Lower peaks and shallower troughs: financial implications from soil health principle adoption

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Executive Summary

Five principles for managing soil have been proposed to improve soil health: keeping the soil covered; plant species diversity; minimising soil disturbance; growing plants as long as possible; and livestock incorporation. Termed the five soil health principles, these principles aim to improve farming sustainability by minimising nutrient loss and facilitating nutrient cycling and farming system resilience. This study aimed to examine how implementing these principles would influence a farmer's profitability.

By keeping the soil covered, and minimising soil disturbance, farmers can improve water infiltration and aggregate stability, improving water use efficiency. But it also can increase frost risk, necessitate different and more expensive herbicide usage, and increase disease problems. Given the key influence of water availability in dryland agricultural areas, I would expect this to improve profit.

Increased diversity has long been known to improve yields through rotational benefits. There have also been many yield benefits (but logistical difficulties) associated with growing multiple crops at one time, such as vetch and canola. Some farmers have experienced yield improvements of as much as 30% as a result. Provided weeds are managed appropriately, this seems a possible way to increase farm profits.

Growing plants as long as possible is difficult to consistently make work when operating in a moisture constrained environment. Livestock incorporation can make profit out of growing plants not used for harvesting.

From economic analysis investigations, growers implementing these principles generally have lower costs and make lower gross profit, usually resulting in slightly lower net profit, but in a lower-risk enterprise. During poorer years profits can be similar or better where farmers adopt more of the soil health principles. By contrast, in the better years, conventional farmers have better profits.

If profit is your primary motive, farming conventionally may be higher risk, but a more profitable method, especially in good seasons. However, farming enterprises adopting the soil health principles appear lower risk, more resilient enterprises, with relatively better performance in the poorer years. Individual attitudes with regards to seasonal optimism, logistical management, risk management, and environmental altruism will also contribute to whether farmers adopt these principles or not.

Keywords: Soil Health, Profit, dryland, regenerative farming, mixed system

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Foreword

Farming, as with any commodity business, is a competition to produce the highest yield efficiently. This is underpinned by the economic theory where profit maximisation is the goal, over a short-term horizon. The flaw with this comes when a biological system interacts with this economic theory whereby short-term economic drivers rarely promote long-term sustainability.

Methods that improve long-term sustainability are critical for ongoing food production to maintain our very high standard of living. I like the ideals promoted by the soil health principles, but ultimately this needs to be financially sustainable. In my area (Western Australia), there are a number of growers that have promoted this type of agriculture, that are no longer farming. Generally, this is for non-financial reasons, but I cannot help wondering whether that is part of the equation. Hence, I have chosen this study topic: examining the financial implications of implementing the soil health principles.

I hope this report is of value to anyone, especially farmers, considering implementing the soil health principles. There are so many factors when considering changing farming practices, so I wish the best of luck to anyone who does.

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Abbreviations

Ac	Acre
AP	Alternative Practice
C	Carbon
CA	Conservation Agriculture
CV	Coefficient of Variation
DSE	Dry Sheep Equivalent
EBITDA	Earnings Before Interest, Taxation, Depreciation and Amortisation
G	Grams
Ha	Hectare
Kg	Kilograms
L	Litres
LFB	Land Family Business
LTAR	Long Term Agroecosystem Research
mL	Millilitres
mm	Millimetres
NSW	New South Wales
PP	Prevailing Practice
RA	Regenerative Agriculture
SA	South Australia
T	Metric tonne
USDA-ARS	Agricultural Research Service of the United States Department of Agriculture
WA	Western Australia

Objectives

The primary aims of this investigation were to:

- Investigate how applying soil health principles in a semi-arid Western Australian environment changes farm profitability.
- If profitability changes, identify how it changes and what factors drive the change.

Introduction

Our current civilisation and its prosperity can only be sustained with adequate food production by a viable agricultural industry. Many components contribute to a viable agricultural industry; one of which is soil fertility. Changes in soil fertility are governed by soil management practices. Stika (2016) proposed that the implementation of four soil health principles: 1) less soil disturbance; 2) increased plant diversity; 3) living roots as much as possible; and 4) keeping the soil covered would improve soil fertility by building soil, restoring water and nutrient cycles while providing a habitat for soil microorganisms. These principles encompass Conservation Agriculture (CA: Goddard et al., 2008). More recently a fifth principle has been added; livestock incorporation. The Groundswell group in the United Kingdom consider the implementation of some or all of these principles to be Regenerative Agriculture (RA). The aim of these principles is to build soil fertility to sustain food production over the long term.

A farming business combines technical elements, such as animal, crop and soil management, with human and economic elements (Malcolm et al., 2005). Interactions between each element can range from antagonistic to synergistic, along with each farm business manager having their own strengths and weaknesses. These factors contribute to individual farm business performance. Operating within an economic framework that encompasses customers, suppliers, non-agricultural economic sectors, institutional and political factors amongst others, farmers must determine how they optimise current return on capital and where capital is best invested to improve future returns (Malcolm et al., 2005). Being a commodity production business, farmers strive to produce their commodity most efficiently. Scale is a large factor in this, and over time, the number of farms has decreased as they expand. The farmer that can pay debt off quickly and efficiently can purchase more land to assist further expansion of the business.

