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Southern Queensland and Northern New South Wales Regional Soil Capacity Gap Analysis

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1 Summary and Recommendations

A Soil Capacity Gap Analysis has been completed for the Southern Queensland and Northern NSW region.

Prior to commencing the development of this Gap Analysis, the authors expectations of the likely findings could be considered naïve. It quickly became apparent that the circumstances which have led to the point where Australia's soils '*are in poor condition and deteriorating*' (Williams et al., 2021b) are deeply seated and interconnected.

Improving soil and land management with the aim of achieving the goals of the National Soil Strategy (NSS) can be considered a '*wicked problem*' (Head, 2022), based on the complexity of the environment in which soil is managed (e.g. landscape and soil types, enterprise types, organisations involved), the uncertainty with regards to improving soil management and ultimately condition (e.g. efficacy of new/different practices, regional and industry contexts, economics) and diverging values, priorities and interests of the numerous stakeholders.

The NSS has been developed to address this wicked problem. Whilst not explicitly stated, it is evident through the goals and objectives of the NSS (and the National Soil Action Plan (NSAP)) that there is an inherent understanding of the complexities and interconnectedness of issues that require addressing to improve soil management and ultimately condition.

The question thus becomes, will the initiatives included within the NSS (and NSAP) be sufficient to address the underlying issues?

Across the seven elements of the McKinsey 7s model, which was used as the tool to analyse the information collected for the Gap Analysis, significant gaps were identified across many areas (see the relevant Section summaries for each element of the McKinsey 7s model in the main body of the Report for more detail) as well as significant barriers to adopting improved soil management properties.

The core issue related to improving soil management, which is largely tangential to the NSS itself, is the economic and social environment in which land managers and primary producers operate.

The economic environment is the overriding driver of farm business decision making. The current and likely future economic environment is such that for many landholders the capacity to markedly improve soil management will be significantly constrained. The ability to change can be further constrained by the cultural and social environment in which agriculture exists, which can act as either a barrier to, or agent of, change.

These factors are exacerbated by the key gaps identified across the different elements including:

- Soil strategies across different organisations and jurisdictions that are either missing, lack clarity or are unclear as to how the strategy will be achieved.
- The lack of workforce planning to define, generate and maintain the soil expertise required to support improved soil management.
- Skill and knowledge deficiencies across a range of soil related areas.
- A declining capacity in extension that is negatively impacting upon the capability to support practice change through addressing barriers to adoption at farm scale.
- Insufficient funding and resources.
- Challenges with developing and maintaining trust with landholders.
- Incentive systems that run counter to the objectives of the NSS.

Some of the initiatives that have been developed to this point as part of the NSS (e.g. the Registered Soil Practitioner (RSP) program) will go some way to addressing some of the identified gaps. Whilst the first NSAP (of four to delivered by the NSS) is aimed at *'identifying critical gaps and prioritising foundational actions*', given the nature of the gaps that have been identified, current resourcing and institutional priorities, it appears likely at this point that the NSS will result in at best, **marginal improvements in soil condition over the foreseeable future**.

This is assessment is based on a 'rearview' examination of literature assessing major government environmental programs (such as the review of the National Action Plan on Salinity and Water Quality by Pannell and Roberts (2010), the effectiveness of land restoration efforts in Australia over the last forty years (Campbell et al., 2017), previous attempts to address deficiencies in soils Research, Development and Extension (RD&E) capacity (Department of Agriculture Forestry and Fisheries, 2014), assessments of both current soil capacity (de Bruyn et al., 2022) and soil science education (Rogers et al., 2020), the Australian National Audit Office's audit of the early design and implementation of the National Soil Strategy (Lee et al., 2024), and finally the level of funding required to fix at a systemic level Australian soils (Wentworth Group of Concerned Scientists, 2024) compared to current investment.

The range of negative impacts, many of which could be deleterious (at a range of scales from individual landholders through to communities, regions, industries and even nationally), from not improving soil condition highlight the critical importance of addressing at a fundamental level the barriers and gaps that have been identified. Three key risks to the achievement of the NSS have been identified (see Section 1.1).

The levers which governments, and other organisations, can manipulate to address the identified barriers and gaps are for all practical purposes limited. Thus, it is critically important that actions taken to address these gaps are tightly focused and adequately resourced to maximise their impact. The recommendations that follow are far from exhaustive and focus on efforts were the greatest return can be achieved.

The recommendations have been categorised at two levels. The first level are transformative recommendations. These recommendations would require major systemic changes but are assessed as being required to fix at a fundamental level the issues identified in the Gap Analysis.

The remaining recommendations are based on evolutionary changes. These recommendations can be implemented within current frameworks to address lower-level gaps but will lack the capacity to address systemic issues.

1.1 Key Risks

The three key risks to improving soil condition and the achievement of the goals and objectives of the NSS relate to economics, the commitment of resources and the soil workforce.

1.1.1 Economic environment risk statement

Context. Economic and financial factors are the primary driver of on-farm decision making.

Risk statement. Soil and landscapes will continue to degrade caused by economic drivers (including but not limited to rising land prices, debt, interest rates, tight and potentially declining profit margins under future climate/rainfall scenarios). This is likely to result in decision-making being influenced primarily by short term financial imperatives rather than long term requirements to sustain and improve soil resources.

Risk assessment.

Likelihood	Impact	Risk

Almost Certain	Severe	Extreme

1.1.2 Resourcing of the National Soil Strategy

Context. A recent assessment of the funding required to repair the productive base of agricultural soils Australia wide was $578 million per annum over 30 years (Wentworth Group of Concerned Scientists, 2024). Current investment into the NSS is a small fraction of this amount.

Risk statement. Soil and landscapes will continue to degrade caused by a lack of resourcing for programs and policies required to address soils that are in poor condition and deteriorating. This is likely to result in numerous detrimental impacts to agricultural industries, the environment, the Australian economy and society.

Risk assessment.

Likelihood	**Impact**	**Risk**
Likely	Severe	Extreme

1.1.3 Soil workforce

Context. The current and projected soil workforce is assessed as being inadequate to achieve the objectives of the NSS and support the improvement of soil management practices and soil condition.

Risk statement. Soil human resource capability (both in terms of quantity and quality) will continue to regress caused by inadequate education, the absence of a soil workforce strategy and insufficient jobs for soil professionals in a highly atomised organisational ecosystem. This is likely to result in land holders and primary producers being unable to access the support required to improve soil management practices, the rate of adoption of best management practices being reduced, an inability to manage current and future soil degradation issues, and the failure to achieve the objectives of the NSS.

Risk assessment.

Likelihood	**Impact**	**Risk**
Likely	Severe	Extreme

1.2 Recommendations

1.2.1 Transformative Recommendation One: One Health

The purpose of this recommendation is to partially address the economic environment which is the primary driver of on farm decision making and landscape degradation.

The literature on soil security, see for example (Bennett et al., 2019), highlights the interconnectedness of soil to a range of other vital services including food security, biodiversity, water security and ecosystem services. The growing awareness of the interconnectedness between soil health, ecosystem health and human health is encapsulated in the concept of One Health (Blanco and Lal, 2023). Ultimately human health is dependent upon soil health (Brevik et al., 2020).

Yet, as identified in the Gap Analysis, the extent to which primary producers are rewarded for practices that enhance soil condition, and the quality of their produce (outside of narrow metrics), is limited.

Separately, the Australian Government identifies current and continuing challenges to the health system related to increased demand on health services and rising rates of chronic disease (Department of Health and Aged Care, 2019) with health spending accounting for about 10% of GDP.

Preventive health expenditure in Australia is estimated at just 1.3% of all health expenditure (Jackson and Shiell, 2017). An international review of national public health interventions found a median return on investment of 27 to one (Masters et al., 2017). As demonstrated by Willcox (2014) there are major upside potentials for implementing cost-effective interventions to prevent chronic disease (the major cause of death in Australia).

To summarise, there is an enormous synergistic potential to improve public health outcomes/control health expenditure, reward primary producers appropriately for the quality of their produce whilst helping to improve their financial stability/sustainability of agricultural businesses as well as improving soil and land management. Implementing a policy framework that would support the implementation of a One Health approach could be **transformational** for both public health, primary producers and soil condition through the alignment of incentive structures.

Recommendation: The Australian Government, in conjunction with the relevant industries and jurisdictions, develop and implement a 'One Health' framework that seeks to link food quality to landscape and soil health and align incentive structures throughout the supply chain to address public health, farm business sustainability and landscape health.

This recommendation aligns with, and dovetails into the key recommendation from the recent "*Inquiry into food security in Australia*" (Standing Committee on Agriculture, 2023).

1.2.2 Transformative Recommendation Two: A National Soil Service

The purpose of this recommendation is to systemically address the chronic problem of recruiting, developing and mentoring the soil workforce from education and recruitment through to the development of experienced soil scientists and practitioners who can mentor the next generation of soil. This recommendation supports Priority Action Four of the NSAP.

This recommendation aligns with Objectives S3 of the *Blueprint to Repair Australia's Landscapes* (Wentworth Group of Concerned Scientists, 2024) which recommends the revitalisation of advisory, support and extension services to support landholders to optimise outcomes such as maintaining economic productivity, improving catchment health, sequestering carbon and improving biodiversity.

Without a systemic approach to building and sustaining the soil workforce across both the SQNNSW region and the country, it is highly likely that the NSS will fail to achieve its goals and objectives and soil condition will continue to deteriorate. The potential environmental, economic and societal risks that are likely to materialise from such a failure highlight the requirement to address the soil workforce at a fundamental level.

Recommendation: The Department of Agriculture, Forestry and Fisheries (DAFF), in conjunction with the states and other relevant stakeholders create a National Soil Service, with the aims of:

- Building a consistent demand for soil science education.
- Creating a clear career path for soil professionals.
- Encourage greater interest in a career as a soil professional.

- Providing a structured approach and the critical mass required for the supervision, professional development and mentoring of sufficient soil professionals to enable the achievement of the objectives of the NSS.
- Provides a persistent presence in regional areas that enables the development of local soil knowledge and relationships with landholders.
- Supports the need for accelerated practice change as stated in Priority Action Three of the NSAP.
- Provides soil expertise that can work across current organisational constraints including the integration of production and natural resource management.
- Provide support to private industry where the capacity to maintain currency of the latest research/integrate data from different sources as identified in Department of Agriculture Forestry and Fisheries (2014) remains a challenge.

1.2.3 Transformative Recommendation Three: Enhancing On Farm Experimentation

The purpose of this recommendation is to support the acceleration of practice change (Priority Action Four of the NSAP).

Each and every year across the SQNNSW region, primary producers and land managers are trialling new products, practices and approaches to soil and land management. These trials can be considered 'natural experiments' (Leatherdale, 2019). However, there are currently significant limitations as to the effectiveness of these natural experiments, limitations that if addressed present an enormous opportunity to rapidly accelerate practice change.

On Farm Experimentation (OFE) is an innovation process that engagers agricultural stakeholders together to implement experiments that support primary producer decisions (Lacoste et al., 2022). It has been described as an approach that could *'transform global agriculture'* with multiple benefits including harnessing land managers knowledge, focusing the work of other experts, and creating value for all stakeholders through co-learning and knowledge hybridisation (Lacoste et al., 2022).

A vision for adopting/enhancing OFE would be the establishment of OFE nodes across the region to support local land managers address their soil, productivity or environmental issues. Each node would include interested land managers, agronomists/advisors/consultants, and a soil professional (scientist/extension). Through co-design each node would determine their OFE research priorities, the soil professional would support experimental design, as well as the ongoing monitoring and interpretation of results. In any given time period multiple experiments could be run simultaneously across multiple properties. At the end of each experimental period, the soil professional would lead the analysis and interpretation of the results which could be shared with landholders and form the basis of workshops or field days. The results would be used to inform the next round of experiments. The soil professional could interact with other OFE nodes and/or soil expertise to share learnings and obtain advice/support where problems are identified.

The benefits would be multiple and could include increased engagement with local land managers, accelerating practice changes through the identification of products/practices/approaches that work in the local area and the contexts in which they are successful, remove/share much of the burden for design, monitoring and analysis of results from land holders and their advisors who lack time or knowledge to complete these tasks. The overall benefit would be improved land management at the local scale. This approach to accelerating practice change would also be relatively cheap (as it leverages off existing natural experiments that are already being conducted) and arguably more efficient/effective than some existing government funded research and extension programs.

Several what could be considered proto-OFE groups currently exist in the SQNNSW region but lack the scientific support/rigour to make the most of the opportunity that OFE presents.

Recommendation: DAFF, in conjunction with relevant stakeholders (state governments, NRM groups, RDCs) develop and pilot a regionally based OFE model across multiple farming systems to demonstrate the efficacy of this approach. Based on the results of the pilot OFE program, further resources be committed to expanding the program across the SQNNSW region and country.

1.2.4 Recommendation Four: Organisational Rationalisation

The purpose of this recommendation is to rationalise the organisational ecosystem, and responsibilities of organisations within that ecosystem to enhance outcomes in soil RD&E.

The organisational ecosystem is complex, and has grown in the number of organisations involved in the soil RDE&A from 2014 when over 150 organisations were involved (Department of Agriculture Forestry and Fisheries, 2014). There is a significant body of academic research indicating that beyond a certain level of complexity, the performance of a system declines. The Gap Analysis suggests that this is the case for the soils RD&E organisational ecosystem. The consequences include extreme competition for limited funding, duplication of effort, a lack of coordination and sub-optimal outcomes for improved soil and land management.

Recommendation: As part of Priority Action Four of the National Soil Action Plan, DAFF commission a review into the soil RD&E organisational ecosystem for the purposes of:

- Reducing the number of organisations funded to provide soils RD&E in order to minimise duplication of effort, silos and administrative overheads.
- Supporting persistent, rather than project based, funding for organisations involved in soils RD&E.
- Alter the balance of investment between extension/adoption and research with a greater emphasis on extension (as noted in Department of Agriculture Forestry and Fisheries (2014)). This is required to increase/accelerate practice change.

1.2.5 Recommendation Five: Soil Strategy Development

'Failing to plan is planning to fail'

Military truism

The purpose of this recommendation is to address the deficiencies identified in the various strategy related documents at the national, state and NRM region levels.

As was noted in the ANAO audit of the 'Design and Early Implementation of the National Soil Strategy' (Lee et al., 2024) there were significant deficiencies in the development of the NSS. The ANAO noted that when developing objectives for a 'a strategy or program, entities should consider and build into the design process how the objectives will be achieved, and how progress will be monitored, reported on, and evaluated.'

In general, whilst statements of support have been made by the Queensland and NSW governments, the soil related objectives at both the State and NRM region level are absent or lack specificity, how objectives (where they exist) will be achieved is unclear, and what resources are required and assigned to achieve objectives (where they exist) is also unclear.

A distinct risk based on the current framing of strategy documents that incorporate soil, is that the objectives/intentions are so loosely worded that successful attainment of objectives could be claimed even though soil condition continues to deteriorate.

A secondary risk is that because of the lack of specificity of objectives (where they exist) and a lack of clarity of how those objectives can be achieved, the underlying resource requirements required to achieve these objectives is unknown.

Recommendations:

- The Queensland Government appoint a lead department to develop a publicly available soil strategy/plan for Queensland that clearly articulates responsibilities, objectives and how those objectives will be achieved.
- The NSW Department of Primary Industries further develop the soil related components of its corporate strategy (or develop a separate publicly available soil strategy/plan) that clearly articulates responsibilities, objectives and how those objectives will be achieved.
- NRM groups incorporate soil related objectives into their corporate planning documents, where they don't already exist, that clearly articulate responsibilities, objectives and how those objectives will be achieved.

1.2.6 Recommendation Six: Workforce Planning & Development

The purpose of this recommendation is to address the current and likely future deficit in the soil workforce.

The Gap Analysis indicates that from a workforce perspective soil capacity is reducing, that there is no clear path to becoming a soil scientist/practitioner/extension officer and no system in place to systematically develop the soil workforce that is required both now and into the future. These gaps will take decades to fully address.

Given the competing pressures and challenges for labour, both current and predicted, there is a high risk that without a deliberate workforce planning and development program there will be both an insufficient, and inadequately skilled and knowledgeable workforce to support land holders and primary producers.

This is a critical risk to the attainment of the NSS goals and objectives. Private industry will play an important role in developing and sustaining the soil workforce. However, it is assessed that there is a requirement for direct involvement by governments to implement and/or support programs that will first develop, and subsequently sustain the soil work force in perpetuity.

Optimistically this could be viewed as a nation (or state) building activity. Pessimistically, this could be viewed as a nation saving activity.

Recommendations:

- **Long term**. To address the longer-term systemic deficiency in the soil workforce, DAFF, as the lead agency for the NSS, commission a soil workforce strategy and associated development program, and work with key stakeholders to resource the program.
- **Short term**. To accelerate the development of the soil workforce, the Queensland and NSW State Governments (and other organisations where they have the capacity to do so) either directly, or indirectly, develop graduate programs to recruit and commence development of the soil professionals required for the future.

1.2.7 Recommendation Seven: Soil Science Skills and Education

The purpose of this recommendation is to improve the quantity and quality of soil science and related education.

Since the completion of the review into soil science education in Australia (Rogers et al., 2020) it appears that the provision of soil science education in at least some of the universities in the SQNNSW region has declined (the University of New England appears to be an exception with its soil science course being recognised by Soil Science Australia as meeting the educational requirements for both RSP and CPSS accreditation (UNE Media Team, 2023)).

Currently there is only one university in Australia (the University of Adelaide) that offers a Major in Soil Science as part of a Bachelor of Science. The lack of such Majors could be considered a major impediment to establishing a career pathway for soil professionals.

Reductions in the level of soil science education being provided in educational institutions, where there is a clear requirement to improve levels of soil science education, will undermine the ability to achieve the objectives of the NSS and will be a critical requirement to achieve the outcomes detailed in Priority Action 4 of the NSAP. This includes specific areas where there is currently limited education being delivered such as soil conservation and organic farming practices. In these instances, there may be a case to support specific institutions to deliver training/education to ensure that the workforce required to achieve the objectives of the NSS can be equipped with the necessary skills and knowledge. There may also be a case to provide scholarships or other incentives to students to enrol in a soil science program.

Not related to soil science education, but critically importance for accelerating practice change is education in extension. Extension education in undergraduate programs across the region is minimal resulting in graduates in agriculture and environment programs who do not have the background in the extension process to facilitate and support practice change. The most effective way to enhance this education in a systematic manner (there are numerous extension related training and education opportunities available however it is ad hoc and often episodic rather systemic) maybe through micro-credentials or similar approaches. The University of Melbourne for example delivers four micro-credential courses focusing on extension and practice change that can provide advanced standing for a Masters degree. Supporting extension practitioners to complete such education would for minimal expense provide the minimum education requirements to work effectively in an extension role.

Recommendations:

- The Regional Soil Coordinator work with universities in the SQNNSW region to update the review conducted by Rogers et al. (2020) and identify the underlying reasons why soil science education appears to be regressing in some universities.
- Regional universities that deliver soil education that meet the minimum education requirements of the RSP and Certified Professional Soil Scientist (CPSS) accreditation programs apply for recognition through Soil Science Australia.
- Regional universities consider developing a Major in soil science as part of their offerings (Implementing this recommendation would be assisted by the implementation of Recommendation Two and Six).
- Where there are specific deficiencies in soil science education (e.g. soil conservation and organic soil management), DAFF examine opportunities to fund specific institutions to deliver education/training that is necessary to meet the skills and knowledge requirements to enable achievement of the NSS objectives.

- Subsidies and/or professional development funding (such as provided to Sustainable Agriculture Facilitators (SAFs)) be provided to extension related positions to ensure that extension practitioners have a minimum level of extension related education.

Note: The funding requirements to support some of these recommendations may be minimised or negated, particularly over the longer term through building the demand for soil science and extension education via the implementation of the other recommendations.

1.2.8 Recommendation Eight: Facilitating Practice Change

The purpose of this recommendation is to improve the capabilities of staff in NRM groups, research organisations and private industry in facilitating practice change.

The Gap Analysis indicates that the delivery of training and education related to extension has regressed. Whereas there used to be a systematic approach to providing extension practitioners with the skills and knowledge required to be effective this is no longer the case. Many graduates of Bachelor degrees no longer complete courses related to practice change/extension/adoption, or complete only a single subject. Whilst there are numerous opportunities to participate in extension related training and professional development, this can be described as ad hoc. This is exacerbated by the high turnover in staff amongst many NRM and similar groups.

The Gap Analysis concluded that there is insufficient emphasis placed on Extension and Adoption in comparison to Research and Development.

Priority Action 3 of the NSAP focuses on accelerating the "*adoption of land use and management practices that protect soil and improve soil state and trend*." The well-established literature on adoption and practice change in agriculture highlights the prolonged period required for new practices to be adopted at scale. This is particularly the case given the numerous barriers to adoption that exist for adopting climate smart agriculture and improved soil management (Wreford et al., 2017). It can be safely assumed that without a workforce of soil practitioners competent in extension theory and practice that the capacity to '*accelerate*' practices that improve soil state and trend will be greatly diminished. As such, skills and knowledge in extension are assessed as a critical risk to attaining the objectives of the NSS and NSAP.

Existing government grant programs at both national (e.g. Climate Smart Agriculture and Future Drought Fund) and state level could be used to send a market signal emphasising the importance of extension. For example grant applications could incorporate criteria requiring applicants to explain the theories of change they are applying and how they will lead to practice change, what extension model they are using (see for example Williams et al. (2021a)) and the extension related education and experience of project staff. Over time this would support building the demand for systemic education and training in extension as well as improve the efficacy of grant programs seeking practice change.

Recommendations:

- Applications for government funded programs (both national and state) related to improved soil and land management require:
    - An explicit theory of change be incorporated into grant applicants to explain how the project will lead to practice change and increase the likelihood of adoption beyond the life of the project.
    - Applicants be required to demonstrate the extension related education and experience of project staff.

- Minimum requirements for both education and ongoing professional development be stipulated in government funded positions that aim to support landholder practice change/adoption (e.g. RDCs, SAFs, NRM groups, Regional Soil Coordinators)
- The National Soil Science Extension Team (NSSET) and Regional Soil Coordinators work with organisations such as the Australasia Pacific Extension Network (APEN) to identify, update and promulgate extension related education, training and development opportunities that are available to soil practitioners and related people.

1.2.9 Recommendation Nine: Soil Erosion and Flooding

Soil erosion is ubiquitous, both in time and space across the SQNNSW region. It is a forever problem. It is also a problem that is likely to worsen into the future if predicted changes in rainfall patterns (e.g. higher intensity rainfall events) come to fruition. The importance of addressing erosion is further supported in the *Blueprint to Repair Australia's landscapes* (Wentworth Group of Concerned Scientists, 2024) with one of the three soil related objectives focusing on addressing gully erosion. The cost to address erosion Australia wide was assessed at just over $400 million per annum Australia wide (Wentworth Group of Concerned Scientists, 2024).

The Gap Analysis highlights that across the SQNNSW region the capacity to manage soil erosion is regressing. Crucially, much of the expertise that once existed amongst state government soil conservation officers is nearing or passed retirement age, indicating that the ability to manage soil conservation is likely to further deteriorate unless and until significant action is taken to redevelop this capacity. In general, NRM groups have limited internal capacity to support landholders, with expertise largely outsourced for delivering particular projects.

Whilst private industry has partially filled the gap since state governments largely withdrew from providing soil conservation services (the role of the NSW government's Soil Conservation Service is discussed in the body of the Gap Analysis), there are limitations on what private industry can do. For example, private industry has no authority to manage the flow of water across property boundaries. This is a role that can only be performed by government authorities and has been identified as a major issue in many regions resulting in disputes between neighbours, preventable maintenance costs, avoidable damage to farmland and infrastructure, as well as accelerated erosion.

There is significant anecdotal evidence of the significant direct and indirect costs caused by erosion across the region. However outside of certain locations (specifically the Great Barrier Reef) it appears that costs of erosion are not systematically quantified by local councils, infrastructure owners, state governments or the overall implications from a soil security perspective.

Different approaches to managing water and soil conservation are now being implemented across the region (some of which are funded by government programs) that have limited scientific evidence to support the claims made by proponents (see for example a review by Callow and Bell (2021) for an assessment of Natural Sequence Farming in southern Western Australia). The lack of scientific evidence poses two potential risks:

- The potential for accelerated landscape degradation (e.g. through salinity or accelerated erosion) where employing practices is inappropriate for the landscape context.
- The potential for missed opportunities for improving landscape hydration/reducing erosion through a lack of scientific certainty as to their effectiveness.

Given previous experiences with government programs to managing water in the landscape (see the review by Pannell and Roberts (2010) of Australia's National Action Plan for Salinity and Water Quality as an

example) it is imperative that further scientific rigour is applied to these practices to ensure they are fit for purpose over the long term, and where they are, to support accelerated adoption.

Closely linked to erosion and changing rainfall patterns is the impact of flooding and inundation on soils. Across multiple areas of the SQNNSW region a slow recovery has been noted since recent floods. Despite the major, often detrimental, impacts of flooding there is limited research and extension material available to assist landholders in managing soils post flood.

Recommendations:

- DAFF, in conjunction with the relevant state government and other stakeholders, review Objective S2 (Repair gully erosion hot spots across Australia to improve water quality in rivers and expand the availability of healthy land for agriculture and wildlife) of the *Blueprint to Repair Australia's landscapes* (Wentworth Group of Concerned Scientists, 2024) with a view to implement the recommended actions to systematically address gully erosion.
- The NSW and Queensland State Governments implement/expand monitoring schemes to assess both the extent of erosion, as well as its direct and indirect costs. The purpose being to enable the quantification of erosion impacts, justify the ongoing requirement for investment in soil conservation and the effectiveness of that investment.
- The development of the workforce required to support soil conservation measures be included in the workforce plan (see Recommendation Five).
- The Regional Soil Coordinator engage with research institutions and relevant funding bodies with the aim of commissioning research into the effectiveness of landscape rehydration works across different landscapes.
- The Regional Soil Coordinator engage with research institutions, relevant state governments, and potential funding bodies with the aim of commissioning research into the impact of flooding on soils and how to manage flood affected soils. This research should also incorporate the development of extension materials.

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2 Introduction

2.1 Background

A nation that destroys its soils, destroys itself.

Franklin D. Roosevelt

Since ancient times, the importance of healthy functioning soils has been recognised. Yet, the historical record is replete with examples of the dire and long term consequences for societies that fail to manage their soils sustainably (see for example Montgomery (2007)).

In Australia significantly altered land management and use since European settlement has made significant, and largely detrimental changes to the landscape. These changes were reflected in the latest State of the Environment Report which concluded that "*Australia's soils are in poor condition and deteriorating*" (Williams et al., 2021b).

The importance of improving the condition of Australia's soil has been reflected in the nation's first ever National Soil Strategy (Department of Agriculture Water and the Environment, 2021):

Healthy soils are central to delivering resilience to climate change and natural disasters, meeting our emission reduction targets, growing our agriculture industry, and securing human health, food and water security, biodiversity and economic growth.

