Growing Soil Health

Future drivers and critical knowledge growth strategies with a focus on soil acidification

A report for

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Executive Summary

Soils are a critical natural asset. They underpin agricultural productivity and provide the capacity for agriculture to meet future challenges, such as delivering food security and addressing climate variability.

Western Australia (WA)'s soils are well known to be some of the most challenging soils in the world which has driven significant improvements and innovation in soil management in the WA agricultural sector. The need for continual improvement persists as WA soils continue to be impacted by a variety of threatening processes, most notably soil acidification. This research confirms that globally the most widely adopted best management practice for addressing soil acidification is the application of lime. This report provides an expanded view of soil acidification in considering soil in a broader soil health and soil stewardship context. Barriers and challenges around the adoption of best management practice on farm are explored, highlighting that the decision-making process to address soil health issues is impacted by a range of factors, including economics.

Internationally and domestically, there is an increasing strategic focus being placed on soil health. This research explores several future soil health drivers and opportunities. Many of the macro drivers explored are linked to a desire from numerous parts of agricultural supply and value chains to address global sustainability. Of particular significance are the opportunities and challenges which will be faced by growers in relation to the carbon economy and future access to financial capital with the incorporation of sustainability metrics into credit risk assessments.

A range of strategies to support the collective and coordinated growth of soil knowledge are presented and recommended with a focus on continual improvement processes, adaptive learning and the need for end-user (grower) centred design.

The research draws from observations during the authors' global travels to highlight the need for local soil research, development, extension and validation. A focus on farming systems and monitoring and evaluation, from the paddock scale and beyond, is highlighted to drive the increased adoption of best management practice for improved soil health in WA.

Table of Contents

Executive Summary .... **iii**
Table of Contents .... **iv**
Table of Figures .... **vi**
Foreword .... **vii**
Acknowledgments .... **ix**
Abbreviations .... **x**
Objectives **12**
Chapter 1: Introduction **13**
1.1 Soil health and functions 14
Chapter 2: The Status of Soil Health **17**
Case Study: California, USA 17
Case Study: South Carolina, USA 18
2.1 Soil health in the WA landscape 18
2.2 Soil acidification measurement, effects, and management 19
2.3 Management of acidic soils 20
Chapter 3: Barriers and Challenges **24**
3.1 The complexity of soil 24
3.2 Strategic focus for soils 25
3.3 Barriers to adoption 25
3.4 Barriers to addressing soil acidification 26
Chapter 4: Future Soil Health Drivers and Opportunities **27**
4.1 Consumer trends 27
4.2 Standards and verification 27
Case study: Red Tractor Certified Standards, UK 28
4.3 Regulation 29
Case study: Nutrient management environmental reforms, New Zealand 29
4.4 Climate change, carbon farming and soil health 30
4.5 Pressures from agricultural value chain stakeholders 32
4.6 Finance and insurance markets 33
4.7 Market access 33
4.8 Natural capital accounting and the valuation of ecosystem services 34
Chapter 5: Collective and Coordinated Growth of Soil Knowledge **36**
5.1 WA growers indicate soil health as a priority 36
5.2 Research, development and extension and the human side 36
5.3 Grower groups and the importance of local delivery 39
Case study: Teagasc, Moorepark 2019, Ireland 39
.... 40
5.4 Research to support the long-term vision for soil health in WA 40
Case study: Long-term continuous cropping experiment, Los Baños, Philippines 40
5.5 Decision support tools 41
5.6 Monitoring and evaluation to support continued improvement 42
Conclusion **43**

Recommendations **44**
References **45**
Plain English Compendium Summary **50**

Table of Figures

Figure 1: The 2019 China Global Focus Program team at the Reichstag, Berlin, Germany, June 2019. Author fifth from the right (Image: Author) ...viii
Figure 2: Gross value of agricultural commodities produced (ABS, 2020) ... 13
Figure 3: Soils provide for a range of ecosystem services as identified in the above infographic linking soil ecosystem services to the UN SDGs (Murphy, 2021) ... 16
Figure 4: Irrigation, as shown here in Bakersfield, is causing salinisation across large tracts of the productive Central Valley of California (Image: Author) ...
Figure 5: Salinisation in a paddock in the Central Valley, California, 2014 (Photo: Scott Baurer, ESDA, sourced from USGS, 2020) ...
Figure 6: Site visit at the USDA Coastal Plains Soil, Water and Plant Conservation Research Centre, Florence, SC, March 2019, noting the abundance of sorrel in the background (Image: Author) ...
Figure 7: The sandy soils of Florence showing non-tillage (top core) and tillage (bottom core) treatments, Florence, SC, March 2019 (Image: Author) ...
Figure 8: In acidic soil, some nutrients may be insufficiently available to support optimal plant growth and aluminium may become toxic (Gazey C. A., 2019) ... 20
Figure 9: Potatoes growing in Emsland, Lower Saxony, where a liming strategy is in place (Image: Hamish Murray) ...
Figure 10: Lime produced as a by-product of the cooling processes of nearby nuclear power plants is used for agricultural application, Emsland, Lower Saxony (Image: Author) ...
Figure 11: Soil pH status for the south-western WA agricultural region, 0-10cm depth with a target pH_{Ca} of 5.5(Gazey C. A., 2019) ... 23
Figure 12: Soils are exceptionally complex with physical, chemical and biological characteristics that are interconnected (Image: Author) ... 24
Figure 13: The Red Tractor brand is well known throughout the UK (Image: Red Tractor (Red Tractor, 2021) ... 28
Figure 14: The 'Growers' hub' on the Environment Canterbury website provides information on farm environment plans, including 'Got your consent to farm?' (Environment Canterbury, 2021)... 30
Figure 15: Movement of commodities along the supply chain and the resulting data/ information web, highlighting the range of stakeholders who may place pressure on growers to meet broader global sustainability objectives (Lefroy, Rabobank 2017) ... 32
Figure 16: Research and change: a simple understanding. Adapted from Soil CRC (Soil CRC, 2021)... 37
Figure 17: Addressing soil health should be considered a process of continual improvement (Image: Author) ... 38
Figure 18: Researchers presenting directly to growers, Moore Park, Ireland (Image: Author) ..
Figure 19: The Moore Park, Ireland open day drew a crowd of thousands who all seemed very engaged in the learning environment presented (Image: Author)...
Figure 20: IRRI longer term research site, Los Baños, Philippines (Image: Author) ...
Figure 21: IRRI long term research site interpretive information boards, Los Baños, Philippines (Image: Author)...

Foreword

As a young child, I grew in the red dirt of the Pilbara, followed by schooling in Perth, with a short stint in the Goldfields. I had always imagined I would end up in the mining industry, until I met my farmer. Wayne and I were introduced through a family member and opportunities continued to pave the way for a career in natural resource management and agriculture.

Having studied Environmental Science at Murdoch University, I have always been passionate about the environment. This passion however is balanced with a practical and continual improvement mindset, recognising that sustainability is not achieved by focusing on any one pillar: social, environmental or economic. A balance is needed and there are trade-offs.

One of the greatest challenges on our farm is soil acidification, a constraint impacting on many soils, particularly on our Albany property. Across WA, millions of dollars have been invested in solving the issue and decades of research, development and extension has been carried out. Despite this, soil acidification remains one the most significant economic and natural resource threats in the agricultural areas of south-western WA, along with many other parts of Australia and beyond.

With the application of lime or dolomite currently being the most cost-effective method of addressing soil acidification, I was interested to know what is happening in other agricultural areas throughout the world to combat the issue. What I found was that the application of lime is the standard best practice, so no real surprises there. One poignant conversation with a WA grower while in South America was the turning point of my research; "*growers are either going to address soil acidification, or not*". From that point, on my research broadened to investigating the future pipeline of drivers that support soil health improvement more broadly.

My travels in 2019 and early 2020 took me through parts of North and South America, South East Asia, China, Germany, Ireland and New Zealand. It was an interesting time to travel with many significant global events occurring, including Brexit, African Swine Fever, fires in Brazil and at home in Australia, culminating with the global pandemic, COVID-19.

The Nuffield experience has been life changing; my eyes have been well and truly opened. I returned home immensely proud of what we achieve in WA. Yes, there is room for improvement, but we are resilient, innovative and progressive. Whatever comes down the pipeline, I have no doubt that WA growers will rise to the challenge.

Figure 1: The 2019 China Global Focus Program team at the Reichstag, Berlin, Germany, June 2019. Author fifth from the right (Image: Author)

Acknowledgments

I am enormously grateful to Nuffield Australia and CBH Group for the opportunity to undertake a Nuffield Scholarship. Your investment in, and support of me personally and your wider investment in "*building capacity in people to lead and innovate in Australian primary industries and their communities*" is greatly appreciated. I am humbled and honoured to be a recipient. As a Nuffield Scholar, I have been supported in so many ways by the Nuffield family. Thank you particularly to my mentor, Bob Nixon, my report editor, Dr Tim Hutchings and Jodie Redcliffe and Nicola Raymond for all of your assistance and support during my broader scholar journey.

Thank you to every person who opened their door, answered their phone, attended virtual interviews and provided links to their own networks to help with my research. Your insights and willingness to share enabled my research to progress and I am incredibly grateful for your time and assistance.

I will be forever grateful to my husband, business partner and brains trust, Wayne. You are enduringly supportive of my ambitions to explore and learn, and my Nuffield journey has been no exception – thank you. To my children Sophie, Cameron and Nathan, thank you for understanding that learning is not just for children, it is a lifelong opportunity. I hope that you will also appreciate and realise the opportunity when you are older.