Managing soil fertility to ensure farm profit is sustained in both the long and short term is a key consideration for all farm managers. Changing farm management practices, specifically soil management practices (for this report) is considered risky because the current methodology has created the current financial position. Implementing the five soil health principles is considered by many to be a more environmentally sustainable method of farming. But how will implementing these principles change the financial position of farmers choosing to incorporate them? Investigating this is the aim of this report. This report will focus on the short-term financial implications of implementing these soil health principles on broadacre focused cropping enterprises. This report will not consider any profitability changes to a farming enterprise because of product marketing changes associated with compliance to standards of a certification body (e.g. Biological Farmers of Australia, Wildfarmed (UK)). Changes in profitability associated with carbon are also not considered as part of this report.

Total Soil Cover

Total soil cover is where the soil is completely covered by organic matter (Figure 1). Switching from low soil cover farming to a high soil cover farming system affects the soil properties and farming system in many ways (Table 1). These effects have varied impacts on profitability. The aim of this chapter is to discuss what physical, chemical and biological properties within the soil change, and investigate profitability implications of these changes.



Figure 1: Image showing soil completely covered with residue. (Source: Author)

Table 1: Pros and Cons of implementing total soil cover. (Source: Author)

Pros	**Cons**
Minimises evaporation	Decreased herbicide efficacy for some herbicides
Lessened soil compaction	Crop establishment can be more difficult
Improved soil structure	Increased frost effects
Decreased erosion	Nitrogen immobilization
Weed suppression	Increased disease risk

2.1 Soil Structure

Soil aggregate stability increases with increased crop residue retention (Karlen et al., 1994), allowing improved water infiltration and decreasing water erosion. The physical cover of the residue lessens compaction (Fuhrer, 2023), decreases evaporation and stops wind erosion.

In a Nebraskan (USA) growing environment, Jasa (pers. comm., 2023) suggests that standing stubble can save 50 mm (2 inches) ha^{-1} of water from their winter into their summer growing season, with more to be saved when harvested using a stripper front instead of a cutter bar. Further, Jasa (pers. comm., 2023) suggests improved water infiltration can potentially allow another 50 mm ha^{-1} (2 inches) ha^{-1} of water to be crop available, depending on rainfall patterns and timings. Assuming 50% efficiency and using the French and Schultz (1984) model of maximum water use efficiency of 20 kg ha^{-1} mm^{-1}, this would suggest an extra 1 t ha^{-1} of grain could be grown.

By contrast, in the Mediterranean-type climate experienced by much of southern Australia, stored moisture from the non-growing season will be primarily limited by rainfall, and then by the efficiency of moisture storage. One farm experiment on the Yorke Peninsula of South Australia showed on average 10 mm ha^{-1} more moisture stored where a stripper front had been used for harvest compared to a draper front (Pontifex, pers. comm., 2023).

2.2 Soil Organic Matter

Soil organic matter content is governed by organic matter inputs (can be applied, but generally grown in broadacre systems) balanced with losses (decomposition; Hoyle *et al*., 2011). Increasing soil organic matter can increase soil water holding capacity. Changing management practices can aid in shifting current soil organic carbon contents from current levels to potential levels (Hoyle *et al*., 2011). I visited multiple growers in Australia and USA that stated they were building soil organic matter. These growers used discs when seeding combined with a rotation of 3 or more species, incorporated legumes and fertilised with adequate levels of nitrogen fertiliser. Management practice differences were attributed to obvious soil colour and structural differences between soil samples collected from either side of the road, but managed by two different farmers near Regan, North Dakota, USA (Figure 2; Fuhrer, pers. comm., 2023).

2.3 Erosion

Any wind or water erosion leaves the soil less fertile because the finer, more fertile, particles are eroded more easily (Moore et al., 2004; Coles and Moore, 2004). How much this influences soil fertility in the short and long term will depend on the degree of erosion. Consequently, the degree of profit decrease due to yield reduction, increased nutrient application requirement, or shallower soil depth will vary with the amount of erosion.

2.4 Plant Emergence

Crop residue of about 5 t ha^{-1} is required to decrease weed emergence (Fuhrer, 2023), but can also decrease vegetative biomass and yields of canola (*Brassica napus*) by 56% and 23% respectively (Bruce et al., 2005). This is because the physical barrier increases the length of the hypocotyl (the stem between the seed and cotyledons) which limits early resource allocation to leaves and roots and increases disease susceptibility (Bruce et al., 2006a; Bruce et al., 2006b). A South Australian grower I visited, when implementing a four-year cereal, canola, cereal, legume rotation on a stripper disc stubble management system, was considering stopping growing canola (Zwar, pers. comm., 2024). After shifting to a

three-year wheat (*Triticum aestivum*), bean (*Vicia faba*), canola rotation, the impact has been minimised. An alternative could be to use residue managers when seeding to shift residue to the side (Figure 3), away from the emerging seedling.



Figure 2: Shovels from two soils (Regan, North Dakota) across the road from each other displaying soil type difference possibly due to contrasting management. The farmer with the soil with the improved structure on the right is adopting principles associated with conservation agriculture. (Source: Author)



Figure 3: A residue wheel used to move soil cover that can impede seedling growth (Source: Author)

2.5 Temperature

Residue soil cover provides insulation to lessen temperature rises associated with long and hot days during the summer growing season of the major grain growing regions of the Northern Hemisphere. By contrast, in southern Australia, the main growing season is winter. Colder temperatures seen on wheat stubble can reduce plant growth (Bruce et al., 2005), increasing time required to reach growing degree day thresholds for plant development, possibly delaying anthesis until a hotter, drier period of the season. Increased stubble load can also increase frost damage (Biddulph et al., 2019) possibly due to ice-nucleation-active bacteria, which produce a protein that increases the freezing temperature of water (DPIRD, 2020).