The NSS recognises a fundamental conundrum, where despite significant funding to improve soil health over time, our soils continue to degrade with negative impacts for Australia's economy, environment and society (Department of Agriculture Water and the Environment, 2021).

The goals and objectives of the NSS, and associated programs, can be considered as the response to this conundrum.

One of these programs is the National Soil Science Extension Team (NSSET) Community of Practice and the establishment of Regional Soil Coordinators (RSC) employed with each of the Future Drought Fund's (FDF) Hub's.

The major output required of the RSCs is the development of a Regional Soil Improvement Plan. The initial broad guidance was collaboratively developed by the RSC through the NSSET into a Soil Capacity Gap Analysis Framework (attached as appendix 1) which has guided the development of this report.

In 2023, the first NSAP under the NSS was released (DAFF, 2023). Priority Action 4 of the NSAP focuses on the identification and development of the soil workforce and capabilities to meet current and future challenges. One of the tasks within Priority Action 4 is to "*assess the gaps, barriers and incentives for improving the soil workforce's knowledge and capacity and develop the scope of work required to address this workforce issue*."

This SQNNSW region Soil Capacity Gap Analysis, along with those developed for other regions, will inform future programs being developed under the NSS and NSAP.

2.2 Objectives

The objectives of the Soil-Capacity Gap Analysis are to:

- Provide an overview of the regional soils, stakeholders, and current projects related to providing soil-capacity to end users.
- Summarise the major soil productivity and environmental issues occurring across the region and opportunities to increase best land management practices.
- Evaluate the gaps in soil-capacity, or barriers to adoption, of best soil management practices, and align these with the priorities of the National Soil Strategy Action Plan.
- Prioritise capacity gaps for their regional importance and identify opportunities for development.

These objectives were developed collaboratively amongst the RSCs.

2.3 Limitations

The region covered by this Report is extremely large and highly diverse across multiple domains including climatic zones, landscapes, soil types, number and types of agricultural enterprises as well as the organisations, businesses and individuals involved with land management.

With only one person allocated to the development of this Report there are inherent limitations on the depth to which information can be gathered and gaps identified and analysed. However, during the process of developing this report it has become clear that across much of the SQNNSW region, the identified gaps and issues are largely systemic in nature. As a result, it is assessed that findings of this Report provide a reliable identification of the major gaps and barriers to adoption of improved soil and land management practices across the SQNNSW region.

2.4 Report Structure

This Report is structured as follows:

- **Summary and recommendations.** An overview of the Gap Analysis and key recommendations.
- **Introduction**. Including the methodology used to develop the report.
- **Regional overview**. A brief overview of SQNNSW region including key regional soil issues.
- **Gap Analysis.** This is the core of the Report identifying the major gaps in soil capacity across the SQNNSW region.
- **Barriers to adoption.** A summary of the barriers to adoption for improved soil and land management practices.

2.5 Funding Acknowledgement

The activities of the SQNNSW Innovation Hub's RSC, including the development of this Report, has been funded through the Australian Government's National Landcare Building Landcare Community and Capacity Program and the Australian Government's Future Drought Fund.

2.6 Participant Acknowledgement

The author would like to acknowledge those people who participated in the information gathering for the gap analysis, whether that be the completion of the National Soil Survey or through an interview. In particular, the enthusiasm, passion and deeply held care and concerns for Australia's most precious resource, our soil, from those interviewed was noted by the author with many interviews running much longer than the allotted time.

2.7 Methodology

2.7.1 Information Gathering

Multiple sources of information were used to collect the information used to development this Gap Analysis. This included:

- **Literature review**. Relevant literature and previous reports related to soil capacity.
- **Semi structured interviews**. 65 semi-structured interviews with 112 people were completed during the development of the Gap Analysis. Ethics approval was granted by the University of Southern Queensland (UniSQ HREC Approval Number: ETH2023-0082).
- **National Soil Survey**. A National Soil Survey was developed by the RSCs (Fisher et al., 2023). 204 participants across the SQNNSW region completed/partially the survey (94 landholders and 110 advisors). Ethics approval was granted by the University of Melbourne.
- **Anecdotal observations**. The RSC attended over 50 events whilst developing the Gap Analysis. Anecdotal observations were recorded contemporaneously based on presentations and conversations with a large number of farmers, agronomists, researchers and members of natural resource management, Landcare and community groups.

2.7.2 Analysis

The approach to analyse the collected information was the widely used McKinsey 7-S framework (Figure 1). A primer on the McKinsey 7S model is provided by Jurevicius (2023).

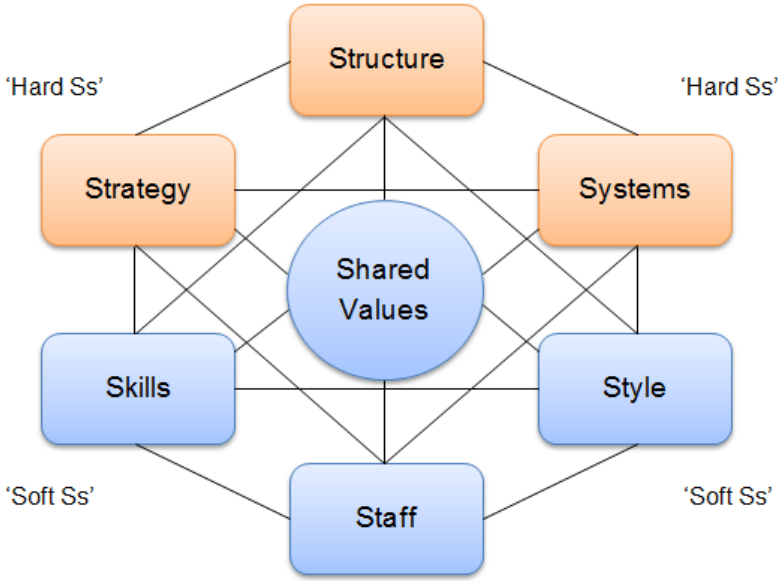


Figure 1 McKinsey 7-S Framework (Image source: Jurevicius (2023))

This organisational analysis model examines seven key elements that make an organisation, or in this case an organisational ecosystem, successful. The elements are: strategy, structure, systems, shared values, style, staff and skills (Singh, 2013). The power of this framework is the identification that each element is interconnected, with success occurring when all elements are effectively addressed and reinforce one another. Conversely, weaknesses in any one of these elements can undermine the effectiveness of the overall system.

This model was selected as it provides a useful analytical framework against which to assess the gaps in soil capacity.

3 Regional overview

3.1 SQNNSW Region

The SQNNSW Innovation Hub is one of eight regional Hubs funded by the FDF. The FDF provides secure, continuous funding for drought resilience initiatives. The FDF focus is on initiatives that provide Better Climate Information, Better Planning, Better Practices, and Better Prepared Communities.

The SQNNSW Innovation Hub region (Figure 2) covers 1.7 million square kilometres of southern Queensland and northern NSW.

Figure 2 SQNNSW Innovation Hub Region

3.2 Organisational Overview

An incomplete summary of organisations involved in soil management from a production and natural resource management perspective is provided in Figure 3. Figure 3 excludes private business (e.g. agricultural consultants, agronomists and relevant agribusiness), research organisations, and primary producers but does highlight the complexity of the organisational ecosystem.

Some of the major organisations represented include:

- Commonwealth:
  - Department of Agriculture, Forestry and Fisheries (including the Future Drought Fund)
- NSW Government:
  - Department of Primary Industries (DPI)
  - Department of Planning, Industry and Environment
  - Local Land Services (LLS)
- Queensland Government:
  - Department of Agriculture and Fisheries (DAF)
  - Department of Environment, Science and Innovation (DESI)
  - Department of Resources
- NRM groups:
  - NSW:
    - North Coast LLS
    - Northern Tablelands LLS
    - North West LLS
    - Western LLS (part of area covered by Southern NSW Hub)
    - Central West LLS (part of area covered by Southern NSW Hub)
    - Hunter LLS
  - QLD:
    - Healthy Land and Water (southeast Queensland)
    - Southern Queensland Landscapes
    - Desert Channels Group
    - Burnett Mary Regional Group
- RDCs:
  - Cotton Research and Development Corporation
  - Grains Research and Development Corporation
  - Horticulture Innovation Australia
  - Meat and Livestock Australia
- Community not for profit. Examples including GLENRAC, Macintyre Ag Alliance and the Burnett Catchment Care Association.
- Local Landcare groups

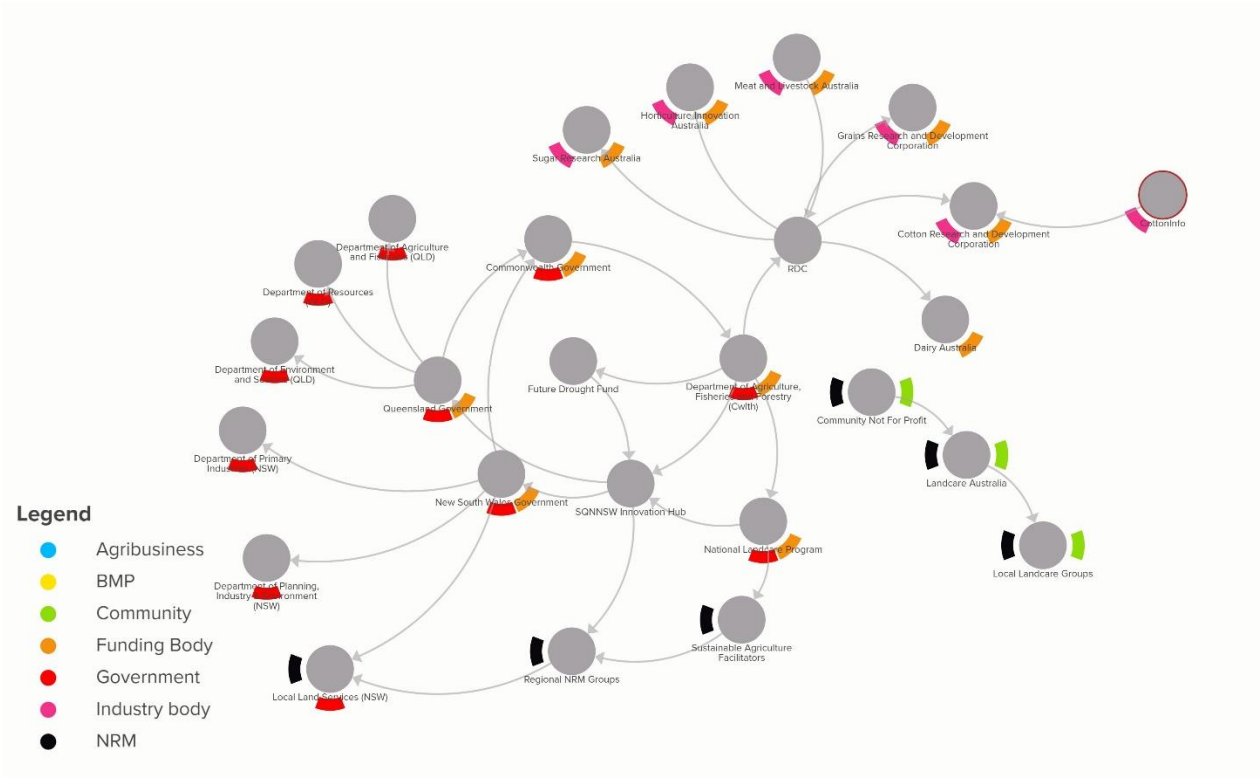


Figure 3 Summary Organisational Ecosystem

3.3 Agricultural overview

The SQNNSW area covers five of Australia's 11 agro-ecological regions described in Williams et al. (2002), with a large diversity of landscapes and agricultural systems. A summary of these regions is provided in Table 1.

Table 1 Overview of agro-ecological regions in SQNNSW (Source: (Williams et al., 2002)

Region	Landscape	Major agricultural systems
Subhumid, subtropical slopes and plains	Hot summers and mild winters, tends toward summer dominant rainfall. Plains are characteristic, divided by low ranges in the north, slopes in the south and upland areas in the east. Cracking clay soils extensive. Open eucalypt and brigalow forests dominate but largely cleared	Mixed wheat/sheep/cattle farming Irrigation (cotton) Oilseed and wheat Grazing – particularly in the west
Subhumid, subtropical highlands	Rolling, undulating and hilly uplands between the coastal ranges and inland slopes and plains. Rainfall is generally uniformly distributed in the south tending to summer dominant in the north. Extensively cleared eucalypt forests.	Intensive livestock grazing (Sheep and cattle) Pockets of horticulture

Semiarid Tropical and Subtropical plains	Largely alluvial plains. Climate hot, seasonally wet/dry. Vegetation eucalypt, acacia, melaleuca and casuarina woodlands and tussock grasslands associated with Vertosols	Extensive sheep and cattle grazing
Wet Subtropical Coast	Warm and wet climate, uniform to summer dominant rainfall. Coastal lowlands, plains and bordering ranges. Cleared alluvial plains back by forested hills characterises the landscapes	Dairying, beef grazing, intensive cropping (including sugarcane)), horticulture and forestry
Temperate Semiarid Plains and Arid Interior	Warm to hot. Generally low relief. Riverine floodplains, plains, dunefield and undulating upland and stony hills	Extensive livestock grazing on natural vegetation

3.4 Regional Soil Issues

Significant research efforts have already identified major soil issues across Australia, including the SQNNSW region. Williams et al. (2002) identifies the major soil and land degradation issues broken down by agro-ecological region. Across SQNNSW the major identified soil degradation issues were:

- Decline in soil nutrients and biological activity
- Decline in soil structure
- Water erosion and lack of soil conservation practices
- Salinity and acidity (selected regions only).

More recently McKenzie et al. (2017) provided an overview of trends in soil condition across Australia's agricultural landscapes broken down by NRM regions (some of which have since changed). The results of this analysis are provided in Table 2.

Table 2 Priorities for soil issues by NRM region from McKenzie et al. (2017). R = widespread issue, Y = localised issue, G = minor/manageable issue

NRM Region	Acidification	Carbon	Hillslope Erosion	Nutrient Decline	Nutrient Excess	Wind Erosion
Northern New South Wales						
Central Tablelands	R	Y	Y	G	Y	G
Central West	R	Y	R	G	Y	G
North Coast	R	R	R	Y	R	G
North West NSW	Y	R	G	Y	Y	G

Northern Tablelands	R	R	Y	G	Y	G
Southern Queensland						
Burnett Mary	Y	Y	Y	G	R	G
Condamine	G	G	Y	G	G	G
Desert Channels	G	G	G	G	G	R
Maranoa Balonne and Border Rivers	Y	R	Y	R	Y	G
South East Queensland	Y	Y	Y	G	R	G
South West Queensland	G	R	G	R	G	Y

The latest Queensland Government State of the Environent Report (Department of Environment and Science, 2021) contains little information on current soil condition in Queensland.

The latest NSW State of the Environment Report (State of NSW and the NSW Environment Protection Authority, 2021) contains indicators of six soil indicators as detailed in Table 3.

Table 3 NSW Soil Indicators and Status

Indicator	**Status**	**Environmental Trend**
Acidification	Moderate	Getting Worse
Organic Carbon	Moderate	Getting Worse
Wind Erosion	Poor	Getting Worse
Hillslope Erosion	Moderate	Stable
Salinisation	Moderate	Stable
Acid Sulfate Soils	Moderate	Getting Better

The overall assessment of soil health in the latest State of the Environment report concluded that Australian soils are in poor condition and deterioriating (Williams et al., 2021b).

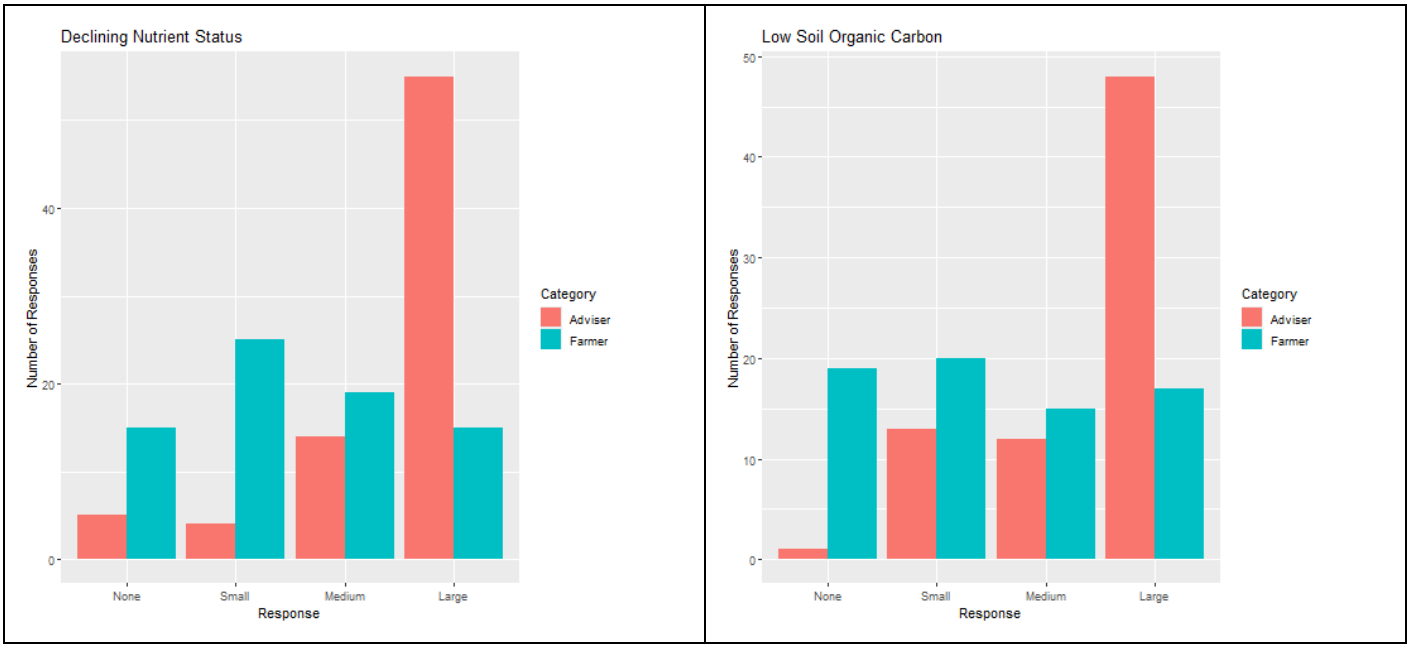
3.5 Soil Issues

The identification of regional soil issues was identified through both the National Soil Survey and interviews.

The major issues identified in the National Soil Survey related to declining fertility (nutrient decline and low soil organic carbon), soil structure (compaction in both the topsoil and subsoil as well as poor infiltration), water erosion and water logging (although not specifically focused on flooding/inundation as discussed below). The results are provided in Figure 4 with:

- 88% of advisers[1] and 46% of farmers reporting a medium or large impact from declining nutrient status,
- 81% of advisers and 45% of farmers reporting a medium or large impact from low soil organic carbon levels,
- 82% of advisers and 64% of farmers reporting a medium or large impact from topsoil compaction, and
- 77% of advisers and 48% of farmers reporting a medium or large impact from subsoil compaction.

Across all four of these categories advisers responses indicate a much greater concern/prevalence of soils issues than do farmers. There are multiple reasons why this could be the case but this cannot be answered by the survey data.



[1] Note that advisers includes anyone who completed the survey but was not a landholder/primary producer (e.g. extension officers, scientists, researchers, NRM group staff, government officers).

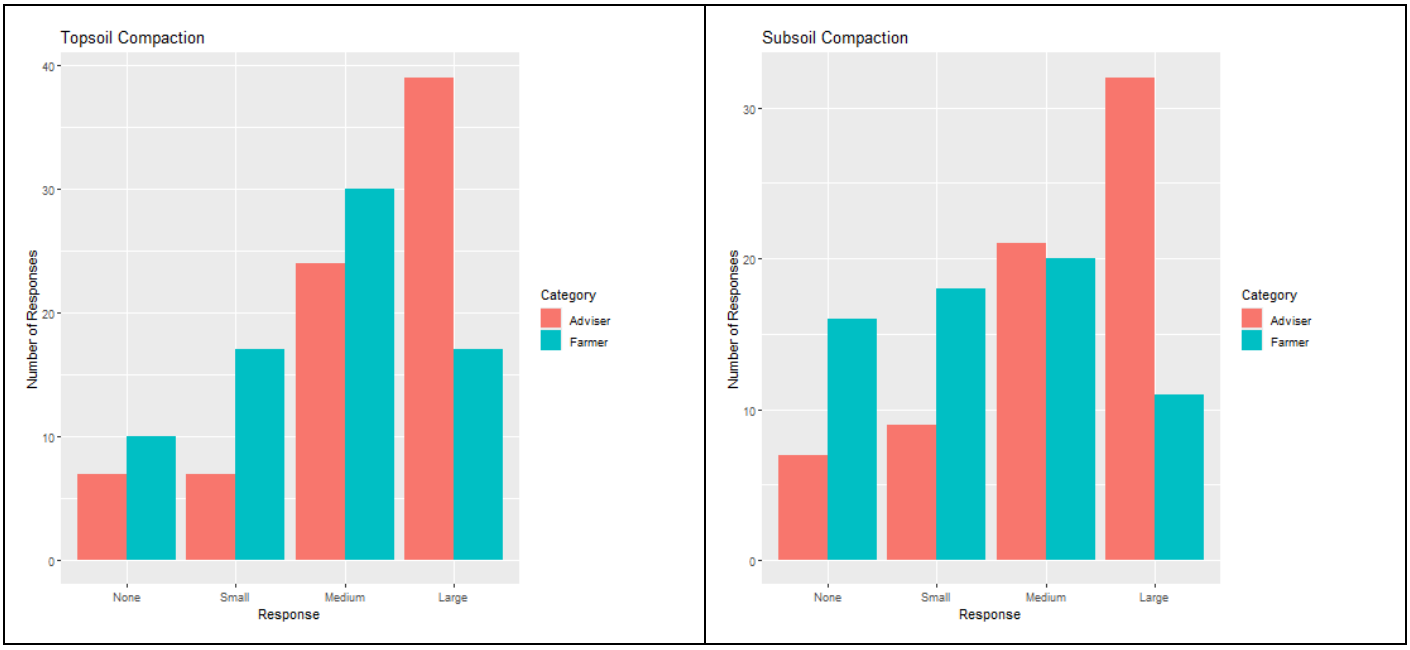


Figure 4 Reported soil issues from the National Soil Survey results; Declining nutrient status (Top left), Low Soil Organic Carbon (Top Right), Topsoil Compaction (Bottom Left), and Subsoil Compaction (Bottom Right).

As part of the interview process, interviewees were asked what were the major soil issues that they observed. The feedback generally aligned with the soil issues identied in Section 3.4. The predominant soil issue identified in a majority of interviews, across most regions was water erosion. Another issue that was identified in affected areas, but has not received much attention in the way of research or extension support is the the impact of flooding and/or inundation on soils. These two issues, which are partially interrelated, are discussed in more detail below.

3.5.1 Water Erosion

"Erosion is a forever issue."

"The key soil issue; erosion, erosion, erosion! It will always be the number one issue."

Quotes from interviewees

During the semi-formal interviews, erosion (primarily by water), was clearly raised as a predominant soil issue. This section will provide a brief summary of both the causes and impacts of erosion identified by interview participants that have led to erosion being identified as a major soil issue across the SQNNSW region. Specific gaps are covered throughout Section 4 of this Report.

3.5.1.1 Causes

Numerous interviewees stressed the importance of ground cover as being of primary importance in minimising erosion with concerns raised over practices that lead to inadequate cover. Related to this was the identified link between poor soil condition overall (e.g. nutrient decline or other degradation issues) leading to reduced groundcover and increased erosion risk. The analysis of Bowen and Chudleigh (2018) highlight that there is a large economic advantage from increasing grazing pressure above recommended rates. Based on the principle that incentives drive human behaviour this is a critical indicator highlighting that (short term) economic factors outweigh concerns over soil conservation and long-term sustainability.

Some interviewees highlighted the lack of whole farm planning, leading to inappropriate siting of on-farm infrastructure such as fences, tracks and waterpoints being a cause of erosion. Another factor is generational change, particularly after prolonged periods of drought, where younger generations have not experienced the impact of erosion on land where surface water flows are not managed. Changes in land use is also a causal factor. For example, large areas previously farmed to sugarcane are transitioning to perennial horticulture in the Burnett region. However much of the RD&E work previously developed was focused on sugar cane and not necessarily relevant or applicable to horticulture.

A two-way tension between primary producers and local governments/utilities owners was also identified as a cause of erosion, with the lack of coordination between one or more landholders creating erosion related issues for other landholders. One local Council reported that landholder redirection of soil conservation structures/lack of maintenance has resulted in major increases in road maintenance costs with repair works required after every major rainfall event in some areas.

The lack of understanding (or investigation) of basic soil properties, leading to inappropriate land use or development, was also identified as a cause, with dispersive subsoils being an example.

The sub-division of formerly agricultural land into lifestyle blocks and/or lot sizes too small to support viable agricultural enterprises due to land prices has also been identified as a cause of erosion. Residents on such land may have no experience or knowledge of how to manage land/erosion and are unwilling/incapable of managing runoff on their property which can create erosion issues for downstream landholders/ to invest.

Healthy Land and Water delivered an Erosion and Sediment Control (ESC) Community of Practice workshop in February 2024 (see Healthy Land & Water (2024) for a summary). This event included representatives from all councils in Southeast Queensland and the Great Barrier Reef catchment. Significant capability, capacity and budgetary shortfalls were identified by many councils, but in particular those outside of Southeast Queensland. The lack of capacity and capability is leading to ESC plans for urban development not meeting best practice and low levels of compliance. One interviewee indicated that the willingness of local councils to enforce erosion and sediment control related requirements is declining.

3.5.1.2 Impacts

Interviewees provided anecdotal evidence of the impact of erosion. Examples include:

- A soil scientist indicated that greater than $200/hectare of nutrients could be lost from a single erosion event.
- Sediment resulting from a Controlled Traffic Farming system running upslope in the Darling Downs has led to multiple road closures over several years. Some instances have occurred during cotton harvesting time where trucks carrying an estimated 1000 tonnes of cotton per day had to reroute, adding 50 km in travel each way for two days until the sediment was cleared.
- One Council reported expending a total of $200,000 in repetitive road maintenance at one small site over the last few years with remediation works costing around $40,000 per maintenance activity after each major rainfall event.
- One interviewee indicated that hillslope farming is on a ‘long term trajectory towards extinction’ due to the rate of erosion (even though erosion rates have decreased) being multiple times the rate of soil formation.

There appears to be no systematic collection of the extent or costs associated with the direct and indirect impacts of erosion in either NSW or Queensland (with the exception of the Great Barrier Reef catchment).

A brief review of the literature has identified no recent or systemic reporting of the cost of erosion in either NSW or Queensland, however there are some studies that focus on specific issues (e.g. a study of road maintenance costs from flood damage by Beecroft et al. (2017)).

Several interviewees raised concerns over the future costs of erosion resulting from rainfall events of increasing intensity. With the majority of erosion being caused by high intensity rainfall events and the growing consensus that there will be increases in high intensity rainfall events (Wasko et al., 2021, Gründemann et al., 2022) this further emphasises the importance of managing landscapes for soil conservation.