To my parents and my in-laws, Domenic and Brenda and Don and Val; without your support in keeping the home fires burning, this would never have been an opportunity – thank you.

To all my fellow Nuffield Scholars – thank you. Enduring friendships and networks are formed throughout the lifelong Nuffield experience. I look forward to continuing the learning and friendship journey with you all.

Abbreviations

ABS	Australian Bureau of Statistics
AEEA	Australian Environmental-Economic Accounts
APRA	Australian Prudential Regulation Authority
CBH	Cooperative Bulk Handling
CDFA	California Department of Food and Agriculture
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWE	Department of Agriculture, Water and the Environment
DPIRD	Department of Primary Industries and Regional Development
EC	European Commission
FAO	Food and Agriculture Organization (of the United Nations)
GDP	Gross domestic product
GHG	Greenhouse gas
GRDC	Grains Research and Development Corporation
GSBI	Global Soil Biodiversity Initiative
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
ISCC	International Sustainability and Carbon Certification
ISCN	International Soil Carbon Network
ITPS	Intergovernmental Technical Panel on Soils
MLA	Meat and Livestock Australia
NAB	National Australia Bank
NFAS	National Feedlot Accreditation Scheme

NFF	National Farmers Federation
NZ	New Zealand
ROSA	Ranking Options for Soil Amelioration
SC	South Carolina
SCBD	Secretariat of the Convention of Biological Diversity
SCNRM	South Coast Natural Resource Management
SDG	Sustainable Development Goals (United Nations SDGs)
SEEA	System of Environmental-Economic Accounting
UK	United Kingdom
USA	United States of America
USDA	United States Department of Agriculture
WA	Western Australia

Objectives

Understanding, protecting and improving soil health is critical for managing WA's natural assets and agricultural productive capacity. There are many soil health issues impacting on the productivity of WA soils, soil acidification being a notable challenge. While it is widely recognised that addressing soil acidification makes good productivity and profitability sense, adoption rates of liming remain below recommended levels. This research report looks beyond the direct production benefits of implementing current best management practice and investigates future drivers and knowledge growth strategies to support improved soil health in WA.

Specifically, the research objectives were to:

- Review the status of soil health, from the global to the local scale.
- Review and explore barriers and challenges impacting the adoption of best management practice.
- Explore future soil health drives and opportunities.
- Propose key strategies to support collective and coordinated growth of soil knowledge in WA.

Chapter 1: Introduction

"All terrestrial life relies on the functionality of our soil and the ecosystem services that our soil supplies." *T. Overheu, 2020.*

The National Farmers Federation has laid down a bold vision for agriculture in Australia: to "*exceed $100 billion in farm gate output by 2030*" (NFF, 2019). In 2018-2019 the value of agricultural commodities produced in Australia was over $60 billion gross value, with WA contributing $10.7 billion, as shown in Figure 2 (ABS, 2020). Australian agriculture's capacity to increase productivity sustainably and meet industry targets and anticipated world food demand by 2050 will depend heavily on the maintenance and improvement of soil health.

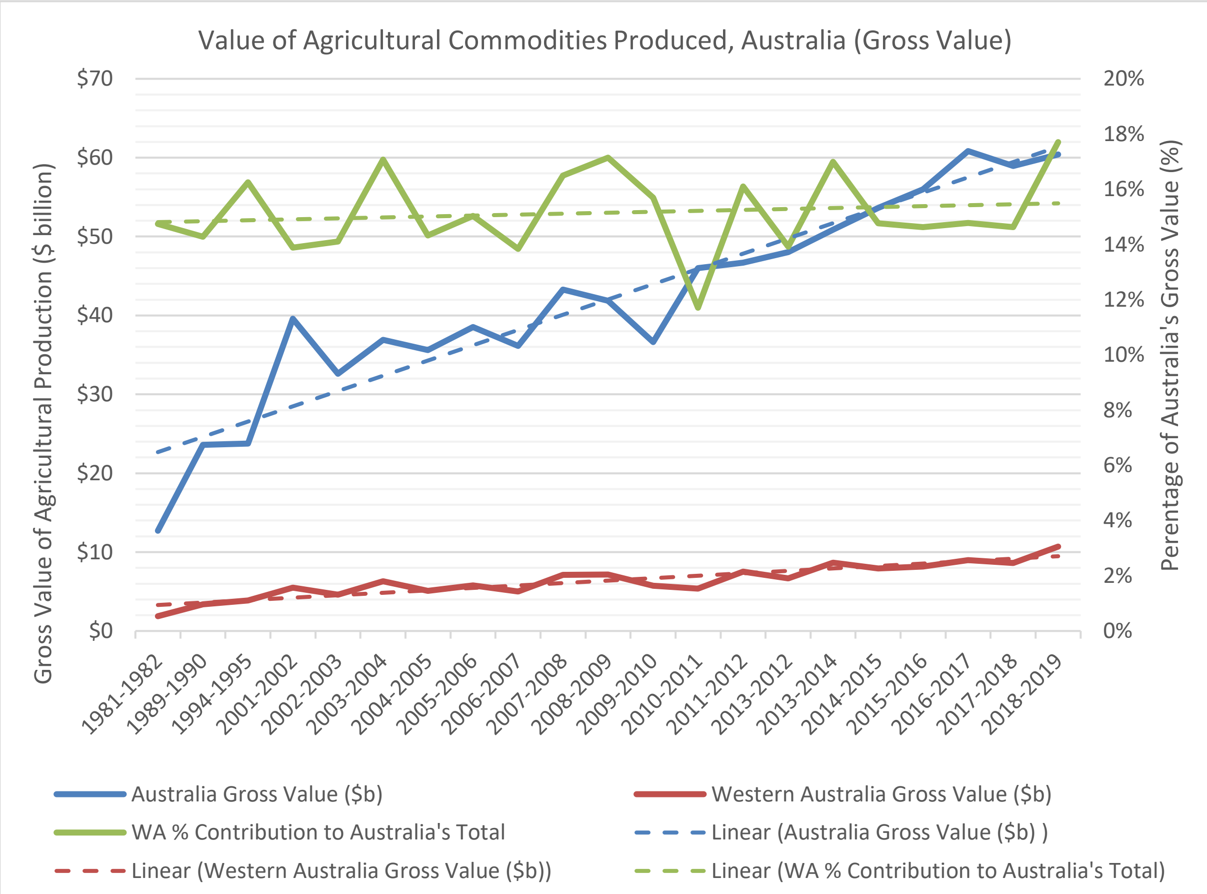

Figure 2: Gross value of agricultural commodities produced (ABS, 2020)

Soil is essentially a non-renewable resource, often taking millennia to form and being degraded in a fraction of the time. Since the beginning of cultivation some 12,000 years ago, soils have been changed by farming, both purposely and unintentionally (Sandor, 2017). Today, the world over, there are soil health issues impacting on production and more broadly, on global environments, economies and communities.

Globally there is a wealth of research, development and extension information to assess and promote best management practices for soil health issues including soil acidification. Much research has uncovered barriers to adoption to understand why growers do not adopt best management practices. Further, policies and programs have been implemented to drive adoption, yet soil health continues to decline and in with soil acidification in WA, liming rates are reportedly below recommended levels, a well-established best practice for addressing soil acidification in WA (Gazey C. D., 2014).

1.1 Soil health and functions

As a term, 'soil health' is analogous to the concepts of environmental health, human health, plant health, and animal health whereby living things can have health. Viewing soil as a living ecosystem reflects a fundamental shift in the way soils are considered and managed (USDA, 2020). This research report defines soil health as '*the capacity of soil to function as a vital living system, within ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant, animal and human health*', a definition which has been adopted in the developing WA Soil Health Strategy (Soil and Land Conservation Council, WA, 2020). In support of this definition, it is important to respect that soil is not an inert growing medium. Rather, it is a living resource with varying physical, chemical and biological properties depending on its location and seasonal and environmental conditions.

Apart from enabling the provision of food, fibre and fuel, healthy soils provide a range of ecosystem services, or functions, including carbon sequestration, water purification, soil contaminant reduction, climate regulation, nutrient cycling, habitat for organisms, flood regulation and cultural heritage, as shown in Figure 3 (FAO, 2015). In consideration of broader sustainability, soils play a role in supporting at least 12 of the 17 United Nations Sustainable Development Goals (SDG) which further highlights the importance of soils and the broad reaching impact of either their health or degradation (Murphy, 2021).

Healthy soils are recognised as soils which retain and supply nutrients, water and oxygen for healthy plant growth. Healthy soils resist erosion and disease and allow water to infiltrate freely, yet store water with the existence of a range of pore spaces for the water. Ability to facilitate gaseous exchanges with the atmosphere and the ability to support a large and diverse population of soil biota are further indicators of healthy soils. Poignantly for this research, healthy soils are not acidifying or salinizing (Agriculture Victoria , 2020).