2.6 Herbicide influences

In a typical Western Australian broadacre farm, with a tyne seeder setup, trifluralin herbicide is a dominant pre-emergent herbicide used for ryegrass control. Total soil cover by crop residue minimises soil herbicide contact and facilitates organic matter binding, limiting trifluralin efficacy. Consequently, herbicide options are limited, and more expensive (Table 2). Total soil cover increases the likelihood of stubble blockages within the airseeder bar and typically, when a total soil cover system is adopted, growers change to a disc seeder setup (Figure 4).

Table 2: Prices for various common pre-sowing herbicides. (Source: Author)

Herbicide (Common Trade Name)	Cost	Rate	Hectare Cost
Trifluralin (Treflan®)	\$5.30 L^{-1}	2 L ha^{-1}	\$10.60 ha^{-1}
Prosulfocarb (Arcade®)	\$6.18 L^{-1}	2.5 L ha^{-1}	\$15.45 ha^{-1}
Pyroxasulfone (Sakura®)	\$200.00 kg^{-1}	118 g ha^{-1}	\$23.60 ha^{-1}
Flumioxazin (Terrain Flow®)	\$130.00 L^{-1}	125 mL ha^{-1}	\$16.25 ha^{-1}
Prosulfocarb and Metolachlor (Boxer Gold ®)	\$10.65 L^{-1}	2.5 L ha^{-1}	\$26.62 ha^{-1}



Figure 4: A disc seeder (left; located near Long Island, Kansas, USA) can seed through large amounts of residue compared to a tyne machine (right; located near Woodeaton, Oxfordshire, UK). (Source: Author)

Many farmers within WA report increasing ryegrass problems when retaining large quantities of stubble. The growers I visited have overcome this by increasing the proportion of broadleaf crops grown in the rotation. A rotation of beans, canola, and wheat has allowed good ryegrass control through the use of herbicide diversity (clethodim in beans, glyphosate in GM canola and pyroxasulfone in wheat). This shift to stubbles with a lower C:N ratio has also decreased hairpinning. Hairpinning is where discs push the stubble into the ground, rather than cutting through it. This can leave seed in contact with stubble rather than soil, causing seed rot or disease transmission.

2.7 Soil Invertebrates

Increased soil cover can provide a greater habitat for soil biology particularly mesofauna. Increased snail and slug damage has occurred on many farms I visited, since they adopted greater ground cover. Mollusc baiting was the primary method used to combat them, but one farmer suggested applying biologically based products to hasten decomposition of stubble, removing their habitat (Clayfield, pers. comm., 2024). It is unknown how the population of other invertebrates changes with increased soil residue cover.

2.8 Disease

Increased disease in crops has occurred with greater stubble retention (Cook and Haglund, 1991). To prevent disease, Langley, of Bordertown, South Australia sows his seeds deeper (Langley, pers. comm., 2024), to ensure the roots avoid contact with stubble and hence disease. He also rotates his crops in a three-year bean, canola, wheat rotation, which allows time for disease-hosting stubble to decompose prior to another crop of that species being grown again.

2.9 Summary

Changes in soil properties caused by the implementation of total soil cover by residue (summarised in Table 3) suggest that there are more factors that cause profit to decrease than increase. This is possibly why few growers have adopted the total soil cover principle in southern Australia. Cost increases caused by the need for baiting and increased herbicide costs are tangible and needed annually. By contrast, the factors increasing profit, such as water retention, are far more difficult to calculate, as they are incremental, and benefits may be considered subjective when assessing at a farm scale. Erosion can be largely restricted when ground cover is greater than 60%.

Table 3: Profitability changes caused by increased soil cover. **(Source: Author)**

Properties changed by total soil cover	**Profit Increase or Decrease**	**Other Comments**
Aggregate stability and Water Infiltration	Increase	More water retained will increase profit, but is influenced by rainfall timing and quantity
Organic Matter Content	Unsure	Scientific research says soil organic C is unlikely to increase, but farmers are saying it is, which would increase profit
Wind and Water Erosion	Increase	Decreased erosion assists keeping finer more fertile particles in the soil profile
Canola hypocotyl length decrease	Decrease	Decreased canola profitability will make the rotation less profitable
Frost Incidence	Decrease	Decreased temperature on stubble can exacerbate frost incidence, potentially lessening yields
Herbicide change	Decrease	Facilitates the shift to more expensive herbicides
More snails and slugs	Decrease	Managed by increased mollusc baiting
More disease	Decrease	Managed by changing rotation

Plant Species Diversity

In agriculture, plant species diversity benefits are widely known. The Arikara and Mandan tribes in North Dakota grew corn, squash and beans together to utilise synergies, from the tall corn, leguminous beans, and ground covering squash. In forestry, tree species diversity can promote forest productivity (Fichtner et al., 2018). In modern cropping, generally one plant species is grown at a time. Monocropping allows seeding depth, herbicide and fertiliser strategy decisions to be optimised for production. This section discusses diversity within (termed multispecies crops or intercropping) and between seasons (seasonal rotation) and how multispecies crops have performed financially before assessing drawbacks of multispecies crops, like disease, weed and pest management. This discussion is summarised in Table 4.

