of the year creating long growing seasons that can support perennial plantings or two crop or pasture phases in one year. Most properties publicising their use of regenerative agriculture practices, operate primarily as grazing enterprises.

For the low rainfall areas of south-eastern Australia, the agricultural landscapes and systems contrast significantly. Soils are mostly lighter textured sands to sandy loams, receiving low rainfall between 250-350 mm per annum, predominantly between April to October with little and unpredictable summer rainfall. Most crop and pasture growth occurs across these winter and spring months, and remnant crop stubbles and pasture residues cover soils in summer and autumn. About 75% of farm businesses are integrated, primarily cropping (70-85% of land) with sheep, and the other 25% are crop only systems.

Modern conservation farming practices and lower input-natural systems practices are being monitored at various locations of low rainfall cereal-sheep zones across Australia, to establish how practices influence soils and biodiversity, and how best to implement techniques for success in different environments.

We focus here on these agronomic management aspects and how they may or may not be regenerative in the low rainfall Mallee regions of South Australia and Victoria.

Understaning Agriculture That Is Regenerative

What does the term regenerative agriculture mean?

The definition of the word ‘regenerative’ means to regrow, be renewed or restored, especially after being damaged or lost. In turn, regenerative agriculture should replace or renew elements of natural capital and ecosystem services that may be altered by agriculture compared with the environments original natural state.

There is no legal, regulatory or widely accepted definition of the term ‘regenerative agriculture (Newton, Civita, Frankel-Goldwater, Bartel, & Johns, 2020) (Dempster, Davies, Gazey, & Piggott, 2021), and there are disparities among definitions reflecting different goals between practitioners using the term. Definitions are based around either principles or farming outcomes (enhanced soil health and biodiversity), or use of farming practices (eg. no-till, multispecies cover crops, eliminate fertilisers and pesticides), or combinations of both.

Addressing the Grasslands Society of Southern Australia 2021 conference, Dr Judi Earl said ‘The term 'regen ag' triggers a range of emotional responses. There might well be as many answers as practitioners if asked 'what is regen ag'? Responses will include any practice which improves soil health or soil carbon, to lengthy descriptions including improving ecosystem function, social justice, and food security. Some might say it is what we have always practiced, while for others it is a completely new way of approaching their agricultural enterprise, which they may be doing with some trepidation.’

Principles and practices of regenerative agriculture

Looking across definitions, the principle of regenerative agriculture is to promote a holistic, conservation and rehabilitation approach to farming systems and food production – focussing on the interconnection of farming and ecological systems, working with natural systems instead of against them as much as possible.

Regenerative farming techniques aim to integrate management of soil, water, vegetation and biodiversity, to enhance natural resource use efficiency. Some advocates claim it may have lower or even net positive environmental impacts[2], but others are more cautious[9,10].

The main principles of regenerative agriculture[11], and their practices and aims, are commonly to:

Improve soil health

- **Minimise soil disturbances:** minimum or no-till practices that limit physical, biological, and chemical soil disturbances to help increase water retention, nutrient cycling, and retaining topsoil.

- **Keep groundcover:** keep the soil covered with vegetation and natural materials through stubble retention, mulching, cover crops, and pastures to protect the soil from wind and water erosion, reduce soil surface temperatures and evaporation.
- **Keeping living roots in the soil:** to ensure that paddocks are never bare and help stabilise the soil, keep soil biology active, retaining excess water and nutrient runoff. Can use grain or forage cover crops, annual and permanent pastures, shrubs and trees.
- **Encouraging natural biological cycles and nutrient transfer:** by reducing or ceasing synthetic chemical inputs, applying organic composts, fertilisers and bio-amendments, incorporate green manure or under-sowing of legumes.

Increase biodiversity

- **Increase plant diversity:** helps build healthy soils with active microbial function, and has ecosystem benefits for wildlife and pollinators. Use diverse winter or summer crop rotations, intercropping (sowing two or more crops together, or in close proximity), pasture cropping (winter crops sown into perennial summer active pastures), multi-species cover crops and borders planted for bee habitat and other beneficial insects.
- **Integrate livestock:** use grazing management and animal impact as ecosystem development tools. Rotationally graze with higher animal densities to reduce selective overgrazing, wastage and build-up of manure from camping, and enable plant regrowth and recycling of nutrients, building biodiversity and forage quality.

Other practices also regarded to be regenerative include[12]:

- Adopting holistic management – strategic whole system and business decision making, integrating enterprises and people
- Constructing interventions in the landscape or waterways to slow or capture the flow of water
- Fencing off waterways and implementing water reticulation for stock
- Investing in revegetation

Many of these principles and practices are already adopted into management systems of agriculture. In the Australian Farm Institute, Farm Policy Journal – Winter 2021, (Dempster, Davies, Gazey, & Piggott, 2021) produced Figure 1 (over the page) to represent their perception of adoption of practices across the broad aims of different agricultural management systems. Its purpose is not to suggest which practices achieve, or not, the management system outcomes, but to highlight differences in implementation of practices across management systems.

1 Timing of sowing related to lunar and astrological influences on soil and plant development.

2 Lime can incorporate a range of liming products.

3 Continuous cereal can be a valid and sustainable practice in low rainfall areas when combined with tactical fallow.

4 In conventional systems control of weeds in fallow is commonly undertaken, usually using herbicides, while in regenerative systems the desire to maintain living roots and ground cover for as long as possible will mean that volunteer 'weed' species will often be allowed to grow during fallow periods.

5 Involves burying and maturing of manure for recovery and future application as a fertiliser.

6 Full stubble burning has mixed acceptance in conventional systems, with targeted burning of windrows or chaff dumps also practiced.

Figure 1: An interpretation of the continuum of braodacre and regenerative agricultural practices

The thickness of the bars represents the relative acceptance of individual practices acros the continuum. Broken bars represent variable acceptance.

Exploring the Relevance of Management Practices on Soil Health and Biodiversity in Mallee Regions of South Australia and Victoria

Practices in Figure 1 are being used in the Future Drought Fund project 'Regenerative Opportunities for Increasing Resilience in Low Rainfall Farming Systems – Mallee regions of South Australia and Victoria' and will be discussed for their relevance towards being "regenerative" for soil health and biodiversity in the Mallee, with production, sustainability, and profitability in mind.

Where possible, relevant South Australian and Victorian Mallee data are referred to. Sometimes extrapolation of a practice from another area is needed, however climate, soil type and other factors may mean that implementing or removing those practices from the Mallee may not have the expected results. As well, to change a practice on farm may mean other management practices need to change to accommodate it.

For the discussion, soil health is defined as 'the capacity of the soil to function as a living system that sustains plant and animal productivity, maintains or enhances water and air quality, and promotes plant and animal health' (Doran & Zeiss, 2000). Enhanced soil health supports crop and pasture production.

Soil health parameters include physical properties (eg. soil structure, bulk density, infiltration, plant available water), chemical properties (eg. cation exchange capacity, buffer against acidification), and soil biology and function (resilience after drought, access and release of nutrients to plants, resistance to soil borne plant diseases). Soil organic carbon (SOC) is of particular importance.