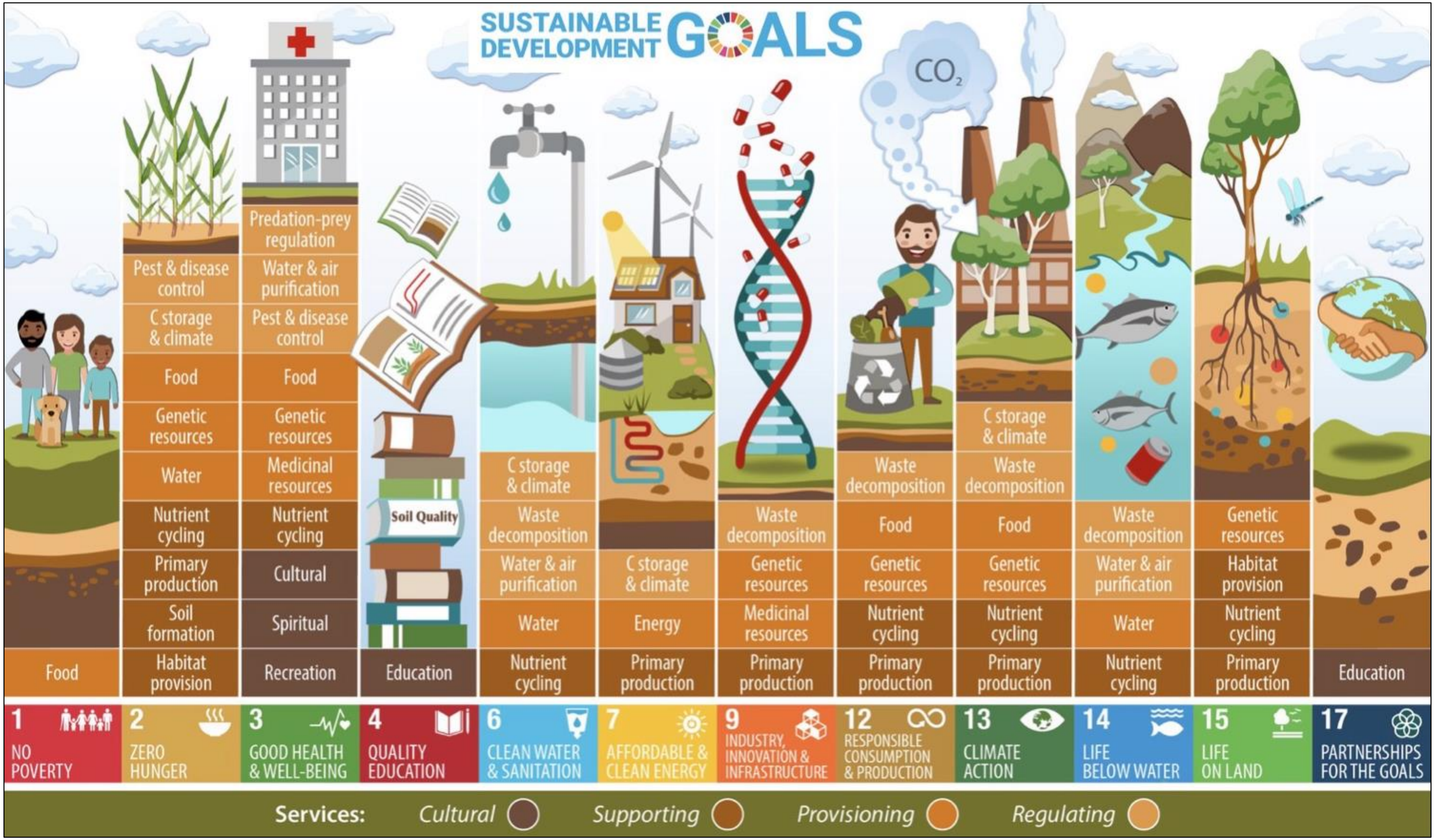

Figure 3: Soils provide for a range of ecosystem services as identified in the above infographic linking soil ecosystem services to the UN SDGs (Murphy, 2021)

Chapter 2: The Status of Soil Health

In 2015, the Food and Agriculture Organization (FAO) of the United Nations released the "*Status of the World's Soil Resources*" which identifies what the author observed during global travels; every agricultural region across the globe has, to some degree and relative to the local environment, soil health issues (FAO & ITPS, 2015). For example, while in the United States of America (USA), the author observed salinity in California and soil acidification in South Carolina. The author visited many of the world's most productive soils and anecdotally observed that some of the more naturally productive and fertile soils were noted to be some of the most degraded. This highlighted that no matter what the soil health baseline is, the management of soil as a premium natural asset, is critical, especially to ensure global food security goals can be met.

Case Study: California, USA

California leads the USA in agricultural production with the state accounting for 13.5% of domestic agricultural cash receipts in 2019 (USDA, 2020). With over one third of the USA's vegetables and two-thirds of the country's fruit and nuts grown in the Golden State, California's soil health clearly underpins a range of economic, environmental and social metrics for the state and wider nation (CDFA, 2020).

Figure 4: Irrigation, as shown here in Bakersfield, is causing salinisation across large tracts of the productive Central Valley of California (Image: Author)

Figure 5: Salinisation in a paddock in the Central Valley, California, 2014 (Photo: Scott Baurer, ESDA, sourced from USGS, 2020)

Like WA, California's soils face many challenges, the most serious being salinity with thousands of hectares having been retired from agriculture in the Central Valley because "*the soil is now* *too saline to grow food*" (Gies, 2017; Desai, 2018). While the cause of the salinisation differs (irrigation salinity in California as opposed to dryland salinity in WA), the threat remains the same; soil health is compromised resulting in productivity losses and impacts on natural resources.

Case Study: South Carolina, USA

Most South Carolina (SC) cropland soils require lime to correct soil acidity, and then, maintenance applications to ensure the pH is optimal for plant health. While at the United States Department of Agriculture (USDA), Coastal Plains Soil, Water and Plant Conservation Research Centre in Florence, SC, the author observed the predominantly sandy soils (Figures 6 and 7) of the region and identified the presence of sorrel (Figure 6) which has long been regarded as an indicator of acid soils (Meadley, G.R.W., 1957). With an average rainfall more than 1,000mm, the sandy soils facilitate heavy leaching requiring regular lime applications to address soil acidification.

Figure 6: Site visit at the USDA Coastal Plains Soil, Water and Plant Conservation Research Centre, Florence, SC, March 2019, noting the abundance of sorrel in the background (Image: Author)

Figure 7: The sandy soils of Florence showing non-tillage (top core) and tillage (bottom core) treatments, Florence, SC, March 2019 (Image: Author)

2.1 Soil health in the WA landscape

"Australian growers work under extremely variable conditions and with some of the world's poorest soils."

WA has many different soil types across its diverse and complex, natural and modified landscapes. Unlike the productive Central Valley of California for example, southwest WA is dominated by ancient landscapes and widespread sandy soils that are strongly weathered. By world standards, the soils are infertile and have a range of physical and chemical constraints to plant growth (Soil and Land Conservation Council, WA, 2020). The sustainable management of soils is essential to the continued viability of the WA agricultural industry and to minimise offsite impacts.

While it is acknowledged that WA growers have made significant advancements in soil management, the soils continue to be impacted. Soil acidification, waterlogging, salinity, compaction, erosion and water repellence are some of the key constraints impacting on production and the natural environment in WA; in many instances a particular soil may be impacted by multiple soil constraints. Of particular interest to the author is soil acidification.

2.2 Soil acidification measurement, effects, and management

"Soil acidification is an inevitable and ongoing consequence of productive agriculture. When ongoing soil acidification is managed as an integral part of the farming system, soil can be prevented from becoming acidic".

Surface and subsurface soil acidification is an economic and natural resource threat impacting on large areas of south-western WA. Soil acidification is a natural process, accelerated by productive agriculture, mainly through inefficient use of nitrogen and the export of alkalinity in produce.

Soil acidity is measured in pH units (in calcium chloride solution in Australia, abbreviated to pHCa) which is a measure of the acidity or alkalinity of a soil. pH is defined as the negative logarithm of the concentration of hydrogen ions in solution. The lower the pH, the greater the acidity. Small changes in pH value represent significant soil chemistry changes. Plant growth and most soil processes, including nutrient availability and microbial activity, are favoured by a soil pHCa range of 5.5 to 8 (Gazey P. , 2020).

Soil acidity can limit crop and pasture choice, production and profitability (Gazey C. A., 2019). Specifically, the effects of acidic soils are linked to aluminium toxicity, restricted availability of key nutrients and impacts on microbial processes. Aluminium toxicity in the subsurface is a major source of production loss associated with acidic soil and can be avoided by keeping the subsurface pHCa above 4.8 (Gazey C. A., 2019). The availability of key nutrients to plants is impacted by soil pH. In acidic soils, the availability of major plant nutrients (including nitrogen, phosphorus, potassium, sulphur, calcium, magnesium and the trace element molybdenum) is decreased and may be insufficient to support optimal plant growth, as illustrated in Figure 8 (Gazey C. A., 2019; Midwest Laboratories Inc., 2021). Most soil microbial processes, including the breakdown of soil organic matter and cycling of nutrients, are negatively impacted in acidic soils. This is due to the growth and activity of soil microorganisms being constrained by physiochemical and hydraulic properties of these soils (Gazey C. A., 2019).