Table 4: Summary of profit implications caused by increased plant species diversity between and within seasons. (Source: Author)

Plant species diversity practice	Profit Change	Other Comments
Seasonal Rotation	Decreased	Short term profit is maximised by growing highest gross margin crop, which is generally wheat
Seasonal Rotation	Increased	Profit is sustained longer term when rotating to improve weed, disease and nutrition management.
Intercropping	Increased	Many instances of improved production discussed in overyielding paragraph
Intercropping	Unsure	Disease impacts of within and between seasons of multispecies crops need further investigation
Intercropping	Unsure	In-crop herbicide options are far more limited compared to monocrops
Intercropping	Unsure	Possible increase in water extraction ability by intercropping?
Intercropping	Unsure	Possible benefits from differing plant susceptibility to different pests, but potential harbouring of different pests for future crops.

3.1 Seasonal Rotation

Seasonal rotational benefits are well known to both farmers and advisors alike. A budgeted yield increase for wheat after a legume, like lupins, can range from 0.15 (Lawes *et al*., 2021) to 0.5 t ha^{-1} (Cornwall, pers. comm., 2024). Similarly, a budgeted yield increase is seen for wheat after canola compared to one after wheat. With a purely short-term focus, research shows continuous wheat is the most profitable rotation; by contrast, over a longer-term horizon the rotational benefits are clear (Lawes, 2016). This is because longer term analysis

and considerations include weed, disease and nutrition management and also diversifying risk (Moodie and Wilhelm, 2016; Fletcher *et al*., 2021; Swan *et al*., 2023).

3.2 Overyielding

Overyielding is an observed phenomenon whereby plant productivity is increased by growing multiple species together, over and above the productivity of growing them individually. One farmer in the UK has improved yield by 30% by sowing beans (*Vicia faba*) and oats (*Avena sativa*) together compared to beans alone (White, 2023). The resultant gross margin increase was from £780 ha^{-1} to £1033 ha^{-1} (White, 2023).

Similarly, on Kangaroo Island, SA, in 2019, canola yield (2.3 t ha^{-1}) was the same in paddocks grown with or without beans, except the paddocks with beans had an extra 0.3 t ha^{-1} beans, and a lower rate (lower by 23 kg N ha^{-1}) of nitrogen applied (Pontifex, pers. comm., 2023). This resulted in a gross margin increase for the multispecies crop of \$103 ha^{-1} (Pontifex, pers. comm., 2023).

In a more temperate environment, with evenly distributed monthly rainfall at Marrar, NSW, many types of multispecies crops have been grown such as canola with vetch (*Vicia sativa*) or beans. One comparison was where canola was grown with vetch. Canola by itself yielded 2.3 t ha^{-1} compared to 2.6 t ha^{-1} of the canola grown with the vetch, which contained 40% vetch and 60% canola (Figure 5; Pattison, pers. comm., 2024). A greater income from the canola and vetch mix (vetch selling for \$1000 t^{-1} and canola selling for \$800 t^{-1}) combined with lower nitrogen inputs provided a higher gross margin for the multispecies crop (Pattison, pers. comm., 2024).



Figure 5: A grain sample from harvested vetch and canola multispecies crop. (Source: Author)

3.3 Disease Management

One drawback from multispecies crops is disease management. The beans and canola mix on Kangaroo Island was only grown once (Pontifex, pers. comm., 2023). In this system a three-year rotation of wheat, beans and canola is grown, and one year of wheat between bean crops did not provide enough of a disease break for the beans following, resulting in an unacceptable level of disease (Pontifex, pers. comm., 2023). In this instance, it could be worth investigating whether there is another crop that could be added to the rotation to allow further extraction of the greater gross margin.

Vetch is prone to disease, often requiring multiple fungicide applications (Burges, pers. comm., 2023), but fewer applications appear necessary with a canola companion, because the vetch can climb up the canola, allowing far greater air flow through its foliage (Pattison, pers. comm., 2024).

3.4 Weed Control

Weed control within multispecies crops is one of the more difficult aspects to manage. In-crop herbicide and residual pre-emergent options are very limited. Some of the utilised multispecies combinations, such as beans and oats, are not sprayed in crop with herbicides (White, 2023). Anecdotal evidence suggests that weeds grow in smaller numbers and are less productive within the multispecies crop (Adams, 2023). I saw evidence of this when in Salina, Kansas, USA (Figure 6). The Land Institute aims to develop a perennial grain crop from intermediate wheatgrass (*Thinopyrum intermedium*); termed Kernza®. One of their trial plots compared Kernza® with lucerne (*Medicago sativa*) and combinations of both. In replicated plots, Kernza® and lucerne grown alone both contained weeds (as plots were not sprayed or hand weeded), yet in the combined plots, no weeds were present (Figure 6). Although this effect is likely to vary with plant combinations, and for annual plants compared to these perennial plants, it is worth further investigation.



Figure 6: Images showing weeds in lucerne (left) and Kernza® (right), but very few weeds in the plots with both Kernza® and lucerne (centre). This effect was replicated. (Source: Author).

3.5 Water Extraction

Water extraction is also reported to improve with multiple species growing. Although I did not see this throughout my studies, Stika (2016) reports that during a drought in Burleigh County, North Dakota, in 2006, when only 1.8 inches (45 mm) of rain fell from April to late July, single-species plantings had almost died by late July, yet multispecies cover crops were alive and green. Stika (2016) suggests that contrasting root architectures and microbial associations allowed greater water extraction with plant diversity. Whether the same degree of response would be seen with a two-species grain crop is unclear, but it is possible that a similar response could occur in some combinations.