Biodiversity considers diversity of life at all levels; microbes to livestock and native animals, different crops and pastures existing together or in rotation, and natural habitat. Biodiversity provides ecosystem services such as plant root and leaf disease management, regulates the effect of wind and micro-climate for crops, provides shelter for livestock, and for native animals (eg. insects, reptiles, birds) that facilitate pollination, pest control and waste decomposition. Here, the agronomic emphasis focuses on soil microbial diversity.

TILLAGE, SEEDING, AND TRAFFIC

Soil organic carbon contained within organic matter can be prevented from mineralising to CO_2 by forming aggregates with soil particles. These aggregates limit microbial access to reaching the organic matter, preventing mineralisation. At the same time, microorganisms contribute to soil aggregation through their production of polysaccharides that bind soil particles and fungal hyphal networks that hold numerous aggregates together.

When soil is cultivated, tynes break up these aggregates, increasing aggregate turnover rates and hence carbon lost as CO_2. As well, loose cultivated soil is also at greater risk of soil erosion to wind and water, exacerbating SOC losses. Microbial functions that supply nutrients to plants and provide protection from pathogens are compromised.

Sowing systems have been developed using a single pass with tillage points, narrow tynes or discs to reduce the amount of soil disturbance and the need for tillage to control weeds. Working below the seed with a low disturbance point or disc also enables the safe placement of higher fertiliser rates (separation from the seed) and Rhizoctonia control at sowing, both enhancing plant establishment and growth.

Controlled traffic (tramline) systems confine machinery wheels to specific traffic lanes, separating the crop zone from the wheel tracks. Depending on the soil types, less compaction across the crop zone can improve water infiltration, less water erosion, and there is less physical wheel damage to the crop. Adoption of controlled traffic is still at or below 10% in many of the low rainfall zones across Australia (Umbers, 2016).

While not always considered a regenerative practice, a strategic deep tillage or ripping can be used to ameliorate soil compaction layers for better water infiltration and plant root penetration.

Research findings on the effect of tillage, seeding, and traffic on SOC and biodiversity

Mallee

- A review of challenges to crop production on southern-eastern Australian sandy soils (siliceous or carbonaceous) identified soil constraints to be principally water repellence due to low clay content (where keeping soils wet is not an option), compaction and hard-setting, low fertility and where there's high carbonate, further reduction in nutrient availability. Tillage strategies to mitigate repellent issues at sowing and improve plant establishment and crop yields included sowing with furrows for water harvesting, twin boot systems, a scooping share to move repellent topsoil to the interrow, and near or on-row sowing to increase water infiltration (Unkovich, et al., 2020).
- A 2012 survey of growers in the South Australian Mallee and Victorian Mallee found adoption of no-tillage (using narrow points or discs) of 70 per cent and 68 percent respectively. It was anticipated those figures would grow to 74 percent and 76 percent in the following 5 years. (Llewellyn, E'Emden, & Kuehne, 2012).
- Adoption of conservation agriculture has resulted in substantial increases in the labile and biologically available pools of SOM. Accounting for 20-35% of total carbon in the 0-5cm surface

layer, this particulate organic matter forms centres of both beneficial and deleterious microbial activities, thereby increasing the gradient of microbial biomass distribution, with most (50-75%) soil microorganisms occurring in this soil surface layer (Gupta, Roper, Kirkegaard, & Angus, 1994) (Roper, Gupta, & Murphy, 2010).

- Optimum conditions for microbial activity are short and infrequent in low rainfall Mallee systems, due to soils receiving lower and more sporadic rainfall events followed by long dry periods, often with warm to hot conditions (Figure 2). No-tillage systems conserve soil moisture, providing more opportunity for microbes to function (Gupta, Rovira, & Roget, Principles and management of soil biological factors for sustainable rainfed farming systems, 2011).

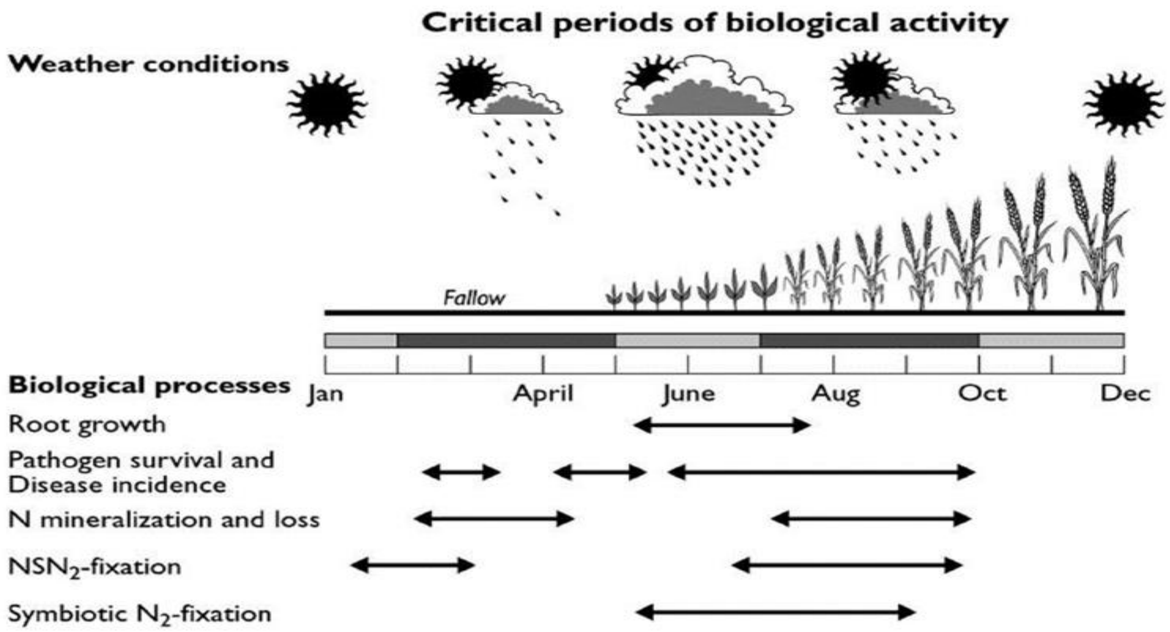

Figure 2: A conceptual model describing soil biological processes and their impact in a Mediterranean-type climate such as the Victorian South Australian and Mallee regions, where winter rainfall predominates between May to October (modified from (Gupta, Rovira, & Roget, Principles and management of soil biological factors for sustainable rainfed farming systems, 2011))

- A trial at Waikerie (1998-2006) found crop residues broke down faster with tillage resulting in an overall decline in soil quality (Gupta, Roget, Davoren, Llewellyn, & Whitbread, 2008)
- A trial at Jil Jil (1999- 2012) found that the 'fuel burner' farming system, which involved full soil disturbance at sowing and the cultivation of fallows, had lower organic carbon levels than no-till and reduced-till systems when measured in 2012 (McClelland, 2012).
- A trial at Walpeup (1982-2009) found zero-tillage (narrow points) increased SOC compared to traditional tillage (multiple cultivations) in a medic pasture/fallow/wheat rotation. In the medic pasture/wheat and fallow/wheat rotations SOC trended higher under zero-tillage systems but was not statistically significant (Robertson, et al., Effect of cropping practices on soil organic carbon: Evidence from long-term field experiements in Victoria, Australia, 2015).
- A trial at Loxton (2015) showed that on a deep sand, despite years of traffic in a conventional farming system, that repeated passes of modern heavy equipment can still further damage soil properties and result in yield decreases. Single pass machinery traffic did not result in yield decreases at Loxton, and rarely at any of the other soil types in the project. Deep sands lack

shrink-swell properties and cannot remediate from compaction naturally, so where feasible, deep ripping and single pass trafficking under a CTF system would be important (Browne, Fisher, Wilhelm, & Tullberg, 2019).

