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Building the soil carbon sponge at Murray Wells Farm, Tambellup, Western Australia

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Department of Primary Industries and Regional Development
GOVERNMENT OF WESTERN AUSTRALIA

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Prepared by Wendy Bradshaw

Our farm

Summary

Name: Peter and Wendy Bradshaw

Property: Murray Wells

Location: 25 km west of Tambellup, Western Australia

Size: 1,200 ha, of which 1,000 ha are arable

Rainfall: Average annual is 450 mm; growing season (April–September) is 314 mm (30-year average)

Enterprises: Barley, oats, Merino sheep and prime lambs

Usual rotation: Crop, pasture, pasture, pasture

Effective areas: Crop 30%; pasture 70%

Sheep numbers: 3,200 in winter, 2,100 in summer; 91% lambing at marking

Agriculture practices: Regenerative agricultural practices for more than 25 years

Our farming philosophy

We view agriculture as an ecological enterprise – one that includes ourselves as part of the ecosystem and believe diversity (in a personal and biological sense) is fundamental to the growth and wellbeing of the farm ecosystem, enterprise and community of which we are a part.

Soil biology, grazing animals and profitability underpin management decisions for our farm property.

We try to limit the 'leakiness' of our farming operation so that inputs stay where they are used and don't harm the broader landscape – creating the soil carbon 'sponge' is fundamental to this.

Landscape, soil and vegetation

The landscape of 'Murray Wells' farm is mostly moderately undulating with clearly defined valleys and creeklines. Soil on mid to upper slopes is commonly a moderately drained sandy duplex, often with ironstone gravel, grading mid-slope to well-drained sand over gravel over clay, which is more than 30 cm below the surface. Native vegetation found on these soils includes wandoo (*Eucalyptus wandoo*), marri (*Corymbia calophylla*), rock sheoak (*Allocasuarina huegeliana*) and jam (*Acacia acuminata*).

Shallow sandy or loamy gravelly topsoils overlying cemented laterite are a dominant feature on the crests of low hills and rises. Associated native vegetation includes mixed mallee species, marri and wandoo. Jarrah (*E. marginata*) occurs on sandy gravel.

Flooded gum (*E. rudis*) and, less commonly, flat-topped yate (*E. occidentalis*) are found on poorly drained duplex soils (clay is less than 30 cm below surface) low in the landscape.

Red to brown loamy soils that grade to clay with depth are associated with dolerite dykes and granite loam. Wandoo and brown mallet (*E. astringens*) most commonly feature on shallow topsoil, and flooded gum features on perched watertables.

Our principles of regenerative agriculture

1. **Maximise soil cover** to protect soil from heat, cold, wind and rain, and to increase soil moisture and biological activity.
2. **Maintain living plants** to feed soil biology and minimise soil disturbance to build the soil carbon sponge.
3. **Integrate livestock** by using planned grazing to maximise nutrient cycling and the capture of sunlight by pastures.
4. **Reduce and buffer or eliminate synthetic inputs** (chemicals and fertilisers) to minimise negative impacts on soil biology and the ecosystem.
5. **Encourage biodiversity** to create stable and resilient landscapes and production systems.
6. **Value diversity of opinions** (within shared visions and goals) and use these as an opportunity for mutual learning and innovation.
7. Where possible, **seek consensus rather than compromise** to maintain the energy and commitment of all involved.

Maximise soil cover and maintain living plants

Through attending many workshops, much reading and decades of practical experience, we have learnt the importance of maximising soil and living plant cover to keep the ground cool and biologically active in summer – groundcover reduces the risk of soil loss through wind or water erosion, reduces soil surface temperature and evaporation, and supports greater microbial biodiversity. This fundamental message also came from workshops by internationally renowned soil and plant biologists and regenerative agriculture practitioners including Allan Savory, Christine Jones, Walter Jehne, Maarten Stapper, Rick Bieber and Nicole Masters.

The strategies we use to maintain living plants and maximise soil cover for livestock include planned grazing, summer cover cropping and perennial plants. Summer cover crops (for example, sunflowers, millet, tillage radish and lablab [Figure 1]) are sown in spring into annual pastures that need to be rejuvenated to maintain as many living plants and as much groundcover as possible year-round. We dropped lupin and pea monocultures from the cropping program because they leave the ground too bare in summer and thus susceptible to erosion.

Figure 1: Summer cover crop including sunflowers, millet and tillage radish

The summer-active cover crop species we chose had to be very drought tolerant because these species continue to feed the soil microbes through their root exudates after annual pasture species have died. This helps build soil carbon and improves the water-holding capacity and nutrient supply of our soils (Frish 2019; Masters 2019).

Our goal is to maintain living plants as much as possible to support thriving populations of beneficial and symbiotic soil microorganisms, which together build the soil carbon sponge. We've heard conflicting views on whether multispecies cover crops or summer-growing plants reduce soil moisture at the beginning of the following growing season. However, we understand that increasing the period that green plants are in the soil will increase soil organic carbon, thus enabling the soil to store more moisture in the longer term.

Cover crops are also a source of green feed over the summer–autumn feed gap. Our observation is that cover crops have the potential to at least double the carrying capacity of the pasture that follows, especially in paddocks dominated by Guildford grass. We now also realise that Guildford grass is an indicator of compacted, bacteria-dominated soils. In summer 2019, we had our millet and sunflower roots examined under a microscope. These roots showed mycorrhizal fungi associations, indicating their role in maintaining populations of fungi that help with soil aggregation (the opposite of soil compaction; Figure 2).