These qualitative comments are supported by the results (Figure 5) obtained from the National Soil Survey as well as the participant surveys from two “Keep Your Dirt” soil conservation events organised by Condamine Headwaters Landcare, Southern Queensland Landscapes and the SQNNSW Innovation Hub which were held in September 2023. These events were organised in response to the significant erosion events that occurred in the eastern Darling Downs in early 2022. The National Soil Survey results indicated that 73% of advisers and 35% of farmers see water erosion as an issue of medium or large impact whilst the median impact of soil erosion (on a 10 point scale) from attendees at the “Keep Your Dirt” events was six.

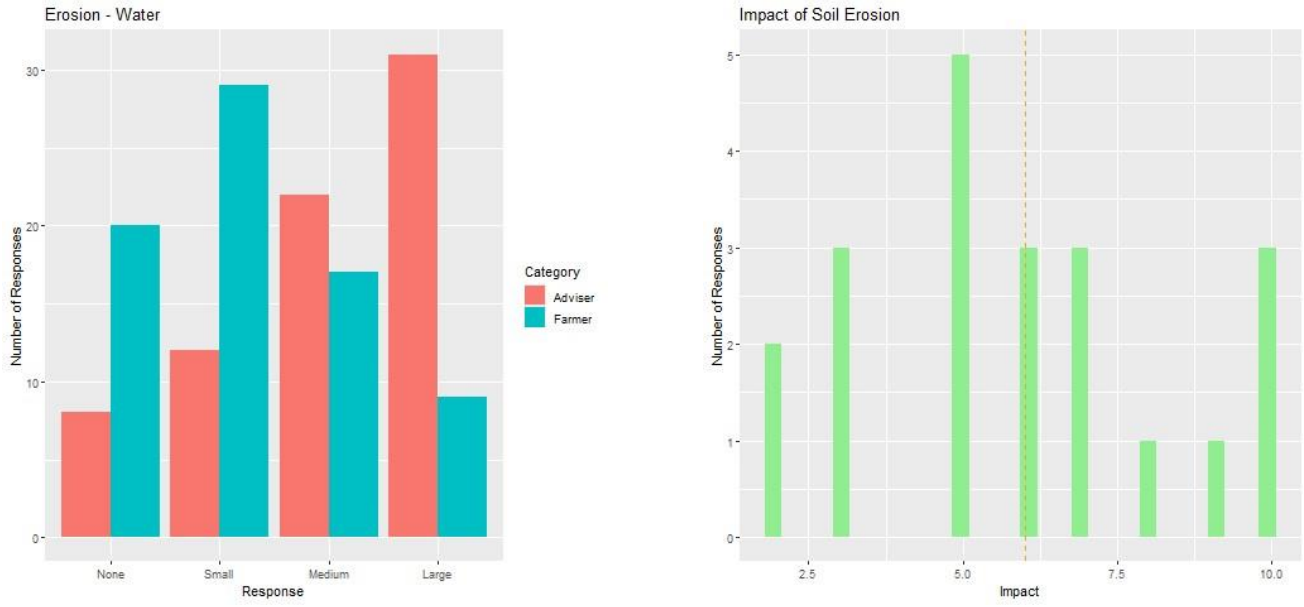


Figure 5 Erosion impact from National Soil Survey (left hand) and "Keep Your Dirt" Field Day attendees.

3.5.2 Flood affected soils

There has been widespread flooding in many regions of SQNNSW in recent years. Whilst flooding/inundation is not exceptional/abnormal in the region, the slow recovery of inundated areas has been identified as a concern by many landholders and NRM groups in regions including the Burnett and Mary river catchments, the north coast of NSW and the Darling Downs.

The impacts of flooding/inundation on soil have included:

- Deposition of silt containing extremely high levels of aluminium. This has resulted in areas incapable of growing anything, including weeds.
- Some properties have been flooded multiple times. One property has been flooded 15 times in 20 years including eight where it was completely submerged. The owners have sold the land as it is not

economic/too high a risk to attempt to restore the land/recover from the almost complete productivity loss.

- Poor pasture response and emergence of weeds has been prevalent in multiple areas. In the Inland Burnett region ‘big patches of soil where nothing grows’ have been observed.
- In some areas flooding has resulted in many metres of water (up to 10 m in some instances) flowing across paddocks. Periods of prolonged inundation for six months or more have also been reported. In some instances up to two metres of soil in cropping country has been lost from a single flood event (see Figure 6 for an example).

Figure 6 Example of flood damage in the Darling Downs from the January 2022 flooding. From the bottom of the washout to the top of the original soil is almost two metres deep.

- A concern of some interviewees was prediction of more intense rainfall events into the future and consequent impact of more damaging flooding.
- There is a view amongst several people interviewed that the damage from flooding and associated erosion is exacerbated by lack of coordination of water management on floodplains. ‘Craters of soil’ have been lost in some areas. This can be exacerbated by new landholders who don’t understand how water moves over landscape and have installed structures that have created major erosion during flood events.
- Flooding has excaberated other soil issues. For example salinity issues have arisen in areas around Bundaberg following flooding of the Burnett River. Other areas have noticed increased impact from dispersive soils.
- Multiple reports of a long slow recovery post flooding/inundation. Up to 18 months has cited as the time to get back to production as a result of the flood impacts on soil chemical and biological properties.
- Conversely some properties have seen very limited impact even after severe rainfall events (e.g. over 700mm over a couple of days).

The National Soil Survey did not specifically focus on the impact of flooding/inundation, however two related questions focused on the impact of water logging and poor infiltration (see Figure 7). 68% of advisers and 35% of farmers see water logging as an issue of medium or large impact whilst 77% of advisers and 53% of farmers see poor infiltration as as an issue of medium or large impact.

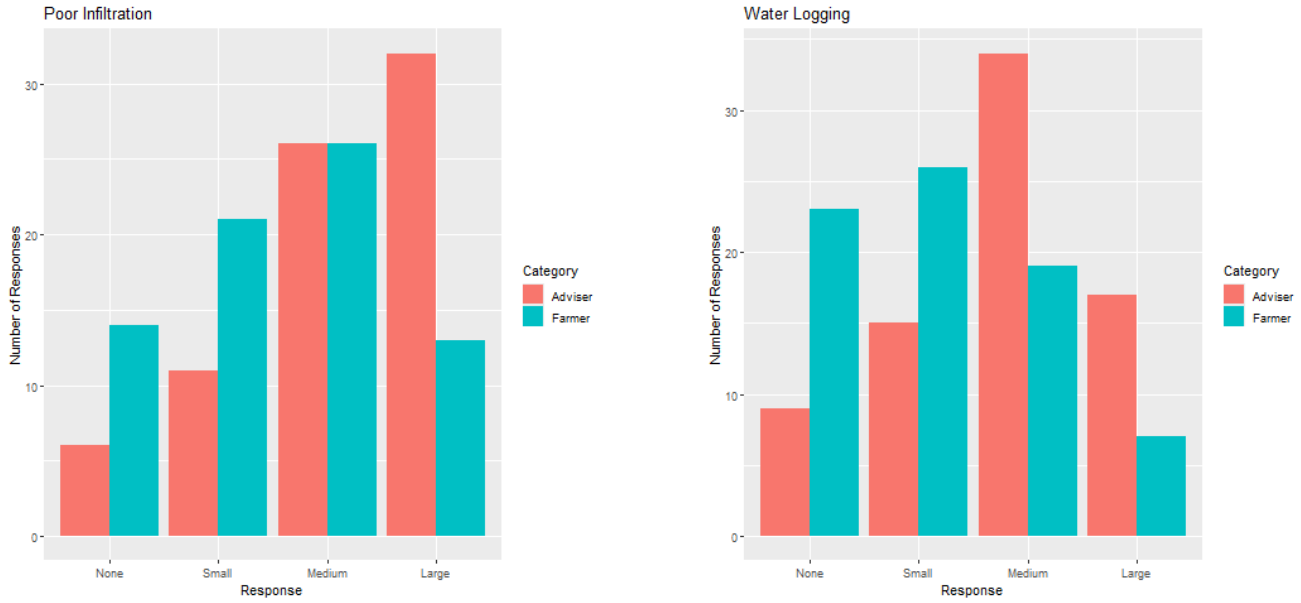


Figure 7 National Soil Survey Results on the impacts of poor infiltration (left hand side) and water logging (right handside)

These impacts have identified a number of gaps, both current and likely future, in soil capacity related to flooding. The gaps include:

- Very little literature or extension material on the management of flood affected soils. A brief literature search was conducted to identify associated scientific and extension related material (see Appendix Two). There is little information available in the form of extension material, whilst the scientific research highlights that recovering from flooding is site and often episode specific.
- A lack of expertise, particularly in responding to the diverse range of soil related impacts that flooding can create.
- The lack of knowledge and/or provision of advice for new landholders whose actions can have unintended consequences.
- A lack of coordination between landholders on flood plains.
- A knowledge gap as to why some properties recover rapidly from flooding whilst others don't.

The RSC, with support from the Burnett Mary Regional Group, conducted a small-scale preliminary investigation into the impact of prolonged inundation on soil chemical and biological properties. No conclusive results were obtained as to the impact of the inundation on soil condition, highlighting a need for protocols to establish the root cause of flood impacts (as has been identified in some of literature, see for example Shaw et al. (2013)).

The impact, both current and predicted future (with expectations of rainfall events of greater intensity), of flooding on soil condition, when combined with the limited information and expertise available to support landholders highlights the need for both greater research and extension support into the management of flood and inundation affected soils.

4 Results – Gap Analysis

The results of the Gap Analysis are presented in this section, with a separate sub-section for each element within the McKinsey 7s framework.

An overall assessment for each element is provided at the end of each sub-section.

4.1 Strategy

The following areas are covered within the Strategy element:

- Strategy with a focus national, state and NRM region strategies
- Relevant legislation, regulation and policy

4.1.1 Strategy

4.1.1.1 National

The NSS was released in 2021 (Department of Agriculture Water and the Environment, 2021) as a joint strategy between the Australian and State/Territory governments. The NSS includes three goals and 12 objectives.

An audit of the design and early implementation of the NSS was completed by the Australian National Audit Office (Lee et al., 2024). The major audit findings were:

- The design and early implementation of the strategy and the national action plan was not effective, except for its stakeholder engagement activities.
- The design processes established to support the achievement of the government's objectives were partly appropriate.
- Effective arrangements are not in place to support implementation of the strategy and the national action plan.

An interim action plan was released with the NSS which has been followed by the release of the first (of four planned) NSAP (DAFF, 2023) in late 2023. The NSAP contains four Priority Actions which "will focus national efforts on those areas that require early attention to provide the necessary base for achieving longer term outcomes."

The NSAP includes statements of support from participating jurisdictions (including both NSW and QLD state governments) as well as the description of the responsibilities of the state and territory governments. These responsibilities are:

- participate in relevant fora to direct, design and support soil priorities under the action plan,
- monitor the performance of soil activities in their jurisdiction, including their contribution towards the action plan,
- provide information required to assist the department in monitoring and reporting on the action plan, and
- continue to pursue resourcing to better address soil priorities.

4.1.1.2 NSW Government

As indicated in the NSAP, the NSW Department of Primary Industries (DPI) is the lead organisation within NSW for the implementation of the NSS/NSAP and will work closely with relevant NSW agencies and other organisations.

NSW DPI *Stronger Primary Industries Strategy* (Department of Primary Industries (NSW), 2022) describes six strategic outcomes of which two are closely related to soil, being *Sustainable Resources and Productive Landscapes* and *Carbon Neutrality and Climate Resilience*. Strategic priorities, intent and key deliverables are described for each outcome.

Seven key deliverables and one measure relate to directly to soil. The measure is: *Shift all soil health indicators to stable or improving by 2030*. NSW has six soil indicators (as described in Table 3 NSW Soil Indicators and Status).

Assessment. Whilst the publicly available NSW Government strategy related documents identify the importance of soil to the State, and describe a range of broad objectives and outcomes seeking to maintain and/or improve soil condition in NSW, the following concerns are identified:

- The majority of key deliverables lack specificity. It is unclear what success for many of the key deliverables would look like.
- Few metrics are provided against which to assess performance and where they are provided the granularity is coarse.
- It is unclear how deliverables will be achieved and whether sufficient resourcing is available to implement the key deliverables or achieve the strategic outcomes.

4.1.1.3 Queensland Government

As indicated in the NSAP, three Queensland Government departments are primarily responsible for soils in Queensland being the Departments of Resources, Environment, Science and Innovation, and Agriculture and Fisheries.

Each Department has a high level, public facing corporate strategy. Soil is not mentioned in any of the strategy documents.

The Queensland Government soil management website (Queensland Government, n.d.) provides a range of information sources on soils and soil related issues however nothing that could be identified as a soil strategy or policy.

The summary of the latest Queensland State of the Environment Report (Department of Environment and Science, 2021) makes little reference to soil and provides no metrics, other than change in land use and groundcover, related to soil condition.

Assessment. Other than the high-level statement of intent included in the NSAP it appears that the Queensland Government does not have a strategy to implement the NSS/NSAP, including the integration of the activities of the three departments primarily responsible for soil.

4.1.1.4 NRM Groups

A brief review of NRM groups' strategy documents (from both Queensland and NSW (through regional Local Land Services)) identified a range of emphasis on soil from not being mentioned through to quite extensive emphasis on the importance of soils. In general, NRM group strategy documents:

- Identify that soil health/condition requires improvement,
- Identify that soil health/condition is important for both productivity and environmental reasons, and
- Detail objectives and/or actions that focus on improving soil health/condition.

Assessment. Common themes in NRM group strategy documents are:

- A lack of specificity as to soil related objectives, and
- How the objectives will be achieved and whether there are sufficient resources available to achieve the objectives.

4.1.2 Legislation, Regulation and Policy

Numerous comments were received with regards to legislation, regulation and policy, a themed summary of which is provided below.

4.1.2.1 Regulatory burden/fatigue

Several comments were received with regards to regulatory burden/fatigue. The major concerns raised included:

- Concerns over a lack of differentiation for regulation based on the size of an enterprise (scale appropriate regulation). Examples were provided where the regulatory requirements and cost of applications for a small flock/herd compared to largescale piggeries and chicken operations are the same. This makes it difficult for landholders to diversify income sources (e.g. by 'stacking enterprises') and provides a competitive advantage to large scale producers. It was suggested that there should be thresholds for certain regulatory approvals.
- The overall regulatory burden continues to increase across the full range of regulation. The burden/fatigue comes at a cost to businesses (generally without a corresponding increase in income), particularly for smaller and family businesses. From a soil perspective, one interviewee noted that the increasing focus on regulatory requirements takes away from the landholders' capacity to focus on improving soil and land management.

4.1.2.2 Land use and land management

Multiple comments were made about legislative and regulatory settings relating to land use and management.

Vegetation

Several interviewees, primarily from the Rangeland regions of Queensland made comments with regards to vegetation management (Queensland legislation: *Vegetation Management Act 1999*).

A serious concern raised was that the application of the Vegetation Management Act in Mulga (*Acacia aneura*) was having counterproductive impacts leading to land degradation. Specifically, graziers and NRM officers explained that limitations on the ability to manage Mulga are leading to a thickening of vegetation. The thickening vegetation results in canopy/near canopy closure which shades out understory vegetation. The negative impacts include greater deaths of Mulga itself during drought (too many trees for the available moisture) and increased erosion during rainfall events (as a result of a loss of groundcover). One interviewee described Mulga as the biggest environmental weed in the region, indicating that a review of the regulations are required to enable landholders to restore greater balance between trees and grass.

Water and landscape rehydration

Several comments were made (from interviewees in both Queensland and NSW) with regards to the difficulty of implementing structures in waterways to manage for soil conservation and landscape rehydration.

A summary of the issues identified included:

- The time and expense to gain approvals. Which may involve both state and local government, multiple state government departments, multiple pieces of legislation, and different sections within departments that do not communicate with regards to the same development application.
- Misclassification of some waterways/streams (and regional ecosystem classification). Specifically, erosion features being classified as a waterway, and thus triggering the requirement for an

application, which can be costly and time consuming for the project proponent. One interviewee indicated that there was no process to trigger a re-assessment whilst another indicated that they were able to have a stream re-assessed (using historical photographic evidence). **Comment**. This has not been ground-truthed but does indicate confusion about the process.

- Concerns that the approvals process can cost significantly more than the cost of the works – particularly for minor works.
- Concerns that greater environmental damage is being accrued by not implementing in-stream works in degrading/eroding landscapes.

These issues have been identified as being of concern nationally. The Mulloon Institute is advocating a for national code of practice for landscape rehydration works with the aim of supporting ecosystem restoration whilst minimising the regulatory burden of such works (Mulloon Institute, 2023).

4.1.2.3 Urban development

Several concerns were raised about the loss of fertile agricultural soil and landscapes to urban and other development.

This issue was identified in the recent Inquiry into food security in Australia (Standing Committee on Agriculture, 2023) which made the following recommendation:

"The Committee recommends the Australian Government, in conjunction with State, Territory and Local governments, develop a strategic plan to protect agricultural land from urban sprawl and utilisation for non-agricultural purposes."

Given that many of the most fertile agricultural soils are in proximity to major urban centres, the protection of agricultural land from urban sprawl is of critical importance.

4.1.2.4 Soil Conservation

Soil conservation legislation exists in both NSW and Queensland. The relevant legislation is:

- NSW: *Soil Conservation Act No. 10 1938*. Administered by
- Queensland: *Soil Conservation Act 1986*. Administered by the Department of Resources.

In Queensland, Part 3C (Offences relating to water contamination) of the *Environmental Protection Act 1999* is a second piece of legislation partially related to soil conservation. This part of the Act has been devolved to Local Government but does not appear to have been used/used widely as an enforcement mechanism for soil conservation.

Numerous comments were received with regards to legislation/regulation related to soil conservation. A summary of observations are:

- **(General)**. Many earth moving contractors do not have an understanding of the requirements for soil conservation work, indicating a requirement for a qualification/accreditation requirement contractors implementing soil conservation works.
- **(General)**. A major gap in the coordination of soil conservation works between landholders/stakeholders. Several interviewees noted that multiple contractors are capable of designing and implementing soil conservation designs. However they are not contracted to, nor do they have the authority, to coordinate soil conservation works between different landholders/stakeholders. Several interviewees indicated that no-one is currently responsible for this coordination in Queensland which leads to detrimental outcomes such as accelerated erosion. A 'fear of litigation' is seen as one reason why key stakeholders (e.g. Department of Resources,

Department of Main Roads and Transport, local governments) are unwilling to assume responsibility for coordination of runoff.

- **(General)**. A lack of quality control/assurance for soil conservation works that are implemented by private contractors.
- **(Queensland)**. When land is sold, or a development is proposed, there is no requirement for a title search to check whether a soil conservation plan is active over the property.
- **(Queensland)**. Existing soil conservation plans are not being monitored or enforced.
- **(Queensland)**. Retired soil conservation officers indicate that many infrastructure works are not following the recommended guidelines for road building to minimise erosion and runoff. A farmer also posed the question as to whether there was still a requirement to implement soil conservation measures having observed infrastructure works no longer implementing guidelines.
- **(Queensland)**. A proponent for a new soil conservation plan (apparently the first in several decades) described how difficult the process has been and that the Department of Resources now lacks the internal capability to assess soil conservation plans.
- **(NSW)**. One interviewee noted that the NSW Governments Soil Conservation Service is not providing a service to landholders and that their documentation (designs) isn't transparent to the public.

4.1.2.5 Public Good vs Private Benefit

Many interviewees made comments related to soil and the public good versus private benefit.[2] A summary:

- Soil and water are a commons. Water is seen as a commons and managed much more as such, whereas this is not the case and not as easy for soil.
- Preventing soil degradation, particularly wind and water erosion is a public good and should be managed as such. The prevention of dust storms caused by wind erosion was provided as an example where soil management results in a public good. Other comments went further and indicated that the more productive the land, the better it is for the environment, therefore there is room for some overlap between public good and private benefit.
- One interviewee recognised that government should not be subsidising industry for what industry is, or should be, doing itself.
- Several comments were made that many programs/policies (examples cited included vegetation clearing, fencing off land, and climate change targets) were primarily about generating off farm benefits with limited benefit to the landholder, indicating that where this is the case it is difficult to motivate landholders to engage with the program as there is little private benefit.

4.1.2.6 Standards

Several comments were received on the importance of soil and land management standards. Examples were cited (Isbell, 2016, National Committee on Soil and Terrain, 2009, Rayment and Lyons, 2011). Standards were identified as making management and decision making easier for all stakeholders.

The importance of funding to support the maintenance of standards, or creation of new standards where appropriate, through groups such as the National Committee on Soil and Terrain was highlighted.

Areas where standards were identified as being deficient included:

- A definition of soil health

[2] This has been included here as the determination between public good versus private benefit is a policy decision.

- Categorisation, labelling and standards for soil biological products (which unlike synthetic fertilisers generally have no labelling requirements).

4.1.2.7 Miscellaneous

Many miscellaneous comments were received related to legislation, regulation and policy. A summary is provided below:

- **Accreditation**. Except in a few distinct areas (e.g. contaminated land, acid sulphate soils), the requirement for an accredited level of soil expertise is often not required in government programs/regulations, or a generic term such as a 'suitably qualified person' is described. Comments were received indicating that requiring accreditation such as Certified Professional Soil Scientist (CPSS) or Registered Soil Practitioner (RSP) would both build the demand for such accreditation as well as improve the quality of advice being provided.
- **Addressing root causes**. Some interviewees noted that governments are monitoring issues (e.g. water quality) but doing little to address the root cause of issues.
- **Development**. The decision to create environmental harm (e.g. through development approvals) are made at a policy level. Once a decision is made there is no going back, the result being that land will be degraded permanently. A view was expressed that this permanent environmental harm is not sufficiently incorporated into regulatory tools at all levels of government.
- **Loss of capability**. Several interviewees noted that the loss of soil related capability over the last several decades was a result of decisions made by State governments. The implications of these decisions was not taken into account at the time the decisions were made resulting in short term cost saving with long term detrimental impacts. One comment highlighted that NRM groups are "*under-resourced so they can't deliver or provide ad hoc/very targeted delivery*"
- **Erosion and Sediment Control**. Responsibility for ESC has been devolved in Queensland to local government. As identified at the Water By Design ESC Community of Practice workshop (held 24 February 2024), most local governments have insufficient capacity and capability to regulate ESC activities resulting in low compliance rates, increased sediment lost to erosion and negative water quality impacts.
- **Eligibility criteria**. Eligibility criteria, particularly related to off-farm income, for government programs was identified as a concern by multiple interviewees. Tight eligibility criteria often excluded many landholders and did not recognise that businesses often seek off farm income to provide additional income post natural disaster. Thus, by excluding businesses in such circumstances it actually makes it more difficult for businesses to get 'back on their feet.' Another example was provided where a landholder at a critical point in a catchment was excluded from a flood damage scheme because of off farm income even though repairing the flood damage was important at a catchment scale.
- **Farm Business Resilience Plans**. Several interviewees highlighted how useful/important farm planning was and encouraged the continuation of programs that supported such planning. However, some comments were received that highlighted that many plans were not implemented due to a lack of available funding.
- **Silos**. Several comments were received with regards to a lack of understanding both within and between government departments of the responsibilities and activities of other departments/programs.
- **Recognition of regional NRM plans.** Comments were received that the Queensland Government does not recognise plans developed by regional NRM groups. This results in a lack of integration of different programs.

- **Regulation of agriculture.** Some comments were received with regards to the implementation of 'Reef regulations' in Queensland. Positive comments were received about how the regulations have been incrementally initiated providing landholders with time to adapt to the changes. Comments were also made how some businesses/industries are looking at certification of practices to ensure social licence and minimise/prevent future regulation of agricultural activities. The requirement for both a stick (legislative/regulatory) and carrot (rewards) approach to practice change was identified with a preference for a focus on rewards and support being preferred.

4.1.3 Strategy – Assessment

"The loss of essential ecosystem services is irreversible and in some areas is approaching a tipping point, where ecosystems could transition to a permanently altered state. The security of NSW water resources, quality of air and richness of soil and forest are also deteriorating, which has implications for our future wellbeing and livelihoods."

Science Economics and Insights (SEI) Division (2024)

The key assessment from the review of strategy documents at national, state and NRM region level indicates that outside of the relatively small community of people who share deep concerns about the condition of the SQNNSW regions soil and the implications of continuing soil degradation (as highlighted in the quote above from Science Economics and Insights (SEI) Division (2024)), soil has not yet reached a threshold amongst the broader policy/decision making community to warrant the level of commitment and investment required to address soil management at a fundamental level. This is evidenced by:

- The lack of specificity of the objectives relating to soil condition/degradation and landscape management,
- A lack of urgency towards achieving the objectives (where they exist),
- An unclear path as to how objectives will be achieved, and
- An inadequate mobilisation/commitment of resources to support the attainment of the stated objectives.

The implications are that progress in improving soil condition under the NSS/NSAP will necessarily be slow and likely at a scale that is insufficient to halt let alone reverse the trend of deteriorating soil condition across Australia as reported in Williams et al. (2021b).

This situation highlights and reinforces the requirement for soil advocates at all levels from local to national to continue to mount the argument for a higher prioritisation of resources and commitment towards improving soil and land management at a landscape level.

4.2 Shared Values

In the context of achieving the goals and objectives of the NSS as well as the Priority Actions of the NSAP, shared values across the organisational ecosystem involved will be of major importance. Trust, incentives, decision making and priorities, and belief systems have been identified as gaps or issues related to shared values from the interviews conducted for the Gap Analysis and are discussed below. This is followed by an overall assessment and implications of these findings for the NSS/NSAP.

4.2.1 Trust

"Public trust levels are very low, including in the Not For Profit sector. Relationships are everything."

NRM Group Interviewee

"If a farmer offers a cup of tea, accept it. The exchange of hospitality is a form of building trust."
Retired Soil Scientist Interviewee

Numerous interviewees identified trust as a major issue for furthering improved soil and land management. Trust is demonstratively a multi-faceted issue affecting relationships between numerous groups within the organisational ecosystem. This includes trust in government (at all levels), Not for Profit organisations, advisers/consultants/agronomists, sellers and resellers of products (including both 'conventional' and 'regenerative'/'organic' products)), information sources, and even farmers trusting in their own ability to make decisions.

These observations are not surprising, particularly set in the broader context of declining levels of trust in institutions (see for example Commonwealth of Australia (2023) and Edelman Trust Institute (2024)).

Some key observations include:

- Trust is viewed as largely about relationships and people.
- Regular changeover of staff in organisations makes it difficult to build and maintain trust. One industry group identified that working with the same partners over time was a critical part of their model to help build trust.
- A critical issue for programs with an extension focus is trust between the extension practitioner and the landholder. One interviewee explained that farmers want to 'interview' the extension officer.
- Time is a critical factor in building trust. One interviewee indicated that they had attended field days where they had worked with three generations of farmers noting that it is hard to earn their respect.
- Several farmer interviewees noted that farmers often know more than their advisers however lack confidence in their own decision making and instincts.
- Extension officers can be much younger and less experienced than landholders (who may have been farming for a lifetime) making it extremely challenging for new extension officers to be able to establish trust and respect. One interviewee highlighted that this disparity was a contributory factor to the high turnover rate of staff in NRM groups.