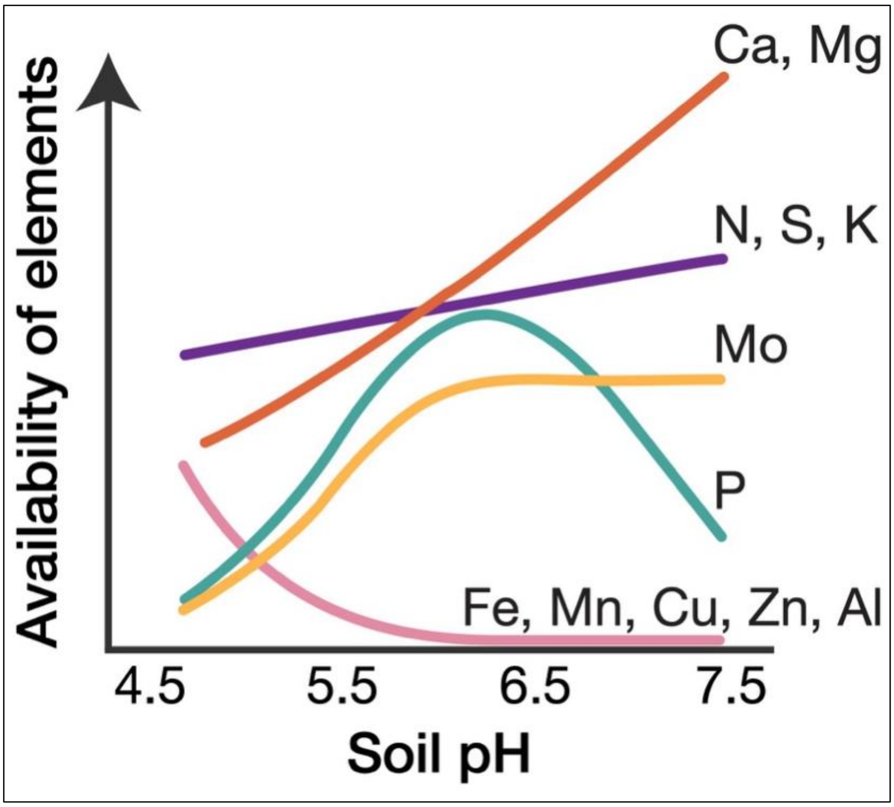

Figure 8: In acidic soil, some nutrients may be insufficiently available to support optimal plant growth and aluminium may become toxic (Gazey C. A., 2019)

Further to the immediate productivity and profitability losses of soil acidity, the off-site impacts of soil acidification resulting from decreased water and nutrient uptake include the degradation of waterways, groundwater pollution and dryland salinity which represent significant threatening processes impacting on ecosystems and broader environments (Gazey C. D., 2014).

2.3 Management of acidic soils

Soil acidity can be effectively treated, with the application of bulk lime in the form of lime sand, crushed limestone or dolomite currently being the most cost-effective management options (Gazey C. A., 2019). Managing soil acidity through lime application is considered both achievable and profitable and was observed to be the most widely accepted and adopted best management practice in many global production areas during the authors travels, including in Lower Saxony, Germany, where lime was produced as a by-product from the cooling processes of nuclear power generation (Figures 9 and 10).

The process of identifying and addressing soil acidification is quite simple:

1. Soil test (topsoil and at depth),
2. Develop a liming program,
3. Source and test lime for required rate (accounting for neutralising value and particle size), and
4. Apply lime.

Lime sources and access to lime was identified as a challenge in many locations, however it was not observed to be a barrier to prevent application.

A range of management practices have been investigated and are being implemented to varying degrees to maximise the efficiency of lime use. Managing fertiliser use to reduce nutrient leaching involves actions such as using less acidifying fertilisers, split fertiliser applications and variable rate technology application for more targeted fertiliser applications. Reducing nutrient leaching can be achieved through the establishment of perennial pastures and through fertiliser management techniques (such as those previously mentioned). The incorporation of lime via deep tillage to facilitate the placement of lime at depth to address subsoil acidification has been effectively trailed across various agricultural regions of WA, as well as the use of variable rate technology to match lime requirements to application rates. Increasing acid tolerance of crop and pasture varieties through biotechnology and conventional breeding represents a further opportunity to support the management of acidic soils and complement a liming program (Fry, 2015).

Figure 9: Potatoes growing in Emsland, Lower Saxony, where a liming strategy is in place (Image: Hamish Murray)

Figure 10: Lime produced as a by-product of the cooling processes of nearby nuclear power plants is used for agricultural application, Emsland, Lower Saxony (Image: Author)

Alternative liming agents have been explored globally and in WA; however, the application of lime remains to be the most cost-effective practice (SCNRM, 2018; Gazey C. D., 2014). Alternative liming agents include wood ash, the Water Corporations lime amended BioClay®, Red Lime™, and Alkaloam™ (Fry, 2015).

The extent of soil acidification in WA topsoils (to is shown by the results of soil assessment cm) is shown in Figure 11. The data used to generate these images was captured between 2005 and 2012 by the WA Department of Primary Industries and Regional Development (DPIRD). These research shows that over 70% of topsoils (0 to 10cm deep) are below the recommended minimum pH, which is pHCa 5.5. Further, nearly half of subsurface soils (10 to 30cm deep) are below the recommended minimum, which is pHCa4.8 (Gazey C. , 2020).

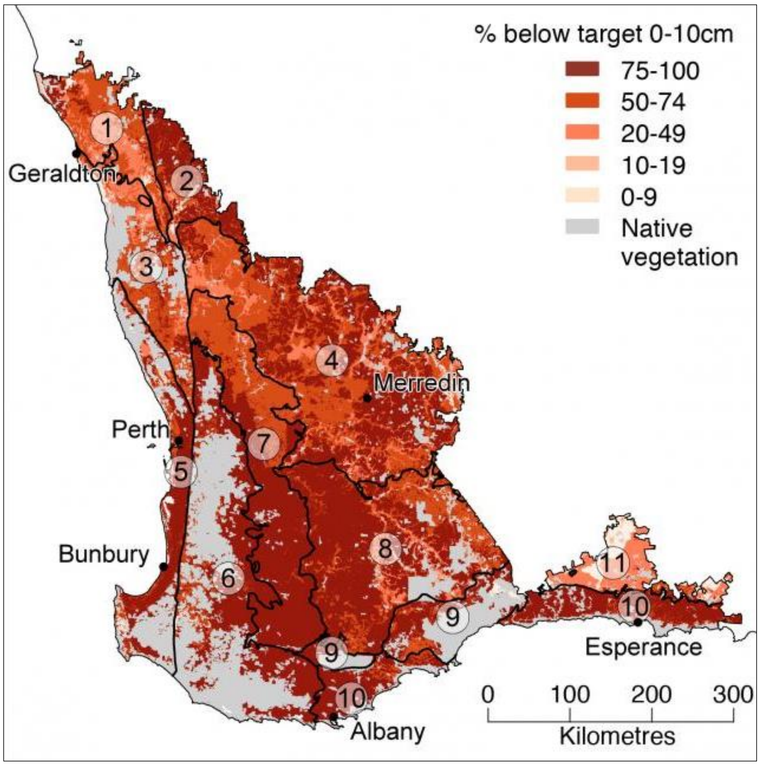

Figure 11: Soil pH status for the south-western WA agricultural region, 0-10cm depth with a target pH$_{Ca}$ of 5.5(Gazey C. A., 2019)

The WA DPIRD reports that "*liming over the last 20 years has been insufficient to counter acidification*" (Gazey C. D., 2014). In the absence of appropriate management, soil acidity will continue to cost growers the opportunity to achieve their rain-limited yield potential and have off-site impacts from a natural resource management point of view. The question is, why are soil acidity issues not being addressed at levels required to secure the productive potential of WA soils and support soil health in WA? The barriers to adoption were explored as part of this research (Chapter 3).

Chapter 3: Barriers and Challenges

Fostering the uptake of sustainable soil management is a complex process (FAO, 2021). Not only does it involve the development of the practice (ideally supported by sound and locally relevant environmental and economic research), but also being aware of, managing and addressing barriers to adoption, establishing supporting policies and structures to enable action, effective communication and engagement throughout the process and of course, investment to support the whole process. This chapter outlines barriers to adoption in relation to best management practice change.

3.1 The complexity of soil

Soils are complex! Soil health encompasses physical, chemical and biological properties or characteristics of the soil as shown diagrammatically in Figure 12. The complexity of soils and fully understanding the characteristics and interrelations, and the impacts of such, represents a significant challenge for the agricultural industry at large.

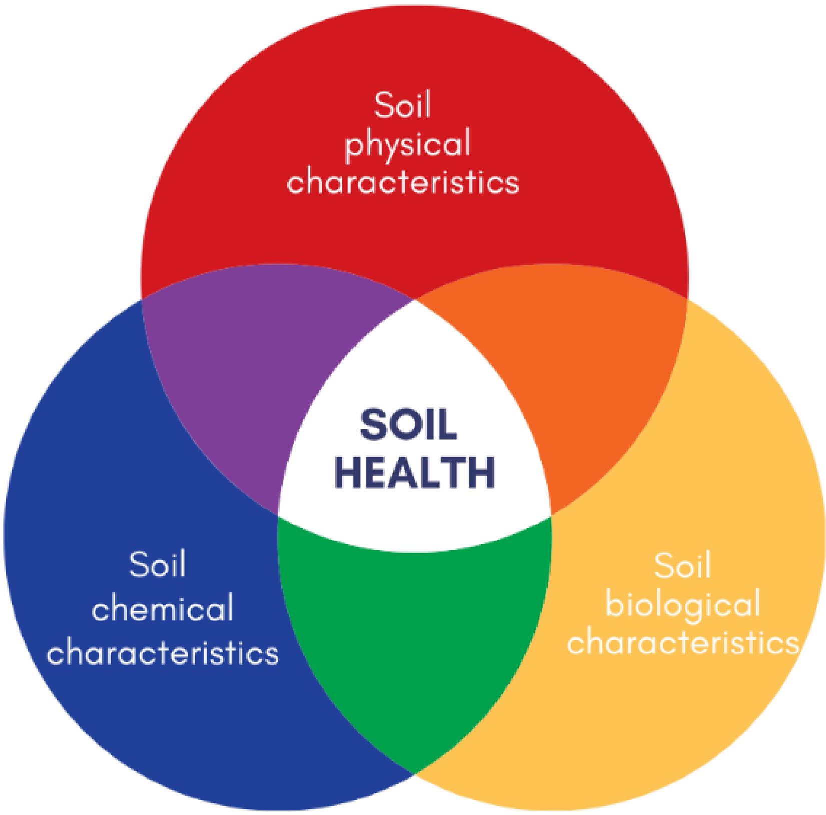

Figure 12: Soils are exceptionally complex with physical, chemical and biological characteristics that are interconnected (Image: Author)

While the physical and chemical properties of soils are often a focus and seemingly are well known across the world's soils, the author spoke with many soil health experts and the consensus was that there is much work to be done to better understand soil biological characteristics and the interrelations. The challenge with soil acidification is that soil pH can, both directly and indirectly, influence the occurrence, distribution and activity of microorganisms (Murphy, 2021).