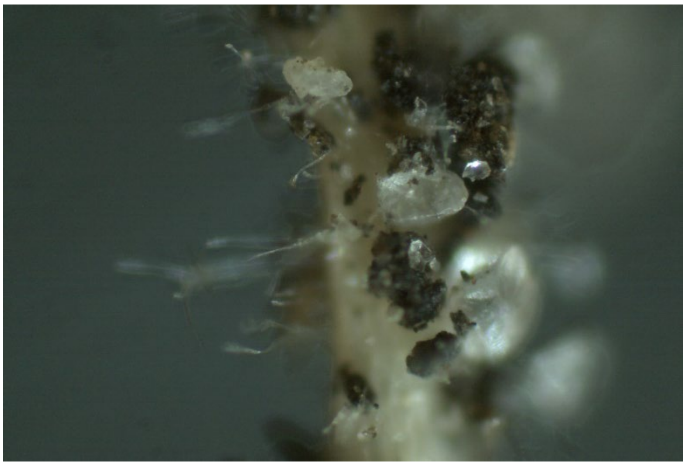


Photo: Louis Poiron, Australian Mineral Fertilisers, December 2019

Figure 2: Clear/white hairs are the mycorrhizal fungi attached to the root of a millet plant

We sow summer cover crops by spraying out pasture paddocks early enough in spring to ensure sufficient soil moisture remains. We then graze those crops in summer–autumn when green feed from annual pastures is almost non-existent. Summer–autumn rainfall determines the timing and duration of grazing of the summer crops – we graze for a period of days when the crop is well established and take the sheep out before it is overgrazed (i.e. eaten down close to the base) to allow the crops to recover before being regrazed.

Integrate livestock

Grazing animals (sheep, in our case) play a critical part in our regenerative agriculture approach. Our cropping program no longer includes wheat because sheep use oat and barley stubbles more efficiently, and the stubbles are denser and provide better groundcover than wheat.

Sheep husbandry is a priority for us – our lambing percentages are good and our wool is high tensile. Our wool broker tells us our wool always gets good support at auction because it is very sound and processes well.

We have established perennial pastures on about 100 ha of land prone to waterlogging, including hillside seeps. Alleys of woody fodder shrubs such as tagasaste, saltbush and *Acacia saligna*, and small native trees such as *A. acuminata* (jam tree) and *Casuarina obesa* (swamp sheoak), are integrated with the perennial pastures. *Acacia saligna* is a fast-growing, short-lived (about 10 years) shrub and therefore is only a short-term feed and shelter source for stock. Saltbush needs time to recover sufficiently between grazings or it will be killed by overgrazing. Alleys provide shelter for stock, add biodiversity value, and use water in the paddocks prone to waterlogging (Figure 3, Figure 4). The bushes and trees were planted as bare-rooted seedlings using a Chatfield tree planter, which scalps, rips and direct seed or plant seedlings in one pass.

Figure 3: Mixed perennial grasses and alleys of *Acacia saligna*, jam wattle (*Acacia acuminata*) and swamp sheoak (*Casuarina obesa*)

Figure 4: Mixed perennial grasses and alleys of old man saltbush (*Atriplex nummularia*), and swamp sheoak (*Casuarina obesa*) in the background

Until 2019, we cropped annual pasture paddocks for 2 to 3 years, then grew pasture for 3 years. From 2019, we transitioned to 3 years in pasture then 1 year in crop. We manage our pasture paddocks to maximise groundcover and enhance the soil carbon content of the farm.

In 1998, we completed a course in holistic management which changed our perspective (Savory Institute n.d.). One key change was understanding the importance of groundcover and animal impact in sustainable grazing systems.

The Savory method advocates that animal impact is needed to flatten standing biomass onto the ground so that the microbes excreted by the animals and those within the soil can recycle nutrients (and the carbon held in the biomass) back into the soil. This management process, which is designed to maximise groundcover and animal impact, is called planned

grazing. Our aim is to practice planned grazing by controlling grazing density and the time animals spend in each paddock to maximise pasture growth and recovery rates.

Implementing a planned grazing system required us to add a lot of fencing to make paddocks smaller, which means we graze at high densities for short periods of time with the aim that the paddock is grazed evenly and then sheep are moved to the next paddock. More paddocks allow longer recovery periods between grazing. Because we split ewes into smaller mobs for lambing and don't put them back with their original larger flock until after marking, we lose a lot of potential pasture biomass production because there are fewer livestock to flatten the biomass back onto the ground and enable nutrients to recycle more quickly. But we found lambing losses in larger flocks were too great to leave ewes and lambs in with the others.

When spring is very short, we prefer to reduce animal impact over summer by splitting ewes into mobs of around 400, and each mob has a cell (i.e. a number of allocated paddocks) in which they move. Smaller mobs are also more manageable following consecutive dry seasons (such as that experienced in summer 2019–2020) when water availability is constantly being managed.

We have established 2 'hospital paddocks' of native plant species, based on the work of the Enrich Project (Future Farm Industries CRC 2014). These paddocks help provide autumn feed that has proven health benefits for grazing stock.

Reduce and buffer or eliminate synthetic inputs

Cropping has been a roller-coaster ride of experimentation for us, as we tried to reduce or eliminate synthetic fertilisers. Around 2002, we changed to mineral-based fertilisers (which do include some synthetics) and varied their application rates over the next 10 years. From about 2010, our fertiliser input rates have been very low.

In 2012, we purchased a compost extractor and built a liquid injection system into our tine seeder. Since then, compost extract has been the backbone of our liquid biological inputs, while also experimenting with other biological stimulants, including worm juice and liquid fish. We add humic or fulvic acid to all soil and foliar applications. From 2013, we fluctuated between synthetic fertilisers and a range of mineral-based fertilisers, using variable rates and achieving variable results (Figure 5).