4.2.2 Incentives

"Show me the incentive and I will show you the outcome"

Charlie Munger

Issues identified with incentives can be grouped under several categories, being:

- 'Perverse' incentives that encourage practices and/or behaviour that are detrimental to improved soil/land management,
- Incentives related to financial (or other) gains by those recommending a practice, service or product, and
- A lack of incentive to change from the status quo.

Perverse incentives

A primary example of a perverse incentive is the large economic advantage that can be obtained from increasing grazing pressure above recommened rates despite the adverse impact upon both declining land condition and animal performance as found by Bowen and Chudleigh (2018).

One grazier who had transitioned from cropping to grazing stated that the land values assigned to native perennial pastures in their region was less than half of that assigned to cultivated land. They highlighted that as their focus was on the ecological improvement of the landscape this is currently not viewed as the highest possible/most profitable land use, and their land valuation has dropped accordingly. The provision of habitat for endangered communities that this business is providing is not considered in land prices. The grazier highlighted that land valuaton is unbalanced in one direction towards maximising productivity rather than preserving and improving the landscape. This incentivises land use towards enterprises that are detrimental to land and soil condition.

The trend of ever increasing land prices was also identified as a perverse incentive (see paragraph 5.1.3 for more on land prices) leading to situations where a profit can still be made even where management results in land degradation.

Sales/financial incentives

Numerous interviewees raised concerns about the ability to obtain independent advice as well as conflicts of interests between those providing advice and selling a product. Multiple interviewees identified that independent agronomists/consultants as well as government funded agronomists/extension officers are few and far between, with most people providing advice/recommendations being linked to the selling of products. There is a common view that this connection influences recommendations, sometimes regardless of soil tests results.

Several interviewees identified that the current reward model for agronomists based on yield per hectare has some undesirable outcomes. This includes recommendations erring on the side of increased yield rather than profit (which benefits the agronomist but not necessarily the landholder) and a short-term season to season approach. For example, one independent agronomist lost clients after recommending practices focusing on longer term sustainability (such as the planting of cover crops) but which resulted in less profit per hectare in the short term. Another interviewee suggested that "*only a handful of agronomists look at soil issues from a long-term timeframe*" with most focusing on the short term (i.e. the current crop).

Lack of incentives

Increasing requirements are being placed on landholders across a spectrum from workplace health and safety through to Environmental, Social and Governance requirements. One soil scientist identified a concern that farmers are being asked to make changes to land management for which they will not benefit. An annual horticultural farmer explained that they were well aware of, and had trialled/used, many different practices to improve their soil (e.g. cover crops, compost additions etc). However, these practices come at an extra cost for which there is no financial reward within the current market pricing mechanisms.

The CSIRO ADOPT model is a tool to predict the rate and peak level of adoption (Kuehne et al., 2017). One of the four quadrants of the model is the 'Relative advantage of innovation'. Priority Action Three of the NSAP seeks to accelerate the adoption of land use and management practices that protect soil and improve soil state and trends. The aforementioned issues identify the critical importance of establishing incentive structures that will increase the advantage of any given practice change to encourage landholders to adopt improved soil management practices. Where these incentives do not exist, it can be expected that the adoption process will be both slow in adoption rate and low in adoption level.

4.2.3 Decision making and priorities

Several interviewees made comments upon decision making and prioritisation that impact upon land and soil management. These included:

- Many primary producers are time poor. This limits the capacity to learn about, research, trial and apply new or different practices.
- Many primary producers also have off farm employment which imposes a time and capacity burden from a practice change perspective.
- There is a lot of pressure on producers of which the health of the landscape is just one. Several interviewees commented that ‘paying the bank manager’ comes first.
- Producers often only start looking at alternate approaches when there is an issue with the current approach/the old approach no longer works.
- Soil for many landholders is traditionally seen as a reactive rather than proactive issue.
- For producers that engage external advisers, decision making is often a shared process, highlighting that both the producer and their advisors need to be consulted where practice change is involved.

4.2.4 Belief systems and social pressures

A number of interviewees identified that belief systems play an important role in both farming practices and extension/adoption.

Some interviewees commented on a ‘quasi-religious’ or ‘cult’ like approach to certain land management philosophies. Examples were provided of people being verbally abused at field days by other attendees when questions were asked of well-known figures presenting on some of these approaches.

Social pressure was identified by a number of interviewees as being a barrier to change in some regions, where producers who tried new practices could be socially ostracised or criticised. Different farming philosophies can create in-groups and out-groups with personal identities being tied to the selected approach.

Social pressure can also be a major source of friction between generations.

A belief in soil ‘silver bullets’ by some landholders was also identified as a concern. One experienced agronomist/extension officer highlighted how some landholders (often new landholders) latch onto and implement ideas that are unlikely to be successful/lack a scientific evidence base. An interesting anecdote from one interviewee was that the choice of laboratories for soil analysis often came down to a philosophical choice rather than a cost choice.

Another interviewee commented on beliefs that technology would improve land management/soil condition, yet despite all of the increases in technology land condition is generally deteriorating compared to its former state.

Many factors influence landholder decision making. An example is provided from fertiliser trials conducted by Leech et al. (2019) which compared different types of ‘conventional’ and ‘alternate’ fertilisers on phosphorus deficient soils and provided a clear indication that from a cost and efficacy perspective single superphosphate was the most effective. Yet experience from this trial identified that decisions around fertiliser are not always based on science and economics.

One experienced extension officer explained that for extension to be successful you have to sell landholders a philosophy, highlighting that this is where public sector extension can work well as it is not selling a product. The same extension officer indicated that the growth in interest in ‘Regen Ag’ is an example of the effectiveness in selling a philosophy.

The issues highlighted by interviewees around belief systems highlight the complexity of the social aspects related to practice change and adoption and require careful consideration in developing programs and projects that will result in both meaningful engagement with and by landholders as well as successful

adoption of improved soil management practices. It also highlights the ongoing importance of trials and demonstrations to provide an evidence base against which the efficacy of practices or approaches can be established.

4.2.5 Shared Values - Assessment

There are several important implications arising from the Shared Values component of the Gap Analysis.

The development and maintenance of trust is of the utmost importance if the programs being delivered by the NSS are to be successful, and ultimately the objectives of the NSS itself are to be achieved.

Trust was recognised as being largely about relationships between primary producers and those supporting and advising them. This highlights the importance for consistency in staff employment which in turn requires consistency and reliable funding as well as timely transitions between one funding round to another.

With extension officers and related staff often being on the ‘back foot’ from an age, experience and sometimes gender perspective, it is imperative that they are appropriately trained, educated and mentored to maximise their effectiveness as well as provided with a career path that supports the development of experience over time. This is currently lacking as is described elsewhere in this Report and undermines the capacity of extension programs to achieve their objectives.

Human psychology highlights that most humans most of the time will behave based on the incentives structure that exist. Currently there are a range of incentives within the broader agricultural and economic environment that are acting counter to the objectives of the NSS. Seemingly ever-increasing land prices is a prime example, as are some of the rewards structures for those advising primary producers. Whilst these are difficult and complex issues to address, they are also fundamental to improving soil and land management.

The capacity for producers to change is often limited due to the broad range, and often competing, pressures upon them. Recognition that a farming business is a complex system, and that each farm business is unique, highlights both the challenges faced in improving management of the regions soil resources and the level of commitment and support required to facilitate practice change.

The social complexity of agriculture and rural communities is well known. It can have both positive and negative impacts. Achieving successful outcomes within this complexity requires staff with a high level of expertise in extension theory and practice. As highlighted in other areas of this Report, the development of this expertise is an area which systemically weak and increases the risks of program failures. The social complexity also highlights the importance of co-design (to ensure producers needs are addressed) and providing opportunities for groups of like-minded producers to work together in a collegiate and supportive environment (several successful examples of which were identified in the SQNNSW region).

The different belief systems and philosophical approaches to farming further emphasise the importance of readily available access to experienced soil practitioners with both technical and extension skills (including accreditation such as CPSS, RSP or Fertcare Accredited Adviser), the ready access to reliable and scientifically sound information (such as provided by Soil Science Australia (2024)) as well as the ever present requirement to build basic soil knowledge amongst landholders and producers. These approaches are necessary to minimise risks associated with ineffective and potentially detrimental approaches to soil and land management that either cost producers financially with little reward or lead to land degradation. It also highlights the importance of continued research into new and evolving practices (and dissemination of results) to provide an evidence base against which efficacy can be judged. As highlighted in other areas of the Gap Analysis there is currently an insufficient level of support available to meet these requirements.

Whilst it is unrealistic to expect governments to be able to address many of the identified issues directly, indirectly governments can play a major role in establishing the frameworks, policies and programs upon which these issues can be addressed, managed and potentially resolved. Indeed, it will be imperative that government does so if the objectives of the NSS are to be achieved.

4.3 Structure

4.3.1 Commentary

"An estimated 150 organisations contribute to the national soil RD&E effort. This is a large number of contributors … it is reasonable to inquire what arrangements exist for national coordination and collaboration of effort to reduce duplication and inefficient use of resources. The short answer is: relatively little"

Department of Agriculture Forestry and Fisheries (2014)

This section of the Gap Analysis focuses on the organisational structure related to soil management. As can be seen from Figure 3, which is only a partial representation of organisations involved in soils, it is a complex organisational ecosystem. The organisational ecosystem has evolved over time, becomingly increasingly atomised, as more and more organisations have been created which work in various aspects related to soil RD&E activities.

For much of the second half of the twentieth century, soil research and extension capacity resided with the CSIRO and State governments (with soil staff generally working in one department). This relatively simple organisational ecosystem has evolved over subsequent decades to include universities, NRM groups, RDCs, private industry as well as soil capabilities being split across multiple departments within state governments.

Numerous comments were made relating to organisation structure during the interviews. A summary of comments includes:

- That whereas landholders used to be able to obtain a wide range of information from a single source (e.g. a local DPI office) that information/advice is now spread across multiple organisations who often have no direct relationships and some of which now needs to be paid for.
- A view that partnering in research between organisations is declining, an indicator of increasing competition for limited resources. Similar comments were made related to the overlap of activities between different organisations (universities, NRM groups, state governments, private businesses) which are now competing for the same funding, a change from the past.
- The centralisation of state government resources into major regional centres.
- A lack of coordination between the broad range of organisations involved in soils. Additionally in some areas extension has been separated from research and development (e.g. NSW DPI and LSS). This is viewed as leading to sub-optimal outcomes with regards to the adoption of research.
- A lack of integration between production (e.g. RDCs) and natural resource management (NRM). Several interviewees indicated that unless these two elements are integrated it will be very difficult to improve soil management. One NRM group interviewee indicated that the NRM groups can't do research but want to help out and could see opportunities to offer researchers, industry placements, PhD projects to support NRM group activities.

- The reallocation of soil science functions to multiple state government departments has created silos with limited interaction and awareness. This can have multiple negative impacts including competition and duplication of effort.

4.3.2 Summary - Structure

There is an extensive literature on organisational entropy. Highly ordered (low entropy) and highly disordered (high entropy) organisational ecosystems can be dysfunctional/ineffective (Chappell and Dewey, 2014). Given the current organisational ecosystem, and comments made by interviewees, it appears that structure has evolved towards a disordered system. Arguably the organisational ecosystem has progressed past the point of optimal entropy (see Figure 8) leading to inefficiencies and potentially being a contributory factor in the continued degradation of Australian soils despite significant investment over decades.

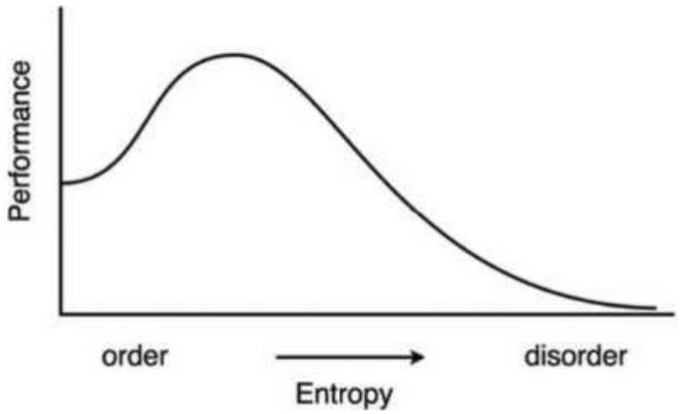


Figure 8 Theoretical link between an organisations performance and its entropy. Sourced from (Chappell and Dewey, 2014)

This leads to the conclusion that there may be a requirement to rationalise the organisational ecosystem involved with soils RD&E to improve overall performance.

4.4 Systems

The Gap Analysis has identified gaps, issues and concerns related to systems across the following areas:

- Awareness
- Soil Information
- Soil Data
- Research
- Education
- Funding.

4.4.1 Awareness

Numerous comments were made by interviewees with regards to a lack of awareness from multiple perspectives including the broader community, landholders and soil practitioners.

4.4.1.1 Community Awareness

Concerns with regards to a lack of community awareness included:

- A lack of understanding from the broader community as to how their food is produced and the lack of connection with food production, agriculture and soil. One interviewee suggested incentivising households to grow at least some of their own food would be useful in rebuilding the connection between food and land/soil and thus public perception of the importance of soil more broadly. Another identified that many people are disconnected from the world at large, highlighting the challenge of re-establishing connectivity between the community and the land that sustains the community.
- A need for improved marketing of soil and the role of soil in maintaining living standards including the link between soil health, food quality and human health. This can be encapsulated in the concept of 'One Health' (Blanco and Lal, 2023) which links the health of the environment, including soils, with human health.
- A general lack of recognition amongst the general public of actions that producers are taking to improve the health of the land and soil. **Comment**. There are some positive examples of successful engagement and awareness raising. An example being Landcare Australia's video *Rehydrating Thirsty Land – Regenerative Rangelands* (Landcare Australia, 2023) which has 130,000 views on YouTube.
- The need for more people to have the opportunity to engage with/experience soil science. One soil scientist indicated that they didn't know anything about soils until they were required to do complete a soils unit as part of an agriculture degree. Anecdotally it appears that many people who work in soils/soil science came across it by happenstance rather than as a deliberate career decision.
- A lack of understanding of scientific principles, particularly with regards to statistics, which can lead people to believe in ideas or concepts that lack scientific validity.
- One interviewee suggested that if every student at some point in their high school or university career spent a week on a farm this would break down a lot of barriers, particularly for city dwellers.

4.4.1.2 Landholder Awareness

Concerns related to landholder awareness covered a range of topics including:

- A general lack of knowledge amongst new landholders about soils, soil management and the link between soil condition and productivity.
- The impact of generational changeover leading to proven practices being abandoned. An example being the removal of contour banks for erosion control amongst a younger generation that has lived mainly through periods of drought and thus unaware of the impact of erosion during major storm events.
- The importance of practices such as maintaining ground cover for protecting soil.
- The subtleties of managing different landscapes. Some interviewees identified concerns over graziers applying practices that work in one region but are inappropriate in other regions which can result in overgrazing and landscape degradation.
- A lack of awareness of existing legislative/regulatory requirements such as Soil Conservation Plans and Good Quality Agricultural Land (Queensland).
- The beneficial impacts of composts and other organic amendments for soil health/condition.
- The potential negative consequences of inappropriate placement of farm infrastructure such as tracks, water infrastructure etc that can lead to erosion/degradation, particularly during flood events.
- A lack of understanding of soil constraints such as acidity/acidification of agricultural lands.
- There are a growing number of landholders that are very interested in initiatives such as carbon projects/natural capital accounting. The thirst for more information about these topics is clear.

Several comments were made with regards to the lack of engagement by landholders with organisations such as Landcare. One interviewee suggested that less than 20% of land holders engage with Landcare or similar organisations. As evidenced at one field day which the RSC attended, where the first question asked by a land holder was "*why don't more people attend Landcare events*?"

4.4.1.3 Soil Practitioner Awareness

A number of concerns were raised, both by landholders and soil practitioners, of the lack of awareness of soil practitioners. Examples included:

- Practitioners unaware of soil related tools that are available, such as the NSW Government's eSpade.
- State government employees being unaware of the activities of other employees in other Departments work on soil (an example of silos).
- Instances of government staff being unaware of relevant pieces of legislation, soil conservation legislation being one example.

4.4.2 Information

"The information landscape has shifted from a deficit to an overload, making it challenging to capture farmers' attention and navigate complexity"

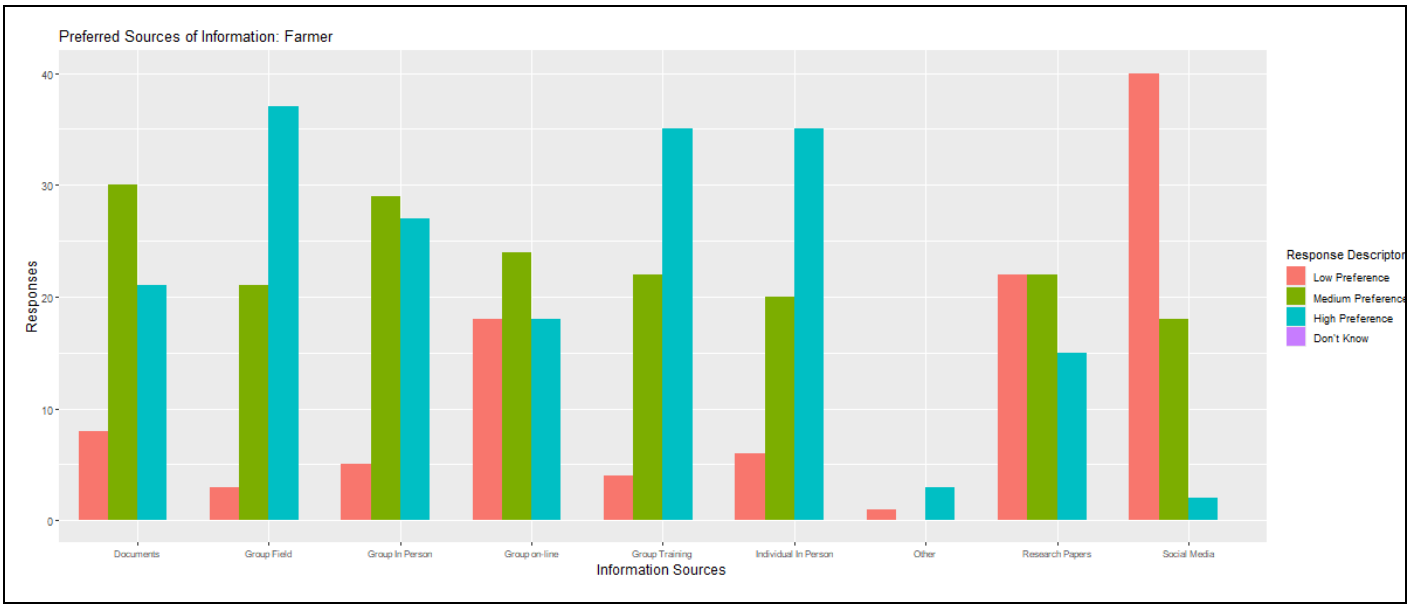
Soil CRC Factsheet

The results from the National Soil Survey relating to information and a summary of the key themes obtained during interviews are provided below.

4.4.2.1 National Soil Survey

Two questions related to soil information were included in the National Soil Survey relating to preferred sources of information, advice and support (Figure 9) and the most important sources of information (Figure 10).

For both farmers and advisors, the responses indicate a clear preference for receiving information via face-to-face human interaction. Advisors show a higher preference for information being sourced from documents and research papers in contrast to farmers who have a lower preference for these sources. These results are not surprising.



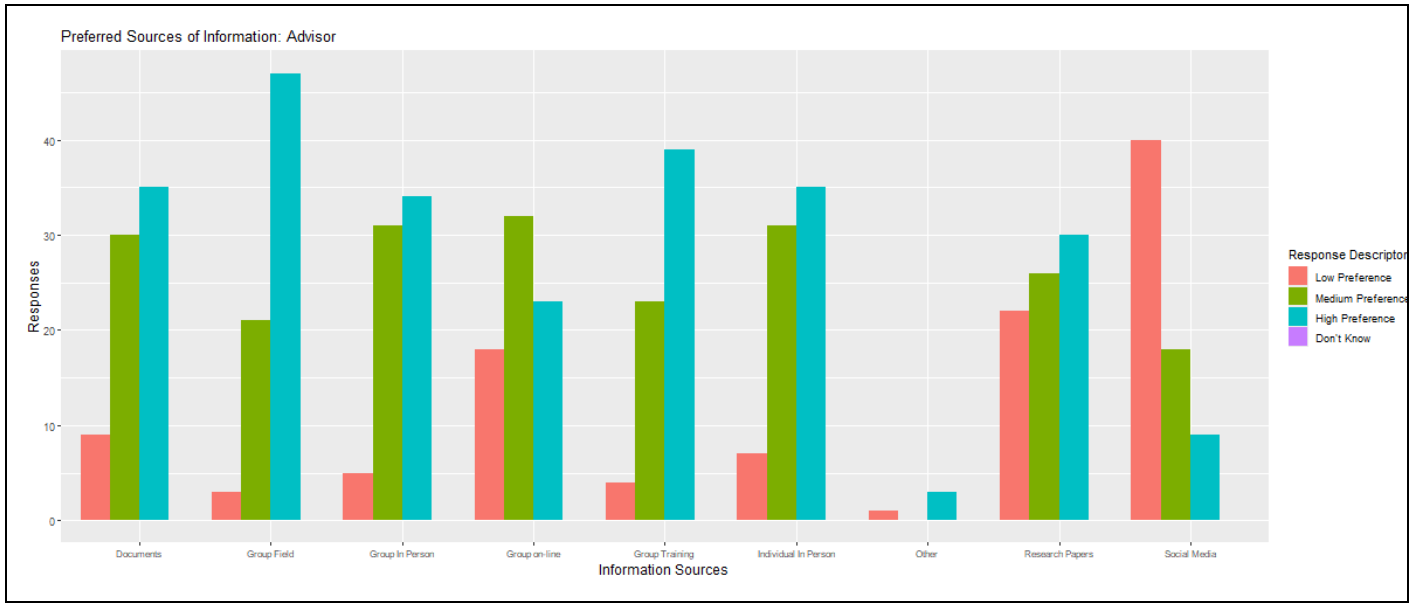
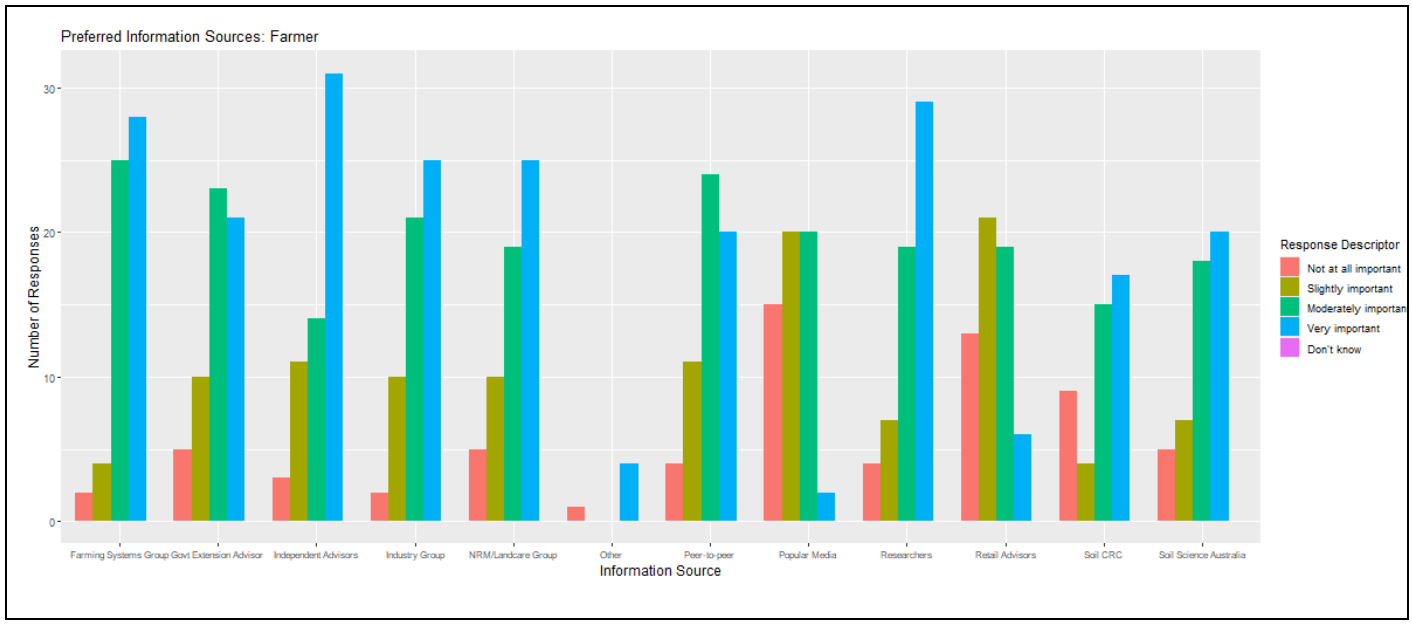


Figure 9 National Soil Survey Question: How do you prefer to receive information, advice and support for managing soils? Preferred Sources of Information (Farmer responses top chart, advisor responses bottom chart)

From an organisational perspective, farmers seek information from a range of sources with researchers, independent advisors and farming system groups viewed as being the most important. This is similar for advisors. Of note is the lower importance assigned to popular media and retail advisors.