3.2 Strategic focus for soils

At a global level, soil health is implicit in the United Nations SDGs. As presented earlier and shown in Figure 3, soil plays an important role in supporting at least 12 of the 17 SDGs. The SDGs are important to reference as they provide a global strategic focus. During this research, it was identified that many parts of agricultural supply chains are looking to contribute to the achievement of the SDGs.

Domestically, there has been recognition by both the Commonwealth and WA government of the need to focus on soils. At the time of writing this report, both the Commonwealth and WA governments had released draft soil strategies for comment. These strategies will provide clear national and state-wide strategic focus on soil health. What will be most important are the policies, programs and investments that are developed to support these strategies. It is noted that the national strategy will draw links to the SDGs (Department of Agriculture, Water and the Environment , 2021). A further opportunity for strategic focus is for natural resource management regions and catchments to develop strategies which will provide for opportunities for growers to connect locally with soil health initiatives.

3.3 Barriers to adoption

This research recognises that a significant body of work has been produced in Australia and internationally to uncover the motivations and barriers to the broader scale adoption of proven best management practices. Essentially there are many factors that can influence a grower's decision to make a practice change. Understanding these factors is critical as it will ensure that the programs and investments made in soil health align with the needs of the farming community, particularly in the continually evolving economic, social and environmental conditions.

It is the authors opinion that the financial barriers to adoption cannot be ignored, and it cannot always be assumed that it is simply a case of growers not wanting to invest. At the end of the day, growers, in the main, carry the majority of the risks and costs associated with practice change. While a lot of research has been undertaken on the economics of practice change e.g., a lime program to combat soil acidification, the incorporation of these longer-term investments into short-term budgets is a real challenge for many farm businesses.

3.4 Barriers to addressing soil acidification

The application of lime is the best management practice for addressing soil acidification, yet in WA, liming is not currently occurring at the rates or scale required to address the magnitude of the state's soil acidification issue (Gazey C. D., 2014). Barriers identified in relation to soil acidification include:

- the cost of lime (purchase, cartage and spreading),
- the short-term benefits being not immediately evident leaving growers to question return on investment compared to other investment opportunities,
- timing of the process being difficult to manage,
- the adoption of a "wait and see approach" i.e., wait for acid-tolerant varieties , and
- difficulties associated with addressing subsurface soil acidification (SCNRM, 2018).

Additional barriers that were personally identified by the author during the research period were a distrust in the best-practice method of lime application and frustration with, and distrust in the quality of lime in WA from various sources.

Chapter 4: Future Soil Health Drivers and Opportunities

Globally, increasing interest is being shown by civil society, consumers, markets and government, around environmental stewardship. When soil is considered as the basis of agriculture and a key component of environmental stewardship, it is the opinion of the author that the management of soils on-farm will most likely become of greater interest to a range of agricultural supply and value chain stakeholders going forward. This chapter will explore several potential future soil health drivers and opportunities.

4.1 Consumer trends

Consumers are a powerful force and have the potential to greatly influence farm production decisions with their buying power, a topic of much research globally. In Australia, the Soil Cooperative Research Centre (CRC), also known as the CRC for High Performance Soils, has a current project titled "*Opportunities for activating consumer markets for good soil stewardship*" which is investigating the potential to activate Australian consumer markets for rewarding primary producers for quality soil management practices (Soil CRC, 2021). To date, the project has identified that consumers are willing to pay for some farm management variables (e.g., organics, higher animal welfare), however, there is little to no evidence in the academic literature that Australian consumers are willing to pay for soil management practices (Soil CRC, 2021). A consumer focus group study discovered that what consumers want is complex and that while Australian consumers are willing to pay for specific attributes of products (i.e., free range), they do not know much about soil (Soil CRC, 2021).

While Australian consumers have indicated that they are prepared to pay a price premium for food products which are produced to satisfy their aspirations or expectations, this contrasts with German consumer behaviour anecdotally reported to the author. During the research it was informally reported to the author that German consumers are placing increasing demands on the way food is produced, but they are not willing to pay more to counteract the cost of practice change or verification at the farm level.

4.2 Standards and verification

Certified standards, such as the Red Tractor Certified Standards (case study below) can provide the opportunity to verify grower and broader industry claims throughout the supply chain, either to capture price premiums or to ensure market access. In Australia, environmental stewardship factors underpinning standards such as the National Feedlot Accreditation Scheme (NFAS), which incorporates environmental management elements into the standards. Currently the reference to soils in the NFAS standards is limited to persistent chemical residues which affect food safety, rather than promoting a standard which maintains and improves soil health (AUS-MEAT Limited, 2018).

Case study: Red Tractor Certified Standards, UK

A not-for-profit company, Red Tractor was established in 2000 to rebuild trust in British agriculture after a spate of food scares. Today, Red Tractor is the United Kingdom's (UK) largest food standards scheme, owned and funded by organisations and trade bodies from across the British farming and food industry (Red Tractor , 2021). Red Tractor seeks to provide links between farming, processing, packaging and distribution, with 95% of all UK farms reportedly adopting the farm assurance program. Most British retailers and food services companies require all the food products they purchase or handle to be "Red Tractor" assured which again provides a strong incentive for growers to be accredited. The quality criteria that growers must meet when obtaining certification have been set by people in the farming and food sector, an important factor in the high-level acceptance of the scheme by growers, as reported in an Australian review (Australian Farm Institute, 2021). Consumer awareness of the brand (Figure 13), and what stands behind it are quite high: almost 80% of British shoppers recognising Red Tractor and viewing it positively (Australian Farm Institute, 2021; The Pig Site , 2021).

Figure 13: The Red Tractor brand is well known throughout the UK (Image: Red Tractor (Red Tractor, 2021)

Red Tractor standards are recognised as some of the most comprehensive, independently validated farm and food standards in the world, covering more types of food and drink than any other assurance scheme (SAI Global , 2021). The Red Tractor Certified Standards guarantee the British origin of the farm product and must address four principals: animal welfare, environmental protection, food safety and food traceability (Red Tractor, 2021).

As an example of standards relating to soil, the Red Tractor Combinable Crops and Sugar Beet Standards, V.4.1, includes the requirement for growers to "*Minimise the adverse impact the farm has on wildlife, flora, fauna and the environment, including soil, water and air*" and to ensure that "soil is managed in a way that helps maintain soil condition" (Red Tractor, 2021).

4.3 Regulation

Managing the environment is part of farming; however, managing exposure to environmental liability is an area that the author feels Australian growers will need to be increasingly aware of and actively address in future. This would involve understanding environmental legal requirements and liabilities, ensuring their workforce is trained in identifying and managing environmental risks and ensuring there are appropriate risk management processes and systems in place. While undertaking research in New Zealand, the author investigated the role of regulation to enforce best practice management.

Case study: Nutrient management environmental reforms, New Zealand

Agriculture is a significant industry in New Zealand (NZ), contributing 5.8% to gross domestic product (GDP) in 2017, compared to 2.7% in Australia in the same year. Importantly, primary industries export revenue ($48NZ billion in 2020) comprises approximately 70% of total exports (Ministry for Primary Industries, 2020). Despite the reported significant investments by New Zealand growers and the agricultural industry to improve environmental performance, environmental reforms to address water quality concerns in Canterbury have required growers to account for a greater range of environmental impacts through the development and implementation of audited farm environment plans, see Figure 14 (Holgate, 2019).

While Environment Canterbury reported that water quality trends were improving in Canterbury in its August 2018 report, growers and industry representatives anecdotally commented to the author on the negative impacts of regulation, notably land prices

(Environment Canterbury, 2021). New Zealand dairy land values were reported in early 2020 to have been “stuck in neutral” since 2010 with nutrient regulation and environmental change expected to contribute to softer land prices (Gray, 2020).

