SOIL CRC

Performance through collaboration

FINAL REPORT

WHY SOIL MANAGEMENT PRACTICES ARE ADOPTED

PROJECT 1.2.002

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The Soil CRC recognises the value of knowledge exchange and the importance of objective peer review. It is committed to encouraging and supporting its research teams in this regard.

The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2018), and provided constructive feedback which was considered and addressed by the author(s).

PROJECT PARTICIPANTS

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EXECUTIVE SUMMARY

While agricultural soils are a government priority, adoption of programs and techniques for improved soil management has been relatively slow. This project was undertaken to investigate why new tools and approaches for improving soil management are under-used by farmers, and how adoption can be improved. Building on existing models of adoption, the project aimed to provide a holistic understanding of adoption practices, taking into account social, cultural, economic, bio-physical and geographical influences. To achieve the project aims, qualitative data was collected through workshops and interviews with farmers, staff and other stakeholders from seven farming systems groups within mixed farming regions across Australia. The data informed the development of a draft adoptability framework that was taken back to these groups for testing in a second round of workshops. Through facilitated discussion with each group, the framework was customised to meet local soil improvement priorities and challenges. The diagnostic adoptability framework developed through this project provides a more useful and useable approach to understanding and assessing the adoptability of an innovation than existing models. In contrast to existing models, the framework has been co-developed with its intended users – farming systems groups and local extension personnel who are involved in the implementation of improved soil management techniques and technologies, and who have an intimate understanding of regional soil priorities and challenges. The adoptability framework developed through this research will assist regional farming groups and other extension personnel to better target soil management resources and communications to their members/clients. Integration of the framework as part of the project application/review process in future Soil CRC funding rounds will also help soil researchers and policy-makers in developing soil management tools and programs that will be more widely used by farmers.

OBJECTIVES

1. Investigate the efficacy of current strategies used by regional farming groups for the promotion and adoption of improved soil management.
2. Develop a framework of commonalities and differences in relation to adoption priorities, drivers and pathways for improved soil management across different regional contexts.
3. In partnership with farming groups from across Australia, co-develop criteria of adoptability, and a set of principles and recommendations for increasing adoption of improved soil management across different regional contexts and farming systems.
4. Based on the project findings, develop a proposal for Phase 2 research that investigates the broader political and institutional drivers for adoption of improved soil management to enable policy and commercial settings to better support adoption.

RESULTS

Objective 1 – Investigate the efficacy of current strategies used by regional farming groups for the promotion and adoption of improved soil management.

Existing strategies for promoting soil improvement techniques and technologies are working generally well for regional farming groups in engaging farmers, primarily because they build on farming knowledge and experience, use trusted and credible sources of advice, and have practical relevance to the management of local soil issues.

However, the efficacy of current strategies in transforming farmer engagement into improved adoption is contingent on a number of adoption drivers, some of which are outside the control of farmers or farming systems groups.

Objective 2 – Develop a framework of commonalities and differences in relation to adoption priorities, drivers and pathways for improved soil management across different regional contexts.

The adoption priorities identified by participants in the interviews and first round of workshops are diverse and reflect specific biophysical, climatic and production challenges in each region.

In contrast to much of the soils adoption literature, the common drivers of adoptability reported by participants that influence local capacity to address adoption priorities are largely institutional/policy or market related. These include a lack of financial or market incentives for improved soil management practices, tensions between priorities or practices of research organisations/researchers and regional soil management practices/priorities, lack of resourcing for farming systems groups to address regional soil management priorities, and limited resources for improved soil data management and interpretation. There is a remarkable degree of similarity between farming groups in terms of these key influences on adoption.

Objective 3 – In partnership with farming groups from across Australia, co-develop criteria of adoptability, and a set of principles and recommendations for increasing adoption of improved soil management across different regional contexts and farming systems.

A major output of this project is a draft framework for understanding and assessing adoptability of soil management innovations. The framework was developed by the researchers by analysing the qualitative data collected from semi-structured interviews and a first round of workshops in Year 1 of the project. This was refined through a second round of workshops in Year 2 where farming system group leaders contributed to customising the framework to make it more useful and useable to their specific soil management priorities and regional context.

Our adoptability framework differs substantially from others in that it is:

- co-designed with end users, and
- incorporates multiple drivers of adoptability at different scales, including characteristics of the innovation/practice, characteristics of the producer and their socio-cultural context, and characteristics of the knowledge and power relations that frame how an innovation/practice is developed and promoted.

Objective 4 – Based on the project findings, develop a proposal for Phase 2 research that investigates the broader political and institutional drivers for adoption of improved soil management to enable policy and commercial settings to better support adoption.

The influence of institutional and political drivers on implementation and adoption of local adoption priorities is clearly evident in our findings.

As such, we argue that rather than developing a Phase 2 research proposal, the focus of Soil CRC activity in this area in the future should be actionable strategies that address the political and institutional impediments to adoption identified in this research project.

NEXT STEPS	TIMING
• The longer-term pathways to impact from this project rely on social and institutional change to support improved adoptability. • These cannot be fully realised or evaluated within the life of this two-year project. They are expected to accrue from the findings and recommendations of this project being embedded in later Soil CRC projects and delivery activity, and in application of the adoptability framework by a wider cross-section of farming groups.	• The recommendations from this project should form part of the development of priorities for Soil CRC funding calls, 2022-2025.

INTRODUCTION

Agricultural soils are a government priority. However, while significant resources (time, money, enthusiasm) are expended on developing new tools and approaches for soil improvement, these are rarely or poorly used by farmers (Bennett & Cattle, 2014; Carlisle, 2016; De Graaff et al., 2008; Lobry de Bruyn & Andrews, 2016). Why poor uptake occurs, and how it can be improved, is the core question for this project. The purpose of this project was to work in partnership with seven farming groups located in different geographic regions across Australia to develop an in-depth understanding of why and how farmers adopt, or do not adopt, programs, practices and technologies aimed at improving soil management. Specifically, the project aimed to generate usable knowledge on the major drivers of, and pathways to, increased adoption by focusing on four objectives.

The purpose of Objective 1 was to investigate the efficacy of current strategies used by regional farming groups for the promotion and adoption of improved soil management. Specifically, the research aimed to determine the effectiveness or otherwise of current strategies – and their associated technologies, techniques and/or practices – being trialled or used by regional farming groups to improve soil management. Exploring this from the perspective of those involved in regional soil extension and implementation was considered essential for identifying the soil improvement strategies already being used on-ground by farming groups, and the efficacy of those strategies in terms of the quantity and quality of farmer adoption.

Drawing from the knowledge developed from Objective 1, the aim of Objective 2 was to determine how farmers across different farming systems and geographical contexts integrate understandings of improved soil management into their planning and practice. Exploring specific soil improvement interventions in each of the seven selected regional areas was important in providing understanding of the extent to which farmers view specific soil management technologies, techniques and/or practices as adoptable. It was also necessary for developing insight into shared features that encourage adoption, as well as the impacts of regional differences on adoption of particular tools and strategies. For example, soil types, climate, geography, commodity types and farming systems are likely to influence uptake of particular strategies and techniques. This knowledge brings the end users' perspectives into assessing adoptability of the technologies, techniques and practices for improving soil management.

Objective 3 was centred on working in partnership with farming groups across the seven regions to co-develop models of adoption drivers, and a set of principles and recommendations for increasing adoption of improved soil management practices across the different geographical contexts and farming systems. Objective 3 enabled refinement and empirical testing of the criteria for adoptability developed in a previous Soil CRC scoping study (Scoping Study 1.2.01). This process also aimed to contribute more broadly to Soil CRC Output 1.2, an interactive tool to assess the adoptability and feasibility of soil technologies and policy.

The final objective focused on the development of a proposal for a second phase of research based on the findings of Objectives 1, 2 and 3. Objective 4 intended to build on key findings from this project to expand understanding of drivers of adoption and adoptability from regional and farm-level to incorporate institutional and organisational-level drivers. It was envisaged that a second phase of the research would provide critical information about broader social and institutional pressures that influence farmers' adoption environments and how

interventions to counteract such pressures can be developed. Phase 2 of the project was considered important in contributing to Soil CRC Program 1 Milestone 1.2.5 – development of a web decision support tool to assess adoptability of practices and technologies to improve soil performance.

BACKGROUND

PREVIOUS RESEARCH & LITERATURE

Despite the many tools and technologies that have been developed to improve soils, questions around why such tools are not readily adopted remain. Within the context of agriculture, the adoption literature has been dominated by 'top-down' approaches informed principally by Rogers' Diffusion of Innovation model (Rogers, 2003). According to this approach, agricultural research conducted by researchers in scientific and academic institutions is the main source of innovation in agriculture. A common feature of top-down adoption approaches is that they assume linearity (Godin, 2006) in which adoption takes place in definitive stages, with the transfer of knowledge being one way – from scientific or technical experts, to extension agents, and to 'innovative' farmers. Wider diffusion is then anticipated in which other landholders start to adopt the new ideas and innovations over time. This occurs in stages, with early adopters taking up innovations first followed by the early majority, the late majority, and finally the 'laggards'. The diffusion of innovations theory posits that adoption and subsequent use of innovations is influenced by the characteristics of the innovation and of the adoptees (Rogers, 2003). A good example of an adoption model based upon the top-down approach is the CSIRO's ADOPT (Adoption and Diffusion Outcome Prediction Tool) (Kuehne et al., 2017). Underpinning such models of adoption, however, are assumptions of the supremacy of scientific rationalism, and pragmatist management values. Within these approaches it is assumed that adoption of change is always necessary, and that there is an agreed upon 'best way' of going about ensuring its adoption. On this basis, 'material patterns of action … are organized around the common, implicit understanding of the actors' (Neumann, 2002, p. 629). Top-down approaches are also largely developed from the perspective of scientific or technical experts with little input from other actors such as farmers. Therefore, a disparity between what and how scientific or technical experts believe farmers should adopt and the needs and realities of farmers can create barriers in terms of understanding the useability of particular tools and techniques. This can impact eventual adoption.

The diffusion of innovations model, discussed above, views farmer attitudes, motivations and social networks as important in influencing the nature and rate of adoption – that is, *what* influences adoption behaviour. However, this approach gives limited attention to understanding *why* landholders adopt or do not adopt, and *how* they do so. In the last 30 years, rural sociologists, geographers and anthropologists have engaged with these questions. Their collected body of research has resulted in what can be referred to as a 'bottom-up' socio-cultural approach that gives greater attention to farmers' 'local' and experiential knowledge, and the socio-cultural context in which farmer knowledge and behaviour is located. The concept of 'farmer-first', Scoones and Thompson (1994, p. xv) argues for the importance of farmer knowledge on the basis of their on-farm knowledge through their roles as 'observers, analysts, experimenters, monitors, and evaluators'. This view is further evident in later work by Van der Ploeg et al. (2000) who argue that taking farmers' expertise into account is essential when determining how new practices will apply to specific farming contexts. The importance of integrating farming knowledge is also highlighted

by Higgins et al. (2017) who argue that not paying enough attention to farmer knowledge and expertise contributes to a loss of trust in scientists and researchers, leading to potential future problems related to collaboration. A key benefit of a socio-cultural approach is that it provides insights into the significant influence of farming knowledge, farmer values, priorities, and cultural understandings of 'good' farming on adoption practices. Farmers are more likely to adopt new farming practices that resonate with existing knowledge, values and experiences. For example, farmers who value conservation are more likely to adopt practices that encourage ecological solutions (Bardsley et al., 2019). This indicates that farmers are 'more likely to use certain technologies if these are located within their broader farming culture' (Gardezi & Bronson, 2020, pp. 4-5). An Australian example that applies aspects of a socio-cultural approach is the work of Ticehurst et al. (2011). The socio-cultural approach to adoption can be criticised for focusing too much on the social and cultural relations that underpin farming knowledge and practices. In doing so, the broader economic, institutional and power relations that influence landholders' knowledge and practices are downplayed or overlooked entirely. In addition, farming knowledge under this approach is often treated as distinctive from scientific or 'expert' knowledge. In practice, there is a fluid and dynamic relationship between the two; knowledge building is increasingly recognised as a co-production between scientists, extension personnel and farmers.