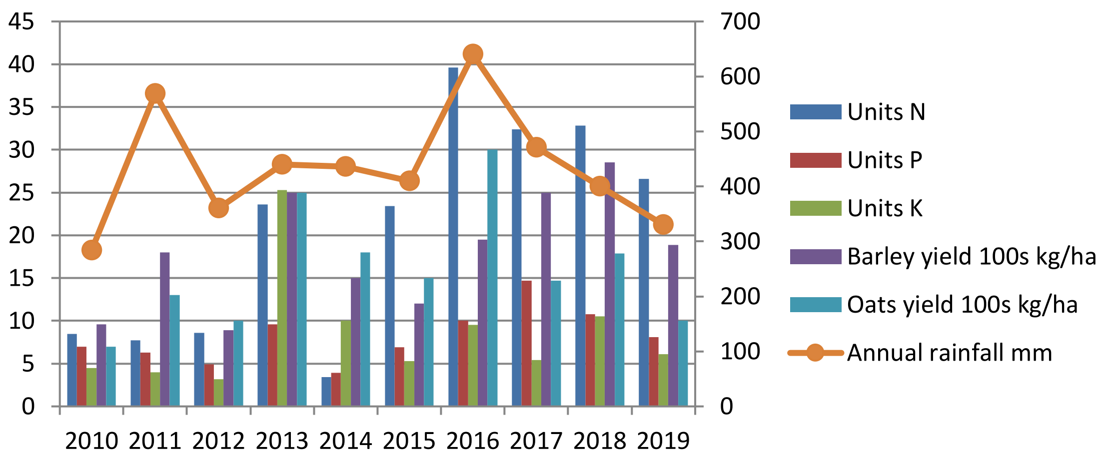


Figure 5: Oats and barley yields on Murray Wells farm in relation to annual rainfall, nitrogen (N), phosphorus (P) and potassium (K) inputs, 2010–2019

In 2014, we had a prototype disc seeder built (with coulters and liquid injection) that could do polycropping (Figure 6). In hindsight, we transitioned to a biological approach too quickly, without addressing the key limitations preventing beneficial (including symbiotic) soil fungi and bacteria to flourish.

Figure 6: Filling the prototype seeder with liquid, seed and fertiliser (June 2019); the seeder is designed for polycropping and has coulters to create tilth under the seed

We used the prototype seeder to sow field peas and canola (Figure 7). But we found it was too difficult to separate the seed of both crops without damage, making the final product difficult to sell. Another issue was finding paddocks that were 500 m away from the previous crop to prevent the spread of black spot on peas. The current recommendation by Dr Christine Jones (soil ecologist, personal communication, February 2023) is that canola, oats and faba beans are good companions because their different seed sizes make them easier to sort.

Figure 7: Peas and canola were grown as a polycrop in 2014

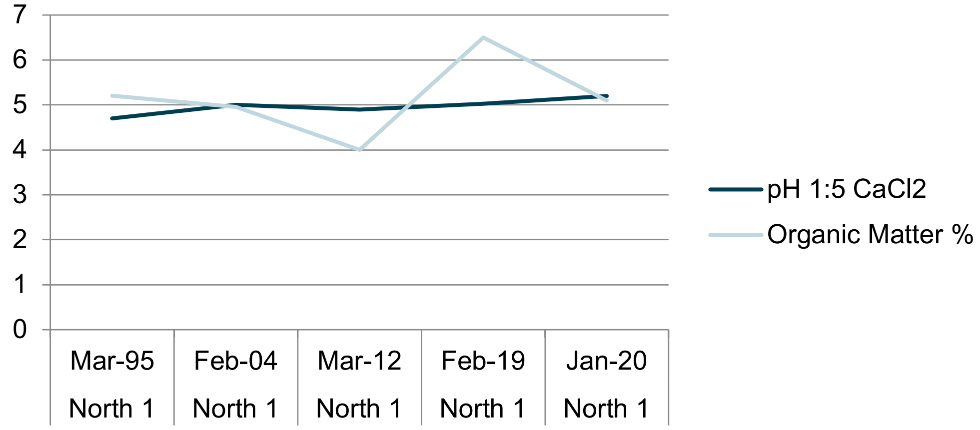
A successful biological or regenerative approach relies on the beneficial soil microorganisms doing a lot of the 'heavy lifting' in providing plant nutrition. The soil fungi create the macro-aggregates that form the soil carbon 'sponge' (Figure 8), which is necessary for creating good soil structure (providing air spaces), building soil organic carbon, creating suitable habitat for free-living nitrogen-fixing bacteria, and increasing water and nutrient retention. Tillage can reduce soil aggregation, and aggregates in sandy soils are highly fragile because there are few clay particles to hold them together (Masters 2019). Therefore, we focused on minimising soil disturbance, providing food for soil organisms as much as possible (e.g. by maximising living plants for as much of the year as possible), buffering chemical inputs with a carbon source, and sowing crops with biological stimulants from a range of sources.

Figure 8: Soil aggregates adhering to roots of an oat plant dug up mid-October 2019. These aggregates, created by mycorrhizal fungi, yeasts and bacteria, create a well-aerated, permeable soil structure and stable soil organic carbon (or soil carbon sponge)

As we understand it, too much synthetic fertiliser suppresses the plant root exudates that feed bacteria and drive nutrient transfer systems (nature doesn't squander energy), and these exudates can't do their job until conditions are suitable for them to flourish.

At the time, we didn't understand that key limitations must be dealt with before the microbiome can feed the crop effectively. But it is now evident there was no way we could just drop the synthetics and expect to grow a decent crop. Firstly, the free-living nitrogen-fixing bacteria that we would rely on take time to build up and so we needed to reduce nitrogen inputs gradually (Jones 2014). More recently, we came to understand that to get good results from compost extracts and teas, you need to have at least 50% base saturation of calcium (calculated as the percentage of cation exchange capacity occupied by calcium cations) (Masters 2019). We have also learnt to always feed the fungi when applying lime (Masters 2019). In 2020, after examining the soil test results, we used a labour-intensive process to concoct a calcium and fish brew containing around 20 kg/ha calcium hydroxide (slaked lime),10 L liquid fish and 1 L/ha fulvic acid. Despite the calcium hydroxide being very dusty, we were able to apply it effectively through our boomless nozzle sprayer onto crops and pastures that were particularly low in calcium base saturation.

General trends from soil tests over the past 20 years or so indicate that soil pH and soil organic matter are being maintained within a similar range across the farm. Soil pH is more acidic than we would like (4.5–5.1 [$CaCl_2$]) and organic matter fluctuates between 4% and 6%. Soil organic matter appears to fall after cropping (Figure 9) and we are trialling different management approaches to address this. We have dropped canola from our cropping system because it is non-mycorrhizal.