Other areas

- A trial at Longerenong (1998-2010), found zero tillage (stubble retained and left standing) did not increase SOC stocks relative to traditional tillage (stubble retained and incorporated) in a canola/wheat/pea rotation. However, traditional tillage (stubble retained and incorporated) slightly increased SOC compared with reduced tillage (stubble burnt) (Robertson, et al., Effect of cropping practices on soil organic carbon: Evidence from long-term field experiements in Victoria, Australia, 2015). Unfortunately, it is not possible to draw conclusions based solely on the cultivation practices, due to the confounding nature of the different stubble management practices.
- Meta-analysis of published data (studies between 1984-2021) on the responses of soil C to improved agricultural practices (conservation tillage, residue retention, use of pasture and fertiliser N) compared to unimproved controls, found all improved management practices increased soil C for up to 20 years, primarily in the 0-10cm layer, with greatest change in the first 10 years. In the 0-10cm layer, conservation tillage increased soil C concentration by 10% and soil C stocks by 139 kg C/ha/year and provided benefits to soil C for 20-30 years. (Lam, Chen, Mosier, & Roush, 2013).

SOIL AMELIORANTS AND AGRONOMIC INPUTS

Coarse textured, sandy soils have poor capacity to protect SOM from breakdown, so tend to have low SOC content and low soil biological activity.

SOC (fine-fraction/humus) has relatively consistent ratios of nutrients to carbon; 10,000 C: 833 N: 200 P: 143 S (Kirkby et al. 2016), or a C:N ratio of about 10:1. However, the carbon inputs into the system have lower ratios of nutrients to carbon, eg. wheat stubbles tend to have C:N ratios of around 80:1 whereas legume stubbles are more commonly around 35:1.

Every 1 ton of wheat stubble contains 450kg of carbon, of which 135kg can be retained. For microbes to convert this into humus requires 10.8kg N, 2.7kg P and 1.9kg S (Kirkby, Richardson, Wade, Conyers, & Kirkegaard, Inorganic nutrients increase humification efficiency and C-sequestration in an annually cropped soil, 2016); (van Rees, Jackman, Taylor, & Baldock, 2018). If these nutrients are not available in quantities sufficient to balance the amount of stubble, the carbon in the stubble will remain as particulate organic carbon where it is more vulnerable to being lost from the system.

SOC levels can also be decreased if there are insufficient nutrients in the soil to meet crop demand. If nitrogen levels are too low in the soil microbes can mineralise the SOC to make the nitrogen available to the plants, through which the carbon in the SOC is converted to CO2 and lost to the atmosphere. Having nutrient deficient soils can also reduce the biomass produced, limiting the carbon inputs into the system (Hunt, Murray, & Maddern 2020).

'What is good for animal nutrition is good for plant growth is good for soil microbes. Just like animals and plants, microbes need a balanced diet. If they don't have access to the nutrients they need, they can't perform their functions well. Some microbes can capture N from the atmosphere, eg. diazotrophs such as Rhizobia and other free-living N fixers. Other microbes can access soil nutrient reserves through enzymes such as phosphatases, but they cannot create P or other nutrients. As all Mallee soils, like most Australian soils, are low in total P, S, N and K, plant and microbial extractions of these nutrients is mining the soil. They must be replaced in order to be sustainable.' explains Dr Cassandra Schefe (pers comms).

Removing or reducing soil constraints on plant growth, such as sodicity, compaction and acidity, can facilitate plant root development, water and nutrient availability, leading to increased biomass and hence increased above and below ground inputs of carbon into the soil.

A strategic deep tillage can be used to delve and mix clay with surface sand to increase water holding capacity, and to bury crop residues, manures, soil amendments and fertilisers deeper into the soil profile. At depth, decomposition rates are slower than on the surface, protecting SOC.

Research findings on the effect of soil ameliorants and agronomic inputs on SOC and biodiversity

Mallee

- Eight years of field trials on coarse textured Mallee soils in SA, Vic and NSW demonstrated that management practices that increased productivity and increased carbon inputs (fertiliser and stubble retention with direct drill tillage), were the driver for greater microbial activity and functions related to nutrient cycling and disease suppression. The soils were very responsive to the increased carbon inputs due to inherently low soil carbon levels, and rapid turnover of added carbon due the limited protection offered by the soil type. While there was no increase in total soil carbon after eight years for reduced tillage treatments, soil carbon declined for treatments with cultivation or low input pasture phase (less fertiliser and biomass produced) (Gupta, Roget, Davoren, Llewellyn, & Whitbread, 2008).
- The Harden trial (below in 'Other areas') was replicated, except for the pulverisation of stubble, across four trials at Birchip, Hart, Minnipa and Temora (2012-2016). At both Birchip and the other trial sites, the treatments did not result in any significant changes to SOC. It is important to note that these trials were conducted during two dry seasons (van Rees, Jackman, Taylor, & Baldock, 2018)
- A trial at Curyo (2018-ongoing) to determine if N fertiliser applications can be used as a tool to maintain and/or increase SOC in local conditions (using the China trial method below in 'Other areas'), has shown that applying enough nitrogen to ensure that soil N is not depleted (running a positive N balance) leads to increased biomass, grain yields and profitability compared to the national average N applications. It has been estimated that applying the national average N has lost 194kg/ha of SOC (Hunt, Murray, & Maddern, Managing N fertiliser to profitably close yield gaps, 2021).
- In a review of challenges to crop production on sandy soils, sandy soil amelioration strategies were considered with variable results; soil wetting agents (low success), clay spreading, soil mixing or inversion using delving (can be successful depending on location and quality of clay source and incorporation), spading and mouldboard ploughing (success when there's a significant textural change to sands deeper than 40cm). Deep ripping (to shatter compaction layers) enables greater root penetration and subsequent extraction of soil water, although experience suggests effects are short term between 1-3 years (Unkovich, et al., 2020).

- Trials at Netherby (2020 - 2021) showed deep ripping changed root structure in pulses and increased following wheat yields. Poultry manure was a valuable soil ameliorant yielding higher in 2020 (thought to be higher P content), although matched synthetic fertiliser rates performed similarly in 2021. Availability, transport and cost of manure can be high compared with synthetic fertiliser. Clay spread treatments yielded poorer, likely due to difficulties with incorporation using small pot machinery compared with grower equipment using shears or off-set discs combined with smudge bars (Taylor, 2021).
- Trials (ongoing) in the northern Mallee have measured a 40-100% increase in crop growth and yield in response to deep ripping compacted sands. Several demonstration sites have been established with farmers in collaboration with industry experts to help address some key questions around deep ripping such as best timing, tyne spacing, depth of operation and the use of inclusion plates (Mallee Sustainable Farming).