A further approach to adoption is the co-constructivist approach that to date, has been associated with knowledge constructed through communities of practice, peer-to-peer learning, or community-based informal or social learning opportunities. The co-constructivist approach acknowledges that no individual or group holds all or complete knowledge about either how to define issues or how to address them. From this perspective, adoption is supported through a range of collaborative partnerships promoting 'a sense of community and "working together" for enhanced accountability and shared decision-making that enhance sustainable development' (Tilbury & Cooke, 2005, p. 48). Within the Australian agricultural context, an increased emphasis on participatory community-based engagement is evident alongside traditional 'top-down' agricultural extension. For example, aspects of Australian rural/ agricultural and natural resource management extension activities have been linked with 'building social and natural capital' (Lockie, 2001, p. 292). Rather than drawing solely upon scientific expertise, local community expertise is also used, engaging with different actors to solve problems. This collaborative approach creates knowledge that is not only scientifically credible, but socially legitimate and practically relevant (Cash et al., 2003). A benefit of the co-constructivist approach is that it does not attribute knowledge to a particular group of stakeholders such as is evident in diffusionist and socio-cultural approaches. Rather, knowledge is co-created between different actors (such as farmer and researcher) 'to develop shared ways of knowing' (Ensor & Harvey, 2015, p. 511). Ensor & Harvey (2015, p. 511) further highlight that a co-constructivist approach is also likely to involve 'a shift in power relations to bring excluded or marginalized voices into … decision-making processes'.

GAPS IN CURRENT KNOWLEDGE

Most research on adoption of soil management practices draws on a diffusion of innovations approach, with growing recognition by researchers of the social and cultural relations that underpin farmers' soil practices and decision-making (Carlisle, 2016; Pannell et al., 2006). However, to date, there has been limited application of a co-constructivist approach in research on adoption of soil management practices (Ingram, 2008b; Krzywoszynska, 2019), especially in an Australian context. Consequently, little is known about the role of scientists, researchers and research organisations, in adopting farmers' soil knowledge. This project

builds on current knowledge by being one of the first studies in Australia to take an explicitly co-constructivist approach to investigating the adoptability of soil improvement techniques and technologies. It does so by working with farming groups to co-develop a set of criteria and a framework for understanding and improving adoption across different regional contexts.

METHODOLOGY

As the project was primarily aimed at working in partnership with farmers, the research was designed to enable exploration of how individuals construct meaning and knowledge, and how this meaning and knowledge is shaped by specific social and cultural contexts. On this basis a social constructionist approach (Patton, 2015) was adopted to facilitate a detailed qualitative investigation of how different understandings, priorities and resources relating to soil management influence the implementation and adoptability of soil improvement strategies and techniques. This was particularly important for understanding the drivers and pathways that lead to farmers' decisions to adopt, adapt or reject particular soil management techniques, technologies, or practices.

To explore farmer adoptability of improved soil management practices, the research team partnered with seven farming groups – the Western Australian No Tillage Farmers Association (WANTFA), Mackillop Farm Management (MFMG) (South Australia), Agricultural Innovation and Research Eyre Peninsula (AIREP) (South Australia), Birchip Cropping Group (BCG) (Victoria), Riverine Plains Inc. (NSW), Central West Farming Systems (CWFS) (NSW), and NRM North (Tasmania). Three complementary methods of data collection were used in an iterative analytic cycle to co-construct the adoptability framework, which is the major output of this project (See Figure 1).

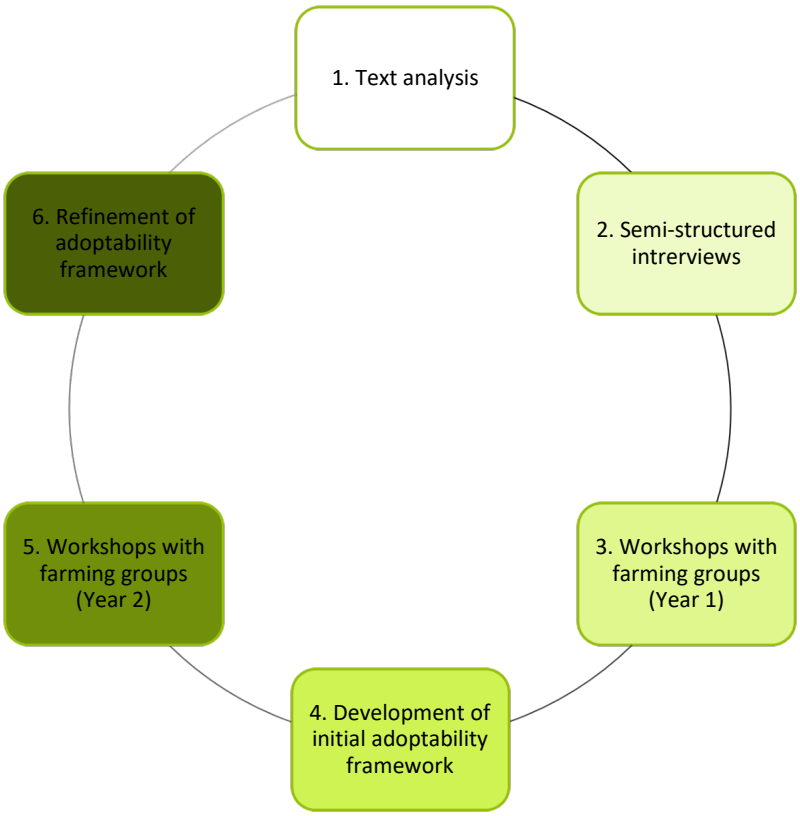

Figure 1.

The first phase of data collection involved a policy review and analysis. This was a text analysis of soil policy, programs and strategies at a national and state level. Analysis was conducted in the first six months of Year 1 with the aim of partially addressing Objective 1. Findings from the text analysis were used to design semi-structured interviews as the second phase of data collection. Semi-structured interviews were conducted in the second half of Year 1, which also enabled the research team to address Objective 1. Four to six interviews were conducted in each of the case study regions with agronomists (retail, private/independent), farm advisors, representatives of natural resource management groups, and farming group leaders. Participants were recruited through a combination of purposive and snowball sampling.

A third phase of data collection was then completed through workshops at two points in the project. In the second half of Year 1, face-to-face workshops were conducted across seven regions of Australia. These workshops included the farming groups involved in the project with a view to developing an understanding of adoptability of improved soil management practices across different farming systems, geographical and environmental contexts. Drawing on the experience of each of the farming groups, a purposive sampling technique was used to recruit farmers and to ensure that a diversity of farmers and enterprises were included. The workshops each involved eight to 10 farmers per region, with some workshops including agronomists and advisors who operated a farm. The aim of the first workshop was to develop an understanding of farmers' experiences and to co-construct knowledge of soil management practices. The workshops conducted in Year 1 involved a semi-structured discussion format that was informed by findings of the literature review, text analysis, and semi-structured

interviews. Findings from the interviews and seven workshops were used to develop the draft adoptability framework.

Initially, the research team intended to repeat the workshops in Year 2 with the same participants so that the draft adoptability framework could be taken back to participants for further input and refinement. However, travel restrictions caused by COVID-19 meant that a second visit to the case study locations was not possible. Rather, the second workshops were held in Year 2 with a smaller group of participants (approximately four to six in each group) from each of the farming groups to test the workability of the adoptability framework and to seek additional input into the development of the framework, principles, and recommendations. In each of the seven virtual meetings further input was gained by working through a specific soil improvement challenge or priority identified by participants from workshop 1 to determine whether the adoptability framework was appropriate, and what might need to be changed. To test for veracity, a second challenge or priority was then identified by the participants in workshop 2, and the adoptability framework re-worked within the context of the second challenge to determine fit and/or further refinement that may be needed.

Consistent with the social constructionist approach, data collected from the individual interviews and the first workshop discussions were recorded then transcribed into text and analysed inductively to enable the key themes in the data to emerge. In using this approach, open coding was firstly conducted to find common descriptors, followed by a second cycle of axial coding which seeks to develop connections and relationships between codes (Miles et al., 2019). Based on the analysis, narratives were developed for each of the farming groups based upon a soil challenge or priority identified in the Year 1 interviews and first workshops. The narratives were used to develop the draft adoptability framework into a useable tool ahead of the workshops in Year 2 of the project, and endorsed as accurate by the workshop participants. These narratives are included in Appendix A.

RESULTS

POLICY REVIEW AND ANALYSIS

The policy review and analysis provided an important context for investigating how the strategies and techniques used across the seven farming regions encompassed by this project accord with current policy guidelines and thinking on improving soil management (Project Objective 1). A full version of the review was submitted to the Soil CRC to fulfil Milestone 5. A summary of the aims and key findings are provided in this report.

The policy review and analysis examined current Australian federal and state-level[1] policies for soil management and investigates:

- the extent to which adoption and adoptability of soil management practices and techniques are considered key issues by policy makers, as opposed to the technical processes associated with measuring and understanding soil
- whether there are clear guidelines on the practices and techniques that farmers ought to be adopting

[1] Soil management policies from five states covered in this research project are examined – New South Wales, Victoria, Tasmania, South Australia and Western Australia.

- which models or/approaches to adoption and adoptability are currently dominant
- the limitations of current policies in promoting adoption of improved farm soil management.

The federal and state policies and strategies examined highlight an overwhelming emphasis on technical processes associated with measuring and understanding soil. There is limited attention given to the practices and techniques that farmers should be adopting, or strategies for improving adoptability. The 2014 National Soil Management Strategy's goals describe improvements to the access, communication and application of new knowledge (generated by data enhancements) to farmers. The Australian state policies generally concentrate on landscape-scale soil management, amelioration (for example subsoil constraints) and agricultural industry productivity goals. Two states (New South Wales and Victoria) provide separate sections that elaborate on soil and land management in agriculture, although projects relating to soil management such as erosion are often present as part of weed eradication and biodiversity enhancement.

In evaluating how policies provide clear guidelines for which practices and technologies farmers might adopt, the review found almost no consideration of adoptability by end users. This reflects a focus on investments in the technical aspects of soil management, such as improvements to data and technology, as well as a reliance on soil science expertise in developing and communicating soil improvement knowledge to extension providers. Specific pathways are described as part of strategies for capacity building and up-skilling the extension workforce. However, policy guidelines are not available for when land managers face tensions between productivity imperatives and soil science advice, or when soil science research does not engage in meaningful ways with local land management knowledge and priorities. Soil management technologies and practices that contribute to soil improvement will vary between farming enterprises, catchments and regions, and states. Other limitations relate to a reluctance to define 'good practice' in soil management, and the dominance of a 'productivist' approach to soil management which prioritises overcoming soil constraints for productivity gains.

The analysis of policy did not find evidence of intended pathways/frameworks or provide clear guidelines for practices and technologies that farmers might adopt. In determining the extent to which policies and programs guide land managers it was found that some programs, such as Landcare (National Landcare Program), report on the success of investment strategies to increase adoption of practices and that soil degradation issues such as erosion and acidification have been addressed in some regions. By investing in soil programs, it could be assumed that governments are implicitly providing guidance. Instead of providing explicit guidelines on improved soil management for healthy soils, there is an almost exclusive focus on technical processes associated with measuring and monitoring soil such as remote sensing, digital mapping, spatial attribute modelling, and real-time soil measurements. At the same time, how extension agents and farmers might manage conflicts between economic/productivity imperatives and soil conservation is not discussed. It is assumed that building the capacity and skills of the extension workforce is key to improved farm-level soil knowledge and practices. However, this assumption fails to address what information on soil technologies and practices the extension workforce should be promoting to farmers. Concentrating on the extension workforce and technology does not explore or address methods that could be used to encourage land managers to adopt technology.

Overall, the policy review and analysis found that soil management policies and strategies in Australia give limited attention to adoption and adoptability. When they do, a top-down, diffusion of innovations extension model is dominant. The top-down delivery model is based on flows of information from soil scientists to extension agents to farmers. This approach to

extension assumes that soil scientists research the issues that concern farmers, the technology is trialled, that information will flow to land managers using the range of communication skills needed, and that land managers value the information provided. Reliance on this approach neglects farmers' local soil knowledge-practices, the approaches already being used by farming groups and networks in different regions to improve adoptability, and the multiple influences on adoption at local, regional and national scales.