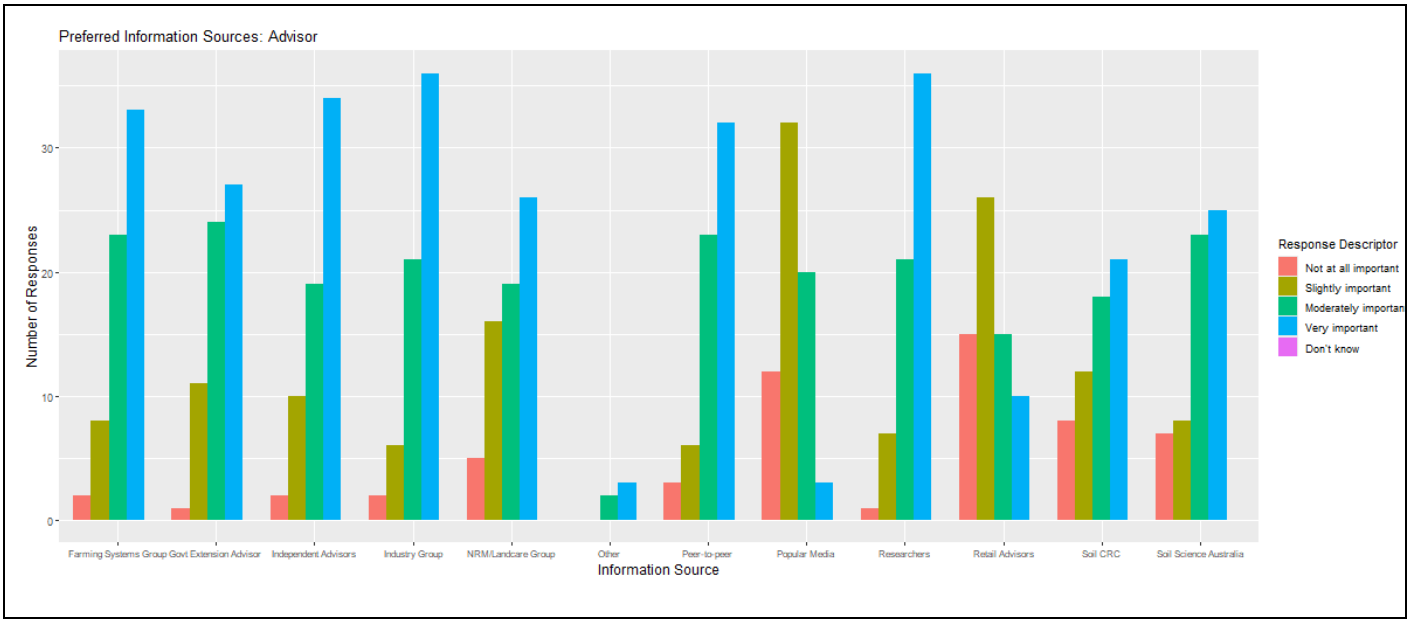


Figure 10 National Soil Survey Question: "Who are the most important people and organisations you rely on for quality information, advice or support on soils management?" (Farmer responses top chart, advisor responses bottom chart)

These results align with many of the comments made during the interviews. Producers seek information from a wide variety of sources with individuals tending to use a range of mediums.

4.4.2.2 Information – Key Themes

Multiple comments were received relating to information. The key themes included:

- There is an enormous amount of soil information available but knowing where to look (or start looking) can be a challenge. This is a distinct change from the pre-Internet past where the communication pathways were few, compared to hundreds of pathways now.
- Several interviewees noted that there is a lot of information of available but unless you know specifically what you are looking for it may be difficult or impossible to find. This can be a result of the loss of corporate memory and organisational changes.
- The sheer volume of soil information available can lead to information overload. There is a well-established literature highlighting that beyond a certain point, further information can surpass the cognitive ability of an individual to make decisions (see for example Falschlunger et al. (2016)). In these case individuals tend to resort to what they know.
- Often people are unsure of exactly what information they are looking for. This can create added confusion and frustration due to the volume of information that can be found on specific soil topics.
- In extension related material there is a growing trend towards generalisation (LLS soil information was cited as an example which tends to be generic and not region specific), which often is unhelpful as it doesn't account for regional, soil type, production system or other context dependent requirements, which are often the questions that producers need answered. This is recognition that producer's soil related information requirements are often unique.
- Keeping abreast of current research is also difficult, particularly for practitioners whose time capacity is limited. The requirement to pay or have a subscription to access research was also identified as a restriction.
- The time that people have available to find, read and analyse information is limited.

- There is a lot of older soil information around that is still useful/available but people are unaware of or consider outdated. Examples included the SOILpak series and Queensland's Land Management Manuals.
- Soil biology was identified as one area where there is a lot of confusion.
- Concerns were raised with regards to the accuracy and relevance of information.
- Some interviewees noted that a lot of soil information focuses on a single issue/constraint however soil constraints often occur together.
- The maintenance of information is not sufficiently addressed. This is particularly the case where projects end or organisations close/change. One example of many, is a range of Government funded booklets related to soils and pastures created by the Condamine Catchment Management Association from government funding, which can no longer be found online but are still a useful source of information.
- Concerns were raised about the amount of information that has effectively been lost (but may still exist as hardcopies, in filing cabinets of retired soil scientists etc) as well as the amount of research that is repeated. One experienced soil scientist stated that "*Very little that we do today is new*" yet organisations will pay large sums on consultants to relearn lost knowledge.
- Information/reference material isn't being updated. An example is the Western Arid Region Land Use Study (Department of Primary Industries (QLD), 1974) covering the Rangelands of Queensland. These studies, whilst still relevant, have not been updated in 30 or more years, are difficult to find/navigate, of poor quality with regards to readability/searchability compared to contemporary documents, and use some terminology that has been superseded.
- Another concern was only a small proportion of scientific research is translated into forms that can be used to inform soil managers. Several comments highlighted that there is an imbalance between research and extension/adoption.

Whilst there are a number of structural issues and practical actions that are needed to address the issues identified with soil information, the key theme that links many of these comments and observations is the centrality of knowledgeable soil practitioners in the soil information ecosystem.

4.4.3 Soil data

4.4.3.1 Resolution

Multiple comments were received about the resolution of soil data in both NSW and Queensland. The resolution of soil data varies considerably across regions, dependent upon the extent of soil survey activity that has been completed. Thus, some areas have significant access to relatively high-resolution soil data (e.g. Bundaberg and the North Coast of NSW) whereas others are sparse with sparsity increasing for both western NSW and western Queensland.

However, even in areas surveyed at relatively high resolution, the availability of soil survey data to inform decision making at property scale, was seen as lacking.

Several environmental consultants identified that they were often involved in projects where soil data is sparse, requiring the conduct of soil survey activities to meet their clients' requirements.

Ongoing funding of soil survey activities by the responsible government departments was identified as being required to fill in data gaps and improve the resolution of soil data region wide.

An observation is that some end users of soil mapping products don't understand the uncertainties resulting from the scale of sampling used to produce the mapping product.

4.4.3.2 Accessibility

The accessibility of soil data was raised by multiple interviewees across different industries and roles. It was identified that there is a lot of data that is not readily accessible to potential users both within and between organisations/industries. In some instances, because it is difficult to find data, soil data collection and research efforts can be repeated.

Several comments were received with regards to government funded programs collecting soil data but that data not being available outside of the project or once a project ends. It was noted that there are programs in some industries to address this. Several interviewees were also interested and optimistic about the opportunities that the Australian National Soil Information System (ANSIS - https://ansis.net/) will provide whilst others expressed concern that it will be of limited use at farm or local scale.

Several interviewees identified that there are significant opportunities for data sharing between different organisations and sectors that would be beneficial to a range of users (both government and private industry). The sharing of soil data was seen as being able to save a significant amount of money for both government and industry.

Whilst concerns were raised with regards to soil data quality collected from different sources, some interviewees suggested that it is better to be 'roughly right' rather than 'precisely wrong.'

Soil data and landscape information can be accessed in Queensland via Queensland Globe and in NSW via eSpade. Both positive and negative comments were received about both systems and the usability thereof. This highlights a continued need to both improve the ease of use of such tools and provide support to assist users in how to use these tools.

4.4.3.3 Benchmarks, standards and interpretation

Several comments were received about the lack of/limited soil benchmarking data at local scales as well as for different industries/production systems. As a result of a lack of benchmarks in some circumstances (such as local government) default values for soil properties are used which could lead to poor decision making.

The lack of benchmarks for soil biology data was also identified as a concern making it difficult to make sense of the data. One interviewee suggested that the decomposing cotton material (https://cottoninfo.com.au/soilyourundies) test provides more useful information that microbiology test at a laboratory. Criticisms of soil biology testing were received which included that the laboratory analysis has no context, the datasets that are compared against don't always rely upon Australian data, results are not reproducible between laboratories, data and methods are proprietary and testing is expensive.

The complexity of interpreting soil data was also identified, which is amplified by multiple factors including different methodologies, testing protocols/methods, units and critical values. How soil data is interpreted varies significantly as well with some landholders entirely reliant upon an external source for interpretation through to those that interpret the results for themselves.

In the cotton industry, an idea was presented of using On Farm Experimentation (OFE), supported by digital technology to create local calibrations for each paddock to help improve soil health monitoring and decision making.

It was identified that in general; land holders have no soil data or information on their properties prior to the settlement date, meaning that land holders are effectively starting from scratch each time a new property is purchased.

4.4.3.4 Usage

The interviewees made clear that there are a large range of use cases for soil data including in some situations soil data not being used at all as it is largely irrelevant to on farm decision making (e.g. in the Rangelands where groundcover monitoring via satellite data is more important). Some estimates of soil testing were made with levels as low as 10% - 25% being suggested by different interviewees. A range of purposes for soil testing were identified including for fertiliser recommendations and problem solving (e.g. why is this area underperforming).

Some interviewees suggested that a greater use of available soil information could be made, but the benefits for doing so, particularly for development/policy etc had not been made clear enough for decision makers.

Comments were made about the lack of statewide layers for soil properties in Queensland.

Some comments were also made with regard to people not understanding how to interpret a soil map (e.g. not understanding the impact of scale and how multiple soil types may exist in within a mapped area because of local variability).

4.4.4 Research

The National Soil Survey asked a question with regards to access to soil researchers (Figure 11). Over half of farmer respondents and nearly half of advisors indicated that they didn't have sufficient access to soil researchers when needed with only 17% of farmers and 25% of advisors indicating that they had sufficient access.

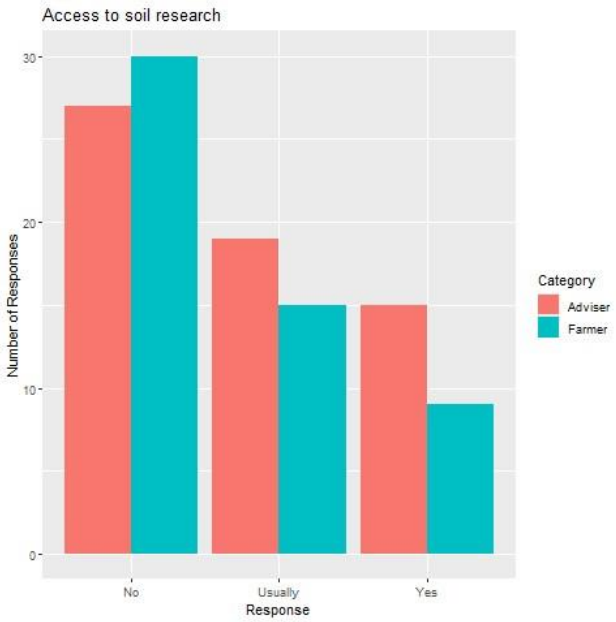


Figure 11 National Soil Survey. Question: Do you have sufficient access to people working in soil research when you require it?

Wide ranging comments and observations were made with regards to research related to soil and soil management. Comments identified issues which can be grouped into a number of categories.

- Farmer involvement
- Science lagging
- Timescale
- Organic soil management
- Identification of research gaps
- Regional focus

4.4.4.1 Farmer involvement

A number of comments were made with regards to farmer involvement in research. These included:

- Farmer input is required before research starts. **Comment**. For some industries farmer input is systematically incorporated into research priorities (e.g. GRDC) however this might not be happening in all industries.
- Some farmers are trialling farming practices including fertiliser application rates at well below industry standard, but companies/research organisations are not interested in trialling low-rate fertiliser applications. There is a view that research of this nature is stifled by financial incentives for high application rates.
- Supporting producers to conduct on farm trials/research would be useful. However, producers need assistance to design trials (including how to measure data and assess the results). The requirement for meta data to be documented was also highlighted (e.g. contextual information to help make sense of the results).

4.4.4.2 Science is lagging

Several interviewees suggested that science is lagging behind on farm practices. Comments included:

- Practices or products that are based on unproven science make it difficult for some farmers to trial a new practice or product.
- There is a lot of hype and talk about Regenerative Agriculture but there is little scientific data to demonstrate that it actually benefits soil condition in the long run.
- In the Rangelands there is a significant amount of landscape restoration/rehydration works being successfully implemented but limited data to provide scientific evidence of the efficacy of these practices.
- There are some ‘wild crazy’ claims made with regards to some products (soil biology products were highlighted) that require more information and research to assess the efficacy of these products.

4.4.4.3 Timescale

A number of comments were made with regards to the short timeframe of much research. Some interviewees highlighted the need for research programs that last for 20 or more years to fully test products, practices and programs across the full range of climatic extremes. Well documented longer-term research was identified as providing information which would improve decision making.

4.4.4.4 Organic soil management

A number of comments were made with regards to organic soil management. These included:

- There are limited public resources for research being invested into organic cropping systems (e.g. crimping, mixed farming, other options to herbicides). Whilst, as an example, GRDC claims that 90% of their research is relevant to organic producers, an organic industry representative disagreed arguing that a lot of the research is not transferrable.
- The majority of research is on conventional/chemical approaches to farming.
- There is limited research into organic amendments (composts etc). Industry representatives indicated it is very difficult to get funding for research into organic amendments as financial incentives are not present. This includes challenges with attracting post graduate students.

- There is a view that ‘natural farming’ doesn’t pay but there is a lack of research to determine whether this is the case or not.

4.4.4.5 Regional focus

Some comments were made highlighting that a lot of research isn't region specific with much of it coming from overseas and not necessarily relevant to the Australian context.

Interviewees from Rangeland grazing systems indicated that there was limited research being completed in these areas.

4.4.4.6 Research gaps

Interviewees suggested a number of research/potential research gaps were identified[3]. These include:

- The effect of chemical application upon soil biology
- There is a lot of research on adoption but little on why people abandon new/different practices.
- There is limited cost benefit analysis, particularly recently, on the direct and indirect impact of erosion versus the cost of soil conservation practices.
- Exotic legumes are prevalent in grazing systems now. There is little research into the potential long term acidifying effect of legumes in sub-tropical pasture systems.
- Concerns were identified about the lack of research into the benefits of deep placement of nutrients and nutrient stratification.
- Concerns were raised that much soil biology research occurs in the laboratory rather than in the field environment. This poses as an issue as many species of soil microbes can’t be cultured in a laboratory environment.
- The impact of soil biology upon pasture dieback hasn’t been researched.
- A cotton industry representative identified that product requirement and application was less important than on-farm logistics (e.g. operations management ensuring that farming practices can be implemented at the correct time and place to maximise productivity) however there was no appetite to investigate this from a research perspective.
- The impact and effectiveness of landscape rehydration works. Comments were noted that the limited research into the effectiveness of the programs means that there is an inadequate evidence base to create policies and initiatives that could encourage accelerated adoption of these practices.
- There is limited research on the impact of biosolids as an organic amendment.

Of note, NRM Regions Queensland (2020) has developed a Research Prospectus that identifies the management challenges and research needs for Queensland NRM groups. The areas of research interest include promoting soil health, addressing major ecosystem degradation issues, reducing regional greenhouse gas emissions and protecting soil biodiversity.

4.4.5 Education

A detailed review of soil science education in the university and vocational sectors was completed by Rogers et al. (2020). This review found major gaps in both the breadth and depth of soil science education across Australia. Whilst this review has not been updated, anecdotally it appears that the gaps may have widened with known instances in at least one SQNNSW region university where the number of mandatory soil science courses students has been reduced and another environmental degree where there is no requirement to complete a soil science course.

[3] Author’s comment. These research gaps have not been validated. In some instances it may be that research is not reaching those who would benefit from the research.

On a positive note, one university (the University of New England) has had its soil science curriculum recognised as meeting the minimum requirement for soil education when applying for both (CPSS) and Registered Soil Practitioner – Soil Management (RSP-SM) accreditations.

The National Soil Survey asked a question on the type of soil science education that respondents had completed. Results for the SQNNSW region are provided in Figure 12. The results indicate that the majority of farmers have no formal education in soil science however most advisors have some level of formal tertiary or vocational soil training.

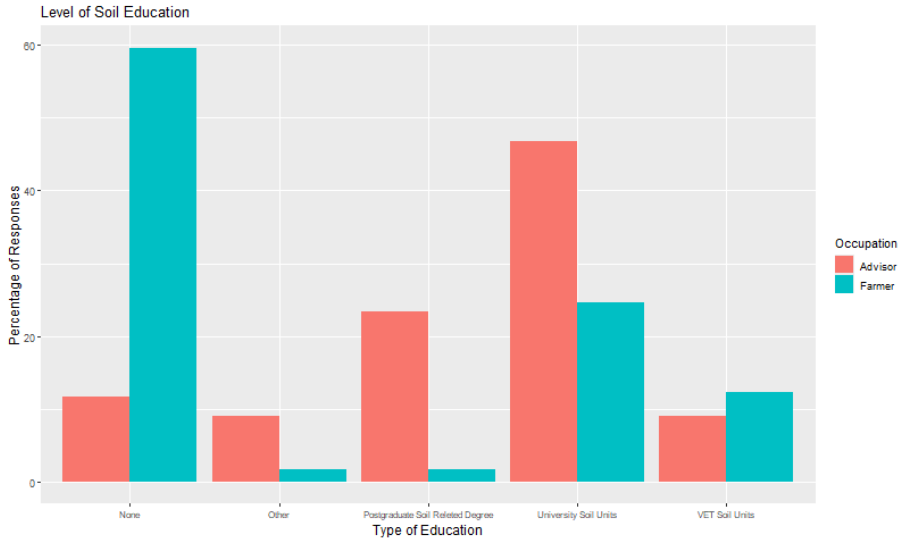


Figure 12 Soil Science Related Education

Many interviewees raised concerns about soil science education. Comments have been grouped into the following categories:

- Soil science education in schools
- Depth
- Extension
- Hands on experience

4.4.5.1 Soil science education in schools

A number of comments were made with relation to the importance of increasing the level of soil science education in schools. This was seen as important for a number of reasons including:

- broadening the number of potential candidates who may be interested in soils as a career, and
- from a community perspective, increasing the understanding of how food is produced, the importance of looking after our soil for environmental and food security perspectives as well as the role communities can play (e.g. composting of organic waste).

One interviewee mentioned the variable quality of education delivered by secondary schools with agricultural programs, noting that this was linked to the knowledge and enthusiasm of the individual teachers delivering the program.

Soil Science Australia has developed curriculum materials for soil science education in schools. It is unclear however how widely adopted or incorporated into curriculums this program has been.

4.4.5.2 Depth

Multiple comments were made with regards to the depth of education in soil science education. A summary includes:

- Several academics delivering soil science courses at different universities stated that they get a limited opportunity to cover off on the basics of soil. Of those students that study soil science, the majority will only complete one soil science unit.
- One extension officer when presenting a soil science lecture suggested that students didn't have sufficient background knowledge to be able to ask informed questions related to soil and pasture management.
- One industry interviewee described competence as like being a 'T' with a requirement for broad knowledge across a range of areas (the top of the T) but a requirement for detailed knowledge in at least one area (the stem of the T). They commented that universities currently graduate students with neither. This comment was reinforced by an academic who indicated that universities are producing graduates that are not job ready, with courses having been simplified too far.
- Some comments were received from industry interviewees with regards to the recruitment of graduates, highlighting that graduates of generic programs (e.g. environmental science) lacked a sufficient knowledge of underpinning principles related to physics and chemistry. As a result, they preferred recruiting students who had studied physics or chemistry rather than a generic course due to their increased capacity to solve real world problems.
- The lack of time in VET soil courses meant that topics were covered superficially and participants as a result did not understand underlying soil mechanisms and processes.

4.4.5.3 Hands on experience

"Participants will embark on two days of training, which for many is the first time into a soil pit"

Clark et al. (2022)

The importance of hands-on experience (described as absolutely vital) with soil and landscapes was emphasised by multiple interviewees as well as the lack of such experience currently provided in soil science education. This lack of hands-on experience is epitomised by the quote above from the handbook for the 10th Australian Soil Judging Competition.

Several interviewees raised the importance of Soil Judging Competitions (which are run annually by Soil Science Australia) with some highlighting the enormous benefit to participants' skills and knowledge over a short period of time (competitions generally last three days).

Practical examples of the impact of the lack of fieldwork were provided including of a PhD student who was unable to identify sodic soils in the field, a consequence of their research being confined to the laboratory and office.

Several interviewees commented on the importance of students being provided with work experience opportunities in a laboratory and field environment with both industry and government employers. Examples were provided of how small-scale internships, even two to four weeks in duration, could be important in encouraging students to work in soils.

4.4.5.4 Content not taught

Comments were received describing a range of important soil content that is not being taught/minimally taught/taught only in some universities. The content areas include:

- Erosion mechanisms and soil conservation. Education in erosion and sediment control was one of the competency areas evaluated by Rogers et al. (2020). Of the eight universities delivering soil science education in the SQNNSW region, 6 were assessed as delivering no education on erosion or sediment control, and the other two received a score of one and two respectively (on an eight point scale). This indicates that the overwhelming number of graduates from undergraduate programs that include soil science receive no, or at best cursory, education in erosion, soil conservation and sediment control.
- Content related to agroecology, regenerative agriculture and organic agriculture, with the focus primarily being on 'conventional' farming. One interviewee commented that this is because there is no funding/profit impetus to focus on alternative approaches to agriculture.
- Pedology, landscape geomorphology and land capability assessment.
- Extension.

One industry representative noted that no university is delivering training in the specialised work of their business and as such they are required to train their own staff.

In the VET sector, a Diploma of Organic Farming used to exist (code: AHC51816). This has been superseded by the Diploma of Agriculture (code: AHC50122) with an organic specialisation requiring the completion of four units containing from the AHCORG stream. A review of the RTO registered to deliver these courses (as of June 2023) identified that no provider is currently delivering the courses that would enable a student to be awarded a Diploma of Agriculture (Organic Production).

4.4.6 Funding

4.4.6.1 Unmet Demand

It is apparent that there is a large unmet demand for funding to support natural resource management related programs. An example is provided by the number of projects approved versus the applications for the Australian Governments National Landcare Program. A summary of applications versus projects funded under this program is provided in Table 4. Across the five grant rounds an average of 13% of the projects were funded.

Table 4 Summary of applications for Smart Farms Small Grants

Year	Program	Applications	Projects Funded	Percentage Funded
2017	Smart Farms Small Grants Round 1	800	77	10%
2019	Smart Farms Small Grants Round 2	645	110	17%
2019	Smart Farms Small Grants Round 3	659	113	17%
2020	Smart Farms Small Grants Round 4	775	84	11%
2021	Smart Farms Small Grants: Soil Extension Activities	272	32	12%

One NRM group interviewee confirmed the high demand for soil extension activities but indicated that it was not possible to meet this demand within existing budgetary arrangements.

On a positive note, one NSW grazier highlighted how grateful they were for funding they had received through various grant programs for rehabilitation/revegetation even though it only covered around a third of the cost.

4.4.6.2 Landcare and Grower Groups

Comments from Landcare and Grower groups indicate that many run on '*the smell of an oily rag*' as a result of their funding sources which is a limitation of the activities that they can deliver. Multiple Landcare coordinators reported staff working many more hours than they are financially compensated for, driven by their motivation/commitment to the purposes of these groups. The corollary to this is burnout amongst staff and as a result high turnover.

4.4.6.3 Continuation of funding

Several interviewees raised concerns over breaks in continuation between major funding rounds for NRM groups. For at least one Queensland NRM group delays in finalisation of the new round of partnerships was described as a major contributory factor to staff layoffs resulting in a significant loss of corporate memory, expertise and established relationships with landholders. An NRM interviewee highlighted that the Victorian Government has historically funded gaps between funding rounds to ensure staff remain employed but this does not happen in Queensland, noting that there is never a smooth transition between government funded programs. A major issue with the delays, normally measured in months, and subsequent staff turnover is a reduction in trust with landholders and a reduction in capacity of NRM groups.

An experienced Landcare coordinator highlighted how dependent these groups are upon external, normally government funding. Once this funding ceases the interest in and support to the groups also drops off.

4.4.6.4 Competition and cooperation

Several interviewees highlighted how competitive the environment for funding is. The competitive bidding for projects results in significant time investment into grant applications as groups are competing amongst one another for access to limited funds.

It was identified that groups that used to be funded through separate funding mechanisms are now competing against one another. An example is programs from the Natural Heritage Trust where applicants include NRM groups, not for profit groups, state governments, universities and private businesses. One result of this is that it can create confusion between the roles of different organisations.

One horticultural industry interviewee highlighted that it would be useful to have a cooperative cross commodity investment in soil within the horticultural industry, but this would be difficult because of the funding structure along individual commodity lines.

4.4.7 Systems - Assessment

The Gap Analysis has identified several issues and gaps related to the systems used to support soil management.

A requirement was identified to enhance efforts related to raising awareness of the importance of improving soil condition and landscape function. This requirement covers several audiences, including landholders/primary producers who manage soil, and just as importantly the broader community.

Whilst improving soil condition is a primary focus for many landholders, this is not always the case, as can be attested to from visits to areas across the SQNNSW region. A huge variety of pressures and requirements are placed upon landholders, of which soil management is just one. Continued awareness

raising is critical to create an atmosphere where maintaining and/or improving soil condition is considered a core part of agricultural enterprises, rather than something to be managed reactively when issues arise.

Within the broader community advocating for soils will be critical for raising awareness of the importance of improved soil and landscape management for the community at large, as well as building the support required to ensure the necessary resources and priorities are available to achieve better outcomes. Given the huge range of competing interests for public attention and resources, awareness raising will require dedicated efforts throughout the timeframe of the NSS (and beyond). A key part of this could be increasing education on soil (and food and agriculture more generally) for all school students early on and throughout their schooling career.

Unfortunately, the degradation of Australian soils and landscapes means that much of the public discussion related to environmental matters, including soils, is negative. Efforts to increase awareness must sell a message of hope, an indicator perhaps of why the *Rehydrating Thirsty Land – Regenerative Rangelands* (Landcare Australia, 2023) has been so successful. Organisations such as *Soils For Life* (and many others), through their case studies also provide stories of hope and inspiration.

Expanding such examples can have multiple benefits amongst different target audiences (e.g. landholders, policy makers, potential employees in agriculture/soil science, and the general public) and is likely a prerequisite for accelerated practice change, particularly when linked with scientific data (to provide evidence that practices work) and economic data (to provide evidence that practices are financially viable). From the primary industry perspective, such stories are also likely to become increasingly important for agricultures social licence to operate and Environmental, Social and Governance (ESG) objectives/requirements.

Whilst there is already a huge amount of soil information and data available, it is also clear that there are instances of too much information, which can lead to information overload/decision paralysis, and areas where data availability is insufficient to meet the needs of end users. This indicates two key requirements. The first is increasing efforts to collect, analyse and promulgate soil data in forms that are usable and meet the needs of end users. The second is the importance of people (particularly soil/agricultural/environmental scientists and soil extension staff) who can find, access, synthesise, analyse, interpret and translate soil information and data for landholders, primary producers and other users of soil information and data. Without the availability of this expertise, the capacity for users to use soil information/data to improve their management practices will be suboptimal and a barrier to adoption of improved soil management practices.

Research will continue to be important in improving our soil knowledge and addressing the many and varied practical soil management problems that can vary by soil type, landscape, climatic zone and production system. A number of potential research gaps have been identified, including organic soil management and landscape rehydration in Rangeland environments.

Importantly, as was identified in by Department of Agriculture Forestry and Fisheries (2014) and during interviews, greater emphasis is required on the extension component of RD&E to ensure that research is trialled, refined and adopted to a greater extent to facilitate accelerated practice change.