Other areas

- A trial at Harden, NSW (2007-2012) applied nitrogen, phosphorous and sulfur to the soil to ensure that there were sufficient nutrients available for 30% of the above ground plant residue to be converted into fine-fraction SOC (less than <0.4mm). The stubble was pulverised, and incorporated into the soil using a rotary cultivation. The trial found that applying additional nutrients did increase soil C by 5.5 t C/ha soil organic-C (SOC) stocks to 1.6 m soil depth, but were reduced by 3.2 t C/ha without nutrient addition, with 2.9 t C/ha being lost from the 0–10 cm layer. With additional synthetic nutrients, a net difference of 8.7 t C/ha was achieved in a cropping soil over a 5-year period, despite the same level of C addition (Kirkby, Richardson, Wade, Conyers, & Kirkegaard, Inorganic nutrients increase humification efficiency and C-sequestration in an anually cropped soil, 2016) .
- A well-regarded study on the Loess Plateau, China (1984-2009) applied five different nitrogen rates (0, 45, 90, 135 and 180kg N/ha) each year to a continuous wheat rotation that was cultivated twice annually. It was found that SOC concentrations were significantly increased by nitrogen fertiliser, with SOC increasing for all treatments except the 0 kg N/ha treatment. Modelling the results suggest that each kg of fertiliser N applied increased SOC by 0.51 kg/ha in the top soil from 1984 to 2009 (Guo, et al., 2012).
- Meta-analysis of published Australian data (studies between 1984-2021) on the responses of soil C to improved agricultural practices (conservation tillage, residue retention, use of pasture and fertiliser N) compared to unimproved controls. In the 0-10cm layer, using fertiliser N increased soil C concentration by 10% and soil C stocks by 47 kg C/ha/year, and provided benefits to soil C for 20 years. (Lam, Chen, Mosier, & Roush, 2013).
- A global review of 64 long-term crop fertilization trials from around the world found that application of mineral N fertilizer was associated with an average 15% increase in microbial biomass and 13% increase in soil organic carbon compared to an unfertilized control. The effect of fertilization on the microbial biomass is strongly pH dependent; when pH was 7 or higher, microbial biomass increased by 48%. Increases in microbial biomass were largest in studies with at least 20 years of N fertilization (Geisseler & Scow, 2014).

Crop rotation and diversity

Crop rotations enable a grower to increase water use efficiency and grow more biomass by reducing disease levels, increasing groundcover, and increasing soil nutrients such as nitrogen in pulse rotations.

Crop rotation involves what crop type is grown where, when, how often, as a monoculture or a mix, and the end use which varies from forage, hay, grain, grazed mature, green or brown manured, and fallow management. These decisions influence diversity across the cropping area, fertiliser and pesticide applications, and the composition of residues above and below the ground.

A fallow is the period where there is nothing growing in the soil and is often used to reduce weed and disease levels, and conserve soil moisture for sowing the following crop. Depending on the soil type in the Mallee, fallows can begin as early as August the previous season to store winter rain, or after summer or autumn rains in the months pre-sowing. In our current minimum/no-tillage farming systems, fallowing is implemented using broad spectrum herbicides such as glyphosate, rather than cultivation. Natural fallows also occur over the summer period when conditions are hot and dry. As there are no plants growing in a fallow, there are no inputs of carbon into the system. Meanwhile, the SOM in the soil continues to be broken down by microbial processes, enhanced by warm conditions and hopefully wetter soil. Over time, this depletion with reduced inputs leads to a decrease in SOC (Sanderman, Farquharson, & Baldock, Soil Carbon Sequestration Potential: A review for Australian agriculture. A report prepared for Department of Climate Change and Energy Efficiency, 2010). Longer term fallows are suited to loamier soils with less erosion risk and greater water storage capacity, whereas sandy soil fallows should be shorter term for pre-sowing. A well-managed fallow retains plant residues to protect the soil.

A cover crop is planted in what would have been a fallow period in a conventional cropping system and is not normally harvested. Its primary purpose is to maintain living root systems in the soil for a longer period and provide groundcover. This focus on living plants rather than fallows means that there are smaller periods where there are no inputs of carbon into the system. A cover crop can be a single species or a mix of species to add diversity.

The concept of cover crops arises from the USA, based on summer cropping where crops are sown in Spring once snow has melted and soil temperatures are warm enough for germination. Crops grow through summer and are harvested in late summer – autumn. Because stubble retention is not widely adopted and there is little groundcover, soil is left exposed after harvest and through winter, running the risk of nutrient loss and soil erosion caused by snow melt and spring rainfall. Hence the phrase 'cover crops' was coined, being a crop planted to cover the land and catch excess nutrients and water. Cover crops can be undersown with corn which is cut for silage in autumn, then grow on to keep mopping up water and nutrients in winter, or if it dies, provide physical protection to the soil (Figure 3).

In Australia however, and particularly in Mallee farming systems, cash crops are grown on winter and spring rainfall, and harvested at the end of spring and early summer. With stubble retention and careful grazing management, soils are protected from hot northerly winds, and water erosion caused by rare summer thunderstorm events, up until the autumn sowing.

Growing a summer cover crop is very opportunistic and carries a high risk of not receiving follow up rains and succumbing to multiple days of >40ºC temperatures. Summer cover crops will also use stored soil moisture and summer rainfall that could otherwise be conserved for autumn planting in low rainfall systems. Furthermore, a cover crop becomes a green bridge over summer that may increase disease pressures for autumn crops, provide habitat for insect pests, and withholding periods and breakdown periods of different herbicide chemistries must be considered during dry conditions. If summer covers are not used for grain production, they need to be grazed to recoup their expenses, but that can compromise their groundcover value.

Winter cover crops are more common in the Mallee, using vetch or medic pasture to fix nitrogen while providing a disease and weed break in a cereal dominant rotation. The cover crop can be used for grazing, hay and/or terminated by flowering. Multispecies, winter sown cover crops are now being trialled by dryland growers.