YEAR 1 WORKSHOPS AND INTERVIEWS

REGIONAL SOIL IMPROVEMENT ADOPTION PRIORITIES

To investigate the efficacy of current strategies used by regional farming groups for the promotion and adoption of improved soil management (Objective 1), as well as commonalities and differences in adoption priorities (Objective 2), it was first important to consider what these groups and their stakeholders viewed as soil improvement adoption priorities within their region.

Soil erosion mitigation using ground cover techniques – such as the use of purposefully planted cover crops or retained residual crop stubble – was reported as a key adoption priority in areas with light or fragile soils, such as South Australia's Eyre Peninsula. AIR EP interview and workshop participants reported that there is wide acceptance of the benefits and use of minimum and no-till practices in the region. Ground cover techniques are now deemed necessary to prevent erosion and further improve soil management:

> I think good soil management involves a number of things but probably principally trying to get plant growth on the soil and therefore you've got holding capacity, you've got root growth. (AIREP interview 04)

Good ground cover was reported as being a particularly high priority in areas with light or fragile soils:

> … getting vetches and getting the nutrition into the soil and then getting a good cover over that sand and actually then being able to sow into that limits your lifestyle in that sort of country. (AIREP workshop participant)

> … some guys can have the very best management practices, but when it doesn't rain for two years, it just doesn't matter what you do, because … the Eyre Peninsula is covered in very fragile soils and probably most of WA as well. If you're not careful, you can end up with a 'drifty' paddock, and … that's all your last 10 years of nutrients gone. (AIREP interview 05)

Workshop participants provided a number of examples of successful erosion control using ground cover. For example:

> … when we had a dry year, was it last year or the year before, I had the options available to me because I haven't actually touched any land that I didn't have to sow it ... I didn't have to chase some of these other ones because I'd worked them. I just left them and as I said, I spread all my sheep out and I got my sheep through. I didn't have any erosion, didn't have any problems so I thought to myself well that's success because it's actually achieved the goal that I set out. It's reducing the wind erosion and giving myself flexibility in poorer seasons. (AIREP workshop participant)

> … paddocks that were shit white sand, blow outs, complicated … it just grew primrose and skeleton weed. Now they just fit into our three-year wheat, barley, vetch rotation and they're covered. (AIREP workshop participant)

Using **lime applications to control soil acidity**, including use of variable rate applications, were identified as a priority for improving soil management for two farming groups in this research – CWFS and Riverine Plains. In both regions, participants reported that soil acidity was becoming a significant problem impacting on productivity. For example:

> … we've got soil acidity that is becoming more prominent, but it appears to only be in the top 10 cm so, I think we've got away with masking our soil acidity problem. But again, you get better soils that have a good phosphorus input history, or good nutrition management that are doing quite well. (CWFS interview 01)

Participants also reported wide acceptance of the use and benefits of liming practices to address soil acidity in both regions:

> It's a known input cost in our programs. It's just how you tackle and how often you are replacing what you're taking out of the paddocks… Lime is one of the many inputs that we have to put in every year to try and improve the soils and hopefully leave them in a better place than you found them. (RP workshop participant)

> … people are really aware of soil improvement and soil health … there seems to be more lime going out now than there used to be. (CWFS interview 02)

Within the two regions, farmers reported good results from liming applications using variable rate technology, and extending that technology to address subsoil stratification pH variations:

> Some of those now have moved onto grid sampling, using variable machines. I have some that have now had their whole properties done twice. Looking at some results from those, their levels of pH … they're very even, six plus … now started doing with them some subsoil … But testing has been done on the ones that have had average lime programs … there's some that have done it, that vary rates now, for a number of years with two lots of grid sampling. They're across the board fairly even. One I looked at the other day, his lowest at 10 to 20 was 4.8. He had two under 5.2. So we're pretty happy with that. (RP workshop participant)

For two of the farming groups – MFMG and BCG – **no single priority** was identified for regional soil improvement. For example:

> … we have multiple challenges in that environment on the plains. Then up on the hills and in our sandy soils, we struggle with water-repellents, acidity, low water holding capacity, low nutrient fertility, low organic carbon. All of these, again, constraints can occur in isolation but more often concurrently. It leads to constrained productivity as a result of the combination of those chemical and physical and biological impediments. (MFMG interview 02)

As a consequence, when developing our framework in these regions we have focused on emerging priorities that were identified as having potential for improving soil management. The **use of locally sourced animal (e.g. chicken) manure to replace some chemical fertilisers** was identified by BCG participants as one of a number of priorities to improve soils in the Wimmera and Mallee region of Victoria. The impetus using animal manure relates to replacing or substituting synthetic fertilisers that supply nitrogen, potassium and phosphorous, with accompanying cost savings:

> They're spreading it for purely just nitrogen and phosphorous benefits, well if the cost of synthetic fertilisers go up, well then they're in front. (BCG interview 03)

Chicken manure was reported as having benefits not only because it is cost-effective, but is available locally and has benefits for soil productivity:

> … our neighbour has been using chicken manure for probably 20 years … I think the big thing with the manure is it's really high in potassium and water use efficiency. (BCG interview 01)

> … the chicken manure-spread paddocks, those farms are seeming to get a lot more mineralisation as well, so they're coming into the next season with a lot higher available nitrogen … and mineralised N is a lot better than synthetic N because it's only available when it's actually wet as well, so the crop demand actually just takes it up when it needs it. (BCG workshop participant)

The use of chicken manure was in the early stage of implementation, and for participants it was too early to evaluate the benefits:

> … we'll show it on the benchmarking, if we're actually fixing ground and what our water efficiencies are – we'll get trends. (BCG interview 01)

> We've done a couple of soil samples after we've spread it and we probably haven't … seen a lot of change. So it'll be interesting to see when we do it over a couple of years after that and see where it really seems to kick in. (BCG interview 02)

Nonetheless, there was hope that the use of chicken manure would reap productivity benefits and therefore be widely adopted by farmers in the region:

> We may not reduce our costs, but we might lift our gross margin … because if we increase our yields, our harvesting, our freight and maybe our nitrogen … will rise, but so will our net profit, because you get even better gross margins. (BCG interview 01)

For MFMG participants, there had been moderate success in addressing the diversity of soil management issues in the region. The recent 'Soils 101' program run in the region was viewed as particularly valuable in improving understanding of how to enhance soil productivity:

> Sandy soils projects, and those sort of things have been very good for us. Now at the end of the day, it all starts with the soil, so if we can't get – we need to learn as much as we can about our soils to try and get the most out of it. (MFMG workshop participant)

Precision agriculture **techniques to improve drainage** were reported by NRM North participants as a soil improvement priority in Northern Tasmania. In this region, high winter rainfall leads to waterlogging in paddocks. For example:

> … drainage is a real issue, so that's a big one, because we have a lot of winter rainfall. So getting water off paddocks is a big one. (NRM North interview 02)

> … the canola flats pug up pretty badly in the winter, but they're very good spring grazing … All the canola stuff floods eight to 10 times a year, so it's unusable in the winter really. (NRM North workshop participant)

Workshop participants explained how they integrate a range of technical options into their management of waterlogging. One of these techniques is aerial mapping the terrain:

> If you have an aerial picture that really pinpoints the need for drainage, where the drainage is needed, so that's valuable. (NRM North workshop participant)

Drones were described as increasingly valuable in pinpointing areas needing drainage:

> They do put a drone up through an external contractor to look at a couple of paddocks every year and we try and pick out something which is a paddock that's got about five different soil types. (NRM North workshop participant)

Aerial mapping is an important technique for enabling farmers to build a more accurate and quantifiable picture of waterlogging on their farm, and to better target areas that need drainage.

For WANTFA participants, **mechanical amelioration of water repellent soils** (also called non-wetting soils) were identified as a key priority to improve soils in Western Australia. While soil characteristics and constraints in the regions encompassed by WANTFA are diverse, water repellent soils were identified as a particular challenge:

> The soils across our region are quite varied … Then as you get up the slopes, into the mid-slopes, these move into a lot of white sand, which is low fertility and tends to be water repellent and non-wetting, a lot of iron, like rocky outcrops, that are iron and gravel-stone based. They tend to be highly productive, but also, too, they can be inherently non-wetting too. Other soils that are what we called sandplain type soil, a deep yellow sand and very good at growing crops, now that they've got the nutritional packages right and also, after you overcome the issues with water repellency. (WANTFA interview 01)

WANTFA have been working with the state agriculture department "to develop strategies to combat those issues" (WANTFA interview 01). Two amelioration methods that have been used to address water repellency are mouldboard ploughing and the use of a Plozza plough:

> … mouldboard ploughing, where if there's a single issue, like water repellency, the soil can be mouldboard ploughed to about 30 centimetres deep, which inverts that top 30 centimetres of soil and buries the water repellent layer at depth. So, then you don't have water repellent soil again. Then a last main way of ameliorating soil is through the use of what's called a Plozza plough, that was developed by the Plozza brothers. That involves a modified one-way disc plough with huge discs on it that basically invert soil the same as a mouldboard plough, but with a far lower initial capital outlay and also works quite well in gravel soils, where mouldboard ploughs don't like to go. (WANTFA interview 01)

While farmer adoption of techniques for amelioration of non-wetting soil was reported as having improved in recent years, further integration of these techniques into management of the whole farm was judged to be the next step:

> … there's been a lot, a lot of work done in the last five, 10 years in all the amelioration practices, a lot of soil management. The knowledge is out there, but the next step is how do we optimise it over the whole farm, and within paddocks? I think that's where we can make the biggest inroad from now on … I think farmers have a good understanding of most of the constraints, but understanding how to manage them, 'horses for courses', which paddocks you can do which – and also how you manage that paddock afterwards. (WANTFA interview 04)

Promoting adoption in pasture systems was also identified as a key priority:

> … the cropping people have taken on the soil amelioration, but that's where the research was initially focused and now we're only just starting to look at soil amelioration in a pasture system and how they can improve pasture productivity, as it has for crop production. (WANTFA interview 01)

The data discussed above show that the farming systems groups have clear soil improvement priorities that are relevant to specific soil management challenges in their region. In general, farmers appear to have a good understanding of those priorities and are engaging with techniques and technologies for addressing them. However, to tease this out further and understand the extent to which these techniques and technologies are adoptable (Objective

1), it is necessary to focus on the interventions each farming system group are using to encourage adoption, and the complications and challenges involved in their effective implementation.

INTERVENTIONS FOR PROMOTING ADOPTION OF SOIL IMPROVEMENT PRIORITIES

Interventions for promoting farmer engagement with and adoption of regional soil improvement priorities focus on a mix of farmer and expert-led activities including:

- farmer-driven soil projects
- on-farm trials
- the use of trusted experts, including private agronomists.

It is important to note that a mix of interventions are typically used within each of the regions covered by the farming groups in this research.

Farmer-driven soil projects or trials

Two of the farming groups – BCG and CWFS – engage with farmers directly as part of their governance processes in developing soil improvement projects. The rationale underpinning this approach is that farmer involvement from the outset will ensure greater relevance and benefit, and a higher likelihood of wider adoption.

The BCG uses the region's farmer networks to investigate and trial local soil issues, with a board meeting twice a year to plan and evaluate projects:

> Well we have farmer networks, so we have farmer networks that we use … to ground our research in, but then they partner with a lot of organisations, so Soil CRC, they'll tender for things that they think will benefit their farmers … A couple of times a year we get together and just run through problems that the farmers have got. Then we try and match research opportunities with things the farmers have got. Then some of the trials ... But the benefit is being able to tap into external resources and really push the horizons out. (BCG interview 04)

The BCG feedback group makes project recommendations based on farmer requests. As one participant noted, this is an effective way of ensuring alignment of group projects with local farming priorities:

> They want to know about soil biology, we'll tender for that and we'll try and get some info. So they do try and align as best they can. (BCG interview 04)

Similarly, the CWFS group also works closely with its member farmers in a variety of ways to address soil management issues in the region:

> We have an executive board committee made up of farmers and they direct some of the project work and activities that we do. I talk to a lot of farmers to ascertain what they would like us to do for them; what projects they would like us to pursue and what workshops, who they would like to talk to. (CWFS interview 02)

An important part of this process is setting up field trials. A participant explained the model for engaging farmers with trials:

> My role with farmers is basically trying my best to communicate with them on what they need, on what … the organisation needs fulfilled in a project sense. So, if we have a trial, we need trial sites or we need growers for participation in particular things so, I'll have contact with growers in that regard and I'm always trying to get them to talk to me about things that they need that the organisation needs to help fulfil for them. (CWFS interview 01)

A further important activity pursued by the CWFS that relates specifically to soil improvement is building on-ground/local information on soils. This is achieved via a targeted approach to working with farmers, as described by one participant:

> Boots on the ground – so, we try and talk directly with farmers and the ideal is to bring out the knowledge of which they want. So, if there is a particular researcher that they want to have a chat with we ideally bring them out and have workshops. (CWFS interview 01).