3.6 Pest Management

Multispecies crops also appear to assist in minimising pest damage to crops. In the United Kingdom, where neonicotinoid insecticide use is banned, growing linseed with oats helped deter flax flea beetle from damaging the linseed (Adams, 2023). At Marrar, in a bean and canola mixed crop, where slugs killed the canola, the beans were still there to be harvested, saving the need for re-seeding (Pattison, pers. comm., 2024; Figure 7).



Figure 7: An area where slugs have killed germinating canola either partially (foreground), completely (midground), or not at all (rear of crop near trees). The beans sown with the canola ensured the damaged area was not a total loss. (Source: Author)

3.7 Seed Cleaning

Growing multispecies crops requires a change in mindset when it comes to harvest. In all cases analysed, the cost of cleaning seed was less than the extra return. Cleaning was either done by an external seed cleaner (Pontifex, pers. comm., 2024), or stored during harvest in silo bags, then cleaned on farm upon harvest completion (Pattison, pers. comm., 2024).

3.8 Summary

Ultimately, farming is the ability to convert moisture, light and nutrition into food. By having multiple species of plant growing within the same area, leaf morphology is diversified, allowing capture of more light, prior to it hitting the ground. One can speculate that this better utilisation of available resources could be one reason for greater profitability seen in this study of multispecies crops; greater light capture could also help explain the lower weed numbers seen in some instances of multispecies crops. Diversified root architecture and abilities could also assist with greater resource capture, and nitrogen fixation where legumes are involved. With a greater portion of the field occupied both above and below ground, less space could be left for weeds to occupy. I believe this could be an exciting area for further research.

Growing plants for as long as possible

It has long been known that plants can modify their soil environment. Rhizodeposition, the release of carbon (both organic and inorganic) for microbial consumption (Jones et al., 2004) only occurs whilst plants are living and can be modified depending on soil water status (Preece and Peñuelas, 2016). The aim of having plants living as long as possible is to maximise carbon (C) input into the soil, fostering a larger, more functional soil biological community, facilitating greater efficiency of nutritional resources. Similarly, greater use of light resources could increase profit, but both the use of nutrition and light by plants require adequate moisture to be available. The availability of moisture is likely to be the key influence on how growing plants as long as possible influences profit.

4.1 Moisture

Moisture affects the profitability of growing plants in many ways. Where moisture is surplus, growing plants to decrease waterlogging makes sense. Some farmers in the United Kingdom have found their crops grow best next to trees (as seen at Denby Downs, Yorkshire, UK). One theory is that this is due to a biological interaction between the existing tree roots and crop roots (Fraser, pers. comm., 2023). It could alternatively be due to the tree using the moisture, minimising waterlogging and associated denitrification. In high-rainfall environments, much research has focused on cover and catch crops to minimise nitrogen loss either by leaching (e.g. Aronsson and Torstensson, 1998; Askegaard and Eriksen, 2008) or gaseous losses.

By contrast, the effect of cover crops in drier environments is far less clear. In Mandan, North Dakota (360 mm rainfall area), at the Agricultural Research Service of the United States Department of Agriculture (USDA-ARS) a Long-Term Agroecosystem Research (LTAR) trial compares prevailing practice (PP) with an alternative practice (AP). The PP and AP both rotate spring wheat, corn (*Zea mays*) and soybeans (*Glycine max*), but the AP includes cover crops (to always keep something growing), and straw is not removed. Over the 5 years of this experiment AP soybeans have yielded 11% more than PP soybeans. By contrast PP corn and wheat have yielded more than AP corn and wheat by 20% and 6% respectively (Liebig, pers. comm., 2023). Liebig (pers. comm., 2023) observed that during good growing conditions, cover crops can pay for themselves, but when rainfall is uncertain this cannot be guaranteed. Interestingly, when visiting the trial site in early August 2023, hail damage was very evident in the corn PP treatment from a hailstorm in late June, but not in the AP treatment (Figure 8). This did not translate into yield as there was no difference in corn yield between AP and PP treatments (Liebig, pers. comm., 2024). Interestingly, there was no measured difference in soil moisture immediately post-harvest between the AP and PP treatments (Liebig, pers. comm., 2024).

Yield loss was seen in a wheat crop following a summer cover crop on the Yorke Peninsula, South Australia, in 2017 (Pontifex, pers. comm., 2024). In the summer fallow period a six-species cover crop was sown and compared to the conventional summer fallow (Pontifex, pers. comm., 2024). Measured soil moisture content in March prior to sowing was 20 mm in the cover crop compared to 45 mm in the fallow (Pontifex, pers. comm., 2024). With a water use efficiency of 20 kg mm^{-1} ha^{-1} (French and Schultz, 1984), one could expect a yield decrease of 500 kg ha^{-1}. Final yield of the 2018 wheat crop was 3 t ha^{-1} in the cover crop treatment compared to 3.5 t ha^{-1} without the cover crop (Pontifex, pers. comm., 2024).

Nutritional tie up is another reason supplied by local agronomists not to use summer cover crops; interestingly, in this experiment it appears not to have influenced yield.

4.2 Summary

With the uncertainty of summer rainfall in the Mediterranean-type environment of southern Australia, the likelihood of receiving enough rainfall to harvest grain or a fodder crop is low. Therefore, a farmer choosing to grow plants over the traditional summer fallow period needs livestock to generate income, unless there is some nutritional benefit to the following crop.