Several interviewees identified the need for greater farmer input into research. A common refrain from primary producers is that a particular practice/product/system won't work in their environment/farming system. It is unlikely that this perspective will change (not least because there is a grain of truth to it). Therefore, if the requirement for accelerated practice change identified in Priority Action Four of the NSAP is to be successfully met, it is imperative that research be implemented in a distributed fashion on working farms. Considering that each year there are thousands of 'natural experiments' being conducted on farms across the SQNNSW region trialling different practices and products, there is an enormous potential to

support accelerated practice change through more rigorous and widely applied on farm experimentation (OFE). OFE has the potential to help transform agriculture globally (Lacoste et al., 2022). The primary missing link to enable the upscaling of OFE are the soil scientists and soil extension officers who can support primary producers across the region in experimental design, to support data collection (increasingly viable with current and evolving digital technologies) and the interpretation of results.

A number of significant gaps related to soil education were identified. It appears that soil science education in the SQNNSW region may have regressed since the last systematic review of soil science education (Rogers et al., 2020). Soil science education that is both deeper than currently delivered, and delivered to more people, including land managers, is clearly a pre-requisite for improved soil management.

It would appear that the current model of soil science education will be incapable of meeting either the current or future needs of primary producers and the soil workforce without systemic change. Proposals for alternative approaches are not provided in this Report but should be considered as part of the soil workforce development plan discussed elsewhere (see Section 1.2.6).

The final gap in this section relates to funding. The outcome of current levels of funding and prioritisation for improved soil management is likely to result in incremental changes over prolonged periods of time. Whilst it was beyond the scope of the Gap Analysis to determine funding requirements, the recently released *Blueprint to Repair Australia's Landscapes* (Wentworth Group of Concerned Scientists, 2024) provides a costed model to "*restore the productive base of our challenged and vulnerable soils*".

The cost in 2022 dollars is estimated at **$578 million per annum** across Australia.

Current levels of investment in soil are clearly well below the level required to restore the SQNNSW region and Australia's soil, supporting a conclusion that Australia's soils will continue to degrade over time leading to many of the productivity, environmental, economic and social impacts that the NSS is aiming to prevent.

There is clearly a well justified case to significantly increase the investment into restoring the SQNNSW regions and Australia's soils.

4.5 Skills

The Gap Analysis has identified gaps, issues and concerns related to skills across the following areas:

- General soil and land management knowledge
- Soil sampling and interpreting soil test data
- Organic/regenerative practices
- Soil conservation and erosion
- Extension.

4.5.1 General soil and land management knowledge

A lack of general soil and landscape knowledge was identified by many respondents as a gap. This included landholders as well as those who support landholders.

4.5.1.1 Landholders

Specific concerns related to landholders' level of soil knowledge included:

- A lack of understanding of the importance of grazing management amongst some landholders, particularly with regards to maintaining ground cover.

- Not all landholders understand the importance of using land in accordance with its capabilities with inappropriate enterprises for land capability leading to land and soil degradation.
- Whilst it noted that many landholders have a good practical level knowledge of soil (e.g. understanding the moisture content at which tillage operations are suitable and broad nutrient requirements) they generally have a low level of technical knowledge of soil. The importance of soil structure and soil biology is generally low.
- Some landholders are interested in establishing soil monitoring plans but lack the knowledge and confidence to do so. The study by De Bruyn and Abbey (2003) indicate that this is a long standing problem.
- In many areas, particularly close to metropolitan or major regional centres, there are large numbers of new landholders who have no land management knowledge or experience. This is a continual problem due to the regular turnover of properties (for example in the northern rivers of NSW it was reported that the average length of land tenancy is seven years).

4.5.1.2 Soil Practitioners

Specific concerns related to practitioners included:

- Not all practitioners have a sound general knowledge of the agricultural production systems that they work with,
- A lack of technical training being provided for NRM group staff related to landscape analysis, land capability assessment and general soil knowledge. One interviewee raised that often soil practitioners try to address a soil issue on site without an understanding of the landscape level processes that have caused the issue.
- Acknowledgement that soils are so complex that an individual cannot be an expert in all facets of soil and land management.
- Technical skills are critically important for many projects, such as soil conservation. Some practitioners lack the requisite skills and knowledge which can lead to ineffective or failed projects.
- Concerns that many project officers within NRM groups (a problem linked to limited tenure and high turnover) lack knowledge and skills that is useful to landholders.
- Concerns that staff in local councils have limited knowledge of soil which can lead to problems in developments, maintenance of Council infrastructure etc.

4.5.2 Soil sampling and interpretation of soil test results

Many interviewees raised concerns with the regards to the knowledge required to interpret soil test results, both for landholders and practitioners. Comments included:

- Some comments were made that there is no point in getting soil tests if landholders lack the skills and knowledge to interpret the result.
- A proportion of soil samplers do not use appropriate soil sampling techniques to ensure representative samples are collected at known depths (e.g. insufficient cores collected, use of shovels or other imprecise tools to collect samples to a known depth, collecting composite samples across different soil types).
- A general lack of people capable of interpreting soil test results. One interviewee commented that you need to learn to interpret the results yourself rather than relying upon an external party.
- Difficulty in translating nutrient requirements as identified in the soil test to a fertiliser program, resulting in the application of the incorrect/inappropriate nutrients.

- Comments were made with regards to landholders completing soil tests (particularly soil biological tests) which did not/could not result in a recommendation to solve the problem.
- One agronomist noted that '*you can explain the numbers, but [some landholders] just don't understand the numbers and probably never will. They don't retain it – because it is so complicated.*'
- Some interviewees raised concerns about the difficulties of integrating fertiliser and amendment requirements to generate economically viable recommendations.

These factors might explain why the level of participation in soil testing has nationally, remained at around 25%-30% for several decades (Lobry de Bruyn and Andrews, 2016).

4.5.3 Organic/regenerative practices

A number of comments were received with regards to organic/regenerative practices. These included:

- A lack of skills and knowledge with regards to brewing on-farm bio-fertilisers, some of which is linked to Intellectual Property rights.
- A lack of knowledge amongst soil practitioners for integrating organic amendments (e.g. composts) into an agronomic program and being able to compare the agronomic value of organic versus synthetic inputs.
- A lack of understanding of application methods for organic amendments (e.g. the advantages and disadvantages of surface applying versus incorporating composts).
- A lack of training in composting, vermicomposting and similar skills. Many of these skills are developed through trial and error and other resources (e.g. books, online forums).

4.5.4 Soil conservation and erosion

Multiple interviewees commented on skills and knowledge deficiencies with regards to soil conservation and erosion control: These include:

- Linked to a lack of training and education, landholders lack the confidence to implement soil conservation works or provide guidance to contractors. Some interviewees noted that a lack of knowledge in implementing soil conservation works can make erosion worse.
- An example was cited where the NSW Soil Conservation Service, which largely focuses on coastal and urban projects, no longer provides training for broadacre agriculture.
- In some areas, particularly where locals have experience working in the mines, there are a relatively large number of people competent in operating earth moving equipment. However, several interviewees noted that techniques for soil conservation are different to those used in a civil/mining/environmental engineering context.
- A lack of knowledge by some landholders of the importance of ground cover, trees and buffer zones for minimising streambank erosion. This also extends to land that is not managed effectively, leading to poor fertility and an associated increase in erosion risk.
- A lack of knowledge amongst many staff in NRM groups in being able to provide advice, other than general advice, on soil conservation.
- Specific technical knowledge of soil conservation techniques. Some interviewees provided examples of landholders who had attempted to implement soil conservation measures which had failed badly and actually worsened the situation. An example being fencing placed too close to the edge of a gully, which resulted in cattle moving along the edge of the gully exacerbating the problem. These and other examples highlight that specific technical knowledge and expertise is required to plan and

implement soil conservation measures whether that relates to earthworks, fencing or positioning of infrastructure.
- Some interviewees noted that when landholders were provided with the initial training and mentoring support to implement soil conservation/landscape rehydration works, they could rapidly develop the experience to implement further works on their own.

With the large reduction in individuals trained in soil conservation, one interviewee recommended that a skills analysis be conducted between the skills and knowledge of pedologists and agricultural engineers. A cursory assessment suggesting that between these two professions the skills required of a soil conservation officer could be covered.

4.5.5 Extension

Deficiencies in education in extension have been identified by both interviewees as well as a brief review of extension related education delivery.

The major themes identified from the interviews included:

- Recognition that extension is a skill, just as research is a skill. To be effective it requires an understanding of how a farmer can adopt a practice, not just the practice itself as well as an understanding of farming systems.
- The requirement to understand the environment, agriculture and Natural Resource Management from a systems perspective. Some interviewees identified that this complex system has been oversimplified in university education and with it the understanding that agriculture is part of a system that involves people, politics, markets as well as the environment.
- A significant drop off over time in the extent of extension related education, training and experience being provided to undergraduate students. For example, at least one university previously required students studying rural studies/agriculture to plan, organise and deliver field days/extension activities for local farmers however this is no longer the case.
- The importance of both technical and extension skills. Multiple interviewees identified extension as a specific skillset. The impact of deficiencies in this skillset were identified such as extension material being pitched at too high a level for primary producers (and hence being ineffective), and concerns over well credentialled scientists/academics lacking (in some instances) the communication skills to be able to communicate effectively and engage with landholders. These and other examples highlight that extension is a specific skillset that does not come naturally to everyone.
- A lack of theoretically informed extension activities and programs, with extension resorting to ‘gut feel.’

While one interviewee indicated that there are many opportunities for the training for extension officers, there does not appear to be a systematic approach to training and developing undergraduates involved in extension.

In 2018, the Australasia Pacific Extension Network (APEN) developed a document (https://www.apen.org.au/prof-development/educational-pathway) detailing courses delivering extension training at both Undergraduate and Postgraduate level. Of the 11 extension or extension related undergraduate courses identified as being delivered by universities in NSW and Queensland, an initial review identifies only four courses now being delivered. The implication being that graduates of environmental or agricultural undergraduate programs in both NSW and Queensland will either have no, or only a cursory, background in extension.

Some industries have implemented programs to address (at least partially) this deficiency. An example being Cotton Info which has adopted the Extension Model of Practice (Figure 13) developed by Williams et al. (2021a).

Figure 13 An Extension Model of Practice. Source: Williams et al. (2021a)

Overall, however the system of training and education in extension appears ad hoc. It is assessed that the expertise in extension is surviving on the experience of earlier generations who participated in structured education programs that previously existed (such as that provided by the University of Queensland and former Queensland Department of Primary Industries Rural Extension Centre at Gatton (University of Queensland, 1998). The findings from this Gap Analysis align with similar recent studies (see for example Coutts et al. (2017) related to extension programs in the Great Barrier Reef catchment).

4.5.6 Other

Comments were received on a number of other skill related concerns. These include:

- A shortage of people with biometrics (agricultural statistics) skills leading to experimental designs that may not be statistically valid.
- Acid sulphate soil (ASS) training. Whilst the capacity to provide ASS training remains (at least in the Queensland Government), the turnover of council staff means that maintaining this skillset within a council (who use this training to assess development applications) is difficult.
- Several comments were received about limited landholder capacity to set up, measure and analyse on farm trials of different practices/products to help determine their efficacy. As a result, landholders often revert to a gut feel when making a determination about the success or otherwise of a practice/product.

4.5.7 Skills – Assessment

Priority Action 4 of the NSAP articulates the need to both maintain and build soil expertise and capability across the spectrum of services engaged in soil health, echoing the assessment of National Soil Research, Development and Extension Strategy (Department of Agriculture Forestry and Fisheries, 2014). Education and a lack of farmer knowledge have been identified as a barrier to adoption of climate smart agricultural

practices (Campuzano et al., 2023). It is well recognised that skills and expertise are critical to improving soil management.

Both the results from the National Soil Survey and interviews as well as other literature point to major deficiencies in skills and knowledge related to soil and, importantly, extension. For example as far back as 2014 it was noted that the "*loss of skills and capacity from government agencies has not been completely replaced nor has it been expanded by agribusiness and grower organisations, resulting in loss of some skills and activities, as well as independence*" (Department of Agriculture Forestry and Fisheries, 2014). This assessment was reinforced by many of the comments received during the interviews. Unfortunately, this is suggestive that on the whole soil skills and knowledge maybe regressing rather than improving.

An example is provided by a skills audit completed for NRM Regions Queensland (Ernst and Young, 2021) which identified that soil expertise is something that NRM groups tend to outsource due to their limited internal capacity. The trend of outsourcing soil expertise appears widespread for NRM and similar groups. With State governments largely withdrawn from soil extension, observations by the RSC suggest that this outsourcing is provided by a very small group of individuals and businesses, resulting in a diminishing pool of expertise and a lack of/limited capacity to provide support to landholders outside of specific projects. To address this declining capacity may require either the restructuring of the NRM model to ensure that they have adequate soil expertise as a core skill, or another mechanism to generate a broader range of/access to soil expertise.

The National Soil Survey results, supported by the interviews and anecdotal observations from RSC engagement in soil extension activities, are indicative that the general level of soil knowledge and expertise amongst landholders has significant room for improvement (there are also of course a proportion of land holders who do have significant levels of soil knowledge) with the purpose of improving decision making related to soil and land management.

It is assessed that there is an ongoing (i.e. in perpetuity) requirement to provide access to soil extension activities focusing on building the base level of landholder soil knowledge, including building the capacity to increase understanding of their own soil (i.e. through the conduct of visual soil assessments or similar monitoring tools) and understanding, if not the ability to interpret, information contained in soil test results. This should be viewed as the base upon which more advanced soil skills and knowledge can be developed for specific production systems or landscapes.

The interviews also indicated that there is a need to improve the base level of knowledge of those providing advice on soils. This is arguably more important than enhancing landholder knowledge given the much larger potential negative impact from an advisor providing poor advice (see Section 4.7 for more on this).

Specific knowledge deficiencies were identified in areas including organic and regenerative practices, soil conservation, and the extension related skills of soil practitioners/professionals.

Overall, there is a significant amount of work at a systemic level required to improve the general skills and knowledge of those involved in soil management. Enhancing these skills will be a critical enabler to accelerating the adoption of best practices for soil management.

4.6 Style

The information collected related to style largely revolved around extension related activities, evidence in supporting practice change, and the project model of funding.

4.6.1 National Soil Survey: Extension

The results from the National Soil Survey question focusing on access to soil extension are provided in Figure 14. Only 14% of farmer and 16% of advisor responses indicate that they have sufficient access to people working in soil extension, with 59% of farmer and 47% adviser responses indicated they don't have sufficient access.

This is suggestive of a systemic shortfall in access to soil extension practitioners.

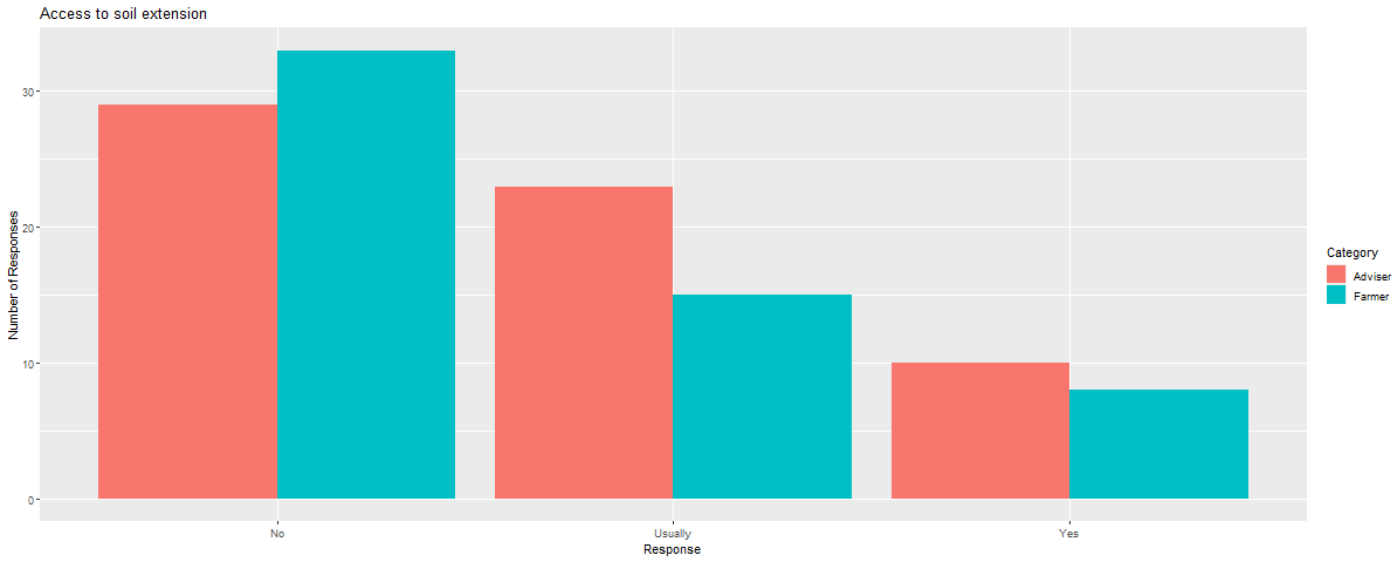


Figure 14 National Survey question: Do you have sufficient access to people working in soil extension when you require it?

4.6.2 Extension

4.6.2.1 Extension Model and Capacity

Many comments were received on current extension models and capacity:

- The current extension model is not working as it should as extension staff (typically generalists) have limited 'reach back' to soil experts to provide detailed advice on issues and questions outside of the expertise or knowledge of extension staff. Where extension staff have excellent technical skills, this is not as much of a problem but that is becoming rarer as the system that developed this expertise no longer exists.
- In many areas it was identified that unless you are willing to pay a consultant, at consultant rates, there is little soil advice or expertise available.
- An example was provided with a CSIRO Gully Erosion project in the Great Barrier Reef catchment, where farmers/graziers were required to collect soil samples. A 30% difference in results was identified between results collected by soil samplers and graziers. The difference being assessed because of graziers not being trained/knowledgeable in the techniques of collecting soil samples.
- Some comments indicated that there is a misunderstanding of what extension is, indicating that some people see extension as being primarily communication.

A number of comments were made with regards to the nature of extension activities.

- Events and activities should not be complex. Need to explain to landholders how the topic of interest works in general, and then how it can work for the landholder specifically.

- The size of the group influences the discussion and questions that are asked. The smaller the group the better the engagement and the more likely that root causes of issues relating to adoption of a particular issue can be identified and addressed. One experienced extension practitioner commentator provided recommendations on group sizes for extension events, namely a maximum of 6-8 people for intensive systems and 1-2 for extensive systems. Whilst this may seem inefficient from a funding bodies perspective, it is more effective. The same commentator noted that one farmer implementing a practice change is more important than 10 extension events resulting in no practice changes.
- Landholders typically enjoy and value extension activities such as field days and visits to other farms (as the results from the National Soil Survey question on this topic reinforces).

Many comments related to extension models/delivery of extension. These included:

- Some industries (e.g. dairy) have moved/are moving back from group extension models to one-on-one extension models. One on one extension is assessed as being more effective in achieving practice change. This is in part recognition that each farming business is unique, operating under different contexts and constraints, that render group-based extension much less effective.
- Public and/or public-industry extension was seen as being a better model as they are not trying to sell products. Whilst the trend is towards private sector extension, some interviewees raised concerns about the influence of profit motives.
- The latest scientific research not reaching the level of the farm.
- Whether primary producers are willing to pay for expertise and advice. Whilst it is clear that some landholders value external advice AND are willing/able to pay for advice, there are also a sizeable proportion who cannot or will not (an agronomist provided an example where a potential client was only willing to pay them '*petrol money*'). This indicates an ongoing market for public sector extension.
- There is a trend towards online extension tools (e.g. fact sheets, YouTube video's etc) as it is perceived as cheaper, although it is assessed as less effective than human centred extension models. Some interviewees suggested that communications has become synonymous with extension, rather than being a subset of an extension program.
- extensionAUS (https://extensionaus.com.au/) was provided as an example of an online extension platform with limited success.
- There is a requirement for a balance between group, peer to peer and individual extension.
- The quality of extension activities can vary considerably. This highlights the importance of communications skills as a crucial skillset of an extension practitioner, rather than just subject matter expertise on a topic.
- The limitation of workshops as extension activities was identified. When it comes to practice change "*There are always sticking points*" which generally need individual advice/mentoring to overcome. This advice maybe required for several years post adoption, which can be an issue where projects are only funded for short periods of time potentially leading to new practices being abandoned.
- Consistency in extension support was identified as being extremely important for its effectiveness. Fly in/fly out extension models are unlikely to be as effective (however are common in government funded extension related projects).
- Because the RD&E ecosystem has become increasingly fragmented, extension practitioners now often lack a systematic 'reach back' capacity to experts/researchers etc which undermines their effectiveness.

- Recognition that consultants speak directly with large numbers of growers regularly. Researchers speak with smaller numbers of growers irregularly. If consultants can be equipped with the knowledge to become a spokesperson for soils this could improve adoption.

4.6.2.2 Extension Requirement

Comments related to the requirement for extension included:

- Regular turnover of land holding in certain parts of the region, such as the North Coast of NSW with an average of 7 years, results in a loss of knowledge, for example how to manage Acid Sulphate Soil. On small land holdings there is often an unwillingness to pay for advice. This implies a continued requirement for extension support for new landholders.
- Short term contracts (sometimes as short as one year) are not viable for extension roles. Longer term employment is essential for a range of reasons include recruitment and retention, relationship building and the effectiveness of extension programs.
- Landholders value from field days and workshops, however struggle with implementation on farm. This is a missing link in extension. Extension projects tend to focus on either on ground works or capacity building yet the important third leg, mentoring is largely missing. This was argued as the most important part of the change process.
- Independent (from a reseller) support to landholders was identified as important to actually identify the soil issues that they are facing. One-on-one extension is important to facilitate change, understanding the unique circumstances of each business and landscape.
- It was identified that many primary producers are not familiar with what a scientific comparison would be. They need support to be able to conduct on farm trials that can result in meaningful information.
- Many landholders are provided with too much information, particularly initially, which can be overwhelming. One experienced extension officer indicated that it is best to start off with just three of the most important parameters, Soil Organic Carbon, pH and Cation Exchange Capacity. From these parameters a story can be told about the soil and landscape. As knowledge grows then other factors can be incorporated to build knowledge.
- One interview suggested the need for a 1800 SOIL help desk to help landholders talk through issues, whilst also emphasising the requirement for regionally based soil expertise. The great diversity in landholders was identified, from those who just want a ‘recipe’ to fix problems to those who want to understand everything related to soil.
- Landholders generally don’t have the time or mental capacity to sift through references. They prefer to talk with someone particularly with expertise. Often this expertise is no longer available or must be paid for.
- One experienced extension practitioner noted that depending upon practices, extension efforts may only be required for a period, whilst in others it is an ongoing requirement. The example of minimum tillage was identified as to where the extension need is no longer required, whereas soil conservation is something that requires continual support.
- Multiple interviewees identified the importance, and greater effectiveness of one-on-one extension. Others commented on the ineffectiveness of piecemeal, reactive extension programs. One experienced extension practitioner described many extension programs as delivering ‘*random acts of extension*’ which reinforces the fundamental importance of the long-term extension programs if practices are to be changed.
- Several interviewees noted that there is too much emphasis on Research and Development, not enough on Extension, noting that without extension and adoption what is the point of the research. It was also noted that not all researchers are effective at extension. The skillsets are different.

4.6.3 Evidence, Efficacy and Return on Investment

Numerous comments were received highlighting the requirements for evidence to be provided that demonstrates the efficacy of new/different products and/or practices. Comments also highlight the importance of being able to demonstrate what the return on investment is for new practices/products.

A summary and examples include:

- Criticisms of some Landcare and NRM projects which are not scientifically robust. This echoes the findings of Pannell and Roberts (2010) with regards to the scientific basis of programs/projects implemented as part of the National Action Plan Water Quality and Salinity.
- There is a huge and growing range of products available, but it is difficult to determine which products are effective. One grazier indicated that he could order anywhere up to 50 different foliar sprays at $4,000 to $6,000 a container, making it very difficult to determine which product to purchase.
- Several comments were made with regards to the importance of case studies, particularly those that include an economic return on investment. One annual horticultural grower indicated that it costs $5,000 to grow a cover crop. Therefore, that cover crop should provide a benefit of greater than $5,000, which is very difficult to measure. Others made comments on the importance of benchmarking for different production systems to enable business decisions to be made. Case studies and benchmarks were seen as important for managing risk.
- Several comments were made with regards to 'snake oil' salespeople selling products where the efficacy is uncertain. Evidence is required to determine what products are effective and under what conditions. A soil scientist highlighted the importance of understanding the modes of actions of products which in some cases is unclear.
- Determining whether there is a need for a product/type of product was also identified. In some instances, particularly in more productive soils, it was suggested that the same yield would be achieved without some of the products that had been applied.
- Many comments highlighted the requirement for on farm trials/demonstration (OFE) to provide the evidence base for whether a product or practice should is effective. One retired soil scientist indicated the importance of trials on actuals farms (as opposed to research stations) as they better resembled real world conditions.
- Localised demonstrations were also identified as a requirement to overcome landholder perceptions that it 'won't work here.'
- One interviewee noted the importance of having reasonable expectations as to what a product/practice could achieve. It was noted by several people that there are no 'silver bullet' solutions to soil problems.
- The efficacy of soil carbon Emission Reduction Fund projects was noted as a concern by a number of interviewees.
- Some interviewees noted that the return on investment for soil testing was unclear for some producers, who would not baulk at paying large figures for fertilisers and ameliorants but would not spend a much smaller amount on soil sampling and analysis.
- The limits on the number of people available to support producers to design, monitor, assess and report upon on farm trials/demonstrations was identified as a barrier to expand these.

Several comments were made specifically about landscape rehydration works. One grazier indicated that they "*couldn't graze this country without it*." One practitioner indicated that some land holders believed that these works when conducted upstream would 'steal our water' but now after seeing the impacts are some of the biggest advocates for these works. Some people see these works as damming water/preventing flows

as opposed to restoring landscape function. There is however little ongoing research and data collection to provide a data-based assessment of such works.

4.6.4 Projects

A number of comments were made with the current project style of funding, ‘projectisation’ as one interviewee described it. A summary of the comments include:

- The need to move from project-based funding for research and extension activity and move to recurrent funding embedded for organisations. The project-based funding is viewed as inefficient/ineffective with multiple negative impacts including knowledge and expertise loss, poor career path outcomes and competition for diminishing resources.
- Programs are viewed as having to be much longer in duration. Five or ten years was described as a minimum.
- There is a requirement for legacy monitoring. Very few projects have monitoring after project completion which means that the effectiveness of practices or changes is unknown over the longer term. One interviewee described the approach as being a ‘quick hit’ before moving onto the next innovation.

4.6.5 Style – Assessment

Several concerning trends were identified with regards to the style of activities being delivered with the aim of achieving practice change. Systemic issues that suggest that the current style is inefficient and not particularly effective over the longer term. The first observation, based both on the survey results and comments, is that whilst there are many extension related activities occurring they are either insufficient compared to demand and/or ineffective in achieving practice change.