For AIR EP participants, the Minnipa Agriculture Centre (MAC) was reported as central in engaging local farmers. The MAC provides extensive trial plots, demonstrates innovations and convenes regular field days to communicate results to farmers. However, it also plays a key role in facilitating collaboration between farmers and experts in the development of locally relevant soil improvement projects. A research participant detailed the way that topics such as improving ground cover are incorporated into projects:

> Twice a year – we usually meet in April – we bring in a group of agronomists, a group of farmers, and we sit around the table and chew over all the issues that are around and try and come up with good projects. (AIREP interview 05)

The board's role is to provide expertise rather than work directly with farmers:

> We don't directly work with the farmers; we instigate the field days and that's how we sort of operate, and then we get the technical expertise in that we think we need for that particular field day to sort of liaise with the farmers. (AIREP interview 05)

The results are evaluated at later meetings and communicated to farmers in fact sheets and at field days.

On-farm trials

On-farm trials are a widely-used technique for improving adoption across most of the farming groups. Trials were seen as valuable in learning about, and having the opportunity to assess, new soil management techniques and practices:

> We'll go and look, and if [name suppressed] has had a trial of something and it's really good because if it fails, you've still learnt … You start on a small area and you can evaluate … (RP workshop participant)

For farming groups such as WANTFA, trialling is critical in learning more about new technology and thereby 'de-risking' it for farmers:

> … our role really is to bring that new innovation in and evaluate it and put it forward so then farmers can come and have a look at it and the risks, the process I take is what I call de-risking. So, where something's new, it comes in, its full of risk/ it's too risky to adopt. So, then we go about a series of trials to understand more about what the particular problem, or the particular solution, or innovation could be. Then during that process, we inherently lower the risk, because we're learning more and more about this new innovation. (WANTFA interview 01)

This process is argued to be particularly effective if farmers' own equipment and knowledge is used in the design of trials:

> We work with farmers on their farms, predominantly … Particularly of late, we tend to work with farmers using their equipment, using their knowledge and what they want to do, based – yes, we guide them in their – how to design trials and so on. (WANTFA interview 04)

On-farm trialling was viewed by MFMG participants as important in working out how soil improvement techniques and technologies can be adapted in managing individual soil types:

> I think that's the thing, I think the farmers actually do a lot of their own trial work on their own place because it's unique to their area and what works … at Beachport mightn't work for Bruce at Bool Lagoon and it might work differently for people north of Naracoorte. So we're all our own researchers at the end of the day. (MFMG workshop participant)

However, learning does not necessarily occur only through the process of trialling. It can also occur through observation of trial plots and results. One of the techniques used by the AIR EP FSG are 'Sticky Beak Days' where a group of interested farmers gathers on a nearby property to inspect a colleague's adoption or trial plot of an innovation. The general format for organising a field day is:

> … someone puts their hand up to organise a Sticky Beak Day, so it's just very informal. It's like, right, we're going to go to Joe Blow's and we're going to go to Jack's, and we're going to go to Tom's and we're going to go and see what Henry's doing – because he's started some newfangled thing – just want to have a look how that worked, or a new crop – cover crop – they looked at a cover crop the other day at the Minnipa Sticky Beak Day. (AIREP interview 03)

This approach is viewed as useful in the Eyre Peninsula where soil types and management technologies vary widely because farmers can see trials that are relevant to their local soil and farm business mix without the need to travel long distances.

Use of trusted experts

The use of local or external soil experts is used by most of the FSGs to inform farmers of local soil improvement priorities, and/or to work with them in adopting innovations for addressing those priorities. Local experts are particularly valued as they are trusted and can translate soil science into a language that is comprehensible and relevant to farmers. For example:

> Right throughout the southeast we are promoting – and this is by working with [name suppressed] … She's a really good communicator, she's just really vibrant and enthusiastic and just loves soils and loves working with farmers, which is great. (MFMG interview 03)

> … having people like [name suppressed] in the room to talk – and an expert who can communicate with them, someone … is really good. There are some fantastic soil scientists out there, but having that middle person who can talk to the farmers in their language about their constraints, and what works and what doesn't work, and I think that's vastly important. (WANTFA interview 04)

At the same time, declining public resources for extension mean that farmers are relying more on the soil advice of private agronomists and advisors.

> … since we've seen the departments of ags disappear, agronomists are the main source of knowledge for most farmers these days. That and field days run by say, Southern Farming Systems or people like that. Yeah, it's really been a change in information extension I think over the last … 15, 20 years … farmers reluctantly go to a field day, (even) very well-run field days, because they know that people like me will go and we'll report back to them. (NRM North interview 02)

Many farmers increasingly use private agronomists as a key source of knowledge, as well as a means to stress-test ideas and inform thinking:

> I pay a private agronomist. He goes on every - well not every farm - but he goes in every region of Eyre Peninsula and he goes to all the updates. He gets all the knowledge and he passes that on to us. That's probably the main way we get it. (AIREP interview 05)

Another participant explained:

> a lot of guys are using consultants. There's a few industry like retailers, commercial operations and they do field days and demo days and stuff. There's some of these guys that aren't coming maybe to a MAC field day will often turn up at those. (AIREP interview 04)

However, the extent to which soil improvement priorities of private agronomists/consultants are aligned to those of farming groups, and the extent to which they collaborate and share knowledge and resources with farming groups, is unclear from the data.

COMPLICATIONS AND CHALLENGES IN IMPROVING ADOPTION

While the interventions outlined above were viewed by participants as mostly effective in engaging farmers, a number of complications and challenges were identified in transforming that engagement into improved adoption.

Tensions between farmers' ethic of caring for the land and farm financial viability

Participants in the workshops and interviews emphasised that farmers have a strong ethic of caring for the land and soil, which is central to ensuring continuity of the farm. For example:

> You have to look after your soil … The better you look after it the better it looks after you. There's no doubt about that … That's the first thing you think of when you go to sow your crop. It's the first thing you think of when you go to throw a mob of sheep in the paddock. We don't talk about it because it's ingrained. (EPARF workshop participant)

> I'm a steward of this soil. I will invest X amount of dollars – that's essentially what a lot of farmers are doing. They are investing in the stewardship of their land. There's always the quote that goes around; my grandfather – I want to leave my land in a better state than when I got it. (RP workshop participant)

> All farmers I know care for their land. I know they get upset when they see it blowing, and I know they get upset when [there's water] erosion. I know they get upset when there's non-wetting and there's patchy germination in the soil. It is a bottom-line dollar thing for them, they are businesses, family businesses. They've got to care for their family, want to be profitable. But it goes beyond that. (WANTFA interview 04)

> I do think [farmers care for the land] because we're in an environment where everyone's more open to talking about improving soil health and soil organic matter, and soil biology, I really think that farmers are keen on looking after their soil health. But I believe that they've always been ones to want to look after their country. (CWFS interview 01)

However, financial constraints were judged to make it difficult for farmers to care for the land in ways that they would like. This leads to decisions and practices that may run counter to their ethic of caring for the land. For example:

> … the number one thing I've noticed with farmers all along, is that they want to look after their land and they want to look after the environment and the trees and all these things, but unless it pays, little is done because they haven't got endless money. So if you want soil improvement to be taken up by the farmers or the communities, for me I would say, number one is it's got to put money in their pocket. (MFMG interview 01)

> … soil improvements, whilst farmers have the best interests at heart, I think it's financially driven. So, growers have an understanding that they need to be checking their soil pH or they need to be doing soil testing, and they need to be liming. But when the yields are low, and the input costs are still high they can't justify spending money on lime. They've got to spend money where they know they can generate a return, and unfortunately that's in urea and fertiliser and chemical, because it's been proven that it generates a return, and a rapid return. (CWFS interview 01)

This is exacerbated by the fact that there are no immediate financial rewards for caring for the soil, which means that soil health is not always a priority in farm decision-making.

> I think they do care for their soils, but they don't put a value on it … Soil health doesn't sit on the balance sheet. So, at times, when you need to, you can treat your soil health quite badly and it doesn't matter … Soil health doesn't directly make you money. (WANTFA interview 01)

More research highlighting the financial benefits of particular soil management practices was judged by some participants to be key to improving adoption:

> I think it's more research, showing the benefits of it … putting a dollar figure to those benefits. That is the thing that will create greater and quicker adoption by people, rather than a policy and regulations and more red tape. Farmers have enough to deal with. They have enough bookkeeping. They have enough recording of information. We need to encourage them because they can see the financial benefits and the long-term sustainability benefits. (NRM North interview 03)

> From a broadacre livestock point of view, I think what would drive change for us, and people like us, is showing that it's worth the effort. If we, for example, pay for 40 soil tests across our farm, if we pay for half a dozen tests per paddock, and then we can reduce our fertilizer by that amount, then you'd go and do it. If somebody could show us that we could do that you'd probably then spend the money on the soil testing. But it's such a change from what people normally do that we need to really show them a reason to do it. (MFMG workshop participant)

Other stakeholders argued that highlighting the financial benefits alone was insufficient in improving adoption, and that incentives are necessary for "recognising or rewarding farmers as custodians of the land." (BCG interview 06). For example:

> The major policy I would like to see is around recognising or rewarding farmers as custodians of the land and in terms of being good custodians of that soil. You know, in terms of being responsible for the quality of the food that we eat and the air that we breathe and the water that we drink, I think that farmers play a crucial role there, and at the moment they're doing it at their own expense. (MFMG interview 02)
>
> I do think there's opportunity to have incentives that they can get, a premium credit if they're doing good soil management. But it comes down to soil management, that can sort of include whether they're doing biodiversity things as well, and things like that. It's looking at the system as a whole, not necessarily as soil isolated. I'm a big believer that the industry needs an index, an agriculture index, like a CANSTAR rating, so something that takes in to account, land capability, soil type, production, you've got your carbon, organic matter, but also taking in infrastructure, location, all that. (CWFS interview 04)

As highlighted by the above quotes, incentives ensure that a financial value is put on soil and its management, which contributes to a higher likelihood of farmers adopting soil improvement techniques and technologies.

Resourcing for farming systems groups

Resourcing for farming system groups is a further theme that emerged from analysis of the data. Funding constraints can mean that there are only sufficient resources for conducting research on local soil improvement priorities, leaving little left over for effective extension activities. For example:

> …we don't have a lot of funding to promote the need to monitor and address soil acidification. If soil research is so expensive or investment in any soil projects – to get good data – is so expensive, it's very hard to focus our dollars as effectively as we could. (RP interview 03)
>
> It's very time consuming and expensive. You need people to do it, and there's no point doing the research if you can't get it out there. There's a lot actually that's been done that just isn't getting out there. For a farming systems group, it's really hard just to keep your core people there to fund them to do that kind of work… I think if you're relying on the farming systems groups to deliver that information, extend it, they've got to have something there to keep the light on. (MFMG workshop participant)

One of the major challenges raised by participants is that research and funding organisations do not always have an understanding of farming system groups R,D and E needs and priorities:

> Sometimes, these big organisations think that these local organisations can exist on fresh air, whereas if they're part of a program or a project, they've got to be treated as equal partners. So they've got to be resourced to be involved, as well as the CSIRO or the universities. They need resources to have the researchers do the work. (EPARF interview 06)
>
> Because we're not for profit and a hundred per cent grant funded, that holds a lot of constraints around being able to deliver bottom-up projects because a lot of it is set by the funding body. Whilst the funding bodies are meant to have scoping groups that provide the research needs and the research questions that are supposed to be in the farmers' best interest they are not always on point. (CWFS interview 01).

This lack of understanding leads to under-resourcing, or funding for delivery of outcomes that have limited relevance to local research and extension needs.