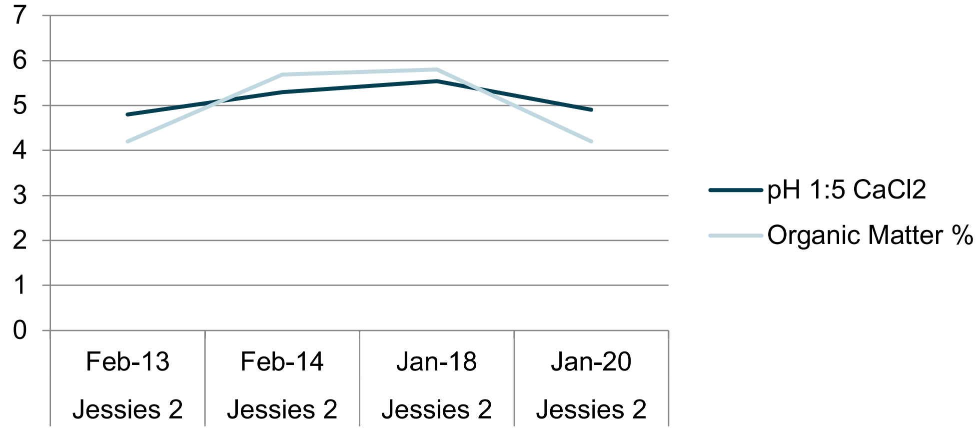


Figure 9: Soil pH and organic matter sampled in late summer/autumn in 2 paddocks (North 1 1995–2020 [top] and Jessies 2 2013–2020 [bottom]). Cropping years for North 1 were 1999, 2004, 2008, 2011 and 2019; and for Jessies 2 were 2011 and 2019

We believe that inadequate available phosphorus (P) has limited crop yields in our farming system, particularly on very gravelly soils in dry years, as indicated by lack of plant vigour and orange–purple colouring on lower leaves (Figure 10). Tissue testing of crops in 2019 confirmed that P was low.

Figure 10: Oat crop in a very gravelly paddock after an early spring cut off where lots of tillers were lost. The orange–purple colouring on the lower leaves indicates phosphorus deficiency (photo taken early November 2019)

We didn’t apply superphosphate for years because we were advised in 1995 that our soils contained enough P from previous years of oversupply. The data show that for North 1 (a very gravelly paddock), the total P hasn’t reduced by much, but the available P has reduced considerably (Figure 11).

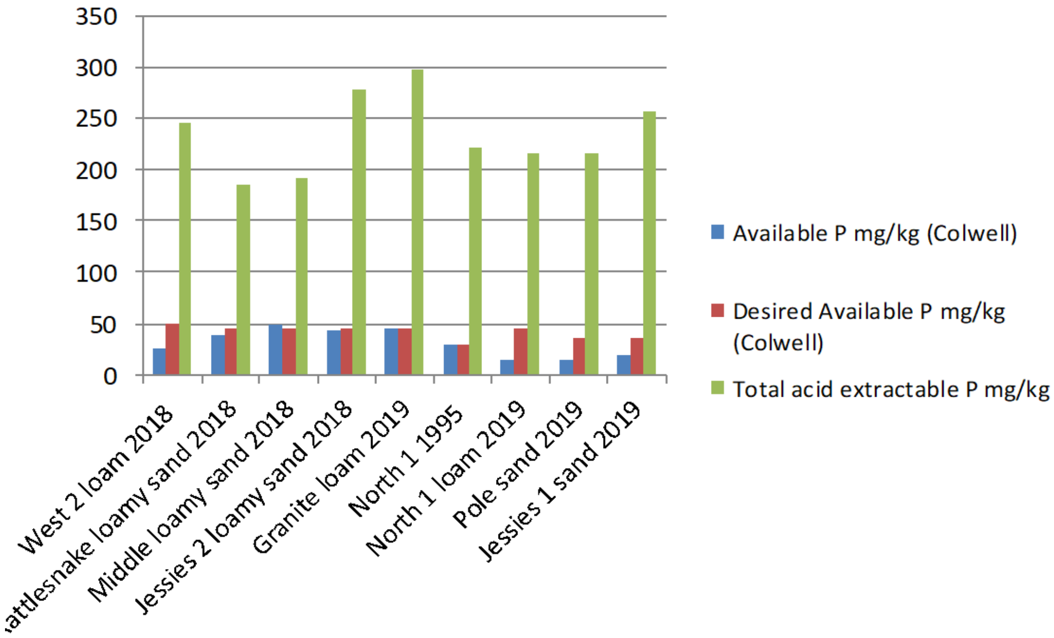


Figure 11: Available and desirable levels of available phosphorus (P) in paddock North 1 in 1995 when regular applications of superphosphate were still being made, compared with levels in other paddocks in 2018 and 2019

We understand that in a regenerative system, mycorrhizal fungi make P available to the plant. In 2020, we implemented a trial in 2 adjoining paddocks (Joes 1 and Joes 2), each containing two 10 ha treatments: one comparing a 90% citrate soluble P guano-based mineral fertiliser with a conventional synthetic fertiliser (Joes 1); the other a blend of 65% monoammonium phosphate (MAP) and guano compared to conventional synthetic fertiliser (Joes 2). The total P in the trial paddocks before cropping in 2020 was 147 mg/kg (Joes 1) and 210 mg/kg (Joes 2).

Results showed that the synthetic fertiliser produced the greatest yield in both treatments. The MAP and guano blend yielded about 84% of the yield of the synthetic fertiliser. The 90% guano citrate soluble P treatment yielded 50% of the synthetic fertiliser. Tissue tests carried out by CSBP showed sufficient levels of P in the leaf.

Phosphorus uptake was also correlated with plant weight. The amount of P taken up by the plant based on plant weight in the guano treatment was tiny (9%) and for the P blend mix was moderate (59%), compared to the amount taken up by the synthetic fertiliser.

The question arises as to what threshold levels of total P are required for the P in more mineral forms to be sufficiently taken up by the plant for higher productivity.