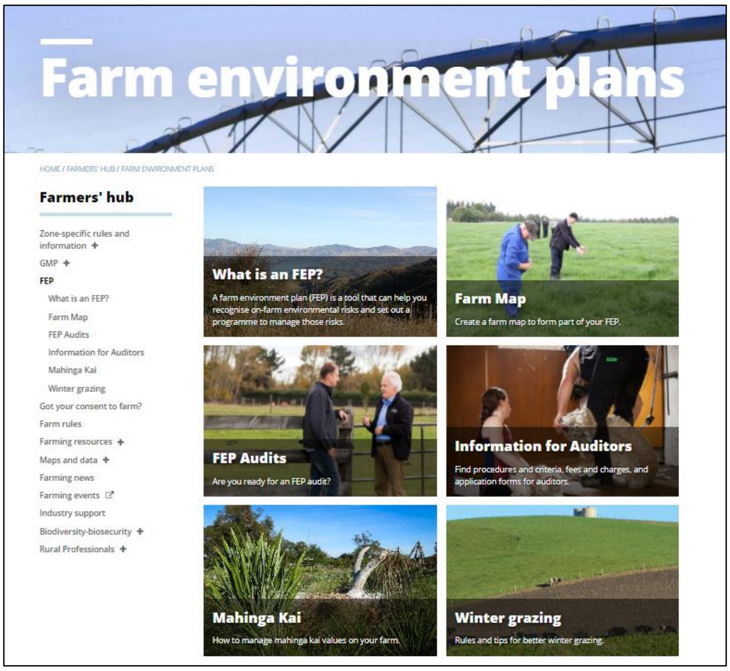

Figure 14: The ‘Growers’ hub’ on the Environment Canterbury website provides information on farm environment plans, including ‘Got your consent to farm?’ (Environment Canterbury, 2021)

4.4 Climate change, carbon farming and soil health

Whether an individual accepts or acknowledges the science of climate change, the author identified that globally and increasingly, interest is being shown by civil society, consumers, markets and governments, towards addressing greenhouse-gas-induced climate change. The opportunity for agriculture is that land, the soil, is both a source and a sink of greenhouse gases (IPCC, 2020).

Under international climate agreements, Australia has an economy-wide target to reduce greenhouse gas (GHG) emissions to 26% to 28% below 2005 levels by 2030 (Australian Government , 2020; National Farmers Federation, 2021). In November 2020, the Government of WA released the WA Climate Policy which identifies ambitions of enhanced climate resilience and net zero GHG emissions by 2050, a goal shared by the National Farmers Federation (Government of WA, 2020; National Farmers Federation, 2021).

Industry is proactively leading on the climate change front domestically. One example is the work of Meat and Livestock Australia (MLA) where they have identified a target to achieve carbon neutrality across the Australian beef, lamb and goat industries by 2030, as stated in the Australian Red Meat Industry's Carbon Neutral by 2030 Roadmap (MLA, 2020). This roadmap reports that, according to analysis undertaken by CSIRO, the Australian red meat industry's proportion of national GHG emissions has reduced form 21% in 2005 to 10% in 2017 (MLA, 2020). Four key work areas identified in the roadmap are leadership building, GHG emissions avoidance, carbon storage and integrated management systems. Key to soil health is the carbon storage area with the key objective being "*to increase carbon storage on grazing lands*" (MLA, 2020).

Examples from the grains industry include the collaboration between CBH Group and Wide Open Agriculture, who in July 2020 signed a non-binding Memorandum of Understanding to explore the feasibility of certification, marketing and global distribution of carbon neutral grain (Beattie, 2020). Further, there is the partnership between the Grains Research and Development Corporation (GRDC) and CSIRO to support the Australian grains industry to better measure and reduce its greenhouse gas emissions. Specifically, the GRDC and CSIRO projects are investigating grains industry emissions in relation to access to markets, access to capital and insurance, consumer sentiment and the competitively positioning Australian agricultural (differentiation). At the 2021 GRDC Grains Research updates in Perth, WA, John Woods (GRDC Chair), stated that "*decreasing GHG emissions is absolutely compatible with increasing productivity*".

From a climate change and carbon farming point of view, the author considers that there is opportunity for WA growers to best position their soil health to enable the potential opportunities that come from action to sequester carbon on-farm. In respect to soil acidification, soil acidification impacts on soil carbon sequestration with soil carbon baseline measurements and soil carbon methodologies not being readily applied in the WA agricultural landscapes. At the time of writing this report, only one soil carbon project was registered in WA with the Australian Governments Emissions Reduction Fund.

Recent carbon farming market research undertaken in WA identified that there are strong indications that landholders will consider carbon offsetting and participating in carbon farming projects in future. Barriers to carbon farming identified in this research included the lack of stable government policy, the financial viability of project partners and the legal encumbrances on land titles associated with long-term carbon-credit contracts (Carbon Positive Australia, 2021).

4.5 Pressures from agricultural value chain stakeholders

Recalling that at a global level, the SDGs place a focus on soil health, it was observed by the author that many agricultural stakeholders are aligning their business strategies with the SDGs. Figure 15 provides a representation of the movement of commodities along the supply chain and further identifies the expected future requirements for data and information transfer which will be aided by blockchain technology. This image also serves to highlight where pressures throughout supply chains may drive action on farms to meet sustainable food, fibre and fuel production requirements, this could include soil health parameters. Data management in relation to soil health is a challenge and as agricultural supply and value chains seek to verify environmental stewardship, data collection should receive more attention.

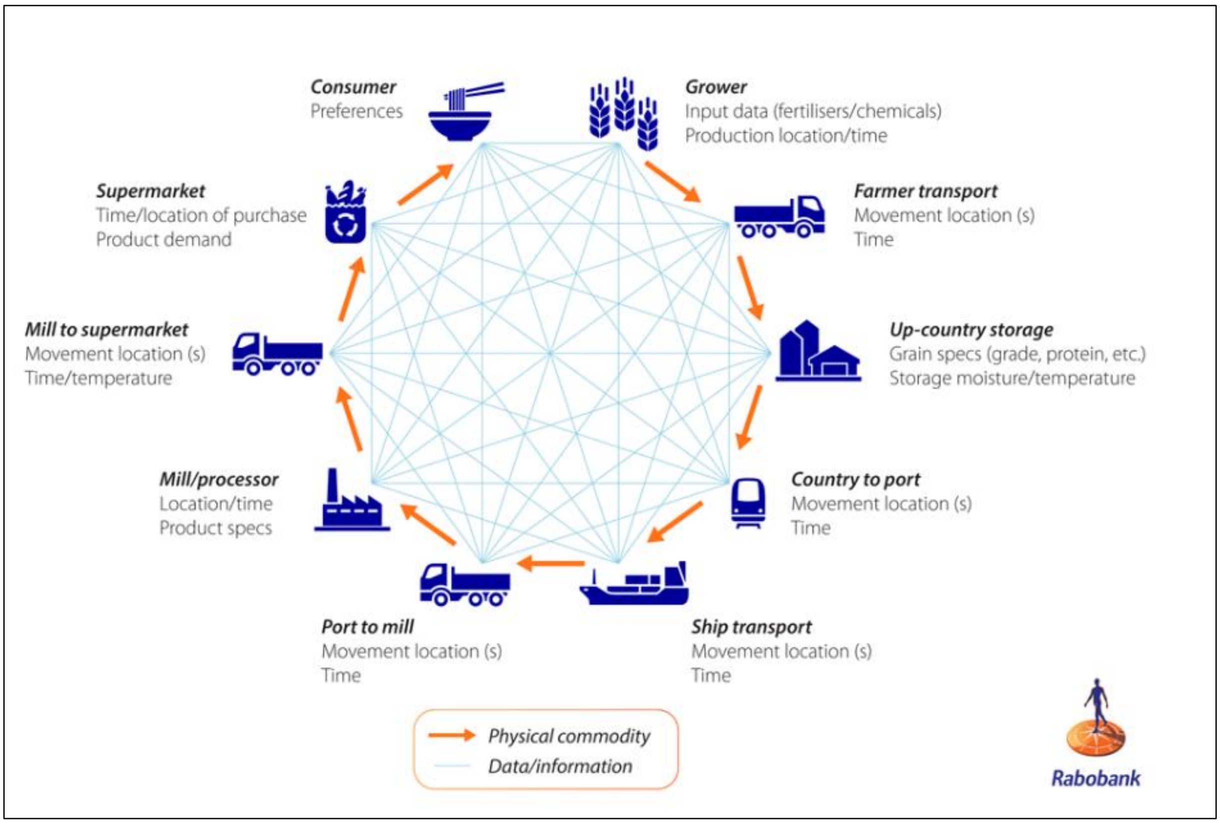

Figure 15: Movement of commodities along the supply chain and the resulting data/ information web, highlighting the range of stakeholders who may place pressure on growers to meet broader global sustainability objectives (Lefroy, Rabobank 2017)

4.6 Finance and insurance markets

In March 2019, the Australian Prudential Regulation Authority (APRA) announced that it will increase its scrutiny of how banks, insurers and superannuation trustees are managing the financial risks of climate change to their businesses (APRA, 2020). Finance markets are under increased pressures from a range of stakeholders to adjust their lending behaviours to meet sustainability requirements. The author spoke with many financial institutions who confirmed that sustainability is increasingly on the agenda in terms of managing portfolio risk. While traditionally financial performance indicators are used to assess the financial performance of a client, many financial institutions are moving to address the triple bottom line in client assessments in future. One example, of which there are many, is National Australia Bank (NAB) which reported that they are "*working in partnership with ClimateWorks Australia to develop sustainability metrics*" (NAB, 2021).

The opportunity of financial markets to drive increased soil health is being researched by the Soil CRC. This research is investigating the potential opportunities and pathways towards the activation of financial markets to reward soil stewardships, including, for instance, improvements to soil health and the impact on farm risk and profitability assessments, land and valuation practices, and agricultural lending, insurance, and investment decisions (Soil CRC, 2021). From the grower's perspective, the Soil CRC has reported that several corporate growers perceived that "land valuation practices failed to account for their investments in soil stewardship" and that data availability contributed to this failure (Soil CRC, 2021).

4.7 Market access

Accessing and maintaining market access was observed by the author as another driver for environmental stewardship. The European Union, and more recently the USA, are reportedly strongly considering carbon border taxes for example which will likely impact on Australian domestic climate change policy, frameworks and initiatives.