Tensions between scientific and local practices/priorities

A broader issue raised by participants concerned tensions between the practices and priorities of soil scientists, and the organisations they work for, and local farming priorities. Participants observed that while farmers have a concern with farming systems, soil researchers tend to focus on discrete parts of the system. This leads to research that at times is of limited relevance to farmers:

> There's always a need for more research, but the research needs to be – from a soils point of view – holistic research, not just based on picking a particular issue and ignoring all the other factors. I think, in reduction of science that's a difficult thing to do. A lot of research has been conducted to really try and find a silver bullet, and with soils it's more about practice change rather than applying a product. (EPARF interview 02)

> I think for the researchers sometimes monitoring our farms might be more useful than just a small trial block … [The problem is] that researchers are reductionists. They need to be able to control the one thing that they're studying. They can't work in systems. (CWFS workshop participant)

> What it comes down to is just the system. Not one thing. You can't do one thing and expect everything else to change. That's what we've found. It seems to be working. (WANTFA workshop participant)

A related issue raised by participants is that what soil scientists view as important is not always useful or useable for farmers. For example:

> You don't want a group of researchers who are fascinated by soils thinking well this really fascinates us so then we'll research it and then we'll go out and try and tell people to use it. We'd like to see the research being on some of the topics that worry and concern us, that we see as challenges … than be of a pure scientific interest to someone. (RP workshop participant)

> If all it is is a researcher telling a farmer you do this, you do this, you do this and not listening to the farmer saying well, I can't do that. Because when you're asking me to do that I'm focussing on, I have to focus on my sheep or I have to focus on my cattle or I have to focus on … my system. (BCG interview 05)

> …they [soil scientists] asked can we test the soil for stuff and the first question from the scientist, what would you like to know? You're like, I just want to know if it's good soil. Yeah, yeah, but what are you calling good soil? The farmers are just like, tell me if I'm doing the right thing and we don't know what question - we know the answer we want, which is yes or no, but the scientist can't run with that. That's not a study, that's not an investigation. (BCG interview 04)

A final issue concerns research organisations not taking adequate account of local farming knowledge, practices and networks as part of their research:

> Even under a research thing, the research is done with the leading farmers. It's not the researcher coming and saying well this is going to [address] acidity and clay and that sort of stuff. Generally, there's already a leading farmer trying this stuff and then the research comes in after they see it done. (WANTFA workshop participant)

> [Organisation name suppressed] didn't throw their hands in the air, but they got to a point here where it was very difficult to understand how much further to measure and manage our soils, and the work just hasn't been done since then. It's really been up to farmers and local people begging and scratching for basic monies to run localised trials and develop our own skills. (MFMG interview 04)
>
> We are getting those bigger R&D organisations who have these bigger projects and are a bit remote from the regions, and they come in to the region to do their work or whatever and they're not connecting with those local networks. That's a situation where you team up to get good buy-in. (EPARF interview 06)

Explicit consideration of local farming knowledge and practices was viewed by participants as critical in driving effective local soil research and extension.

Resourcing for data management and interpretation

A final challenge for farming groups in improving adoption was the lack of resourcing in data management and interpretation. Participants observed that much soil research funding tends to be invested in development of new products or technologies. However, as one participant observed: "technology itself doesn't really do much, it's how you interpret the information, that's the key" (NRM North interview 02). Consequently, some of this funding was argued to be better directed to resources to assist in the management and interpretation of data from existing products. For example:

> We've been having a few courses on PA and that's good … The problem really is a lot of the PA is quite complicated still. The overlaying of the maps and the soil. I think that really farmers need better support to run through all that, so that once they set it up they can – because there's a lot of data out there but it's actually understanding what it all means and how you roll it out. There's a long way to go in that area. (CWFS interview 02)
>
> The amount of data that the actual growers produce themselves on the farm is huge. The analytics that happens with that data they produce is next to nothing … Like we've got soil data and soil tests and harvest data and different applications of different rates of fertiliser and different soils. But you know, to crunch the number on it, it's huge. The growers haven't got time to analyse their own data. (RP workshop participant)

Agronomists and advisors were viewed as key personnel supporting farmers in data management and interpretation. However, participants judged that taking on this role requires that agronomists and advisors have the necessary knowledge and skills to accurately interpret data:

> I think one of the things in terms of our teaching and so on is a better understanding of data management. There's so much data that's collected by growers. What to do with that data and how to get benefit from it. So even the agronomists who are coming up they need to be able to I suppose better understand how to manage data and the scientists as well. I think data management and making decisions from data is going to be a key thing. (WANTFA interview 03)
>
> I think soil analysis is a skill, a method of monitoring, which we would like to promote, but unfortunately a lot of the advisors don't necessarily have good soils knowledge and know how to interpret a soil test for different soil types … It's very difficult because sometimes the analytical procedures are not necessarily correct for the particular soil

> type. Also, interpretation of the data can be very specific to a particular soil type. I think that's the number one weakness we've got. (EPARF interview 02)

For some participants, resourcing is also needed to extend to the local interpretation and extension of research findings. This is something viewed as often being neglected, or an afterthought, in research projects. For example:

> …the volume of information that we've got coming at us is enormous. It takes a fair bit to filter through and make sure it's all kind of relevant and/or to understand it. I guess if we were able to have more people power towards interpreting that information and repackaging it into a format that can be extended out to people, I think that would be really good … There are lots of things that we don't know, however there's a whole heap of existing research that's out there at the moment that I don't think has been extended well. Often the answers are there for people although they think that they are not. (MFMG interview 03)

For this participant, resources could be better directed to the interpretation and extension of existing research findings rather than new research projects.

DEVELOPMENT OF A DRAFT ADOPTABILITY FRAMEWORK

Informed by the literature review on adoption and adoptability, the project team used the findings from the Year 1 workshops and interviews to develop a draft adoptability framework. The **Framework for Understanding and Assessing Adoptability of Soil Management Innovations** builds on the criteria of adoptability outlined in Scoping Study 1.2.01. It is a diagnostic approach to help FSGs and/or other local stakeholders – such as agronomists, advisors and extension personnel – involved in the implementation of soil management innovations (practices, techniques and/or technologies) better understand, and potentially improve, adoptability of those innovations. The framework is also intended as a social learning tool for facilitating discussion with farmers, scientists and other relevant stakeholders on the best ways of addressing local soil improvement priorities and challenges. As such, the framework is as much a guided discussion tool as it is a decision-support tool. A copy of the draft framework is in Appendix B.

The diagnostic approach uses four simple steps that FSG staff and/or local stakeholders can work through to clarify areas for action, collaboration and investment:

STEP 1

Identify a soil improvement challenge or priority in the region. Examples of a challenge or priority to include here might be soil acidity, waterlogging, or soil erosion.

STEP 2

Identify the proposed (generally new or innovative) soil management innovation(s) for addressing that challenge or priority. For example, variable rate liming practices might be considered an innovation for addressing the challenge of soil acidity.

STEP 3

Identify the key adoptability drivers that affect uptake of the proposed soil management innovation(s). While traditional extension models focus predominantly on characteristics of the farm or farmer in driving adoption, the seven drivers outlined here encourage consideration of **multiple drivers of adoptability**, and particularly those drivers that emerged as most relevant in the workshops and interviews. By answering questions relating to each type of driver, FSGs and other stakeholders can develop a clearer sense of which drivers are currently favourable to adoptability of the soil management innovation(s), and which may represent a challenge to improving local adoptability. Drivers that are mostly favourable to adoptability should be shaded **green** in the framework, and drivers that involve one or more challenges to adoptability should be shaded **orange**. **Red** can be used if there are no evident favourable conditions. The driver types are:

- **Personal or family** – The risk/innovation orientation/attitude, identity, and skill and knowledge of farmers themselves.
- **Farm system** – The aspects of the physical farm environment, climate, crops, existing practices and tools with which new approaches need to 'fit'.
- **Financial** – The relative advantage, trialability, marginal gain and potential adverse financial consequences of the innovation.
- **Local network** – The extent and stability of local innovation networks, including peer-to-peer, formal extension and advice, demonstration, volunteerism and regional farming cultures/cliques.
- **Socio-cultural** – Regional/national/global cultures and discourses of farm/soil management and the widespread norms or identities that they condone (or otherwise).
- **Institutional/policy** – National, state and sectoral drivers of collaboration, R&D activity, including science and technology policy and to a lesser degree trade policy.
- **Market** – Largescale drivers of consumer preference that send price signals to farmers to drive change in attitudes, aspirations and behaviour.

STEP 4

Identify interventions for addressing adoptability challenges identified in Step 3. This part of the framework asks for three things:

First, in the left-hand column of the slide participants list those **drivers identified as adoptability challenges** from Step 3 (i.e. those shaded in orange or red).

Second, for each driver, participants **identify research, development and extension interventions** that are viewed as likely to be most locally relevant and effective for improving the relative advantage to farmers of the proposed soil management innovation(s). To assist in selecting the most appropriate intervention(s), two broad strategic approaches adapted from the work of Joks and Law (2017) are used to organise the addressing of specific adoptability drivers. These strategic approaches are:

> ***'Hardening' local knowledge*** – this approach is recommended where there is broad agreement among farmers about a soil challenge or priority that needs to be addressed, but that challenge/priority is not well understood by researchers, or there is limited local data to support a case that the challenge/priority is worthy of scientific research. It involves translating farmers' knowledge and practices into 'hardened' (e.g. standardised, evidence-based) forms that are familiar and understandable to soil researchers and policy makers. This is important in making soil science and

policy more responsive to local challenges and priorities. 'Hardening' may include creating safe spaces for trialling and learning, championing local innovators, and facilitating communities of practice among farmers for recording and interpreting local soil data.

'Softening' scientific and institutional knowledge – this approach is recommended where soil experts have identified a soil improvement challenge or priority, there is a scientific or technical pathway to address the challenge/priority, but greater buy-in from farmers is needed to improve adoption. It involves developing practices that enable scientific research to be translated into locally useable forms that engage farmers' knowledge and decision-making. Some examples include developing projects that catalyse linkages between researchers and farmers through forming temporary communities of interest, partnering with scientific or government agencies in the co-development of priorities and solutions, and maintaining local experts who can represent local interests scientifically.

Third, participants consider **questions relating to the implementation of interventions** that fall under one or both of the above approaches. These questions are intended to highlight issues around the feasibility and practicality of implementing the proposed intervention(s), and how FSGs and other stakeholders can maximise the value of the interventions for improving relative advantage and therefore adoptability of soil improvement innovations.

TESTING OF THE ADOPTABILITY FRAMEWORK AND CUSTOMISING TO DIFFERENT REGIONAL CONTEXTS

The draft adoptability framework described above was tested for relevance through a second round of workshops with members of the leadership team of each farming systems group. Through a facilitated participatory approach, this involved refining and ground-truthing the efficacy of the adoptability framework using real-world local examples of soil management challenges. Overall, farming group participants reported that the draft framework was useful and useable. In all workshops, the framework only required minor changes – mainly Steps 2 and 3 – to more accurately reflect local soil adoption challenges and priorities. The changes contributed to the co-development of seven slightly different adoptability frameworks tailored specifically to the adoption challenges and priorities of each region. An example is provided in Appendix C highlighting the amendments that were made to the framework by one farming system group in the course of the second workshop.

DISCUSSION

This research project sought to address four specific objectives, which are re-listed below accompanied by a discussion of how the project results address those objectives.

Objective 1: Investigate the efficacy of current strategies used by regional farming groups for the promotion and adoption of improved soil management.

The research shows that farming groups use three main strategies to promote adoption of technologies and techniques for improved soil management, namely farmer involvement in the design of research projects or trials, on-farm trials, and by using trusted regional (and sometimes external) soil experts. These strategies involve a mix of 'softening' scientific and

institutional knowledge as well as 'hardening' of local knowledge. They highlight key dimensions of a co-constructivist adoption model involving:

- the use of trusted experts in linking soil science to local priorities and challenges
- farmers contributing to the design of local research projects and trials
- social learning associated with on-farm trialling.