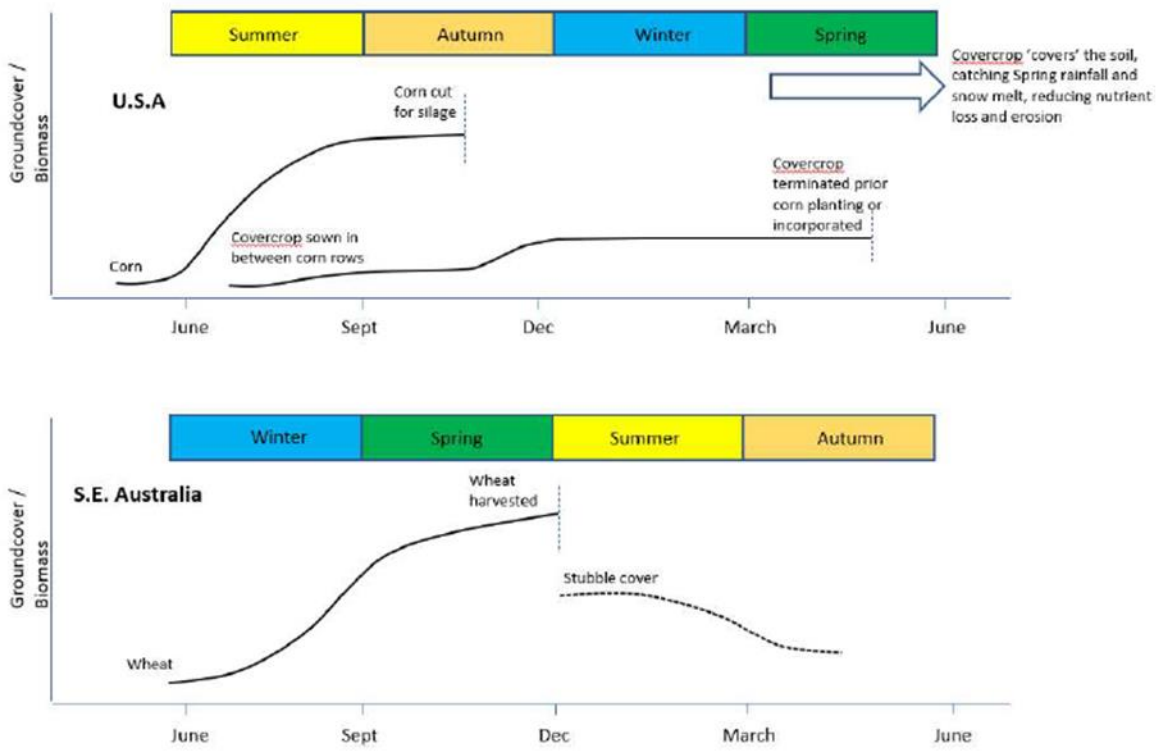

Figure 3: Comparison of cropping systems and seasons in the USA and south-east Australia, using corn and wheat systems respectively (Cassandra Shefe, pers comms.).

Research findings on the effect of tillage, seeding, and traffic on SOC and biodiversity

Mallee

- A Walpeup trial (1982-2009) had greater carbon stocks (8%) in a pasture/wheat rotation than a pasture/fallow/wheat rotation (Robertson, et al., Effect of cropping practices on soil organic carbon: Evidence from long-term field experiements in Victoria, Australia, 2015).

- A trial at Watchupga (2021-2022) is comparing different mono and multispecies cover crops sown in winter, and methods of termination. While the trial is still underway, they make the following notes; if choosing species for nitrogen fixation, you need to choose mostly legumes creating lower diversity. Choosing a large range of species delivers high diversity, but creates seed source and cost, sowing logistics, disease carryover, and weed pressure challenges. Terminating a range of species with different herbicide tolerance and maturity timings has been difficult to manage. Balancing biomass production for groundcover protection and carbon benefits, is counterweighed by greater use of subsoil moisture that would otherwise be used by the following cash crop. The site has been oversown with barley in 2022 (Rose, Draffen, & Gerardi, 2022).

Other areas

- A trial at Longerenong (1916-2010) found that barley/field peas/wheat and oats/field peas/wheat rotations had higher SOC concentrations compared with other rotations in the trial (continuous wheat, fallow/wheat, grass pasture/fallow/wheat, oats/fallow/wheat, oats/grass pasture/fallow/wheat). For the duration of the trial, the stubble had been grazed and burnt in a traditional tillage system, and there was no nitrogen fertiliser applied. Treatments that included fallow had the same SOC levels as continuously cropped treatments. (Robertson, et al., Effect of cropping practices on soil organic carbon: Evidence from long-term field experiements in Victoria, Australia, 2015).
- Another trial at Longerenong (1998-2010) however, including peas in the rotation did not increase SOC. This trial had nitrogen fertiliser applied at 35kg N/ha to wheat and canola rotations each year, and the stubble was only burnt if required. In this trial, including vetch as a green manure had higher SOC stocks than field pea, but was similar to continuous wheat (Robertson, et al., Effect of cropping practices on soil organic carbon: Evidence from long-term field experiements in Victoria, Australia, 2015). The treatment that included fallow in the rotation (fallow/wheat/chickpeas) had lower SOC concentrations than all other treatments (Robertson, et al., Effect of cropping practices on soil organic carbon: Evidence from long-term field experiements in Victoria, Australia, 2015).
- (Heenan, Chan, & Knight, 2004) found that a lupin/wheat rotation reduced the loss of SOC compared to a wheat/wheat rotation in a system that burnt stubble and had three tillage passes (1979-2000).

Biological and microbial innoculants or stimulants

There are several organic matter amendments that are produced off-farm that growers can apply to their soil, such as manure, composts, biosolids and biochar. These products are often high in carbon, and as such represent a way to increase the levels of carbon in the soil simply through their application.

Once this material has been added to the soil it needs to undergo the same microbial processes to ensure that it can be sequestered in a stable form of SOC. If nutrients or necessary conditions are not present, the carbon in these amendments may be lost to the atmosphere in the form of CO_2. However, some amendments, such as biochar are recalcitrant to soil microbial decomposition, which means that the inert carbon within the biochar will remain stable and will not be mineralised to CO_2 (Bell & Lawrence, 2009).

It is also important to note that large additions of high carbon inputs to the soil may tie up nitrogen, making it inaccessible to the crop and/or pasture, and that the composition of these off-site carbon additions is highly variable, which makes it hard to gain consistent results from applications.

Research findings on biological innoculants or stimulants on SOC and biodiversity

Mallee

- A project testing the effectiveness of biological amendments such as microbial inoculants, biostimulants and alternative fertilisers (including manures, humates, composts and biochars) in Australian broadacre grain cropping found limited direct positive effects from these soil inputs in either glasshouse or field trials. Poultry manure lifted yields at some sites but not always, thought to be related to high nitrogen availability. Trials were short term (1-2 years), but authors suggested that even for more established amendments such as manures and composts, multiple years of reapplication may be required before significant results are observed. They advise growers to understand the soil constraints limiting crop production, then understand how a product would address those constraints, and field test. They developed a practical guide to on-farm testing of biological inputs and two web-based calculators (Macdonald, Abbott, Wong, Webb, & Jenkins, 2018).

Other areas

- Published trial results of biochar on SOC are difficult to find, of variable quality and as (Cowie, Macdonald, Murphy, & van Zwieten, 2013) note, the results are variable.

Integrated pest management

Elements of integrated pest management in Figure 1 involve the use of pesticides, herbicides, crop competition and harvest weed seed destruction.

Adoption of conservation agriculture practices has meant the use of herbicides has slowly replaced tillage as the primary tool for weed control. To manage residues from stubble retention at sowing, row spacing has widened from 7-9 inches out to 12 inches so trash flow does not cause blockages around tynes of sowing equipment. While plant density has increased in the sowing row, a wider interrow space has created less competition by crops in between rows. Coupled with more intense cropping systems, this has meant there has been an associated increase in pesticide resistance. For low rainfall areas, this is more likely to be herbicide resistance in ryegrass in continuous cropping systems.

Management that supports healthy plants and biomass production, will facilitate SOC and beneficial soil microorganism populations. When microbial populations are functioning well – a function of rainfall, low soil disturbance and carbon and nutrient inputs – herbicide residues will be broken down faster than when their activity is low.