Figure 8: Photos of two neighbouring corn plots (PP left, AP right). The photos were taken on 9 Aug 2023 after a hailstorm on 22 June 2023. The PP plot shows leaves with moisture stress (curled) and serrated edges, by contrast the leaves in the AP plot look healthy without serrated edges. (Source: Author)

Minimal Soil Disturbance

Within the grain growing region of southern Australia, the dominant form of crop establishment is direct drilling, where crops are sown without any pre-sowing tillage, aligning with the principle of decreased soil disturbance. This method of establishment has been adopted because it minimises the destruction of soil structure, lessens erosion risk, improves water infiltration and hence water use efficiency and saves time. Before travelling on my Nuffield Scholarship, I thought this was primarily about the shift from tyne based implements to discs because I did not realise how much agriculture in other parts of the world tills soil prior to sowing. This section will not discuss the profitability implications of shifting to a direct drilling technique, as the widespread adoption of it is evidence enough. However, after many years of not disturbing the soil, growers have found that strategic, sporadic tillage is a profitable exercise.

Soil amelioration is a substantial form of disturbance that aims to alter soil chemical and physical properties. In WA, the main soil constraints of compaction and water repellence can both be ameliorated through tillage, like mouldboard ploughing, disc ploughing or deep ripping. Soil acidity, the other major soil constraint, can also be lessened by spreading an ameliorant, such as lime, which is then incorporated when ploughing. By ameliorating subsoil compaction in coarse textured soils, through deep ripping, crop yields can increase by 80-135% (Davies et al., 2019).

5.1 Plant based amelioration

When investigating this topic, I spoke to many people who argued that the plant should do the ripping instead of the tractor-drawn implement (e.g. Jasa, pers. comm., 2023; Vince, pers. comm., 2023). Growing deeper-rooted plants, like perennial or summer active plants (e.g. corn and sunflowers (*Helianthus annuus*)), could assist shallower rooted winter annuals by creating deeper root pathways for them to follow. A perennial pasture based grazing phase could be investigated. Alternatively, the summer active annuals could only be grown if opportunistically sown after a summer rainfall event. More research is needed to investigate this theory, as summer growing plants should be able to create pathways deeper than could be ripped with an implement, where soil constraints allow (e.g. acidity). The length of time over which these pathways can be followed by subsequent crops requires further investigation.

In this Mediterranean-type climate, growing summer crops is often at a short-term cost to the following crop. Using the data from the Yorke Peninsula in 2018 (Section 4.1), a wheat yield decrease of 0.5 t ha^{-1} after a summer crop reduced income by \$175 ha^{-1} (with a wheat price of \$350 t^{-1}). This is more than the \$80-90 ha^{-1} cost of deep ripping, assumed by Davies et al. (2017). In this scenario, the break-even yield increase would be 0.25 t ha^{-1}. Any profit-motivated farmer in this scenario would consider deep ripping to improve on farm profitability. This is also the more conventional and tested method to ameliorate subsoil compaction.

Livestock Incorporation

Livestock allow a farmer to generate profit from unarable and poor arable farmland as well as diversify income streams. The primary management difference between graziers focused on soil health compared to those that do not, is that soil health focused graziers rotationally graze. Graziers that changed to rotationally grazing increased pasture growth by between 50% (Millar, pers. comm., 2023) and 100% (Richmond, pers. comm., 2023). By comparison, due to the cropping focus and time constraints placed on sheep management, I am unaware of any local growers that rotationally graze, but after visiting growers quoting such large increases in pasture growth, the opportunity cost of not rotationally grazing may be too great.

Farmers growing multispecies cover crops rotationally grazed livestock, primarily cattle, on them to make a financial return. This is one of the most underrated aspects of the soil health principles according to one Canadian farmer (Vince, pers. comm., 2023).

Financial Comparison

Farm scale analysis comparing farmers adopting soil health principles compared to those who do not is difficult because of the inherent differences between farms (e.g. climate, soil type, managerial decisions, machinery differences). Further, I have not found many studies that compare the financial performance of cropping based systems; by contrast, grazing focused comparisons are more common.

7.1 Forecast financial effects

Several reports have been released forecasting greater profitability of farmers who adopt "regenerative" type farming practices (e.g. Petry et al., 2023; Kurth et al., 2023). Petry et al. (2023) report on a potential scenario where farmers in Kansas increase their returns by 120% by adopting soil health principles. Similarly, Kurth et al. (2023) suggest German farmers can increase their farm profits by 60% by adopting regenerative agriculture. Both studies rely on an immense number of assumptions to reach their conclusion. Petry et al. (2023) do acknowledge the uncertainty of their results, stating "we estimate the total profit loss in the transition period can be anywhere from $15-$45+ per acre ($37-$111+ ha^{-1}) annually in less-than-ideal conditions…" These reports contrast with the findings of studies that analyse farm business performance of regenerative growers, compared to conventional growers.

7.2 Case Study from the United Kingdom

A study in the United Kingdom by the Land Family Business (LFB) compared the financial performance of the LFB client group (conventional farmers) with farmers that implement some or all of the soil health principles (the definition of regenerative farming in the UK), called the Groundswell group, over a period of four years. The four growing seasons in the analysed period were two good seasons (2022 and 2021), one poor (2020) and one below average (2019) (Markham, pers. comm., 2023). Over the analysis period, conventional growers made £97 ha^{-1} more profit than the Groundswell group (Table 5). There are two primary differences between the groups. Generally, LFB growers produced greater output per hectare than the Groundswell group. This was particularly advantageous in 2022 and 2021 when commodity prices rose. With higher grain prices, the greater yields generated by the conventional growers (data not shown) assisted their financial performance more (Table 5). The other primary difference was that generally, the Groundswell group growers spent less on variable costs, and fixed costs (Table 5), providing a more resilient business model. Conventional growers were also more greatly affected by the increased fertiliser and machinery prices in the latter years of the study (Table 5).