The qualitative data across both the semi-structured interviews and the first round of workshops highlight that existing strategies for promoting soil improvement techniques and technologies are working generally well in engaging farmers, primarily because they build on farming knowledge and experience, use trusted and credible sources of advice, and have practical relevance to the management of local soil issues. There is plenty of evidence that these factors provide a strong foundation for adoptability (e.g. Ingram, 2008a; Krzywoszynska, 2019; Prager & McKee, 2015). However, engagement does not necessarily lead to improved adoption. The efficacy of current strategies is contingent on adoption drivers being favourable to the implementation of soil improvement adoption priorities. Some of these drivers may not necessarily be within the control of farmers or farming groups. We discuss these in more detail below.

Objective 2: Develop a framework (conceptual model) of commonalities and differences in relation to adoption priorities, drivers and pathways for improved soil management across different regional contexts.

The adoption priorities identified by participants in the interviews and the first round of workshops are diverse and reflect specific biophysical, climatic and production challenges in each region. For example, using aerial mapping to manage drainage issues was discussed by NRM North participants only. In this case, the priority of improving adoption of aerial mapping is related to high winter rainfall in Northern Tasmania and the drainage issues this creates. Only two farming groups – CWFS and Riverine Plains – shared the common priority of encouraging more strategic lime applications to manage soil acidity. This is reflective of the soil acidity problems that are common to each region. Gauging commonalities and differences in adoption priorities was critical in the development of Steps 1 and 2 of the draft adoptability framework.

In contrast to much of the soils adoption literature, the common drivers of adoptability reported by participants that influence local capacity to address adoption priorities are largely institutional/policy or market-related. These include:

- a lack of financial or market incentives for improved soil management practices
- tensions between priorities or practices of research organisations, researchers and regional soil management practices/priorities
- lack of resourcing for farming systems groups to address regional soil management priorities
- limited resources for improved soil data management and interpretation.

There is a remarkable degree of similarity between farming groups in terms of these key influences on adoption. This suggests that despite the regional differences in adoption priorities, there are opportunities for the development of common and collaborative pathways for addressing the institutional and market drivers that currently impede increased adoption of soil improvement techniques and technologies.

Objective 3: In partnership with farming groups from across Australia, co-develop criteria of adoptability, and a set of principles and recommendations for increasing adoption of improved soil management across different regional contexts and farming systems.

A major output of this project is a draft framework for understanding and assessing adoptability of soil management innovations. The framework was developed by the researchers after analysing the qualitative data collected from the interviews and first round of workshops. This was refined through a second round of workshops where farming system group leaders contributed to tailoring the framework to make it more useful and useable to their specific soil management priorities and regional context. The adoptability framework provides a more practical, applied, and context-sensitive tool for farming systems groups than the criteria for adoptability developed as part of Scoping Study 1.2.01 (see Appendix D). It does so by integrating into all three steps of the framework, characteristics of the innovation/practice (diffusion of innovations approach), characteristics of the producer and their socio-cultural context (socio-cultural approach), and characteristics of the knowledge and power relations (co-constructivist approach) that frame how the innovation/practice is developed and promoted. Other adoption models tend to focus primarily on characteristics of the innovation/practice or the potential adopter, drawing on Roger's diffusion of innovations approach (e.g. Kuehne et al., 2017; Pannell et al., 2006). Socio-cultural drivers are given limited attention, and broader knowledge and power relations related to institutions, markets and policy are not usually considered at all. Our framework also differs substantially from others in that it is co-designed with end users. It therefore takes into account the specific adoption drivers that are relevant to regional contexts in which end users are located, which leads to identification of interventions that are better suited to local practices, knowledge and conditions, and which are more likely to be used by farmers.

Objective 4: Based on the project findings, develop a proposal for Phase 2 research that investigates the broader political and institutional drivers for adoption of improved soil management to enable policy and commercial settings to better support adoption.

It was originally envisaged that political and institutional drivers for adoption would be investigated through a separate project that builds on the findings from this research. However, the influence of institutional and political drivers on implementation and adoption of local adoption priorities is clearly evident in our findings in three key ways:

1. The absence of financial incentives or rewards for the adoption of soil improvement practices or techniques means that farmers are often forced to prioritise short-term profitability over longer-term care for the land.
2. The priorities of research organisations and funding bodies are not always aligned with regional soil improvement challenges and adoption priorities. At the same time, soil researchers are not always engaging in meaningful ways with local farming knowledge, experience and networks, which leads to research outcomes and innovations that do not necessarily take into account the complexity and diversity of local farming systems.
3. National and state soil policies and strategies are concerned almost entirely with the technical aspects of managing soil. Issues related to adoptability and adoption are not considered at all.

As such, we argue that rather than developing a Phase 2 research proposal, the focus of Soil CRC activity in this area in the future should be actionable strategies that address the political

and institutional impediments to adoption identified in this research project. It is essential that actionable strategies are developed collaboratively, among the Soil CRC, other funding bodies, policy makers, farming systems groups, and the project investigators.

CONCLUSION

The diagnostic adoptability framework developed through this project provides a more useful and useable approach to understanding and assessing the adoptability of an innovation than existing models. In contrast to existing models, the framework has been co-developed with its intended users – farming systems groups and local extension personnel who are involved in the implementation of improved soil management techniques and technologies, and who have an intimate understanding of regional soil priorities and challenges. Because the framework has been co-developed with end users, it takes into account the multiple and multi-scalar drivers – local, regional, national – that are most relevant to them in influencing adoption. As a guided discussion tool, the framework is also easily customised to take into account different regional soil management priorities and challenges, and the specific interventions that may be required to address those. It enables stakeholders to determine areas for action, collaboration and investment that contribute to addressing local soil priorities and challenges.

The adoptability framework developed through this research will assist regional farming systems groups and other extension personnel to better target soil management resources and communications to their members/clients. Integration of the framework as part of the project application/review process in future Soil CRC funding rounds will also help soil researchers and policy-makers develop soil management tools and programs that will be more widely used by farmers. The longer-term pathways to impact rely on social and institutional change to support improved adoptability. These pathways are expected to accrue from the findings and recommendations of this project being embedded in later Soil CRC projects and delivery activity, and in application of the adoptability framework by a wider cross-section of farming groups. It is hoped that this project will lead to the development of more adoptable practices and technologies among projects and programs that effectively respond to its recommendations. The farm-level and public benefits will thus accrue through the work of the next users who adhere to the project's recommendations, including:

1. Participating farming groups who are able to work more effectively with farmers to support adoption of improved soil management practices.
2. Soil CRC and related projects that effectively deliver adoptable practices and technologies.
3. Policy makers who better understand adoptability and can ensure resourcing and intervention to enable adoption.
4. Practitioners such as agronomists and advisors who are able to provide more effective advice and support to farmers in adoption.

RECOMMENDATIONS

Based on the major findings from the project, a set of principles and recommendations have been identified that the Soil CRC and other R, D and E organisations, soil researchers, farming systems groups and policy makers can implement to increase adoption of improved soil management across different geographical contexts and farming systems.

Recommendation 1

That farming systems groups are supported when developing workshops aimed at providing farmers with the confidence and skills in soil data management and interpretation. The workshops should be developed in consultation with local agronomists, advisors and other trusted change intermediaries.

Recommendation 2

That the Soil CRC integrate into the project application/review process:

- a requirement that all research involving adoption implications details how the Framework for Understanding and Assessing Adoptability of Soil Management Innovations will be integrated within research projects
- a requirement for documented evidence from end users that the outcomes and/or products from the research are likely to be relevant to locally defined soil management challenges and priorities, and suited to the local geographical and farming systems context.

Recommendation 3

That the Soil CRC collaborate with policy makers, farming systems group partners and soil researchers to develop a strategy that defines best practice soil management standards, and outlines different options for rewarding farmers who meet those standards.

Recommendation 4

That the Soil CRC develop a strategy for resourcing and evaluation of farming system group soil improvement extension initiatives. The strategy should be developed in consultation with farming system groups and extension and adoption experts.

Recommendation 5

That the Soil CRC develop an adoption strategy based on the findings of this research. The strategy would be critical in making progress towards achieving Objective 2a in the Draft National Soil Strategy: fostering increased adoption of more sustainable soil management practices.

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APPENDIX A NARRATIVES USED TO DEVELOP FRAMEWORK INTO A USEABLE ADOPTABILITY TOOL FOR EACH FARMING GROUP

AGRICULTURAL INNOVATION AND RESEARCH EYRE PENINSULA INC (AIREP)

Assessing applicability of the Soil Adoptability Framework using the example of ground cover techniques for soil erosion mitigation

INTRODUCTION

Based on detailed analysis of qualitative data from the workshop and six interviews with AIR EP stakeholders, soil erosion mitigation using ground cover techniques – such as the use of purposefully planted cover crops or retained residual crop stubble – were identified as a key priority to improve soils in the region. The narrative that follows is based on participant reports about how ground cover techniques are being implemented in the region, mechanisms used for encouraging adoption, and the extent to which uptake by farmers has been successful. The narrative helps to clarify how local approaches for promoting farmer adoption of ground cover techniques align with the researcher's Soil Adoptability Framework. This framework outlines two complementary approaches for farming systems groups – 'softening' scientific knowledge, and 'hardening' local knowledge – in translating soil research and farming knowledge-practices into a form that is comprehensible and useful for both farmers and researchers.

ARTICULATION OF THE SOIL IMPROVEMENT PROBLEM/PRIORITY

Participants reported that there is wide acceptance of the benefits and use of minimum and no-till practices in the region. However, the promotion of ground cover techniques is now judged to be needed to prevent erosion and further improve soil management:

> I think good soil management involves a number of things but probably principally trying to get plant growth on the soil and therefore you've got holding capacity, you've got root growth. (AIREP interview 04)
>
> [Farmers are] very conscientious. I just feel like the farmers that are here, want to be here, and they want to – they love their farm, and they want to have good soil cover. (AIREP interview 04)

Good ground cover was reported as being a particular priority in areas with light or fragile soils:

> …getting vetches and getting the nutrition into the soil and then getting a good cover over that sand and actually then being able to sow into that limits your lifestyle in that sort of country. (AIREP workshop participant)

> …some guys can have the very best management practices, but when it doesn't rain for two years, it just doesn't matter what you do, because … the Eyre Peninsula is covered in very fragile soils and probably most of WA as well. If you're not careful, you can end up with a 'drifty' paddock, and … that's all your last 10 years of nutrients gone. (AIREP interview 05)

WHAT HAS BEEN DONE IN THE REGION TO ADDRESS THE SOIL IMPROVEMENT PROBLEM/PRIORITY?

The Minnipa Agriculture Centre (MAC) was reported by participants as central in encouraging local farmers to engage with and trial or adopt ground cover techniques. The MAC provides extensive trial plots, demonstrates innovations and convenes regular field days to communicate results to farmers. This is an excellent example of 'softening' scientific knowledge and making it more useable to farmers. A research participant detailed the way that topics such as improving ground cover are investigated and incorporated into projects: "Twice a year – we usually meet in April – we bring in a group of agronomists, a group of farmers, and we sit around the table and chew over all the issues that are around and try and come up with good projects" (AIREP interview 05). The board's role is to provide expertise rather than work directly with farmers: "We don't directly work with the farmers; we instigate the field days and that's how we sort of operate, and then we get the technical expertise in that we think we need for that particular field day to sort of liaise with the farmers" (AIREP interview 05). The results are evaluated at later meetings and communicated to farmers in fact sheets and at field days.

Another technique for encouraging adoption are 'Sticky Beak Days' where a group of interested farmers gathers on a nearby property to inspect a colleague's adoption or trial plot of an innovation. The general format for organising a field day is:

> …someone puts their hand up to organise a Sticky Beak Day, so it's just very informal. It's like, right, we're going to go to Joe Blow's and we're going to go to Jack's, and we're going to go to Tom's and we're going to go and see what Henry's doing – because he's started some newfangled thing – just want to have a look how that worked, or a new crop – cover crop – they looked at a cover crop the other day at the Minnipa Sticky Beak Day. (AIREP interview 03)

This approach is useful in the Eyre Peninsula where soil types and management technologies vary widely because farmers can see trials that are relevant to their local soil and farm business mix without the need to travel long distances. It provides a potentially important foundation for the 'hardening' of local knowledge, where trials build a local evidence base for good soil management that can inform scientific research priorities.