There are numerous symptoms that have been identified leading to this conclusion, including the ‘projectisation’ of extension and research activities in lieu of long-term core funded support, the lack of monitoring after a project is complete to determine the efficacy of a practice and that some programs lack scientific robustness.

An example of the lack of monitoring is landscape rehydration works. Whilst there are plenty of examples of on-ground works having significant impacts, there appears to be very little scientific literature published. For example a Google Scholar search of ‘landscape rehydration Queensland’ and ‘landscape rehydration New South Wales’ found only one reference (a Masters thesis – see Duff (2023)) that could be considered relevant to the SQNNSW region (several references were identified for the Mulloon Catchment in southern NSW).

Numerous, mostly negative impacts are likely as a result of a lack of monitoring including an inadequate evidence base to demonstrate the effectiveness of practices, potential risks or unintended consequences not being identified (e.g. salinity), the return on investment of practices is unknown, and the ability to upscaling adoption of practices (where this would be beneficial) is hindered.

The importance of locally based data driven (including both production and economic data) case studies was highlighted as being very important to encourage practice change. As was the centrality of skilled extension practitioners to support primary producers in supporting the adoption of new practices.

4.7 Staff

4.7.1 Availability

"Agriculture needs to become an employer of choice, or it will be without a workforce"

Pratley et al. (2022)

Numerous comments were received with regards to difficulties in finding suitable staff. Difficulties in finding suitable staff:

- Are present throughout the region although it is more of an issue in some areas than others.
- Is an issue across many industries/sub-industries and trades/professions from highly qualified technical staff to labourers.
- Includes finding people with sufficient skills and experience. For some businesses requiring high end technical skills, finding suitable candidates internationally is also a challenge.
- Offering wages required to be competitive in attracting employees is problematic.

These findings are not surprising and align with other reporting/commentary such as:

- Pratley et al. (2022) who identified that across the broader agricultural industry that workforce is scarce both on-farm and off-farm with graduates from university and VET programs being well short of requirements.
- Barr and Kancans (2020) which identified ongoing declines in the agricultural workforce and the rising median age of owner-operators of farm businesses.

4.7.2 Soil Career path

Several comments were made with regards to there not being a clear career path for employment in soil/soil related fields. Several interviewees identified that they 'fell' into a career in soils, that there is no clear/dedicated path to becoming a soil scientist/soil practitioner. The same issue was identified for extension.

These comments align with the findings of Rogers et al. (2020) which highlights that university soils education as currently structured/delivered does not actively support the attraction of students to soil science.

One example of an ad hoc initiative to address this is the TERN Australia's Career Grounded in Soils booklet (see: https://www.tern.org.au/educational-resources/).

4.7.3 Continuity

Several comments were made concerning a lack of continuity in employment resulting from short term project funding (see para 4.4.6.3 for more on this). From an employment perspective one of the negative impacts is that employees are seeking alternate employment well before the end of their current contract. A lack of core ongoing funding from government was identified as a root cause.

4.7.4 Government, NRM and industry staffing

Numerous comments were received from interviewees across the region with regards to state government and NRM staffing. A summary includes:

- Some NRM groups contain essentially no soil extension/agronomic capacity, obtaining this expertise externally via project funding. As a result, these NRM groups have little inherent capacity to provide assistance/support to landholders outside of specific project activities. Outsourcing of expertise was not seen as a sustainable model as much of the expertise is at or past retirement age.
- There has been a vast reduction in state government soil/soil extension/soil conservation staff over recent decades. In some instances, private industry has filled this gap but not in all. This finding is reinforced by Department of Agriculture Forestry and Fisheries (2014) and Wentworth Group of Concerned Scientists (2024).
- Outside of major regional centres, localised experience has declined. A result of government offices/staff being centralised with soil expertise tending to be now located in the larger regional centres. The fly-in fly-out/drive-in drive-out model was identified as not enabling the development of local expertise whilst only providing sporadic servicing of more remote regions.
- Retention of staff within NRM groups was identified as a concern (anecdotally several interviewees suggested that the average length of employment in NRM groups was around two years but no data to confirm this has been identified). A junior NRM officer indicated that working in NRM was a sink or swim environment with little support provided, largely because the organisation was too busy to provide effective mentoring and development. Others commented that new employees often had very low knowledge levels which created professional difficulties.
- The requirement for mentoring in the workplace was identified by multiple interviewees. Where effective mentoring was provided, the positive effect on retention and staff satisfaction was noted.
- The number one training mechanism for the soil workforce was identified as employment. University graduates are taught the basics and how to learn. This provides important grounding however most training is actually provided in employment in the workplace. The reduction in state government soil science and extension positions is thus seen as a major cause of the loss of soil science expertise.

Some comments were received from industry groups, with similar constraints to government and NRM groups being identified. Interviewees from industry explained that their employees covered huge regions.

Difficulty of engaging workforce varied by location for some industry groups (e.g. some areas are easy to find suitable candidates, others very difficult). Those areas that are difficult to recruit too, also tend to have higher levels of staff turnover.

4.7.5 Workforce planning

Numerous comments were received that related to a lack of workforce planning for soil practitioners. These included:

- As state governments withdrew from soil extension services, linked to the creation of NRM groups, the outsourcing/privatising of soil extension relied upon the workforce that was developed by state governments over decades. That model is now broken due to the age of staff developed under this system and organisations not having a career path to build soil expertise.
- Because of the knowledge requirements of a soil practitioner, an apprenticeship model is required to build soil scientists and extension staff. There is no longer an apprentice model.
- There is a requirement to be training new staff continuously. However, changes in policy and funding have meant that training/developing new staff is on an ad hoc/periodic basis resulting in significant gaps.
- Some comments were made that employment in state government/NRM groups isn't attractive to people, with better prospects in the private sector. One interviewee indicated that NRM groups are not institutionally organised to keep and develop staff over the long term.

- Currently many people working as soil practitioners are generalists. The old model had a mix of generalists and specialists, which the generalists could reach back to when required. This is increasingly no longer the case, exacerbated by soil practitioners working across numerous organisations which reduces access (unless specific funding/agreements are in place. The model used by CottonInfo, the cotton industries extension arm, provides an example).
- Several interviewees highlighted that through attrition, suitability, changing circumstances and other causes, to ensure that a required number of soil scientists are available in 20 years' time, requires a much greater than that number to be trained and employed now. This is not happening.
- Some interviewees commented on whether industry could develop the workforce required. There was doubt as to the effectiveness of this approach due to factors such as the cost overhead to industry and high turnover rates of employees (which can be exacerbated where one business invests in an individual which makes them sought after by other businesses).

A subset of the workforce planning comments related to a lack of succession planning for the soil workforce. Comments identified that:

- much of the soil workforce is at or near retirement age,
- there has been no or limited effort to facilitate the transfer of knowledge to a younger generation (worsened by a lack of continuity of employment, particularly within NRM groups),
- much regional/industry expertise resides in a small number of people who are not being replaced when they retire.
- There is insufficient critical mass of staff to maintain skills and knowledge – a case of knowledge fragility.

4.7.6 Workload/Capacity

Numerous comments were made with regards to the workload/capacity of existing organisations/staff. These included:

- A limited capacity amongst many agribusinesses, agronomists, consultants and government staff to deliver soil extension related support (excluding the small number of businesses/individuals whose business focuses on soil extension related activities).
- In the organic industry, it was reported that some organic consultants/agronomists are at capacity and can't take on additional clients.
- Some interviewees reported instances of burnout resulting from too much work for too few people.
- Limitations on available staff require that service provision is focused on specific projects. Implying that landholders not captured by a project have limited capacity to gain support.
- There is only a tiny pool of soil experts/specialists within state government which lack the capacity to support NRM groups with soil expertise.
- Several interviewees noted that the range of knowledge required of soil practitioners/extension staff is such that they can't have a detailed knowledge in all areas.
- Some industry interviewees indicated that the workload in soils will continue to increase in the future due to factors such as the expansion in mining and infrastructure projects.

4.7.7 Expertise

Numerous comments were received related to expertise. A summary of comments is provided below under the following categories:

- Loss of expertise

- Development of expertise
- Access to expertise
- Lack of expertise
- Quality
- Regional Expertise
- Organic/Regenerative Expertise

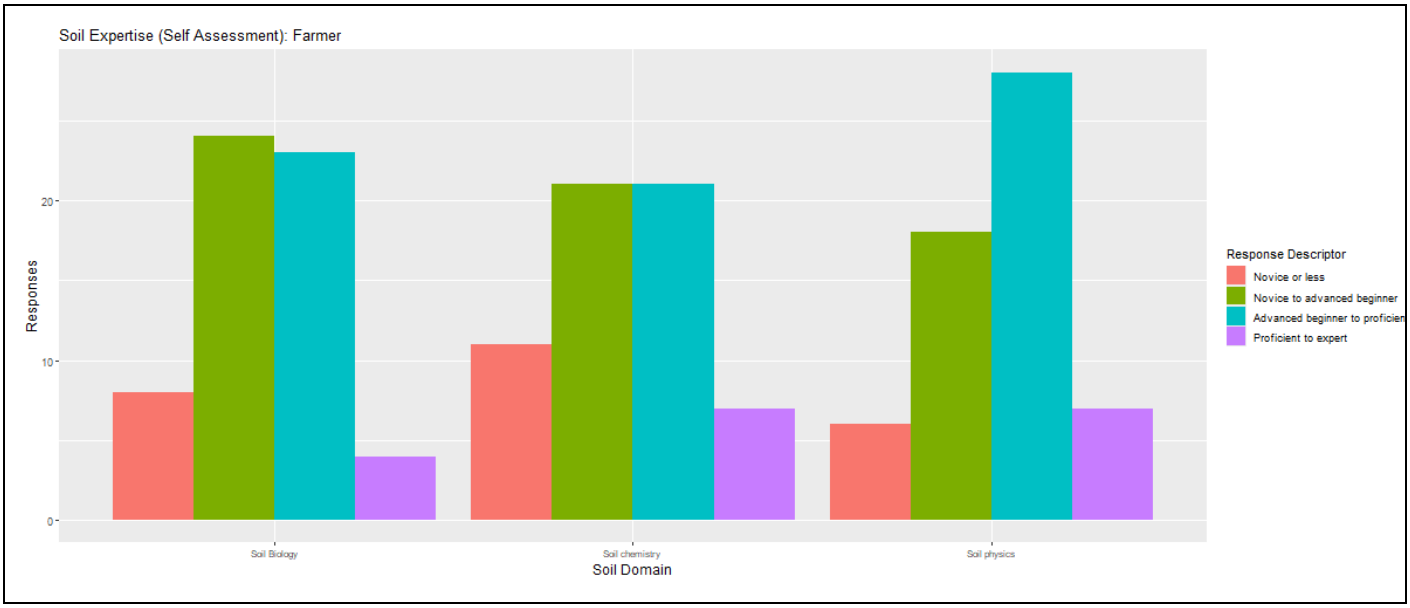
It should be noted that many of the comments raised during the interviews mirror and reinforce those raised in de Bruyn et al. (2022), a paper which identified the requirement for a critical mass of soil scientists who can support land managers through landscape appropriate soil management practices.

4.7.7.1 National Soil Survey

The National Soil Survey asked respondents to rate their level of practical knowledge across the three major soil domains. The results for farmers and advisors are provided in Figure 15.

Interestingly there was an approximately even spread by farmers who rated themselves either above or below the middle point (advanced beginner proficiency) with farmers rating themselves most strongly in soil chemistry (59% above the midpoint) and less so for soil physics and biology (just less than half above the midpoint).

Unsurprisingly, the advisors rated their practical knowledge higher than farmers across all three fields. Approximately three quarters of advisors rated their proficiency above the midpoint for soil physics and chemistry and 64% for soil biology.



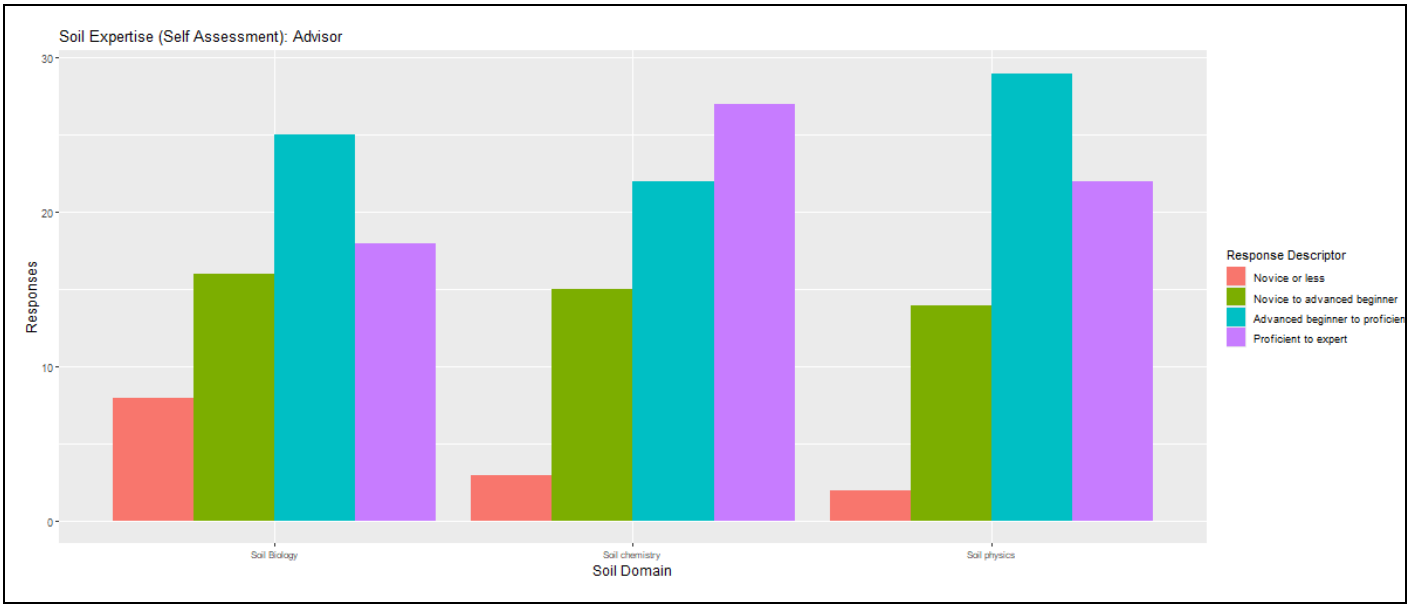


Figure 15 National Soil Survey Question: How do you rate your practical knowledge of managing soil properties? (Farmer responses top chart, advisor responses bottom chart)

4.7.7.2 Loss of expertise

A loss of soil expertise was identified as a serious concern by multiple interviewees. Comments included:

- The requirement to source soil experts from retirement to deliver a range of soil related activities, including workshops, field events and soil conservation works. One interviewee described soil science in Australia as being at a 'minute to midnight.'
- With both NSW and Queensland State Government's largely having pulled out of soil extension over the last 20 years, much of the previous expertise held within their respective agencies is now approaching, at, or past retirement age. This is a particular issue for regionally based soil scientists who had decades of local experience and in general have not been replaced. Multiple comments were made, particularly by landholders who lived through this era as to how effective the State government-based research and extension models were.
- The loss of expertise also extends to the older generation of land managers and first nations land managers as well. A presenter at a Granite Borders Landcare event highlighted the fragility of first nations knowledge transfer systems, decrying how much landscape knowledge has been lost since European settlement. A similar situation potentially awaits soil science in Australia.
- One interviewee commented that there "*are a lot of people running around, nominally extension officers – but they have no idea about extension. They haven't been taught/trained in extension*." Linking this 'massive' loss of capacity to the creation of the NRM groups and withdrawal of state governments. The same interviewee noted that an extension officer is only as good as their extension skills, access to research and access to specialists/experts. Requirements which are now significantly degraded compared to the previous system.

4.7.7.3 Development of expertise

'It will take five years until you are useful.'

Retired soil scientist

The effort required to develop expertise in soil scientists, extension officers and practitioners was clearly identified by multiple interviewees as demonstrated by the quote above provided by a very experienced soil scientist/extension officer who received these words of wisdom as a new graduate from their first manager.

A summary of comments related to the development of expertise include:

- The requirement to set up systems to accelerate the learning process of newly employed soil practitioners given the loss of expertise currently being experienced.
- The requirement for soil practitioners to be consistently working in the field to develop their base skills, an understanding of different landscapes and agricultural systems. One industry interviewee highlighted that practitioners need to have a depth of understanding across soil, water and engineering if they are to be effective in a small team. Another retired soil conservation officer identified that it is only through extensive field work, including failures, that expertise can be developed.
- The importance of mentorship in developing soil practitioners. Whilst training and education is important, the knowledge level of graduates is at a superficial level. Several interviewees identified that given the complexities of soils and landscapes, developing soil practitioners requires a mentorship/apprenticeship model over time. Several interviewees highlighted how vital the mentorship they received was in developing their skills and knowledge. It was noted that the apprenticeship/mentorship model has largely disappeared.
- Multiple interviewees identified the importance of ongoing professional development (OPD) to both maintain, improve and expand the skillsets of soil practitioners, agronomists and NRM staff, with some noting that there is currently insufficient soil related OPD. One interviewee noted that NRM staff knowledge lagged behind leading farmers making it difficult for them to deliver effective extension programs.
- Some interviewees highlighted the importance of maintaining programs of work related to soil survey to avoid the atrophying of skills and knowledge.

4.7.7.4 Access to expertise

Numerous comments were made with regards to the access to expertise. These included:

- One soil scientist indicated that agronomists contact them for advice far more than landholders. Often, they were just after confirmation about a practice/product they planned to recommend to a client was sound. Other interviewees however commented that due to the fragmentation of responsibilities between NRM groups, government departments and universities, unless aligned to a specific project, the ‘reach back’ capacity that existed when research and extension were integrated within State Government departments has largely disappeared. Other comments indicated that the pathways for connecting soil scientists/researchers with practitioners was not systematic but rather based on personal relationships.
- The cost of using university staff for extension support was identified as being costly, with one university charging $2000/day for such services.
- In NSW, Local Land Service agronomists were identified as important for increasing the capacity of land holders to improve their understanding of soil including the interpretation of soil test results.
- One interviewee noted that ‘*keenness and enthusiasm does not replace expertise*’ linking the decline in soil health/condition to the lack of science being applied to support practice change.
- Another interviewee identified that there is a high demand for experts in a field, but that experts have limited time, meanwhile frontline staff, whom conduct most landholder engagements, are limited by knowledge.

- Local government, NRM and similar groups have a tendency to source soil expertise externally for specific projects. The impact of this is limited internal soil capacity and a relatively small pool of external providers delivering soil advice/extension. One interviewee highlighted how the reliance on external contractors is expensive.
- Multiple comments were made about the small number of independent soil practitioners/advisers and agronomists.
- Several comments identified the limited depth of soil expertise that exists in organisations. In some/many instances the loss of one person can have a major negative impact on the soil capabilities of the organisation. One industry interviewee indicated that they are recruiting internationally as they struggle to recruit suitable candidates in Australia.

4.7.7.5 Lack of expertise

A number of comments were made with regards to a lack of expertise being available.

This included acknowledgement within multiple NRM and Landcare groups that they lacked internal soil expertise/capacity. Access to expertise being achieved on a case-by-case basis through independent advisers (generally linked to funded projects meaning outside of project activities access to expertise is extremely limited in most cases).

Comments were made with regards to some agronomists, where their focus wasn't on soil, having limited capacity to interpret soil tests.

The lack of available expertise for the interpretation of soil test results was identified as a widespread problem.

Many comments were made with regards to a general lack of knowledge of 'reseller' staff with regards to soil, leading to poor advice/recommendations being provided to landholders with regards to fertilisers and amendments. One interviewee commented that this lack of knowledge lead to recommendations of products or practices that were 'trendy.'

One agronomist highlighted that there is a distinct lack of expertise about being able link the presence of plant species (whether weeds or natives) and link that to soil conditions.

4.7.7.6 Quality

"*My limitations are my client's limitations*"

Comment by an agronomist

As noted by one agronomist, limitations in their own skills and knowledge, become the limitations of their customers. A comment relevant to all soil practitioners. Multiple comments were made with regards to the quality of advice and recommendations provided by a range of soil practitioners. These include:

- Particularly for retail agronomy, concerns that recommendations were based upon factors other than the best interests of clients. This included recommending unnecessary products, higher rates than were required or products that were readily on hand, as opposed to what was required.
- Anecdotes of some advisers having standard recommendations (e.g. just add gypsum, or just add lime) where soil test results indicated that a particular product was not required. Multiple interviewees commented on the variable quality of advice received from agronomists. One interviewee commented that many agronomists have a limited understanding of soils outside of the major macronutrients (e.g. NPK) and miss the bigger picture because of a reliance on computer programs to develop recommendations.

- Some interviewees mentioned cases of advisers providing advice on soil related issues that lack the background (education, experience etc) to provide that advice.
- One industry interviewee commented on opportunistic competitors who would undercut prices but provide poor advice/recommendations to customers which could result in enormous losses (e.g. in mine site rehabilitation).
- Several comments were made with regards to soil extension/advice largely being taken over by private agronomists. With chemical product driven recommendations being where the major profit lies, this has led to a biasing of recommendations towards chemical product recommendations. One interviewee commented that to 'resellers, data makes no difference. Their metric is the need to sell.'
- Comments were made on the limited expertise within Government to convince landholders of the need to change.
- Comments were made with regards to the varied quality of advice relating to soil conservation as well as the competence of earth moving contractors. Experienced soil conservation officers highlighted that earthworks for soil conservation works are a different skillset to those required for civil works (e.g. road building).

4.7.7.7 Regional expertise

Multiple comments were made with regards to a lack of regional expertise. This is particularly the case for areas located away from major regional cities or intensive agricultural production.

Interviewees in many cases could name all of the individuals with soil expertise in a particular region, many of whom are now past retirement age and have not been replaced.

One interviewee explained how their region did not have an agronomist serving their area for around 20 years and has noticed a major improvement in local productivity since an agronomist is now serving that area.

Several comments were made about the fly in – fly out nature of the provision of soil expertise which is useful for general soil knowledge but doesn't allow for the development of detailed landscape knowledge in areas such as southwest Queensland or far west NSW. The importance of regional knowledge was also identified by a number of soil conservationist officers who highlighted that you can't apply knowledge of landscapes in one region automatically to another region.

Comments were received of the distinct lack of expertise in Rangeland soils, which form by area the largest part of the SQNNSW region.

4.7.7.8 Soil conservation

A general observation from many interviewees was the lack of expertise in soil conservation, particularly for expertise accessible by landholders.

A number of interviewees identified that there are commercial providers who can design and implement works such as major gully restoration, streambank erosion and contour banks. The use of these providers is however subject to a number of limitations. These include:

- Providers are engaged by a single landholder and work at property scale. As a result, they are not paid to, nor do they have the regulatory authority for, the coordination of water flow between properties or at sub-catchment or catchment scale.
- In some cases, much of the design work is completed by engineers to an engineering standard. Whilst this is appropriate in some instances (e.g. major gully or streambank erosion projects) it means that the design costs alone can be prohibitively expensive in an agricultural setting.

- Providers are often engaged for major/large projects. Projects of this scale generally require funding through government programs as they are cost prohibitive/not economic for land holders to fund.

For primary producers gaining access to soil conservation expertise is increasingly difficult due to the lack of individuals with the requisite skills, knowledge and experience. One NRM group indicated that after severe erosion inducing rainfall in early 2022 that they received hundreds of phone calls for support to assist in managing/repairing erosion but had no capacity to provide support other than access to resources (e.g. websites & fact sheets). Of note was that paying for soil conservation works was not the landholders concern, but rather access to advice on how to manage erosion issues. Other interviewees reported that landholders can get stuck in a loop between government agencies, NRM groups and Landcare groups (being on-referred) with none of these organisations having the capacity to help other than provide general advice or resources such as fact sheets.

The lack of active soil conservation trained personnel is having an operational impact on some government programs. An example is the Queensland Government's Grazing Resilience and Sustainable Solutions (GRASS) program which aims to improve the water quality of water entering the Great Barrier Reef lagoon. Graziers participating in this program can receive funding to implement a land management plan. Where that plan includes soil conservation works that requires sign off from an appropriately qualified individual. With only three known soil conservation officers employed in Queensland NRM groups this has been a significant constraint on the program. An alternative is to use an engineer; however, the cost of a design dramatically increases leaving no funds available to implement the works. This highlights an observation between soil conservation and engineered solutions to managing soil conservation/erosion. It was observed that soil conservation solutions need to be cost effective for implementation at farm scale whereas engineering approaches tend to be too expensive in an agricultural context.

Whilst NSW has a Soil Conservation Service, interviewees indicated that its work mostly focused on large scale projects and delivered very little in the way of extension services or support to agricultural landholders.

There are a number of former state government Soil Conservation Officers still providing soil conservation services, however most of these individuals are now either past or near retirement age. Interviews with businesses providing these services highlight the difficulty in:

- finding employees with soil conservation education and expertise (including overseas candidates),
- the length of time and investment required to train staff in house, and
- the difficulty in retaining staff once trained and experienced given their employability.

Several interviewees noted that soil conservation expertise in one landscape is not necessarily applicable in other environments. An example being the differences in landscapes, soil types and climatic regimes between the Murray – Darling Basin and the Great Barrier Reef, highlighting the importance of local/regional knowledge.

4.7.7.9 Organic/Regenerative

Several comments were received about access to expertise for organic and regenerative farming approaches, including:

- A very limited pool of expertise in 'brew it yourself' bio-fertilisers.
- The difficulty in finding agronomists who are both independent and with a regenerative focus.
- The lack of training and education in natural farming techniques.

4.7.8 Staff – Assessment

The Gap Analysis has identified a range of fundamental gaps and issues related to the provision of staff to meet current and future requirements for soil professionals.

These gaps should be considered in the broader context of current and projected population and employment trends, particularly in rural and remote regions.

Whilst the Australian population is growing and is projected to continue to do so (Australian Bureau of Statistics, 2024)), the proportion of the population living in rural areas continues to decline (from over 18% in 1960 to 13% now (World Bank Group, 2018). Most, but not all, regional urban centres are seeing population growth however this is differentiated with larger regional urban centres, urban centres close relative to the coast, and urban centres close to major capital cities experiencing the most growth (which doesn't include many of the regional urban centres in the SQNNSW region). In small regional communities, there are numerous challenges (see for example Irwin (2019)) suggesting that many may be below the critical mass required to rejuvenate them.

With the larger forces driving population dynamics, it is therefore not surprising that many comments were received highlighting the challenges of recruiting and retaining staff throughout the SQNNSW region, with some areas being more affected than others. These challenges were identified across the spectrum of employment from labourers/farm hands through to professionals.

Pratley et al. (2022) identified the challenges that agriculture faces with regards to securing its future workforce. Perhaps surprisingly, and against common predictions, they found that even with increased automation and technology, the demand for agricultural labour is increasing, although the nature of employment is changing (the skills required are increasing). Despite this the graduates of agricultural programs at the national level have remained steady, well below current demand and show little prospect of increasing significantly in the foreseeable future.