A further example of securing and maintaining market access through environmental stewardship verification is the International Sustainability and Carbon Certification program (ISCC). As part of access to European canola markets, Australian growers wanting to access the ISCC pricing premium on grain sales are required to sign a declaration prior to selling grain which assures a range of factors including that "*the crops are produced in an environmentally responsible manner, including natural water courses, ground water and irrigation, soil* *conservation, prevention of erosion and preservation of organic matter and soil structure*" (ISCC, 2021). It is noted that the ISCC references the programs contribution to the SDGs.

4.8 Natural capital accounting and the valuation of ecosystem services

The adoption of best management practice to address soil health, liming in the case of soil acidification, delivers both private and public good. However, the public good benefits which flow from grower investments in soil stewardship are not generally acknowledged and certainly are not currently rewarded in Australia. Australian growers wear the risk and outlay the capital to address issues that provide benefits to broader society. Natural capital accounting and valuing ecosystems services on private land are a potential future mechanism to provide a valuation for environmental stewardship on farm, particularly in soil health as the soil forms the basis of economic productivity on farm.

Valuing natural capital recognises that the best environmental outcomes are achieved by empowering and incentivising landholders to manage their landscapes, including soil (KPMG, 2019). Natural capital accounting is an umbrella term covering efforts to use an accounting framework to provide a systematic way to measure and report on stocks and flows of natural capital (United Nations, 2021). Essentially, natural capital accounting recognises that since the environment is important to society and the economy, it should be recognised as an asset that must be maintained and managed and that its contributions (services) be appropriately valued. This represents a significant change in the value of the environment, where historically economic development and accounting has not accounted for environmental externalities.

Globally there are a range of developments in valuing natural capital and Australian Bureau of Statistics (ABS) reports a growing demand for integrated environmental-economic information in Australia (ABS, 2021). The United Nations System of Environmental-Economic Accounting (SEEA) is an established international statistical standard that uses a systems approach to bring together economic and environmental information to measure the contribution of the environment to the economy and the impact of the economy on the environment (United Nations, 2021). In 2014, the ABS began developing annual Australian Environmental-Economic Accounts (AEEA) which utilised the United Nations SEEA (ABS, 2021). The valuation of the 2019 AEEA was $6.5 trillion, with 90% made up of land and some 58% of that devoted to agriculture (ABS, 2021; NAB, 2021).

In 2019 the Australian Government, in consultation with all states and territory governments, developed the National Environmental-Economic Accounting Strategy, which utilises the ABS AEEA data as a basis. The vision of the strategy is that "*the Australian community understands the environment's contribution to our quality of life, and its condition and value are accounted for in decision making for a prosperous and healthy society*" (DAWE, 2021).

The author feels that growers inherently understand the importance of protecting resources and that they underpin productive capacity. The challenge from a grower's point of view with valuing natural capital is that while there is a lot of discussion and calculation happening, the value of natural capital will not be truly realised until it is assigned on the balance sheet.

Chapter 5: Collective and Coordinated Growth of Soil Knowledge

"Cultivate soil knowledge to grow soil health".

Soils are extremely complex and soil itself is not easily understood. As growers and the broader agricultural industry seek to address the macro-drivers as described in Chapter 4 and make the most of opportunities to address soil health issues, the coordinated growth of soil knowledge will be imperative (Soil CRC, 2020). Chapter 5 identifies some key strategies to support soil knowledge growth in WA.

5.1 WA growers indicate soil health as a priority

WA growers are concerned about soil health and want to know more. Market research undertaken with three grower groups located in the Great Southern region of WA within the past ten years all identified that growers ranked improving soil health, addressing specific soil health issues (notably salinity) and improving soil knowledge highest when asked to identify areas of interest for profitable and sustainable agricultural projects or levels of concern for environmental issues (Tomlinson J. a., 2014; Tomlinson J. , 2017; Tomlinson J. a., 2020).

5.2 Research, development and extension and the human side

"Agriculture is a dynamic human activity, and it is undertaken in conditions of uncertainty and complexity", *Associate Professor Catherine Allan*

Soil research, development and extension plays an important role in improving the productivity and competitiveness of Australia's agriculture and forestry industries and has contributed to improved environmental outcomes (Soils Research, Development and Extension Working Group , 2011). In more recent years, there has been a strong focus on soil health. In 2017 the Soil CRC was established in Australia to give growers the knowledge and tools they need to make decisions on extremely complex soil management issues and there is a lot of amazing information being generated (Soil CRC, 2020).

The challenge that Associate Professor Catherine Allan, Program Leader for Program 1 at the Soil CRC, identifies is that "*agriculture is a dynamic human activity and it is undertaken in conditions of uncertainty and complexity*". In the soil health aspect alone, there are many unknowns, but also there are many unknowns about the human side of learning, and decision-making (Soil CRC, 2021). Human factors that influence decision making processes include life and land use objectives, experience, social capital, values, social norms, social licence, soil as part of a farming system, and limitations posed by whole enterprise (Soil CRC, 2021).

Further research and development designed to improve the extension of soil information and drive best management practice adoption is critical. The author further suggests that soils is a topic which is vulnerable to information asymmetry and recommends that future soil research and extension frameworks allow for information to flow both to and from the growers to enable knowledge sharing across the information value chain. A simple understanding of soil research and how that flows into adoption on farm is shown in Figure 16. It is the opinion of the author that adaptive learning should continually inform the research and change process for all stakeholders; it should not stop with the end user (the grower).

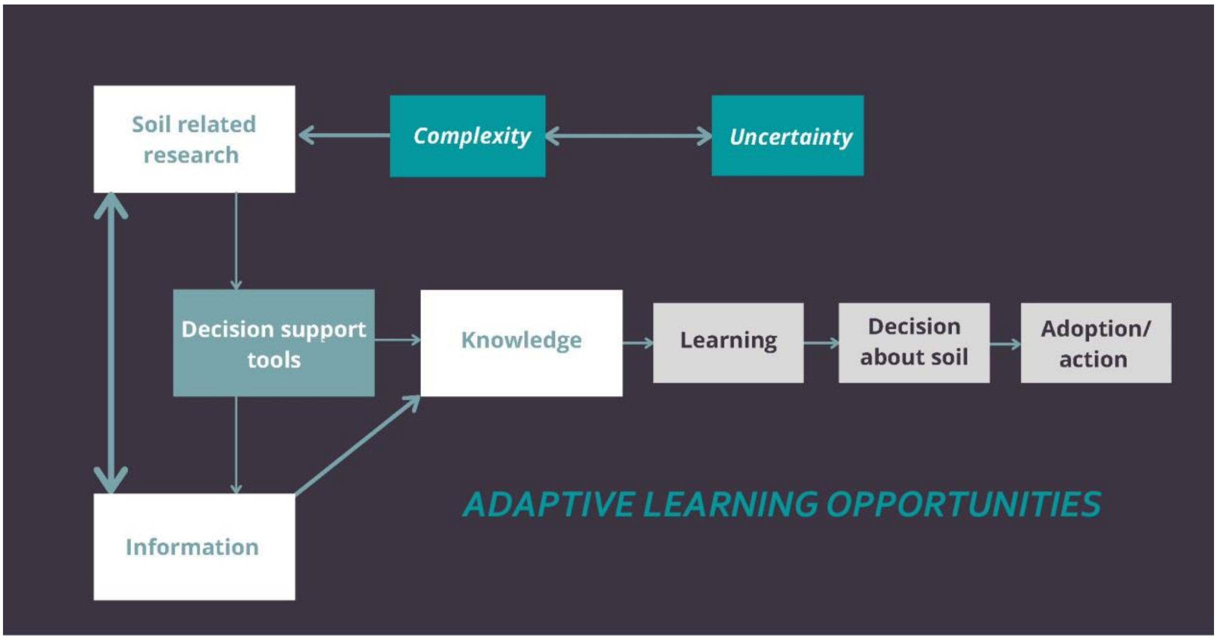

Figure 16: Research and change: a simple understanding. Adapted from Soil CRC (Soil CRC, 2021)

A continual improvement view of soil health is presented in Figure 17. This model suggests a process of soil health knowledge growth with a critical factor being collaboration. It takes commitment, strategy, action, a review process and then the determination to readjust and go again, recognising the learnings and knowledge growth along the way. The model highlights the importance of research, development and extension and that local validation is required, and that adaptive learning occurs. Soil knowledge growth across agricultural industries must continue to account for factors such as changing environments and to enable new generations of growers to build their knowledge.

Figure 17: Addressing soil health should be considered a process of continual improvement (Image: Author)

In Australia, the draft National Soil Strategy acknowledges that there is "*already a growing soil science knowledge gap*" which is attributed to retirement by the 'baby boomer' generation (Department of Agriculture, Water and the Environment , 2021). A similar observation was shared during interviews conducted by the author in New Zealand in early 2020 where one interviewee commented "*there is a lack of soil scientists in New Zealand. They are in high demand and are quite valued. They are few and far between*" (T. McFarlane, pers comm). To enable the delivery of both the Commonwealth and State governments soil strategies, the development of teams of soil health experts, such as the Soils CRC, will be required who can work collaboratively with and within grower networks.

When planning for and delivering research, development, extension and validation, the communication and learning preferences of growers should be reflected in all communications and engagements. Further, given that growers are working in farming systems, soils research, development, extension and validation needs to build towards and present with a focus on the farming system. Again, this provides an end user focus for the development of best management practice.