Research findings on integrated pest management on SOC and biodiversity

Mallee

- It is difficult to find direct reference to the effects of pesticides on SOC and biodiversity in Mallee trials. However, there is a lot of evidence that practices that disturb the soil less, enhance plant production and carbon inputs through stubble retention, wont necessarily improve already low soil carbon levels, but will enhance microbial populations and their functional activity, and protect the soil from wind erosion. These conservation agriculture systems typically use more herbicides in the absence of tillage for weed control, yet show soil health responses, indicating that strategic use of herbicides to manage weed competition and moisture retention for winter cropping can be regenerative.

Other areas

- In general, most studies suggest that the impacts of herbicide application on soil function are only minor and/or temporary. However, there are instances when herbicides effect soil function including earthworms in soils exposed to glyphosate and atrazine; inhibition of soil N-cycling (including biological N2-fixation, mineralization and nitrification) by sulfonylurea herbicides in alkaline or low organic matter soils; and site-specific increases in disease resulting from the application of a variety of herbicides. There are issues with extrapolating the findings to broadacre farming including the lack of a consistent framework for assessing herbicide risk to soil biology, the relevance of the herbicide impact magnitude compared with the impacts of other soil management practices such as tillage or crop rotation, the complexity of herbicide chemistries, and the limited number of long-term field studies (Rose, et al., 2016).

Stubble and residue management

There has been a shift in farming practices in cropping systems from burning stubble to allow for mechanical limitations of seeders and to control weeds and disease, to retaining stubble that can be sown in to with knife-point press wheel seeders, or disc seeders, while conserving soil moisture by keeping groundcover and reducing soil disturbance.

Retaining stubble means that more crop residue is left behind, increasing the amount of plant matter inputs to the system. Retaining enough stubble can also help to reduce erosion and increase water use efficiency by decreasing run-off, increasing infiltration and decreasing soil temperatures.

Burning stubble removes groundcover and can result in the loss of up to 80% of the carbon and nitrogen in the crop residue. Burning also increases the risk of both topsoil and nutrients that remain in the ash being lost from the system via erosion.

Plant matter is also removed from the system when growers cut and bale straw or hay, removing large amounts of carbon, nitrogen, phosphorus and potassium from the system. Oaten and vetch hay production has increased across north-west Victoria and South Australia as a result of improved agronomy knowledge, weed seed management, and increased market access to hay exporters and domestic markets. Cutting hay leaves behind less stubble than a crop grown for grain, and typically increases the fallow period compared to grain crops.

Research findings on stubble and residue management on SOC and biodiversity

Mallee

- Eight years of field trials on Mallee soils in SA, Vic and NSW demonstrated that management practices that increased productivity and increased carbon inputs (fertiliser and stubble retention with direct drill tillage), were the driver for greater microbial activity and functions related to nutrient cycling and disease suppression (Gupta, Roget, Davoren, Llewellyn, & Whitbread, 2008).
- There is a lack of research on the effect of hay rotations and plant matter removal on SOC levels.

Other areas

- The main limitation for microbial functions in soils is a lack of carbon for energy. Stubble retention provides an energy source, sometimes requiring decomposition to available forms. Microbial activity to do this may be limited due to historically low organic matter inputs, however after a few years of stubble retention, microbial communities respond and decompositions rates increase. Rates will depend on and change with quality/type and quantity of stubble, or if stubbles are left standing or in contact with the ground (Adl, 2003)
- Meta-analysis of published data (studies between 1984-2021) on the responses of soil C to improved agricultural practices (conservation tillage, residue retention, use of pasture and fertiliser N) compared to unimproved controls. In the 0-10cm layer, residue retention increased soil C concentration by 8% and soil C stocks by 62 kg C/ha/year (Lam, Chen, Mosier, & Roush, 2013).

Livestock and grazing management

Managed pasture production and grazing can increase biomass production and forage quality for grazing, and pasture residues for groundcover and soil carbon. However, this requires a system that supports plant and soil health, and supports soil carbon inputs from plant biomass.

On Mallee farms where cropping is the primary business, livestock management tends to become secondary, and management of grazing paddocks can end up less than ideal when space for grazing is limited by the amount of land sown to crop.

To ensure biomass and ground cover levels are adequate, rotational grazing methods (animals graze paddocks for 1-3 months depending on season) must be used rather than a set-stocking approach (animals are left on the paddock for several months). In large Mallee broadacre paddocks, grazing efficiency is typically low. Some of the biomass is consumed through grazing and some of that returned as manure, but a portion will not be grazed due to trampling and paddock areas losing feed value as pastures mature. The biomass that is un-grazed is retained in the paddock.

To apply adequate grazing pressure across the paddock to consume feed more efficiently, rotational grazing requires larger mob sizes. Monitoring of feed quantity and quality and groundcover levels determines grazing length time and when to remove animals, to ensure pasture plants have the ability and time to regrow, and to prevent the loss of SOC from groundcover and erosion.

Some alternative pasture species may have the ability to grow more biomass in given conditions than traditional pasture species. They do this by having different growing seasons or perennial growth. These pastures can allocate more energy into root growth (rather than exported grain production) where it is more likely to end up as SOC because it is already in the soil. Potential options for the Mallee are limited to veldt grass, native grasses and lucerne in some situations, that need permanent pasture paddocks.

Research findings on livestock and grazing management on SOC and biodiversity

Mallee

- In a trial at Walpeup (1982-2009), carbon stocks in a medic pasture/fallow/wheat rotation were significantly (21%) greater than under a fallow/wheat rotation (Robertson, et al., Effect of cropping practices on soil organic carbon: Evidence from long-term field experiements in Victoria, Australia, 2015).
- Research regarding the direct system effects of grazing livestock on SOC and soil biology in the Mallee are hard to find and are usually inferences from systems from removed or retained stubble retention systems, or regenerating medic pastures with no inputs.
- Research conducted on low rainfall grazing management on SOC has been conducted on rangeland and pastoral Australia, and hence has less relevance to the Mallee.

Other areas

- Reviews by (Bell, Kirkegaard, Swan, Hunt, & Huth, 2011) and (Hunt, Swan, Kirkegaard, Breust, & Peoples, 2011) found little impact to following crops from shallow surface compaction caused by livestock. More risk is associated with loss of groundcover, but this can be managed with rotational grazing, using confinement areas, and groundcover thresholds.
- A slight positive trend in NDVI of pasture production was measured across rotationally grazed compared with set-stocked native pasture paddock sites in the upper and mid-North of SA (2016), but there were no clear trends in SOC stocks between grazing practices (Sanderman, Reseigh, Wurst, Young, & Ausitn, 2015).
- A trial at Longerenong (1916-2010) had two rotation treatments which contained an annual ryegrass/oat pasture phase; pasture/fallow/wheat and oats/pasture/fallow/wheat. The SOC levels in these treatments were not significantly different to fallow/wheat rotation or oat/fallow/wheat rotations (Robertson, et al., Effect of cropping practices on soil organic carbon: Evidence from long-term field experiments in Victoria, Australia, 2016).
- A trial (1979-2010) found SOC was higher in a wheat/subterranean clover rotation where the clover was mown and left on the plot. The other treatments with a wheat/lupin rotation or a wheat rotation either did not have a significant change in SOC or the SOC declined (Chan, et al., 2011)
- A trial at Condobolin (1998-2015) found that SOC was higher in perennial pasture of lucerne, medic and clover rotations than continuous cropping and mixed farming mixed (cropping and grazed pasture of volunteers fallowed from August) systems, which were had similar SOC (Badgery, et al., 2019).