Whilst people do find a career path in soils, it is also evident that unlike many other professions (e.g. nursing, law or engineering) there is not a clear path to becoming a soil scientist/professional. Several interviewees identified that they fell into a career in soils by happenstance rather than a deliberate decision. Anecdotally this appears to be a common theme.

State governments were historically the training ground and major employer for soil scientists and extension officers. Since the advent of NRM groups and state governments subsequently withdrawing much of their support to extension, it is apparent as confirmed by multiple interviewees that there has been a large reduction in the number of people actively working as soil scientists/soil extension officers. Outside a small number of businesses who provide specialised soil extension services (generally on a contract basis for specific projects) there is a limited capacity for those soil scientists and soil practitioners employed in other areas to support soil extension type activities. Where that capacity does exist, it is often episodic and delivered on a 'drive-in/drive-out' basis. It is assessed that given current workloads and staffing levels, there is limited potential to increase either the quality or quantity of soil extension services through state government, NRM groups or private industry in the short to medium term without a deliberate program to build additional capacity.

It would appear that the separation of responsibilities between funding and delivery (see de Bruyn et al. (2022)) has contributed to the conclusions drawn by Hunt et al. (2011) on retention of "core agricultural extension capacity and expertise at regional levels should therefore be a strategic objective for rural community stakeholders, and industry and government policy makers" having been either missed or forgotten. As noted by the Wentworth Group of Concerned Scientists (2024) there is a requirement to expand and coordinated agricultural advisory, support and extension services to provide an integrated approach to knowledge adoption and support.

Much comment was made with regards to the development of soil expertise. In particular it is apparent that a trainee/mentorship approach is required to develop soil scientists/practitioners who are competent and capable of meeting the demands for soil expertise. Whilst this approach once existed, at a systemic level it has largely disappeared (with the exception of training for PhD students, however this training generally has a narrow focus and is primarily related to research).

The gap analysis has identified that at a systemic level there is no workforce planning processes in place to either identify what the workforce needs are, nor how that workforce will be developed and sustained. One cause of this is the atomised organisational structure within which soil science/soil practitioners are employed. Given the ageing of much of the soil workforce and the limited number of new soil scientists/practitioners being generated, this suggests an overall reduction in soil capability across the SQNNSW Innovation region is likely over the medium term. A reduction in capability that presents a **high risk** to the attainment of the objectives of the NSS.

As noted by Freyens (2010) when reviewing workforce planning in the Australian Public Sector, the challenges of building the required workforce should not be underestimated. It will require a significant investment of time, effort and resources over a prolonged period of time to first stabilise, and subsequently expand the capability required to improve the management of soil and landscapes in Australia.

This assessment highlights the fundamental importance of Priority Action Four of the NSAP (Identify and develop soil workforce and capabilities). Arguably this is the most important of the priority actions contained within the NSAP as without a suitable (both in quality and quantity) soil workforce it will not be possible to effectively implement the other actions.

5 Barriers to Adoption

Numerous barriers to adoption of new or different practices were described by interviewees. An overview of the barriers is provided below and have been grouped into the following categories:

- Economic
- Time and discount rates
- Equipment/technology
- Logistics
- Risk and evidence
- Administration

5.1 Economics

Factors related to economics and financial sustainability were identified by many interviewees as being barriers to the adoption of improved soil and land management practices.

5.1.1 Affordability

Numerous comments were made with regards to the affordability of different services, practices and technologies and the impact that this has on practice change/adoption. A summary of comments include:

- **Advice**. Whilst landholders seek and value advice, particularly independent advice, there is a view that many are either unwilling, or not in a financial position to be able to afford to pay for advice. This is particularly the case in smaller agricultural enterprises/landholdings where paying for advice is not economically justifiable. Larger commercial producers are more likely to have private consultants.

- **Prioritisation**. When times are financially difficulty there is a tendency to minimise expenditure on inputs that have longer term positive impacts. Examples included compost application and soil testing. One commercial composter, as an example, indicated that when '*economic hardship hits, compost is often the first thing to go*.'
- **Cost.** Many landholders are aware of practices that they should be implementing (examples included liming, gypsum, compost & fertiliser applications and maintenance of soil conservation works) for long term productivity/sustainability however lack the financial capacity to do so. Tightening profit margins are a driver of this with one advisor indicating that input costs are a major issue when commodity prices are at the cost of production.
- **Brew It Yourself Fertiliser**. Several interviewees highlighted that brewing your own fertiliser products on farm can cut costs by two orders of magnitude compared to purchased products.

5.1.2 Profitability

Profitability was a major concern of many interviewees. A summary of concerns includes:

- Transitioning away from current agricultural practices to 'regenerative' practices is not achievable/viewed as not achievable in many instances as landholders need to maximise income per hectare to meet debt obligations. This precludes some landholders from even considering changing their current systems.
- On corporate owned farms it is accountants that make decisions rather than farm managers indicating that maximising income is prioritised over practices that improve soil/land condition.
- The profit margins for a proportion of agricultural businesses/some industries are narrow and worsen during climatic extremes (e.g. drought) to the point that they have limited capacity to invest in improving soil condition. As one advisor put it, it is 'hard to be green when in the red.'
- Profitability is a key driver of decision making, therefore practices or changes that improve soil condition need to result in increased profitability. This is difficult for landholders whose decision-making is 'debt driven.'
- Rises in production costs are a major threat to some industries. The Queensland Fruit and Vegetable Growers 'We Give A Fork' (https://www.wegiveafork.com.au/) campaign is an example highlighting the depth of concern over input price increases and related issues.

Several farmers indicated that they knew '*where every cent was spent*' which supported good decision making. The same interviewees indicated that some of their peers had no idea as to how much their cost of production was, which made it difficult/impossible to track performance and make informed decisions.

Conversations with rural financial counsellors have indicated that their workload has increased in recent times. The rise in interest rates and fall in cattle prices has been a key driver of this in the grazing industry.

5.1.3 Land Prices

Related to affordability and profitability is the issue of land prices and in particular rising land prices. A number of interviewees were concerned by the impact of land prices and in particular the resultant debt burden.

One grazier described the current land ownership model as being flawed, forcing enterprises to get big or get out. This has negative consequences such as discouraging young people from getting into agriculture and reducing the population of rural communities.

The high cost of land was identified as driving many landholders to maximise production both in terms of area farmed (examples were provided of land being cropped right up to the edge of waterways reducing

biodiversity and increasing erosion) and the driving the need to be growing crops continually (e.g. near Bundaberg where land is $60,000/hectare land can't afford not to be farmed continuously). Interviewees indicated that some landholders are over-capitalised which can induce significant financial stress.

5.1.4 Natural Disasters

Both historically and in recent times, the SQNNSW region has suffered from numerous natural disasters. It is unlikely that this will change in the future.

A number of interviewees identified the significant setbacks that natural disasters pose for landholders, and the flow on negative consequences for soil and land management in the form of reduced capacity and the time (often measured in years) to restore the business. One grazier also noted how natural disasters tend to increase the equity of banks relative to landholders.

5.1.5 Return On Investment

Several interviewees identified that demonstrating a positive return on investment (ROI) was necessary to support practice change for improved soil management.

One interviewee noted that the ROI for practice change often doesn't exist or stack up, particularly in the short term. An example of fencing off land to protect waterways which benefits the community was cited posing the question as why should the landholder pay for this community benefit?

The requirement to demonstrate a positive ROI on technology adoption was also cited, particularly where major capital investments are required upfront. In some industries, it was reported that some growers are deliberately delaying implementing new practices/products until the prices for products reduce to a lower price point.

Several interviewees also raised that the soil testing value proposition was not clear to many landholders, explaining by example that farmers will spend many thousands on fertiliser but not $200 for a soil test which could save them large sums.

From an erosion perspective, the positive ROI of proactive management for soil conservation which has been known since the extensive research conducted in the late 20th century has been forgotten and there is now limited data to quantify the direct and indirect costs of erosion.

5.1.6 Farmer Reward

A number of interviewees raised concerns over the limited rewards that primary producers receive for implementing practices that improve either the quality of the produce they produce and/or the condition of the soil/land. Several people in the horticultural industry noted that there is no reward for increasing the quality of their products, yet it comes at the cost of additional input costs. One horticultural grower indicated that farmers "*don't get paid for quality, taste doesn't matter. The supermarkets don't care*." Others commented that the ability to measure the nutrient density in food, and the chemical compounds contained therein, would be useful as it would provide a marketing edge/reward for improved food quality.

Other farmers identified that consumers want sustainable and ethical products but are largely unwilling or incapable of paying for them, highlighting that farmers are generally not paid the true value of their products.

Several interviewees highlighted the imbalance between the prices paid to farmers versus prices charged by supermarkets, citing price differences between $10/kg and $30/kg for horticultural products and arguing that a fairer distribution of income is required, or supermarket chains should fund/subsidise the costs of practice change to improve soil and land condition.

For some farmers the biggest barrier is that the commodity price at the farm gate is not linked to the prices on the supermarket shelf. Supermarket prices have gone up but commodity prices have remained largely unchanged for prolonged periods of time.

5.2 Time and discount rates

Several interviewees noted that time was a barrier adoption. Primary producers are very busy people, therefore changes need to be easy to adopt and fit within the overall production system. Time becomes particularly important during extremes such as drought where landholders are 'too busy trying to survive.' One landholder indicated that whilst money talks, sometimes 'time' is the most limiting factor related to the capacity to making changes.

Another observation made by several interviewees related to time is that some landholders implement practices in the short term that they know are detrimental to land and soil condition (e.g. overgrazing) and the overall sustainability of their business because they are desperate – generally as a result of their financial situation.

Another interviewee described the current farming/supply chain system as a "self-reinforcing loop, where declining fertility requires more chemicals which results in declining fertility which requires more chemicals."

These examples are indicators of steep discount rates being applied to the future, with a short-term focus on the present (Hagens, 2020). The 'tyranny of the urgent' as one grazier put it.

5.3 Equipment/technology

A number of comments were raised with regards to equipment and technology.

A lack of connectivity to the internet on farm/out in the paddock was reported as a major limitation for application-based technologies.

The need to be able to demonstrate a return on investment/business case for purchasing new equipment/technology was also noted. This can come down to a scale issue, particularly in regions with smaller property sizes where the economic proposition of some technologies which could improve land management isn't necessarily viable.

The cost of new technologies can be prohibitive. For example, in the horticultural industry where plastic sheeting is used, growers may double or triple crop to avoid changing the plastic/reduce costs. Alternative biodegradable products are available but have limited uptake due to cost and only lasting a single season.

In some areas technology is still immature in both a technology, logistic and research sense. An example being pelletised compost where issues remain with application (not blocking the lines in an air seeder), on farm storage and handling, and the impact of the pelletisation process on the efficacy of the biology and organic matter.

Finally in some regions, particularly where small landholdings exist, farming systems are, relatively, low-tech. In these circumstances the economic argument for some modern technologies doesn't, and is unlikely to, stack up.

5.4 Logistics

Logistic issues, such as freight costs to more remote areas was identified as a barrier. Whilst there are producers who are aware of practices that would improve soil and land condition (e.g. gypsum or compost

application), the freight costs alone are sufficient to make these practices impractical/uneconomic in areas where there is not a local source.

One industry representative noted that whilst there is a lot of research conducted into agronomy and related areas, there is virtually none of the logistics/operational management on-farm, which often limits the application of best practices.

5.5 Risk and evidence

A number of interviewees noted that making changes to a production system involves risk. Therefore, before implementing change, evidence is required that the risk of the change is acceptable.

Some interviewees indicated that there is a perception that Landcare/biodiversity/regenerative agriculture type projects will negatively affect production. Without evidence to demonstrate their benefits it is unlikely that a sizable proportion of landholders will significantly change their practices. Concerns over unintended consequences of changes were also identified.

One interviewee indicated that businesses in the "*agricultural sector these days cannot get it wrong, due to fluctuating and volatile markets*" indicating that for many businesses the risk threshold is quite low.

5.6 Administration

Some people indicated that the administrative overhead of participating in grant projects/programs was sufficient to prevent participation (e.g. the benefit of being involved in a program was perceived as being less than the cost in terms of time and frustration in completing the administrative requirements). An example was provided with regards to the Pilot Soil Monitoring Incentives Program where one farmer (and Landcare coordinator) described it as follows:

"I signed up to this as a farmer, and know another farmer who did also, and we both lost interest pretty quickly, and let it drop as bureaucratic, process heavy, and not of use/interest."

5.7 Summary – Barriers to Adoption

There is a well-established literature focusing on barriers to adoption of new practices/technologies in agriculture (see for example Wreford et al. (2017), Junior et al. (2022) and Campuzano et al. (2023)). Whilst a broad range of barriers were identified by interviewees, without exception no barriers were identified that could be considered unique. This finding reinforces the importance of applying well established principles on adoption in designing programs and policies under the NSS/NSAP to increase the likelihood of achieving program objectives.

The most fundamental barriers to adoption to improved land and soil management clearly relate to economics. In most instances economic considerations are the primary driver of decision making and heavily influence both the capacity and willingness of primary producers to implement changes to their business.

The latest ABARES data indicates that the average rate of return for broad acre agriculture businesses in Financial Year 2022-23 was 1.4% in NSW and 2% in Queensland (ABARES, 2024). Looking to the future, research by Hughes et al. (2022) suggests that the profitability of farming business (without any long-run adaptation or technological advance) under likely rainfall and temperature conditions could further reduce average farm profits by relatively minor to significant amounts. This indicates that the economics will only

become a more important consideration in farm business decision making over time. A likely outcome is that the risk tolerance of producers will also lower.

When economics is combined with other barriers to adoption, it becomes apparent that the totality of the constraints within which an agricultural enterprise operates will limit the capacity for changes to farming systems that improve soil and land management. Particularly when much of the ‘low hanging fruit’ with regards to improving soil condition are already widely implemented (e.g. conservation agriculture).

It thus appears that we are facing a paradox. Whilst the urgency of improving land and soil management has arguably never been more important, the capacity for land managers has arguably been never more constrained.

6 Abbreviations

Abbreviation	Meaning
CoP	Community of Practice
CPSS	Certified Professional Soil Scientist
DPI	Department of Primary Industries
DRSL	Drought Resilient Soils and Landscapes
ESC	Erosion and Sediment Control
FAA	Fertcare Accredited Advisor
FDF	Future Drought Fund
OFE	On Farm Experimentation
OPD	Ongoing Professional Development
LLS	Local Land Services
NRM	Natural Resource Management
NSAP	National Soil Action Plan
NSS	National Soil Strategy
NSSET	National Soil Science Extension Team
RSP	Registered Soil Practitioner
RDC	Rural Research and Development Corporations
RD&E	Research, Development and Extension
SAF	Sustainable Agriculture Facilitator
SFSGSEA	Smart Farm Small Grants – Soil Extension Activities
SQNNSW	Southern Queensland and Northern NSW

7 Appendix

A. Soil Capacity Gap Analysis Framework
B. Soil Flooding/Inundation Literature Search

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Soil-Capacity Gap Analysis Report Framework

A major output from the Regional Soil Coordinator program is an analysis of the gaps in soil-capacity in each drought hub region. This plan describes the objectives and approach to deliver this report.

This plan has been developed by the Regional Soil Coordinators' community of practice to provide a consistent National approach to the collection, scale, and scope of the data collected, and ensure a uniform presentation of results. This consistent approach will prevent potential duplication of effort and enable DAFF to consolidate state results into a National appraisal of the gaps in soil capacity and prioritise future funding.

Objectives

The objectives of the Soil-Capacity Gap Analysis are to:

- Provide an overview of the regional soils, stakeholders, and current projects related to providing soil-capacity to end users.
- Summarise the major soil productivity and environmental issues occurring across the region and opportunities to increase best land management practices.
- Evaluate the gaps in soil-capacity, or barriers to adoption, of best soil management practices, and align these with the priorities of the National Soil Strategy Action Plan.
- Prioritise capacity gaps for their regional importance and identify opportunities for development.

Scope

The content of the Soil-Capacity Gap Analysis will include the following sections:

Current situation

- Overview of major regional soil types and agricultural enterprises.
- Mapping of key soil-capacity stakeholders and organisations.
- Overview of significant current and recent major soil-capacity projects.
- Identify existing data sources and platforms for the dissemination of soil-capacity.

Key regional soil issues

- An overview of the major soil issues occurring across the region, organized by agro-ecological zone.

Gaps in soil capacity or barriers to adoption of soil best management practice

- Identify gaps between key soil issues and adoption of best soil management practices.
- Identify potential causes contributing to the gaps identified. These may include factors such as: limitations of extension services, resource constraints, skills or capacity gaps, or the regulatory or policy settings.

Opportunities and examples

- Identify opportunities arising from the identified gaps in soil-capacity or barriers to adoption of soil best management practice
- Highlight regionally relevant examples where soil best management practices have been successfully adopted.

Recommendations

- Prioritise short, medium, and long term recommendations that will address the gaps identified in soil-capacity.

Literature Search – Flood Affected Soils

Prepared by Chanelle Barrett
(UniSQ student completing a *SCI3302-Work-Integrated-Learning* course under the supervision of the SQNNSW Regional Soil Coordinator)

Search details

Search engine	Key word/s	Limit to	Results
SCOPUS	'flood affected' AND Soil* AND Manag*	Agricultural and Biological Sciences + Australia	88 reviewed; 1 soil, 2 plant
Web of science	'flood affected' AND Soil* AND Manag*	Soil Science + Agronomy + Australia	39 reviewed; 1 plant
ScienceDirect	flood AND affected AND soil AND remediation AND Australia	Research articles Agricultural and Biological Sciences	194 reviewed
CSIRO Publishing	flood* AND affected AND soil* AND manag* AND remediat* AND Australia	Soil Research journal	3542; first 25 reviewed
CSIRO Publishing	flood* AND affected AND soil* AND manag* AND remediat* AND Australia	Crop & Pasture Science journal	6075; first 25 reviewed
Google Scholar	'flood affected' AND Soil* AND Manag* AND Australia AND agriculture	N/A	116; 50 reviewed; 1 soil

Soils

Categories	Link	Citation	Abstract
▪ Impact ▪ Recovery ▪ Management intervention ▪ Cropping ▪ UK	Link to article	Harvey RJ, Chadwick DR, Sánchez-Rodríguez AR & Jones DL 2019, 'Agroecosystem resilience in response to extreme winter flooding', *Agriculture, Ecosystems and Environment*, vol. 279, pp. 1-13, https://doi.org/10.1016/j.agee.2019.04.001	Evidence suggests that climate change is increasing the frequency of extreme weather events (e.g. excessive rainfall, heat, wind). The winter of 2013-14 saw exceptional levels of rainfall across the UK leading to extreme and prolonged flooding (up to 3 months with floodwater depths up to 3 m) in several low-lying agricultural areas (e.g. Somerset Levels, Thames Valley). The impact of extreme flooding and the speed of ecosystem recovery at the field-scale, however, remain poorly understood. The main objectives of this study were therefore to: (1) assess the effect of this extreme winter flooding event on a range of soil physical, chemical and biological quality indicators at 15 flood-affected sites (arable and grassland), (2) determine if these changes in soil health were reversible in the short term (< 1 year), and (3) to evaluate the effectiveness of different mechanical interventions (sward-lifting, subsoiling, slot-seeding and aerating) to accelerate the amelioration of the damage caused by winter flooding at 2 of the 15 sites. Once the floodwater had receded (April 2014), we found that several of the measured soil quality indicators were negatively affected in the flooded areas in comparison with non-flooded areas. This included a decrease in soil bulk density (by 19%), soil pH (by 0.4 units), and available P (by up to 42%). Flooding increased soil microbial biomass (60%), induced a shift in soil microbial community structure and reduced earthworm numbers. After 8 months of recovery, only soil pH remained significantly reduced (by 0.3 units) in the flooded areas in comparison to the unflooded areas. Flooding had a negative impact on the overlying vegetation at the arable sites (biomass production was reduced by between 19 and 34%) but had no major impact at

			the grassland sites in the long-term. In the flood amelioration experiment, the subsoiled plots produced grass with a higher nutrient content (e.g. N - up to 35%, Ca - up to 19% and Mg - up to 58%). However, the four different interventions appeared to have little positive impact on most of the soil quality indicators measured. In conclusion, extreme winter flooding was found to induce short-term alterations in key soil quality indicators and to destroy winter crops, although these effects did not persist in the longer term. Our results therefore indicate that the temperate agroecosystems evaluated here were highly resilient to winter flood stress and that recovery to a pre-flood state could be achieved within 1 year. Improved management strategies are still needed to speed up the rate of recovery after flood events to facilitate a faster return to agricultural production.
▪ Flood affected ▪ Microbes ▪ Soil organic matter ▪ India	Link to article	Haseena, A & Gopal, KS 2022, 'Synergism of Beneficial Microbes Helps to Rejuvenate Flood and Landslide Affected Soils for Sustainable Agriculture – A Review', Eco. Env. & Cons, vol. 28 (August Suppl. Issue) pp. (S135-S146), http://doi.org/10.53550/EEC.2022.v28i04s.020	Climatic disasters, like floods and landslides, are the major causes for the decline in soil fertility or soil organic matter. Soil organic matter influences the physical, chemical, and biological properties of soil; it is the fundamental aspect that discloses soil health. Microorganisms in the soil environment participate a critical task in the enhancement of soil nutrients and soil fertility. Even though microbial bioinoculants are widely studied for improving agriculture, the application of microbial consortium for the restoration of organic matter or soil fertility in the flood and landslide depleted soils are yet to be exploited. The part of living biomass, i.e. soil microorganisms in restoring soil organic matter seems to be crucial, as microbes are the major drivers in escalating organic matter in the soil. The living biomass recycles the nutrients in the soil by utilizing the plant and animal litter in the soil and offers the crops adequate nutrients. Thus, microorganisms can force the accumulation of stable and chemically diverse soil organic matter in poor fertile

			soils. Exploring such vibrant, complex advantageous interactions among microorganisms seems imperative to replenish organic matter exhausted soil. This article reviews the relevance of soil organic matter, the role of soil microorganisms in improving soil organic matter and emphasizes the need for intensive research in raising beneficial microbiome for replenishing soil organic matter and thus to rejuvenate the flood and landslide depleted soils to sustain agriculture.

Plants

Categories	Link	Citation	Abstract
▪ Waterlogging tolerance ▪ Pasture	Link to article	Striker, GG & Colmer, TD 2017, 'Flooding tolerance of forage legumes', *Journal of Experimental Botany*, vol. 68, no. 8, pp. 1851-1872, https://doi.org/10.1093/jxb/erw239	We review waterlogging and submergence tolerances of forage (pasture) legumes. Growth reductions from waterlogging in perennial species ranged from >50% for *Medicago sativa* and *Trifolium pratense* to <25% for *Lotus corniculatus*, *L. tenuis*, and *T. fragiferum*. For annual species, waterlogging reduced *Medicago truncatula* by ~50%, whereas *Melilotus siculus* and *T. michelianum* were not reduced. Tolerant species have higher root porosity (gas-filled volume in tissues) owing to aerenchyma formation. Plant dry mass (waterlogged relative to control) had a positive (hyperbolic) relationship to root porosity across eight species. Metabolism in hypoxic roots was influenced by internal aeration. Sugars accumulate in *M. sativa* due to growth inhibition from limited respiration and low energy in roots of low porosity (i.e. 4.5%). In contrast, *L. corniculatus*, with higher root porosity (i.e. 17.2%) and O_2 supply allowing respiration, maintained growth better and sugars did not accumulate. Tolerant legumes form nodules, and internal O_2 diffusion along roots can sustain metabolism, including N_2 fixation, in submerged nodules. Shoot

			physiology depends on species tolerance. In *M. sativa*, photosynthesis soon declines and in the longer term (>10 d) leaves suffer chlorophyll degradation, damage, and N, P, and K deficiencies. In tolerant *L. corniculatus* and *L. tenuis*, photosynthesis is maintained longer, shoot N is less affected, and shoot P can even increase during waterlogging. Species also differ in tolerance of partial and complete shoot submergence. Gaps in knowledge include anoxia tolerance of roots, N_2 fixation during field waterlogging, and identification of traits conferring the ability to recover after water subsides.
▪ Soil seed bank	Link to article	Osunkoya O.O., Ali S., Nguyen T., Perrett C., Shabbir A., Navie S., Belgeri A., Dhileepan K., Adkins S. Soil seed bank dynamics in response to an extreme flood event in a riparian habitat (2014) Ecological Research, 29 (6), pp. 1115 - 1129, Cited 14 times. DOI: 10.1007/s11284-014-1198-2	A significantly increased water regime can lead to inundation of rivers, creeks and surrounding floodplains- and thus impact on the temporal dynamics of both the extant vegetation and the dormant, but viable soil-seed bank of riparian corridors. The study documented changes in the soil seed-bank along riparian corridors before and after a major flood event in January 2011 in southeast Queensland, Australia. The study site was a major river (the Mooleyember creek) near Roma, Central Queensland impacted by the extreme flood event and where baseline ecological data on riparian seed-bank populations have previously been collected in 2007, 2008 and 2009. After the major flood event, we collected further soil samples from the same locations in spring/summer (November–December 2011) and in early autumn (March 2012). Thereafter, the soils were exposed to adequate warmth and moisture under glasshouse conditions, and emerged seedlings identified taxonomically. Flooding increased seed-bank abundance but decreased its species richness and diversity. However, flood impact was less than that of yearly effect but greater than that of seasonal variation. Seeds of trees and shrubs were few in the soil, and were negatively affected by the flood; those of herbaceous and

			graminoids were numerous and proliferate after the flood. Seed-banks of weedy and/or exotic species were no more affected by the flood than those of native and/or non-invasive species. Overall, the studied riparian zone showed evidence of a quick recovery of its seed-bank over time, and can be considered to be resilient to an extreme flood event.
▪ Waterlogging ▪ Crops ▪ Modelling ▪ Remediation ▪ Australia	Link to article	Shaw R, Meyer WS, McNeill A, Tyerman SD 2013, 'Waterlogging in Australian agricultural landscapes: a review of plant responses and crop models', *Crop and Pasture Science*, vol. 64, pp. 549-562, https://doi-org.ezproxy.usq.edu.au/10.1071/CP13080	This review summarises reported observations of the effects of waterlogging on agricultural production in Australia and briefly discusses potential remediation strategies. Inconsistencies are demonstrated in the current indicators used for assessment of waterlogging potential across agricultural landscapes as well as in parameters measured in waterlogging studies. It is suggested that predictions of waterlogging potential for landscapes should be based on a minimum dataset that includes pedological, topographical, and climate data for the defined area, as well as observations of plant morphological appearance and visible surface water. The review also summarises the effects of low oxygen concentration in soil on rhizosphere processes, and discusses evidence for direct effects on plant physiology of reductions in soil oxygen caused by waterlogging. Finally, the review describes current crop growth, water use, and yield simulation models used in Australia (SWAGMAN, DRAINMOD, and APSIM) that incorporate waterlogging stress. It is suggested that there is scope for modifications to these models based on recent improved understanding of plant physiological responses to waterlogging and on further research. The review concludes that improvements in modelling waterlogging outcomes to assist growth and yield predictions should ultimately enhance management capacity for growers.