5.3 Grower groups and the importance of local delivery

Smaller groups work well for behaviour change. More recent research in WA identified that growers prefer to learn from their peers with research being tested in their local environment (Carbon Positive Australia, 2021). The grower group networks within WA are well established, well supported by their local communities and provide vital functions throughout their communities. They are typically well networked with larger organisations but their unique point of difference is their local ownership and drive. The grower groups in WA represent an important opportunity to deliver on the newly forming Commonwealth and State soil strategies. Appropriate resourcing of the grower groups will be vital to ensure they have the appropriate capability and capacity to deliver on soil knowledge growth and to support behaviour change in their community. An excellent example of the popularity of this approach is the Teagasc Open Day in Ireland.

Case study: Teagasc, Moorepark 2019, Ireland

As part of the China Global Focus Program, the author attended the Teagasc, Moorepark 2019 open day in Ireland. The Moore Park open day is held biennially and brings together a range of stakeholders in Irish dairy with the 2019 open day theme being “Growing Sustainably”. Approximately 30,000 people attended, with literally hundreds of research projects being presented along the path of learning set out for attendees. A network of themed ‘information villages’ for attendees to visit, included demonstrations on grazing management, reseeding, farm infrastructure, body condition and locomotion scoring, and health and safety. There were workshops on milk quality, anti-microbial resistance, new entrants to dairy farming and labour management. It was a family-friendly event and the enthusiasm and positive vibe at the event was strong. Researchers were presenting and mingling with the attendees, (Figures 17 and 18). To support the variety of learning products, a comprehensive 296-page booklet was provided at admission.

Figure 19: The Moore Park, Ireland open day drew a crowd of thousands who all seemed very engaged in the learning environment presented (Image: Author)

Figure 18: Researchers presenting directly to growers, Moore Park, Ireland (Image: Author)

5.4 Research to support the long-term vision for soil health in WA

The influence of healthy soils on the environment means that soil is increasingly being recognised as a significant public good (Australian Government; Department of the Prime Minister and Cabinet, 2020). Landuse changes, the impact of agricultural practices, soil processes and the impact of actions to address soil health issues can take decades to have any measurable effects. This is important to note in the case of soil acidity with its slow development and its logarithmic scale of impact. Long-term experiments are an invaluable resource that can be used to quantify changes that are impossible to detect in short term experiments (Rothamsted Research, 2018). Globally there is a relatively small network (some 250 studies) of long-term soil experiments, some of which are catalogued in an inventory hosted by the International Soil Carbon Network; no sites are located within WA (ISCN, 2020).

In WA, a long-term response to liming trial was established in 1994 in Mingenew, which provides WA-based evidence of the treatment of lime to address soil acidification (Gazey C. O., 2020). Establishing and resourcing a network of local, long-term soil research sites across the WA grain and livestock regions will provide benefits to successive generations of growers. The benefits of such long-term research are demonstrated at Los Baños in the Philippines.

Case study: Long-term continuous cropping experiment, Los Baños, Philippines

The 'Long-Term Continuous Cropping Experiment' at the International Rice Research Institute (IRRI) was established in 1962 and is "*the most intensively cropped experimental site in Asia*"

(Buresh, 2002). The one-hectare site was established largely as a demonstration plot which aims to provide insights into the long-term effects of extensive cropping and how to maintain the resource base and productivity. It allows for the array of biological, chemical and physical processes to be observed to assess the sustainability of the soil fertility.

Figure 21: IRRI long term research site interpretive information boards, Los Baños, Philippines (Image: Author)

Figure 20: IRRI longer term research site, Los Baños, Philippines (Image: Author)

5.5 Decision support tools

Decision support tools exist for a range of land management issues across the globe. In a WA context and in addressing soil acidification and its management, the following is a list of just some of the tools available:

- **iLime**: An app to assist growers identify the most profitable liming strategy for their paddocks, launched August 2019.
- **Ranking Options for Soil Amelioration (ROSA)**: An Excel file to run soil amelioration options based in their cost-effectiveness. In January 2021, 154 people had requested a copy of ROSA, including 43 consultants, 48 growers, 20 DPIRD researchers, 22 external researchers, and six grower groups (J. Lemon, pers comm, January 2021).
- **Soilmapp**: Identifies the likely soils on your property, and includes imagery (maps, photos, satellite images, soil information), physical and chemical characteristics (acidity, soil carbon, available water storage, salinity, erodibility). This model links in with APSIM (Agricultural Production Systems SIMulator), a model that can help with management decisions on crops.
- **Soil quality eBooks**: A freely available series produced by WA soil health experts.

- **Acid Soils SA**: A website launched in late 2020 which has been purpose-built for growers and advisers, containing information, resources and tools to improve the management of surface and subsurface soil acidity in South Australia (GRDC, 2020).
- **Various lime calculators** available freely online including Liebe Lime Profit Calculator, Lime Benefit Calculator, the Optlime mobile app.
- **soilquality.org.au** which is an online platform and library of information and tools for Australian soils.

The important factor to decision support tools is that they have a user-centred design focus and are backed up by well-resourced communication and engagement strategies to maximise use by the end-user. Ideally, decision support tool developers will work directly with growers to identify and diagnose the issues and requirements and work through how the decision support tool can aid in the process of driving change.

5.6 Monitoring and evaluation to support continued improvement

Investment in monitoring and evaluation is critical to enable for continual improvement processes of natural resources, such as soils. Measuring, monitoring and understanding soil properties helps growers to make land use and nutrient planning decisions to improve soil performance. Soil properties are measured using soil performance indicators often categorised as biological, chemical, or physical indicators. Measuring and monitoring soil performance is challenging and correspondingly, establishing site-specific soil performance metrics is also challenging.

Monitoring and evaluation of soil health needs to occur from the farm level, through to the state and national level, where it can then report at the international level. It is the opinion of the author that a more current assessment and state of soil health across WA is required, particularly for soil acidification. This will inform planning and practice change investment by growers and other stakeholders to grow soil health.

Conclusion

Soil health globally is being impacted by a range of threatening processes driving an increasing international and domestic strategic focus on soils. While best management practices have been developed for a range of threatening processes, lime application in the case of soil acidification, adoption rates remain below levels required to effectively address production losses and the broader risks of not addressing soil degradation processes.

This research identifies a pipeline of macro drivers that may provide growers the motivation beyond production gains to address issues impacting on the health of soils. These macro drivers are essentially developing as agricultural supply and value chain participants and broader agricultural stakeholders seek to demonstrate their commitment to supporting the global sustainability agenda.

The research identified that increasing the knowledge of soils within the grower network and facilitating the number of opportunities for grower feedback to be incorporated into broadening the industry knowledge of soils, will provide greater knowledge growth throughout the research and change process. This knowledge growth is a priority to enable real action to address soil health issues, but also to enable growers to respond to drivers and opportunities as they present. A focus on local research, development, extension and local validation will be critical to supporting grower soil knowledge and management skill development in the future.

Recommendations

To support improved soil health in WA, the following recommendations are proposed:

- In support of the Commonwealth and WA soil health strategies, undertake a state of soil health assessment in WA and across Australia, with a focus on establishing soil health baselines to guide research, development, extension and local validation and enable the establishment of effective monitoring and evaluation programs that are embedded at all levels to assess return on investment and the impacts of practice change.
- That a review of current soil health information sources is undertaken with a view to consolidating sources and constructing an innovative, engaging and contemporary platform for learning and sharing that is adequately resourced and supported across industry.
- Support a network of longer-term soil research, development and extension sites throughout the south-west WA agricultural zone. Collaboration is required to maximise the knowledge growth opportunities.
- Adequately resource locally based WA grower groups and natural resource management groups to ensure capacity and capability at the ground level to support research, development, extension and local validation to assist in soil knowledge growth and transfer.

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Plain English Compendium Summary

Project Title:	**Growing Soil Health: Future drivers and critical knowledge growth frameworks to support improved soil health in Western Australia**
Nuffield Australia Project No.:	1913
Scholar: Organisation:	Johanna Tomlinson Tomlinson Agricultural 224 Benson Road KALGAN WA 6330
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Objectives	• Review the status of soil health from the global to the local scale. • Review and explore the barriers and challenges impacting on the adoption of best management practice for optimum soil health. • Explore the future soil health drives and opportunities. • Explore the challenges and opportunities for collective and coordinated growth of soil knowledge in WA.
Background	Soil acidification is a major constraint in southwest agricultural area of Western Australia. This report recognises that soil acidification is increasing, despite existing best practice methodologies, existing locally verified production research and attempts to remove the currently understood barriers to land management practice change. The report then identifies future drivers and opportunities for soil health improvements and focuses on the knowledge growth opportunities to drive practice change.
Research	The author visited USA (Nebraska, Iowa, North Carolina, South Carolina, California, Washington DC, Texas), Singapore, Philippines, Hong Kong, China, Germany, Netherlands, Ireland, Argentina, Brazil and New Zealand.
Outcomes	The research identifies a range of macro drivers and opportunities for growers to address soil health issues, particularly soil acidification. The report emphasises that knowledge growth must be enduring and that increasing the knowledge of soils within the grower network is a priority to enable real action to address soil health issues and to empower growers to respond to drivers and opportunities as they present. A focus on local information and ensuring grower needs are met is needed.
Implications	Soil health knowledge is vital for addressing soil health issues. The programs and investments that are developed to support the Commonwealth and Western Australia soil health strategies will be critical and knowledge growth should be a focus. Growers need to prepare for increased pressures and opportunities to address their soil health.