The biomass imagery of the 2 trial paddocks (available via CSBP's DecipherAg program) captured on 1 and 21 August 2020 shows the difference in plant density (measured using the Normalised Difference Vegetation Index [NDVI]; Figure 12). The synthetic fertiliser treatment produced a much higher plant density than the guano treatment (Joes 1, left paddock). NDVI is an index of plant density with a range from 0 to 1. DecipherAg uses a rainbow colour scale where red is low plant density and purple is high.

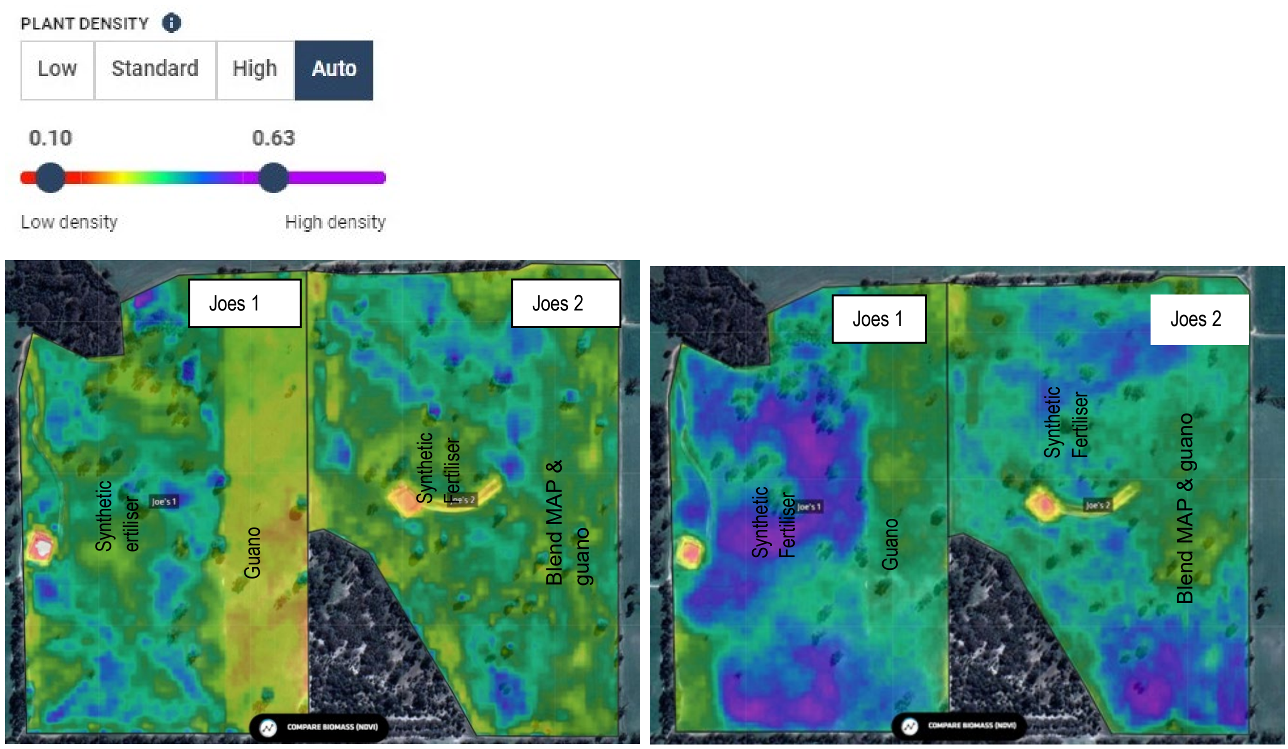


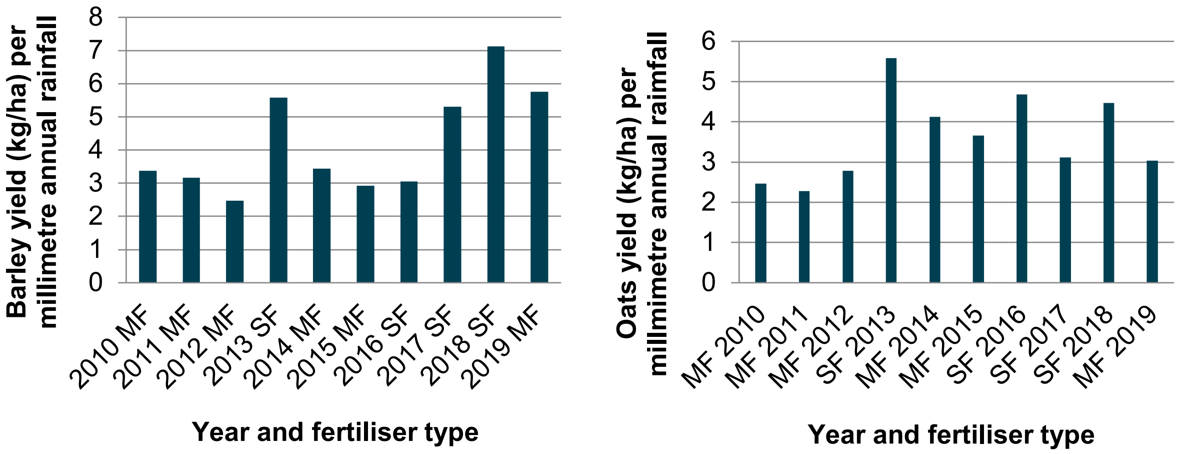
Figure 12: Biomass imagery of trial sites in paddocks Joes 1 and Joes 2 on 1 August 2020 (left) and 21 August 2020 (right)

Since undertaking this trial, some points have come to light following a presentation by Dr Christine Jones (personal communication, 10 February 2023) that may help to understand why the synthetic fertiliser performed better:

- Modern crop varieties are bred with luxury nutrient resourcing rather than reliance on microbial associations of mutual plant–microbiome feeding of liquid carbon in exchange for nutrients.
- The microbiome of the seed is what lives on the roots and foliage of the plant from which it is grown. Seed was treated with fungicide when cleaned – do not put any fungicide on the seed if relying on soil fungi to feed the plant! Seed was inoculated with zinc and biological stimulants (fulvic acid, vermicast) just before seeding. The advice is to not put any minerals on the seed because this stops the plant signalling to the microbiome to scavenge for nutrients to feed the plant.
- Microbial diversity is a key factor that determines soil fertility; however, synthetic fertilisers reduce microbial diversity. Plant functional diversity drives microbial diversity, and at least 4 different plant families are needed to get a diverse microbiome. Research from long-term trials (e.g. Jena Experiment 2017) has shown that sufficient microbial diversity results in higher productivity (including ability to suppress weeds) than under conventionally grown monoculture systems (see also Lange et al. 2022; Dietrich et al. 2023).
- Mycorrhizal fungi will share missing microbes between different plant families through their networked connections between plant roots. But in a monoculture, microbes will compete with each other through a positive feedback loop where a change in one direction causes additional change in the same direction. In this context, increased concentration of the same microbes leads to increased competition rather than cooperation where diverse microbial populations have different niches that provide different benefits to the overall community.

- Increased biodiversity leads to increased soil organic matter and speeds up the process of eliminating the application of nitrogen because the soil aggregation process is sped up.
- Nutrient acquisition occurs when there is a mix of species.
- Systems thinking is needed – you can't assume that what happens in a monoculture will happen in a polyculture.
- Multispecies crop harvest can be sorted by an optical sorter, which cost about $1 million.
- Test soil for nutrient totals – especially organic carbon, calcium, nitrogen and phosphorus – rather than available nutrient levels. Leaf tests are important to check adequacy of trace elements in the plant and any deficiencies should be addressed using foliar sprays in chelated form.
- Plants in a polyculture have stronger cell walls and thus are less susceptible to attack by sap-sucking insects.
- Test diverse cropping in a small paddock before expanding.

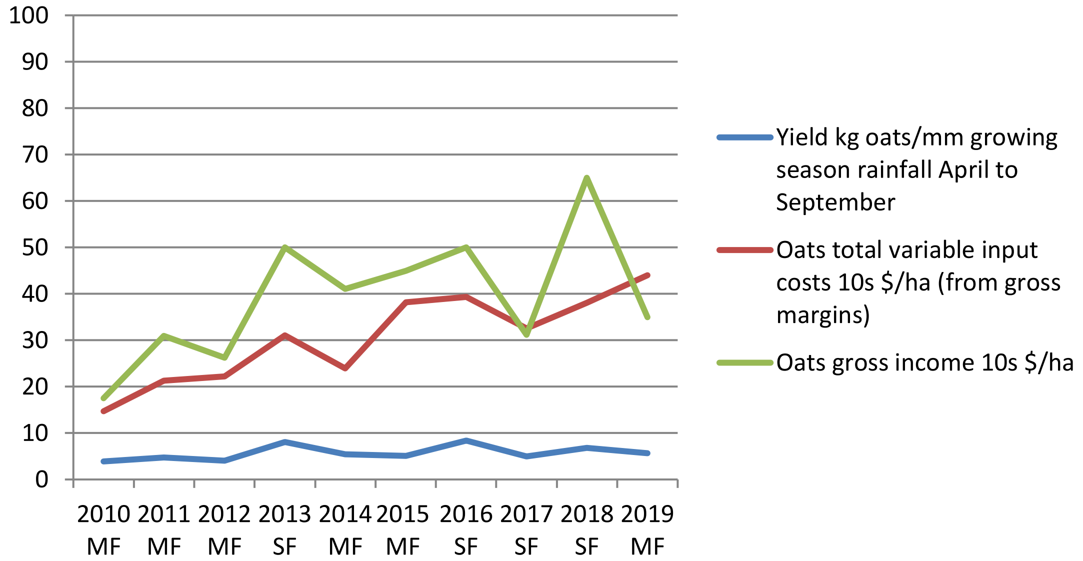
We examined the ratio between yield and both annual and seasonal rainfall. The results were similar, so we used annual rainfall to indicate the relevance of rainfall variability on yield in context of the years (2010–2019) when mineral-based fertiliser (consisting of a blend of mineral and synthetic fertiliser, hereafter named mineral fertiliser) and synthetic fertiliser were used to grow barley and oats (Figure 13).



MF = mineral fertiliser; SF = synthetic fertiliser

Figure 13: Relationship between barley (left) and oats (right) yield per millimetre of annual rainfall, 2010–2019

The ratio was then inserted into a graph showing total variable input costs per hectare compared to gross income per hectare for barley and oats (Figure 14). Generally, the years when synthetic fertiliser was used have the highest profitability and highest yield per millimetre of rainfall. But this was not always the case – in 2017, the oat crop (fertilised with synthetic fertiliser at highest rate of P [15 units] over the entire study period) had lower yield per millimetre of rainfall and lower profitability. Although we can't say the relatively high application rate of P was the reason, we weren't able to pinpoint any other reason for this crop's poor performance, except that it had a very dry start of only 8 mm of rain recorded in June. We wondered if the high salt content in the synthetic fertiliser could have sucked moisture out of the crop when the soil moisture was so low.