Combining the lower profits of growers who adopted the soil health principles (Table 5), with the lower profits generated in the transition period from conventional to "regenerative" (Markham, pers. comm., 2023; as used in the modelling by Kurth et al. (2023) and Petry et al. (2023)), it makes it difficult to justify the risk from purely a profit perspective when assessing the grains only side. One would suggest that for farmers to transition they must already be in a strong financial position to cope with the transition period, and then potentially lower returns. Governmental support in the UK is likely to make the financial

performance more comparable with the Sustainable Farming Incentive scheme, whereby farmers will earn £45 ha^{-1} for not using insecticides and £55 ha^{-1} for growing companion crops (Department for Environment, Food and Rural Affairs, 2024).

7.3 Case Study from Western Australia

The trend of lower profit variation, and better relative performance during the poorer years, seen in this study by Markham (Table 5), matches the study by Plunkett et al. (2023) who assessed the performance of a low input farming system in WA (named Tolga) and compared it to a benchmarking dataset compiled by a farming consultancy called Planfarm (Planfarm, 2023). Plunkett et al. (2023) showed the Tolga farming system gross margin was comparable to the benchmarking dataset median over the analysed period, but with a lower coefficient of variation (CV) in both gross margin and earnings before interest, taxation, depreciation and amortisation (EBITDA). It is also interesting to note that the CV of EBITDA and gross margin of the Tolga operation is similar to the top 25% of the benchmarking dataset, especially over the longer, 15-year period.

7.4 Grazing Case Study from New South Wales

When analysing grazier returns in the box gum grassy woodlands of NSW, Ogilvy et al. (2018) concluded that “regenerative graziers that contributed to the study were found to be more profitable compared to all sheep, sheep-beef and mixed industry farms in a similar geographic region…” This is consistent with the greater profits made by UK graziers when adopting rotational grazing (Huegill, pers. comm., 2023). The problem with this study is that it only assesses profit on a dry sheep equivalent (DSE) basis rather than a profit per area or return on assets. Although this precise data was not shared to allow a perfect comparison, using a similar data set, Francis (2020) found that when analysed using return on assets managed (ROAM), regenerative graziers returned 1.66% compared to conventional graziers at 4.22%.

	Groundswell Group					Land Family Business Client					Difference
	2022	**2021**	**2020**	**2019**	**Avg**	**2022**	**2021**	**2020**	**2019**	**Avg**	
Arable Output	1302	984	800	890	994	1824	1437	905	1169	1334	-340
Variable Costs	461	315	355	381	378	708	461	388	495	513	-134
Arable Gross Margin	840	669	445	509	616	1117	977	518	671	821	-205
Farm Gross Margin (livestock included)	865	675	446	509	624	1117	977	518	674	807	-183
Fixed Costs (Labour and Machinery)	380	398	335	322	359	609	454	432	456	488	-128
Total Margin	316	277	111	187	222	508	465	86	218	319	-97

Table 5: Financial performance of conventional farmers (Land Family Business Client) compared to the Groundswell group (farmers adhering to some or all of the soil health principles, termed regenerative) over four years (Data courtesy of the Land Family Business). All units are in £ ha^{-1}. (Source: Land Family Business)

7.5 Summary

To summarise, these economic analyses show that in general, those adopting soil health principles have lower cost, less variable and hence more resilient systems that perform more consistently, but generally generate less profit than conventional systems. In the better years, the higher production, higher cost conventional farming systems perform better financially, with the reverse true in tougher years. A grower's opinion on whether the season will be good or bad may help determine which production pathway they choose.

Other Discussion Points

Economic theory has been developed using profit maximisation as the primary motive, but when making decisions on farm, profit is not always the primary factor considered. This section will discuss risk, altruism and labour; three other factors considered when farmers determine whether or not to adopt the soil health principles.

8.1 Risk Management

There are many facets to consider when operating a business that relies on environmental factors to grow and then sell food and fibre. Given that each facet involves risk, risk mitigation is a large component of farming. When asking a Canadian farmer from Ontario why they adopted the soil health principles he told me “It’s all about risk, I can’t control the weather, I can’t control the markets, but I can control my inputs and adopting the soil health principles helps me minimise inputs and improve efficiency" (Vince, pers. comm., 2023). By contrast, when I asked a farmer from Cambridgeshire, UK, why he did not adopt them he told me “It’s all about risk, I know what I’m doing works; I’m not against them, I just need to see them work first. When my neighbour adopts these practices and they perform for them I’m happy to change" (Raby, pers. comm., 2023). Both farmers are working to minimise their risk, just in different ways.

8.2 Altruism

Altruism and the satisfaction gained from improving the environment is another factor commonly mentioned by farmers adopting the soil health principles. Many farmers I visited, especially in the UK, stated that they had lost interest in farming. Changing their practices had reinvigorated their interest and enjoyment of farming (e.g. Chapman, pers. comm., 2023).

8.3 Labour Constraints

Time and labour are other constraints to adoption of different practices. In a time constrained environment, it is difficult, firstly, to implement different practices, and then, secondly, and even more importantly, difficult to assess how the practice changes affected the desired criteria change.