- Meta-analysis of published Australian data (studies between 1984-2021) on the responses of soil C to improved agricultural practices (conservation tillage, residue retention, use of pasture and fertiliser N) compared to unimproved controls. In the 0-10cm layer, the use of pasture increased soil C concentration by 13% and soil C stocks by 140 kg C/ha/year, and provided benefits to soil C for 30-40 years – the highest contribution to soil C of all the improved practices (Lam, Chen, Mosier, & Roush, 2013).

The Regenerative Opportunities for Low Rainfall Zone Agriculture

What is the scope for better systems?

Soil organic carbon levels in the Southern Australian and Victorian Mallee are typically low, starting as low as 0.3-0.5% for sand, and ranging up to 0.9-1.1% for loam. Changing soil organic carbon levels in this environment is very difficult with low rainfall and resultant lower biomass production, carbon inputs and microbial activity compared with high rainfall regions.

While studies are showing the potential for changing soil carbon in the Mallee is limited, providing carbon for microbial activity and function and mesofauna is essential for the benefits of nutrient cycling, organic matter turnover, disease control, soil structure, agrochemical degradation.

Table 1 is currently the best summary of the likely results of practice change on soil organic carbon sequestration and the authors confidence to achieve the potential in Australian agricultural systems (Sanderman, Farquharson, & Baldock, 2010), based on a review of research results. This review did not consider the financial viability of implementing these techniques and was written in a broad sense, but it provides a useful summary relevant to Mallee farming systems.

This review is now 12 years old, and many of these practices have widespread adoption in the Mallee over the last 20 years as farmers have sought to maximise production and soil health. It's noted that not all practices are relevant in the Mallee, eg. The opportunity for summer cover crops, irrigation, use of perennial species and organic farming is very low.

Table 1. Summary of major management options for sequestering carbon in agricultural soils. As reproduced from **(Sanderman, Farquharson, & Baldock, Soil Carbon Sequestration Potential: A review for Australian agriculture. A report prepared for Department of Climate Change and Energy Efficiency, 2010)**.

Management	SOC Benefit[a]	Confidence[b]	Justification
1. Shifts within an existing cropping/mixed system			
a. Maximizing efficiencies 1) water use 2) nutrient use	0/+	L	Yield and efficiency increases do not necessarily translate into increased C return to soil

b. Increased productivity 1) irrigation 2) fertilisation	0/+	L	Potential trade-off between increased C return to soil and increased decomposition rates
c. Stubble management 1) eliminate burning/grazing	+	M	Greater C return to the soil should increase SOC stocks
d. Tillage 1) Reduced tillage 2) Direct drilling	0 0/+	M M	1) Reduced till has sown little SOC benefit; 2) Direct drill reduces erosion and destruction of soil structure thus slowing decomposition rates; however, surface residues decompose with only minor contribution to SOC pool
e. Rotation 1) Eliminate fallow with cover crop 2) Increase proportion of pasture to crops 3) Pasture cropping	+ +/++ ++	M H M	1) Losses continue during fallow without any new C inputs – cover crops mitigate this; 2) Pastures generally return more C to soil than crops; 3) Pasture cropping increases C return with the benefits of perennial grasses (listed below) but studies lacking
f. Organic matter and other offsite additions	++/+++	H	Direct input of C, often in a more stable form, into the soil; additional stimulation of plant productivity (see above)

Management	**SOC Benefit**[a]	**Confidence**[b]	**Justification**
2. Shifts within and existing pastoral system			
a. Increased productivity 1) irrigation 2) fertilisation	0/+	L	Potential trade-off between increased C return to soil and increased decomposition rates

b. Rotational grazing	+	L	Increased productivity, inc. root turnover and incorporation of residues by trampling but lacking field evidence
c. Shift to perennial species	++	M	Plants can utilise water throughout year, increased below ground allocation but few studies to date
3. Shift to a different system			
a. Conventional to organic farming system	0/+/++	L	Likely highly variable depending on the specifics of the organic system (ie. manuring, cover crops etc)
b. Cropping to pasture system	+/++	M	Generally greater C return to soil in pasture systems; will likely depend greatly upon the specific of the switch
c. Retirement of land and restoration of degraded land	++/+++	H	Annual production, minus natural loss, is now returned to soil; active management to replant native species often results in large C gains

[a] Qualitative assessment of the SOC sequestration potential of a given management practice (0 = nil, + = low, ++ = moderate, +++ = high)

[b] Qualitative assessment of the confidence in this estimate of sequestration potential based on both theoretical and evidentiary lines (L = low, M = medium, H = high)

Grower experiences with regenerative agriculture in the South Australian and Victorian Mallee

Discussions with growers across the South Australian and Victorian Mallee regions indicate that most growers are farming their systems to be at least sustainable, if not regenerative, as without them in a low rainfall environment, they could not operate long term. Practices and inputs are managed to strike a balance between optimising production outputs and managing business risk.

Whether they consider themselves as being ‘regenerative farmers’ varies between growers. Some growers are comfortable with the concept and most understand that they are using practices that are considered regenerative. But many believe that to be regenerative they need to farm to a standard or set of inflexible practices, and that they only partially conform to the definition regenerative agriculture given they use pesticides and synthetic fertilisers in their low rainfall farming practices. Some view it as too environmentally driven by the regenerative movement and from higher rainfall areas that do not have farms like theirs.

More novel practices and claims can be viewed sceptically, especially when ideas are coming from outside of their district from environments with more rainfall and fertile soils, and with different scale and enterprises. However, low rainfall growers are prepared to consider new science that builds healthier soils, preferring to see how that practice performs in their backyard before changing.

For the most part, majority of growers have made changes to their operations over the past 20 years to the new conventional agriculture, known as conservation agriculture, that aims to protect soils, conserve moisture, and enhance crop and pasture production.

Practices commonly used today include:

- Greatly reduced tillage: minimum till (single pass) or no-till (points or discs) sowing systems
- Controlled traffic: gps guidance has enabled more matching of wheel tracks and less over-lapping, reducing the tyre track footprint on paddocks and subsequent compaction risk
- Stubble retention: ungrazed or grazed for shorter periods than in the past to meet sheep nutrition requirements
- Away from continuous cereal cropping to more diverse rotations using grain legumes, sometimes canola and medic or vetch pastures.
- More diverse, multispecies pastures are sown to provide early feed and groundcover, high protein and energy forage for grazing, and build soil nitrogen, eg. cereal sown into regenerating medic, barley and vetch, or mixes of grains grown on farm including cereals, legumes and canola or tillage radish.
- Integrated mixed cropping and livestock enterprises are managed to value add to by-products, maximise income depending on commodity prices (eg grain used for lamb production), utilise weeds, manage herbicide resistance, canopy management and rotational benefits.
- Rotational grazing to manage feed quality, plant regrowth, feed utilisation and nutrient cycling and importantly groundcover.