Many farmers use private agronomists as a key source of knowledge, as well as a means to stress-test ideas and inform thinking: "…my main way – I pay a private agronomist. He goes on every - well not every farm - but he goes in every region of Eyre Peninsula and he goes to all the updates. He gets all the knowledge and he passes that on to us. That's probably the main way we get it" (AIREP interview 05). A participant explained: "a lot of guys are using consultants. There's a few industry like retailers, commercial operations and they do field days and demo days and stuff. There's some of these guys that aren't coming maybe to a MAC field day will often turn up at those" (AIREP interview 04). The extent to which private agronomists/consultants promote the implementation of ground cover techniques to their clients, and whether or not they collaborate and share knowledge and resources with the MAC, is unclear from the data.

IMPLEMENTATION SUCCESSES, ADOPTION CHALLENGES, AND HOW THESE CHALLENGES CAN BE ADDRESSED

It is clear from the workshop and interview data that farmer participants understand the significance of ground cover techniques in addressing erosion problems: “Good ground cover; don’t want to see dust on days like this. My perspective when I see dust, as a farmer it’s sickening – you’ve made a bad mistake” (AIREP interview 05). Farmers also gave examples of successful erosion control using ground cover. For example:

> …when we had a dry year, was it last year or the year before, I had the options available to me because I haven’t actually touched any land that I didn’t have to sow it ... I didn’t have to chase some of these other ones because I’d worked them. I just left them and as I said, I spread all my sheep out and I got my sheep through. I didn’t have any erosion, didn’t have any problems so I thought to myself well that’s success because it’s actually achieved the goal that I set out. It’s reducing the wind erosion and giving myself flexibility in poorer seasons. (AIREP Workshop participant)

> …paddocks that were shit white sand, blow outs, complicated, angles everywhere, it just grew primrose and skeleton weed. Now they just fit into our three-year wheat, barley, vetch rotation and they’re covered. (AIREP Workshop participant)

However, despite acknowledging the importance of improving ground cover, some participants pointed to challenges in on-farm implementation. One of these challenges is the geographical diversity of the Eyre Peninsula. Ground cover techniques may not be appropriate or relevant to all farmers across the region:

> EP is just so, geographically it’s big and it’s also so different in – it’s also small with a lot of different rainfall and soil types in a small area. (AIREP interview 04)

A further challenge is where adoption of ground cover techniques can create new problems, and prompt a return to previous practices:

> when we solve one problem we sort of lead to another problem … e.g. stubble burning/ removal. (AIREP Workshop participant).

Stubble burning is a disputed practice used to eliminate crop stubble and weed burdens. However, a bumper crop season can create excessive stubble that leads to difficulties in sowing the next season’s crop.

Others suggested that a minority of farmers have the wrong attitude to land management and are therefore unlikely to be adopt ground cover techniques. For example:

> His farm's there for him to rape and pillage and in another 10 years he'll just sell it and he won't be there anymore. So there is farmers that still have that attitude. (AIREP interview 05)

> ...Kimba area is having trouble with holding sand and stuff, but you’ll hear from someone, oh, well, that’s so and so’s property. So, I guess there’s always someone that hasn’t quite adopted what – or done the right practice… (AIREP interview 03).

Broader challenges include ensuring that technical information is communicated to farmers in a language and style that they understand. As one participant observed: “It is very hard to put research into layman’s terms; some of the researchers talk a different language than farmers. So you’ve actually got to have the person that’s got the ability to take the research, understand it, and deliver it to farmers in a language they understand… It’s a specialised job.” (AIREP

interview 05). A further issue identified by participants are the difficulties in accessing scientific expertise:

> …getting the right expertise over here to analyse, assess and develop new solutions for soil management. We're comparatively isolated, so for researchers to come to the Eyre Peninsula, it's usually two days' travel for one day's work. So you're always fighting that battle of getting the right people or the best people over here to work with farmers and farmer groups to look at issues and to build up solutions. (AIREP interview 06)

The issue of geographical distance is a particularly significant challenge in drawing upon scientific expertise and finding ways of making it locally relevant and workable.

PRACTICAL RECOMMENDATIONS/OPTIONS FOR IMPROVING ADOPTABILITY

The demonstrations and field days conducted by MAC, and the use of 'Sticky Beak' days, provide a strong foundation in the region for the 'softening' of scientific knowledge and the 'hardening' of local knowledge. These approaches provide a critical starting point in the creation of a common frame of reference between soil researchers and farmers. Issues to be considered by AIR EP, and other relevant regional stakeholders, in improving the adoptability of ground cover techniques include:

- finding resources to access relevant scientific expertise and communicate soil research to farmers in ways that are understandable
- capitalising on 'Sticky Beak' days by joining up events over a longer period to build communities of practice around trials and innovative approaches to improving ground cover
- building on the above, using communities of practice to trial different approaches to soil erosion mitigation that can be applied in areas where ground cover techniques are unsuitable, and to develop more flexible approaches for farmers to address challenges associated with seasonal variations in stubble loads.

BIRCHIP CROPPING GROUP (BCG)

Assessing applicability of the Soil Adoptability Framework using locally sourced animal (e.g. chicken) manure to replace some chemical fertilisers

INTRODUCTION

Based on detailed analysis of qualitative data from the workshop and five interviews with BCG stakeholders, use of locally sourced animal (e.g. chicken) manure to replace some chemical fertilisers was identified as a key priority to improve soils in the region. The narrative that follows is based on participant reports about how manure application techniques are being implemented in the region, mechanisms used for encouraging adoption, and the extent to which uptake by farmers has been successful. The narrative helps to clarify how local approaches for promoting farmer adoption of manure application techniques align with the researcher's Soil Adoptability Framework. This framework outlines two complementary approaches for farming systems groups – 'softening' scientific knowledge, and 'hardening'

local knowledge – in translating soil research and farming knowledge-practices into a form that is comprehensible and useful for both farmers and researchers.

ARTICULATION OF THE SOIL IMPROVEMENT PROBLEM/PRIORITY

The impetus for using animal manure relates to replacing/substituting synthetic fertilisers that supply nitrogen, potassium and phosphorous, with accompanying cost savings:

> … they're spreading it for purely just nitrogen and phosphorous benefits, well if the cost of synthetic fertilisers go up, well then they're in front. (BCG interview 02)

Chicken manure is reported as having benefits not only because it is cost-effective, but it is available locally and has benefits for soil productivity:

> 10 chicken farms … Plus there's duck farms. There used to be turkeys. So our neighbour has been using chicken manure for probably 20 years … I think the big thing with the manure is it's really high in potassium and water use efficiency. (BCG interview 01, male 01)

> … the chicken manure-spread paddocks, those farms are seeming to get a lot more mineralisation as well, so they're coming into the next season with a lot higher available nitrogen … and mineralised N is a lot better than synthetic N because it's only available when it's actually wet as well, so the crop demand actually just takes it up when it needs it. (BCG workshop participant)

WHAT HAS BEEN DONE IN THE REGION TO ADDRESS THE SOIL IMPROVEMENT PROBLEM/PRIORITY?

The BCG uses the region's farmer networks to investigate and trial local soil issues, with the board meeting twice a year to plan and evaluate projects:

> Well we have farmer networks, so we have farmer networks that we use … to ground our research in, but then they partner with a lot of organisations, so Soil CRC, they'll tender for things that they think will benefit their farmers … A couple of times a year we get together and just run through problems that the farmers have got. Then we try and match research opportunities with things the farmers have got. Then some of the trials ... But the benefit is being able to tap into external resources and really push the horizons out. (BCG interview 03)

The BCG "feedback group" makes project recommendations based on farmers' requests. As one participant noted, this is an effective way of ensuring alignment of group projects with local farming priorities: "they want to know about soil biology, we'll tender for that and we'll try and get some info. So they do try and align as best they can" (BCG interview 03). BCG also employs a research agronomist to coordinate soil testing and trials:

> In relation to soils, I coordinate BCG's commercial soil sampling and I do a bit of stuff on yield profit in regard to setting new farmers up. Then I've got soils-based trials, so two in the Wimmera and then we'll be setting one up in the Mallee next year. Partly looking at soil carbon, partly looking at soil health and just soils and how they relate to yield in general. (BCG interview 02)

Key influencers consider the use of animal manure to have significant potential as a substitute for synthetic fertiliser. However, one participant expressed doubts about its economic viability for farmers:

> We've run a trial and we're getting amazing responses out of spreading chicken litter. So, I think that definitely has promise … but it's really like you've got to cart it, it's hard to spread it properly. There's definitely benefits to it, I don't know yet if it shows enough, it shows promise on a broad scale but whether it's economically viable to convince farmers to do it, I'm not sure yet. (BCG interview 02)

Workshops run by BCG, on-farm trials, and the building of local information on soils, highlight a blend of both 'softening' scientific knowledge as well as the 'hardening' of local knowledge. However, it is unclear from the data how much of this work is focused specifically on the promotion and/or trialling of animal manure applications, or whether it is largely farmer-led.

IMPLEMENTATION SUCCESSES, ADOPTION CHALLENGES, AND HOW THESE CHALLENGES CAN BE ADDRESSED

The use of chicken manure is in the early stage of implementation, and for participants it is too early to evaluate the benefits:

> … we'll show it on the benchmarking, if we're actually fixing ground and what our water efficiencies are – we'll get trends. Over years, we'll get trends. (BCG interview 01, male 01)

> So we've done a couple of soil samples after we've spread it and we probably haven't … seen a lot of change. So it'll be interesting to see when we do it over a couple of years after that and see where it really seems to kick in. (BCG interview 01, male 02)

Nonetheless, there is hope that the use of chicken manure will reap productivity benefits

> we may not reduce our costs, but we might lift our gross margin … Because if we increase our yields, our harvesting, our freight and maybe our nitrogen … will rise, but so will our net profit, because you get even better gross margins. (BCG interview 01, male 1)

Another participant discussed the potential to improve overall soil testing which could combine with larger trials of animal manure use to expand adoptability of the technique:

> Uptake has been, I'd say relatively slow. You used to need soil sample results and so you could argue that the uptake of soil sampling in general has been pretty slow ... It's mainly based around like nitrogen decisions and when you should apply fertiliser and how much and those sorts of things. (BCG interview 02)

PRACTICAL RECOMMENDATIONS/OPTIONS FOR IMPROVING ADOPTABILITY

BCG has a well-developed communication and extension process for its members using workshops and field trials, while building on-ground data from trial plots. This provides a strong foundation for encouraging adoptability of techniques to address soil fertiliser issues. What is clear from the research data is that while animal manure fertiliser application is being trialled at scale by some farmers in the region, there needs to be targeted/focused research and development on potential for animal manures.

CENTRAL WEST FARMING SYSTEMS (CWFS)

Assessing applicability of the Soil Adoptability Framework using the example of lime applications to control soil acidity

INTRODUCTION

Based on detailed analysis of qualitative data from the workshop and four interviews with CWFS stakeholders, lime applications to control soil acidity, including use of variable rate applications, were identified as a key priority to improve soils in the region. The narrative that follows is based on participant reports about how lime application techniques are being implemented in the region, mechanisms used for encouraging adoption, and the extent to which uptake by farmers has been successful. The narrative helps to clarify how local approaches for promoting farmer adoption of regular lime application techniques align with the researcher's Soil Adoptability Framework. This framework outlines two complementary approaches for farming systems groups – 'softening' scientific knowledge, and 'hardening' local knowledge – in translating soil research and farming knowledge-practices into a form that is comprehensible and useful for both farmers and researchers.

ARTICULATION OF THE SOIL IMPROVEMENT PROBLEM/PRIORITY

Research data show that soil acidity is a becoming a significant problem in the region that needs to be addressed. For example:

> we've got soil acidity that is becoming more prominent, but it appears to only be in the top 10 cm so, I think we've got away with masking our soil acidity problem. But again, you get better soils that have a good phosphorus input history, or good nutrition management that are doing quite well. (CWFS interview 01)

Workshop participants also reported the use and benefits of liming practices to address soil acidity in the region. For example:

> … people are really aware of soil improvement and soil health … there seems to be more lime going out now than there used to be. (CWFS interview 02)

> … a lot of these, the soil balance, so you're trying to add enough lime and enough of the other products to try and fix your problems. (CWFS workshop participant)

> … we had some good years so we'd been doing liming. We try and keep putting back in, and rotational cropping and things like that. (CWFS workshop participant)

WHAT HAS BEEN DONE IN THE REGION TO ADDRESS THE SOIL IMPROVEMENT PROBLEM/PRIORITY?