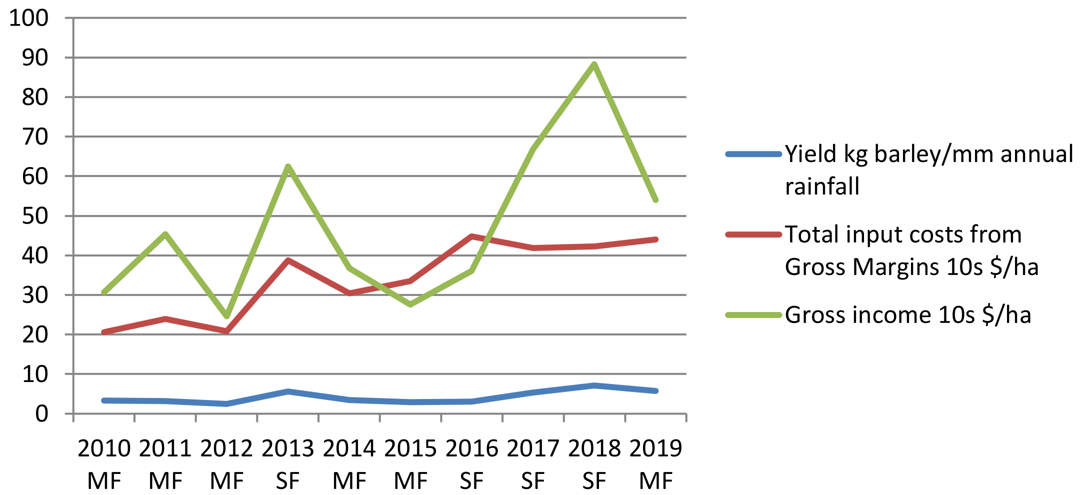


Figure 14: Yield per millimetre of rainfall, total input costs and gross income per hectare from gross margin analyses 2010–2019 for oats (top) and barley (bottom)

We still use herbicides for weed control but have dramatically reduced the number of applications. Herbicide resistance is not a threat because we're now only cropping every fourth year. We never use insecticides on pastures or cereals, and only use them on broadleaf crops if the survival of the crop is threatened.

In 2020, close monitoring of red-legged earth mite (RLEM) on germinating vetches revealed very low numbers (maximum number counted on a germinant was 3 RLEM). There was no sign of detriment to the germinants and no need to spray. This contrasts with the previous year when the germinating vetches were crawling with RLEM and spraying was necessary to avoid high losses. What did we do differently? We added a liquid calcium product at 9 L/ha and boron at 0.3 L/ha to our liquid inject solution at seeding time. The liquid calcium product was mixed with biological inputs (including molasses, fish, humic acid and compost extract) to support soil microorganisms.

We have no doubt our systems approach is taking us in the right direction and suggest that by addressing the low calcium and boron levels in the rhizosphere, we may also be addressing a key limiting factor: plant nutrition. Boron is closely linked to the uptake and efficient use of calcium in the plant (Incitec 2021). Calcium, boron and silicon (which we

have adequate levels of) increase the cell wall strength, thus creating a physical barrier to predation by pests (Dordas 2008).

Humic acid (in soil applications) and fulvic acid (with foliar applications) (both at 1 L/ha) are mandatory additions to fertilisers, herbicides and pesticides. Humic and fulvic acids provide food for microbes and help with absorption while buffering the negative impacts of synthetic inputs on the microbiome (Masters 2019).

We only use fungicide sprays when necessary and not as standard practice. We can now see that pickling the barley seed may have been a problem because we were relying on mycorrhizal fungi to form a symbiotic relationship with the barley plants. We believed we were buffering the pickle with biological stimulant seed dressings such as fulvic acid and worm leachate. We now understand that it doesn't make sense to use fungicides in the soil when we want to encourage beneficial fungi and we really don't know for sure how well the fulvic acid buffers the mycorrhizal fungi against the negative effects of seed dressing applied fungicides. We also put zinc in with the seed dressing but based on what Dr Christine Jones said at a recent presentation (February 2023), putting zinc in with the seed was also a problem because it stops the plant signalling process that tells the microbes to feed the plant zinc in exchange for liquid carbon.

Wendy was involved in the local grower group – the Gillamii Centre's cropping systems soil health project 2015–2017 – where everyone was surprised that, statistically, the most significant indicator of yield in 5 different cropping systems was available copper, closely followed by available P and then nitrogen inputs. Available zinc wasn't far behind. Most importantly, the cropping system with the highest soil organic matter also had the highest yield for the amount of P, nitrogen and potassium applied, and was the standout winner with the best soil health indicators overall, even though it was on a very gravelly soil (Bradshaw and Bailey 2018).

After participating in the soil health project, we understood the importance of trace elements. In 2018, we did sap tests on several crops and found levels of all trace elements, except copper, to be good. Consequently, we included liquid copper in a foliar brew. A subsequent sap test showed plenty of copper and we believe it really helped that crop.

An important goal for us, as a result of promoting healthy soil, is growing nutrient-dense food. This excerpt from Masters (2019:65–66) describes the vital role of fungi in growing nutrient-dense food:

> Plants do not exist in isolation. Ponder this for a moment, many plant vital functions are external to their body; they outsource essential functions to microbes that are responsible for immunity, nutrient and water availability. Their gut, kidneys and thermostat are outside of their bodies. If you consider the primary goal of soil management is to support an optimal digestive system, it is the fungi that supply powerful gut acids, vitamins, enzymes and minerals to fuel energy and health. Can you grow plants without soil and biology? Yes. Will they be healthy, have full genomic expression and be nutrient dense? No.

To date, we haven't tested produce for nutrient density and we'll need to take that step when we seek to market produce based on regenerative agriculture practices.

Encourage biodiversity

We have established about 100 ha of native biodiversity plantings across slopes, buffering watercourses and connecting remnant native vegetation. This forms a stable network for integrating livestock, crops, annual and perennial pastures, and multispecies cover crops. Restored areas help prevent soil erosion, improve the microclimate and absorb pollutants and nutrients (a second line of defence if anything escapes the soil carbon sponge where it was applied), and benefits the broader landscape beyond the farm boundary.

We believe that encouraging biodiversity is a great investment in the current and future wellbeing of the property. Even though invertebrates are at the bottom of the food chain (and above soil microorganisms), we need to maximise their habitat because they perform so many valuable roles in agriculture, such as pollination, biological pest control, soil aeration and waste decomposition, including dung (Saunders 2017).

Of relevance here is a 2019 global review by the University of Sydney, which 'found dramatic rates of decline that could lead to 40% of the world's insect species going extinct over the next few decades. However, some creatures – such as rats and cockroaches – like the change and are increasing'. Causes quoted in that review include 'loss of biodiversity, bioecological pollution and climate change'. The good news from this review was that the key to change is managing agricultural systems, including:

- diversifying vegetation in the area
- minimising the number of monoculture crops in an area
- increasing crop rotations
- using insecticides only when they are needed (Adams 2019).