Whether the grower regards themselves as regenerative or not, they are keen to keep learning about building healthy soils and what is achievable in their environment. Having access to regionally specific information that addresses their Mallee rainfall, soil types and seasons, and peer to peer learning, is most important to avoid making costly mistakes. Further knowledge is needed around understanding the influence of seed source and seed treatments, desirable pasture species including native browse species.

The Mallee opportunity for more regenerative systems

Regenerative agriculture aims for a whole of farm system, integrated management of soil, water, vegetation and biodiversity, that becomes more efficient in the use of the natural resources. Rather than accepting sustainability that maintains current resources, it aims for regeneration to restore what has been lost from the natural environment due to agriculture, or to enhance the state of a resource from its current state.

In the absence of an agreed global definition like conservation or organic agriculture has, proponents of regenerative agriculture agree on general principles to achieve regeneration, and have developed their own sets of system practices that focus on improving soil health and farming ecosystems.

The regenerative system practices vary in the emphasis of what is most important for enhancing different farming system functions such as microbial functions and interactions, plant disease management, soil moisture and nutrient cycling, and livestock health and management. However, the response of different environments to these suites of assumed regenerative practices, with different natural resource and seasonal weather conditions such as the Mallee, will also vary.

While not necessarily referred to being regenerative agriculture at the time, farmers in the low rainfall Mallee regions have been modifying their farming systems to being more regenerative for the past 30 years. Together field researchers, advisors and early adopters have trialled and modified conservation agriculture practices, which have seen broadscale adoption.
We have learnt that in lower organic matter soils of the lower rainfall region, management is the key driver of managing or improving biological functions. Management effects the populations of microbes in the soil, and the type of microbes and their functional capacity.

These management practices are also recognised as regenerative agriculture practices including reducing tillage, retaining stubble and ground cover, growing more biomass and increasing crop diversity.
Changes to Mallee farm practices have included:

- Reduced cultivation with zero tillage or minimum tillage/direct drilling using points or discs. Mechanical fallows have been replaced by no-till herbicide fallows (brown manures), protecting groundcover.
- More controlled traffic using gps guidance for machinery
- More legumes grown for crops and pastures
- Stubble and residue retention: stubble may be grazed, but burning is now limited, legume crop brown manures
- Improvements in crop nutrition: using soil and plant tests, better matching of nutrient rates to potential crop requirements, including type and timing of fertilisers
- Improvements in pasture management in nutrient, pest and weed control to maximise biomass
- Winter cover cropping using vetch, regenerating legume pastures and sown mixed species pastures
- Changes in grazing practices: rotational grazing and meeting livestock nutrient requirements, use of containment
- Soil amendments to reduce compaction and increase clay content for moisture retention and nutrient benefits including deep ripping, clay spreading, delving and spading
- Timing of operations to enhance natural capital, farm and labour resource use

Low rainfall, low soil carbon Mallee regenerative systems differences to higher rainfall regions

- Crop and pasture fertiliser and pesticide inputs: Under conservation agriculture systems, synthetic fertilisers and pesticides are needed to maintain soil biology, and optimise crop production and profitability. Synthetic fertilisers are the most economic way to apply nutrients for plant production and to replace nutrients exported by agriculture. Legumes fix soil nitrogen, but other nutrients must be replaced. Herbicides are needed for weed control to conserve soil moisture, remove weed competition in crop and produce a quality product free of weed seeds desired by grain markets. Healthy crops grow more biomass, returning more carbon to the soil that maintains soil biology needed to breakdown herbicide residues. Pure organic systems are not viable in low rainfall regions.

- Astute grazing management of livestock: Livestock grazing must be very carefully managed to remain regenerative in low rainfall systems. Carbon inputs of low rainfall Mallee grazing systems have been measured to be 2-3 times lower than in full stubble retained system. It is important that winter pasture biomass is supported agronomically and optimised using rotational grazing management, so that at least 50-70% groundcover can remain to protect soils over summer and return soil carbon to support soil biology.
- Achieving crop diversity and living roots: Mixed cover crops provide feed for livestock at different times as they grow through the season, and create more soil diversity than single monocultures. However, they are however more difficult to manage weeds, will have lower nitrogen fixing capacity than a pure legume stand, and are hard to match maturities when balancing peak biomass with a useful termination time that prevents seedset (unless you are wanting it to regenerate for another pasture year). In the low rainfall zone, the biggest bottleneck to productivity and maintaining soil health is availability of water. Growing another crop after the main winter crop affects availability of water for the next winter crop, compromising the total biomass production across a year and potential summer groundcover, and main income earner from winter crops.
- We don't yet fully understand the long term impacts of deep mechanical soil disturbance and manure amendments to applied to Mallee soils.
- Biological additives vary widely between products and results in the field, often with no effect, but there are large investments occurring into inoculants for seed and crops so it is a field to watch.

For the low rainfall, low carbon soils in the Mallee, regenerative agriculture is supported by systems that optimise biomass grown for soil carbon and soil biology by:

Improving soil health

- **Minimise soil disturbances:** minimum or no-till practices that limit soil disturbances to help increase water retention, nutrient cycling, and retaining topsoil.
- **Keep groundcover:** keep the soil covered with vegetation and natural materials through stubble retention, brown manuring, winter cash and cover crops, and pastures to protect the soil from wind and water erosion, reduce soil surface temperatures and evaporation. Place livestock elsewhere, or sell livestock before groundcover is compromised.
- **Focus on living roots in the soil during the growing season:** to help stabilise the soil, keep soil biology active, retaining excess water and nutrient runoff. Use winter cash crops or forage cover crops, annual and permanent pastures (where able), shrubs and trees. Conserve moisture over summer for winter production.
- **Encouraging natural biological cycles and nutrient transfer:** by supporting plant growth and subsequent carbon inputs with adequate nutrition using fertilisers and composts, rotations including legumes, brown manure legumes, or under-sowing of legumes, and stubble retention.

Increasing biodiversity

- **Increase plant diversity:** helps build healthy soils with active microbial function, and has ecosystem benefits for wildlife and pollinators. Use diverse winter crop rotations,

intercropping (sowing two or more crops together, or in close proximity), pasture cropping (winter crops sown into perennial summer active pastures), multi-species cover crops and borders planted for bee habitat and other beneficial insects. Invest in revegetation such as fodder shrubs and timbered areas, and exclude or ensure these areas are strategically grazed.
- **Integrate livestock:** use carefully monitored grazing management. Rotationally graze with higher animal densities to reduce selective overgrazing, camping and wastage, and enable plant regrowth and recycling of nutrients, building biodiversity and forage quality. Graze stubbles lightly, and use standing crops and containment areas during summer.

Integration of whole farm resources

- Holistic farm management: strategic whole system and business decision making, integrating enterprises and people.

Continuing and increasing the use of practices that improve soil conservation, improving physical, chemical and biological properties on the surface, conserve more water, reduce runoff and erosion, and grow healthier and more resilient plants and animals, will continue to build more regenerative agriculture systems in the Mallee.

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T: +61 (8) XXXX XXXX
E: MR.LandscapeBoard@sa.gov.au

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