Conclusions

The soil health principles are a set of broad-ranging guidelines aimed at managing soil to firstly minimise degradation and, secondly, improve fertility. Western Australian growers have already adopted some of them, without labelling it as such. Direct drilling is near universal, break crops are standard in most rotations, and stubble is retained far more than previously. The question for the WA broadacre grower is therefore whether to adopt more of the principles, and what the likely financial implications would be in terms of costs and returns.

From the data presented, the answer depends heavily on the season. In a favourable year, the conventional system produces more grain, and the additional fertiliser and herbicide spend is comfortably repaid. In a poor year returns converge, and the lower-cost system carries less downside. The Tolga comparison to the Planfarm benchmarking dataset showed this (Plunkett et al., 2023): a gross margin comparable to the median, but with a coefficient of variation closer to the top 25%. Lower peaks, shallower troughs.

Our Mediterranean-type climate constrains how several of the principles can be applied. Growing plants for as long as possible is difficult to justify over a WA summer without summer rainfall certainty and without livestock to convert that growth into income. Full soil cover brings tangible but difficult-to-measure benefits from greater water infiltration and decreased evaporation. It also brings other changes like shifting away from trifluralin, along with potentially increased frost exposure and increased need for mollusc baiting. Plant species diversity looks to me the most promising of the five for our environment, provided in-crop weed control can be managed.

Given that farming is an efficiency-based commodity production system, conventional growers spend more to produce their crop, with greater returns in a good year. In a poor year, returns are more similar, but with less risk for growers adopting the soil health principles. Any judgement on which of these is preferred will depend on the attitude of the reader. One with a risk-averse bias will favour the lower cost option. One expecting favourable seasons will prefer the conventional approach. With an increasing population requiring more food, and land quantity not changing, we must continue to improve efficiency with respect to production per hectare. Alternatively, if climate change occurs to produce drier, less favourable growing seasons, a lower risk method of production may prove more favourable. Neither position is wrong; they are different views on risk and future outlook.

Recommendations

I have split this section into recommendations for various sectors of the industry because I think recommendations should vary based on the individual's role or desired outcomes.

10.1 Recommendations for Growers

Growers are in a very fortunate position, with the flexibility to choose their own goals, and how to achieve them. My recommendations for growers reading this report will vary depending on their interests and biases.

If a grower is only interested in profit or is optimistic with regards to favourable seasons, continuing a conventional path will be the best way forward for them, especially in the short term. For those pursuing business expansion, they must continue down conventional pathways and let researchers discover the methods that can help them and adopt them once they become more proven from a research perspective. If adoption of soil health principles becomes clearly more profitable, or logistically easier without compromising profit, then they should adopt them, as has occurred with the widespread adoption of direct drilling. I view this as the easiest option for growers.

If, by contrast, a grower has a pessimistic approach and thinks there will be many tough seasons in the future, switching to a low-cost system is likely to aid in their resilience. Adopting soil health principles is likely to assist this method of farming. This grower will need to be open minded and investigative, as support for this method of growing crops is far less available than the more conventional option.

I also believe there is another possible option for growers. There were a few growers that I saw that convinced me that they were doing both: running profitable enterprises, whilst pursuing soil health principles. These growers were pushing the boundaries in the manner that they farmed, trialling and assessing new practices, being willing to make mistakes on a small scale, to then adopt the lessons on a wider scale. But these growers also kept a constant eye on profit. For the very few growers doing this, I would like them to be open to researchers and allow other growers to learn from what they are doing.

10.2 Recommendations for Researchers

The constant requirement that researchers have for new ideas to trial, and then seek funding to assess these new ideas is difficult; especially when the pool of funds is limited and favours research focused on short term objectives. Collaborating with the third group of growers is a must. Seeking out this group of growers, when they may not desire attention and be happy working alone in the background, is important. Utilising, developing, providing scientific rigour to and extending their ideas and practices will benefit the whole industry.

10.3 Recommendations for Policy Makers

Throughout my travels, most countries I visited had one thing in common: the agriculture sector is generally taken for granted and consumers expect that tomorrow food will be available, because, in living memory, it always has been. I think this train of thought has contributed to the vast number of food production restricting policies that have been implemented in many countries. Examples include European Union-imposed nitrogen fertilisation caps in Ireland, the cessation of the conversion of land to dairy in New Zealand, the legislated phase-out of live sheep exports by sea from Australia, and the beef export ban in Argentina, and the requirement for land to be set aside for non-production purposes in the United Kingdom. To me, this highlights how successful the agriculture sector has been at feeding people. Indeed, I fear only food shortages are likely to change this attitude. All policies should be designed to do the best for their industry, rather than appeasing voters that are not involved with the affected industry.

10.4 Recommendations for the General Agriculture Industry

The agriculture industry has always been asked to contribute food to society. Now we are also being asked to provide environmental services as well as store carbon. Financial returns for food are diminishing marginally, very little value can be obtained from environmental services, and carbon returns are questionable.

As an industry our geographic spread has removed us from the wider population, and generally, from the public eye. Although this has some advantages, it limits our communication with the wider population, and consequently poor policies are imposed on us. To me, one way to overcome this communication breakdown is through social media. As an individual, I genuinely dislike this form of short communication, but it is a medium used by a large section of the population and allows access to our industry without travel. If you are not willing to participate in this communication aspect, I suggest you get involved with your local farm lobby group and assist their industry and policy advocacy.

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