It is interesting to note that:

- invertebrate numbers, not rainfall, determines vertebrate numbers (Majer 2004)
- organic matter is the major driver of invertebrate distributions (Judd 2004)
- heterogeneity (variety) of species and structure (upper, middle and lower storey), vertically (in height) and horizontally (across the landscape), is needed to maximise habitat for invertebrates (Bradshaw and Woodall n.d.).

Vertical and horizontal integration of diversity into the landscape has benefits for wildlife and is crucial for reducing the threat of fire on farms, as quoted from an interview with Professor David Lindenmayer (Adams 2020):

> The way we need to dampen wind speed in agricultural areas is actually to have shelterbelts and tree plantings in the right places [...] away from farm buildings in keeping with farm design is very important. Tree planting is a really important part of reducing fire risk on farms.

The aim is to improve habitat and connectivity for native wildlife, which in turn provides ecosystem services such as pollination, pest control, stabilised ridges and drainage lines, shelter for stock, increased evapotranspiration and therefore rainfall, reduced wind speed and fire threat, reduced waterlogging and salinity across the farm.

We have planted a variety of trees, shrubs, groundcovers, rushes and sedges to match, as far as possible, local vegetation communities using revegetation guides (Bradshaw and Woodall n.d.). We have also established a range of hosts for sandalwood plantations.

We have direct seeded or planted strategic sites along creeklines and near native vegetation with seedlings of mostly local plant species. Our revegetation efforts have stabilised creeklines and the salt scalds are retreating and commonly feature self-regenerating paperbarks and rushes.

Bit by bit, we have seen pockets of healthy ecosystem function returning.

Even though there is always more to be done, our restoration projects have made a huge positive difference to how the farm looks and feels, as well as increasing the farm ecosystem's resilience. We now see and hear bird species such as the grey currawong, which hasn't been seen on the property for decades, and we occasionally see western yellow robins. These indicators tell us that we have moved the farm ecosystem to a higher level of resilience.

This is not just a feel-good thing – we understand that the more we lose ecosystem services that nature freely provides to us, the more it costs us to try to fix the problem.

Value diversity

Our story wouldn't be complete without acknowledging the crucial role played in the last 10 years or so by our son Casey, his wife Amanda, and their family who have joined us on this journey of learning about regenerative agriculture and applying its principles. They are now establishing their own farm business on a property near Denmark, Western Australia, and we still provide critical support to each other.

Getting to this point is the culmination of a process of shared goal setting inside a shared explicit vision, goals and objectives, including workshops and regular farm meetings together to monitor progress and replan as necessary. We also meet each week to plan our work for the coming week.

The challenge of taking on regenerative agriculture in a time and place that doesn't have well-established science can be daunting and results in lots of frank and challenging conversations. We have learnt that difference of opinion is normal and common, but it can easily create conflict. The process of learning to value that difference – and see conflict as a challenge and opportunity for learning, not as a barrier – is crucial to healthy relationships and productive teamwork. It's been a long process, but we believe we're getting better at it with practice. We strive to listen for understanding and then find a solution that is better than any single opinion. This is the fertile space in which the possibility of innovation that empowers growth, in both a personal and business sense, arises.

Important learnings from our journey

- The key indicators of success are vibrant, healthy farmers, landscapes and soils, sustainable profitability and the production of nutrient-dense food.
- The most important thing we need to understand – the soil microbial diversity (microbiome) – isn't visible. Regenerative agriculture is all about managing to create optimal habitat for a thriving soil microbiome.
- The most important thing we need to do to achieve a thriving soil microbiome is generate and manage biomass where diversity and green living plants are key to feeding the soil biology and building soil organic matter.

- It is critical to understand the key interrelated physical, chemical and biological limitations to the creation of healthy, well-structured soils on your property.
- We now believe that a key limitation for us in quite a few paddocks is inadequate levels of calcium, which needs to be applied with fungi food such as liquid fish. Calcium is fundamental to getting the most out of our main biological input – compost extract. We also recognise the importance of ensuring adequate boron to enable the calcium to be used effectively by plants.
- With hindsight, we would not have included coulters with our prototype disc seeder because this created too much soil disturbance.
- Incorporating biodiverse windbreaks and protecting drainage lines with local native vegetation communities adapted to soil types and landscape positions provides stability and resilience to the farm landscape as well as a succession plan for declining native vegetation communities.
- Test strips or trials are important as an initial step to evaluate change and the benefits before jumping in and committing the whole farm to a new system.
- Ongoing monitoring and accurate records and observations is especially important for reviewing and assessing change over time.
- Our lifestyle and wellbeing have dramatically improved as a result of practicing regenerative agriculture, which is an approach to farming that aligns with our values. Economically, it has been challenging, with many ups and downs. It is important to immerse yourself and be constantly questioning whether you are addressing the key limitations to making the system work. It's not easy, but it is exciting! It is a constant journey of discovery involving collaboration with others for mutual learning and understanding.

Afterword

In 2021, we realised that we had earned long service leave and it was time to let Casey focus on his own property. We sold Murray Wells farm in spring 2021.

Continuing to pursue knowledge about how we can farm more regeneratively, Wendy now understands another key factor limiting crop yields is that crops are bred for yield and protein based on synthetic fertiliser inputs that suppress beneficial fungi and bacteria (Montgomery and Biklé 2022). These authors, who support the views of others identified in this case study (e.g. Dr Christine Jones and Nicole Masters), explain the important role these beneficial fungi and bacteria play in feeding the plant micronutrients, phytochemicals and more balanced omega 3 and omega 6 fatty acids that are then available in produce and nourish the livestock and humans that consume these products. If the plant doesn't have these or isn't fed them, they won't be in the food we eat, which has many implications for human health. However, markets generally don't value these micronutrients, phytochemicals and balanced fatty acids and unless the regenerative farmer seeks out special markets targeting nutrient-dense produce, no financial reward is paid for the health-giving properties of such produce.

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