The CWFS group seeks to engage with its members in a variety of ways to address soil management issues in the region:

> we run a lot of workshops. We have an executive board committee made up of farmers and they direct some of the project work and activities that we do. I talk to a lot of farmers to ascertain what they would like us to do for them; what projects they would like us to pursue and what workshops, who they would like to talk to. (CWFS interview 02).

An important part of this process is setting up field trials. A participant explained the model for engaging farmers on trials:

> My role with farmers is basically trying my best to communicate with them on what they need, on what … the organisation needs fulfilled in a project sense. So, if we have a trial, we need trial sites or we need growers for participation in particular things so, I'll have contact with growers in that regard and I'm always trying to get them to talk to me about things that they need that the organisation needs to help fulfil for them. (CWFS interview 01)

A further important activity pursued by the group related specifically to soil improvement is building on-ground/local information on soils. This is achieved via a targeted approach to working with farmers, as described by one participant:

> Boots on the ground – so, we try and talk directly with farmers and the idea is to bring out the knowledge of which they want. So, if there is a particular researcher that they want to have a chat with we ideally bring them out and have workshops. (CWFS interview 01)

Workshops run by CWFS, on-farm trials, and the building of local information on soils, highlight a blend of both 'softening' scientific knowledge as well as the 'hardening' of local knowledge. However, it is unclear from the data how much of this work is focused specifically on the promotion and/or trialling of liming applications.

IMPLEMENTATION SUCCESSES, ADOPTION CHALLENGES, AND HOW THESE CHALLENGES CAN BE ADDRESSED

It is clear from the research data that farmer participants understand the significance of liming as a way of dealing with soil acidity issues. However, financial considerations were reported as a key challenge in affecting the timing or regularity of applications. For example:

> When you have a good year, you have a bit of extra money to then buy lime or whatever. So … it's very seasonal. (CWFS workshop participant)

> … growers have an understanding that they need to be checking their soil pH or they need to be doing soil testing, and they need to be liming. But when the yields are low, and the input costs are still high they can't justify spending money on lime. They've got to spend money where they know they can generate a return, and unfortunately that's in urea and fertiliser and chemical, because it's been proven that it generates a return, and a rapid return so, a 12-month return rather than lime being a five or 10-year return, depending on how bad the soil acidity is. (CWFS interview 01)

A related issue reported by participants was the high cost involved in transporting lime from its source to farms in the region:

> … talking about something like soil amendments where you're putting a fair bit on like lime, distance from a source is an issue. It's not so much the equipment required to do a job necessarily but the amount of cost to get bulk product to somewhere. It's like you know people don't do much carting of water because you need to put cattle on it to make use of the stock and the like which is topical in a drought. Similarly, yes, you don't want to be transporting soil amendments in large quantities, large distances, really affects the economics of it. (CWFS interview 03)

A broader challenge relates to the financial capacity of the CWFS to conduct local research, workshops and run trial plots to address soil acidity issues in the region. One participant described the challenges obtaining relevant project funding:

> Because we're not for profit and a hundred per cent grant funded, that holds a lot of constraints around being able to deliver bottom-up projects because a lot of it is set by the funding body. Whilst the funding bodies are meant to have scoping groups that provide the research needs and the research questions that are supposed to be in the farmers' best interest they are not always on point. (CWFS interview 01)

PRACTICAL RECOMMENDATIONS/OPTIONS FOR IMPROVING ADOPTABILITY

Existing approaches used by CWFS – such as workshops, field trials, and building on-ground data from trial plots – provide a strong foundation for encouraging adoptability of techniques to address soil acidity issues. However, lack of specific data from the workshop and interviews mean that it is not clear on exactly how lime application is being integrated as part of these approaches. As a consequence, it is difficult to gauge, based on the data, how effective existing approaches are in enhancing adoptability. What is clear from the research data is that while lime application is widely accepted by farmers in the region, financial pressures, including the cost of transporting lime, are key challenges in influencing lime application. In addition, research funding constraints appear to represent a broader challenge for CWFS in developing and delivering projects that have the potential to build local communities of practice for addressing soil acidity issues.

MACKILLOP FARM MANAGEMENT GROUP (MFMG)

Assessing applicability of the Soil Adoptability Framework using the example of soil testing

INTRODUCTION

Based on detailed analysis of qualitative data from the workshop and five interviews with MFMG stakeholders, no single mechanism for improving soils in the region was identified. However, the analysis did identify soil testing as an area that needs greater support. The narrative that follows is based on participant reports about how a range of soil management techniques are being implemented in the region, mechanisms used for encouraging adoption, and the extent to which uptake by farmers has been successful. The narrative helps to clarify how local approaches for promoting farmer adoption of improved soil management align with the researcher's Soil Adoptability Framework. This framework outlines two complementary approaches for farming systems groups – 'softening' scientific knowledge, and 'hardening' local knowledge – in translating soil research and farming knowledge-practices into a form that is comprehensible and useful for both farmers and researchers.

ARTICULATION OF THE SOIL IMPROVEMENT PROBLEM/PRIORITY

Participants identified a diversity of soil improvement problems, but no overarching problem or priority in the region was identified. For example:

> … we have multiple challenges in that environment on the plains. Then up on the hills and in our sandy soils, we struggle with water repellents, acidity, low water holding capacity, low nutrient fertility, low organic carbon. All of these, again, constraints can occur in isolation but more often concurrently. It leads to constrained productivity as a result of the combination of those chemical and physical and biological impediments. (MFMG interview 02)

> I think the big one that we've been looking at in the last few years is our depth of soil and how we can manage and manipulate it to increase the bucket size, I guess, for water use and for crop yields. That's been a big one, and measuring some of the things like nitrogen and things in the soils, and how that's relating to crop yield. Then the other swing and roundabout is we've got sandy, acidic soils on the ridges, so overcoming acidity to establish legume-based pastures … Then, we've got on the border region … more sodicity is an issue, so sodic soils, waterlogging, drainage. (MFMG interview 04)

WHAT HAS BEEN DONE IN THE REGION TO ADDRESS THE SOIL IMPROVEMENT PROBLEM/PRIORITY?

MFMG seeks to engage with its members in a variety of ways. An ongoing process in the MFMG group is building on-ground/local information on soils. This provides a good example of the 'hardening' of local knowledge. However, projects conducted are currently geared towards improving productivity and do not have an explicit emphasis on soil improvement:

> We've got … three or four [projects] at least that are focused on soils in some capacity. Most of those are about improving, probably productivity and profitability, so thereby – by association I guess – they are classified as soil improvement initiatives. Then in our wider suite of projects there's probably always an element of something to do with soils because that's obviously our building block, but it may not necessarily be expressly focused on. (MFMG interview 03)

The group also works with scientists to run local programs for engaging with farmers to overcome soil constraints. This is a good example of the 'softening' of scientific knowledge. A current program being run in the region focuses on improving understanding of soils and encouraging soil testing, as explained by one participant:

> Right throughout the southeast we are promoting – and this is by working with [name suppressed] … She's a really good communicator, she's just really vibrant and enthusiastic and just loves soils and loves working with farmers, which is great…. We're actually just about to do sort of a sandy soils 101 information kit. We're probably also going to do sort of a just a general soils 101 probably later on in the year as well with her. That will be really focusing on soil testing and understanding where your soil is at and what the constraints might be. So, identifying the constraints that are particular to you on-farm. (MFMG interview 03)

Participants also discussed the importance of on-farm trialling in adapting tools for their individual soil types:

> I think that's the thing, I think the farmers actually do a lot of their own trial work on their own place because it's unique to their area and what works for us at Beachport mightn't work for Bruce at Bool Lagoon and it might work differently for people north of Naracoorte. So we're all our own researchers at the end of the day. (MFMG workshop participant)

> You've got to dip your toe in the water first and say, well, actually what works and what doesn't work. We all do that, and that's even like crop varieties or crop types, you plant a different thing or you trial a bit of perennial pasture that's this variety here and if it works you potentially go more. (MFMG workshop participant)

It is not clear from the workshops or interviews the extent to which on-farm trialling is integrated into MFMG extension activities.

IMPLEMENTATION SUCCESSES, ADOPTION CHALLENGES, AND HOW THESE CHALLENGES CAN BE ADDRESSED

There has been moderate success in addressing the diversity of soil management issues in the region. The recent 'Soils 101' program was viewed as particularly valuable in improving understanding of how to enhance soil productivity:

> Sandy soils projects, and those sort of things have been very good for us. Now at the end of the day, it all starts with the soil, so if we can't get – we need to learn as much as we can about our soils to try and get the most out of it. (MFMG workshop participant)

Nevertheless, issues with soil testing were viewed as a limitation in further adoption of soil improvement practices. A significant issue for participants was the cost of soil testing versus the perceived economic benefits:

> From a broadacre livestock point of view, I think what would drive change for us, and people like us, is showing that it's worth the effort. If we, for example, pay for 40 soil tests across our farm, if we pay for half a dozen tests per paddock, and then we can reduce our fertilizer by that amount, then you'd go and do it. If somebody could show us that we could do that you'd probably then spend the money on the soil testing. But it's such a change from what people normally do that we need to really show them a reason to do it. (MFMG workshop participant)

> But I think it all comes back to cost … It's got to be economic, and you've got to be able to see benefits from changing, I guess. Often in pasture systems, in crops, in cropping systems, it's quite easy to measure that – but in pasture systems it's probably not as easy to measure. (MFMG workshop participant)

> … the precision soil testing is probably, the cost is, and sourcing someone to do it, is probably the major constraint. (MFMG workshop participant)

Other participants pointed to problems with the accuracy of soil testing, especially in a region characterised by widely geographically diverse soil types:

> The other challenge is that often it actually asks more questions than it answers, so the landscape that we're farming locally is so different to any other area in Australia. (MFMG workshop participant)

> I think in saying that you need the right data to actually make those right decisions. Like it's all well and good having a soil test, but if the soil test is incorrect or doesn't actually give you a representative answer of what is going on then you can't make a decision that is based on science. (MFMG workshop participant)

> Understanding what it actually means, and therefore what you need to do. (MFMG workshop participant)

Challenges for farmers include an 'oversupply' of information from too many sources resulting in an overload and an inability to process all relevant information:

> My feeling is that people are possibly a little bit overwhelmed by the amount of information that they need to know and/or their judgement is clouded by silver bullets that might be presented to them by somebody trying to sell them something. (MFMG interview 03)

For one participant information overload can lead to farmers adopting techniques or technologies that have questionable benefits:

> … those farmers that have been willing to be involved in farmer groups, so group discussion type scenarios, they're engaged, they're willing to learn new things and listen to new ideas … There's certainly a large number of farmers that are willing to progress in that stage. I just think there's a knowledge gap, and people jump on the back of some pretty questionable technologies. (MFMG interview 04)

PRACTICAL RECOMMENDATIONS/OPTIONS FOR IMPROVING ADOPTABILITY

Existing approaches used by MFMG provide a good foundation for encouraging adoptability of improved soil management techniques. The 'Soils 101' program is a particularly important initiative in translating soil science knowledge in locally relevant ways. Issues to be considered by MFMG, and other relevant regional stakeholders, in improving the adoptability of soil testing include:

- Tracking farmer engagement and evaluating what is being learned by farmers from participation in local soil testing programs.
- Developing soil testing approaches that are appropriate to the geographical diversity of the region.
- Investigating further how farmer experiences of on-farm trialling and adaptation of soil management tools can be utilised as part of regional soil improvement communities of practice.

NRM NORTH – NORTHERN TASMANIA

Assessing applicability of the Soil Adoptability Framework using the example of techniques to address drainage issues

INTRODUCTION

Based on detailed analysis of qualitative data from the workshop and four interviews with NRM North stakeholders, various techniques to manage drainage were identified as a key priority to improve soils in the region. The narrative that follows is based on participant reports about how drainage techniques are being implemented in the region, mechanisms used for encouraging adoption, and the extent to which uptake by farmers has been successful. The narrative helps to clarify how local approaches for promoting farmer adoption of techniques for managing drainage issues align with the researcher's Soil Adoptability Framework. This framework outlines two complementary approaches for farming systems groups – 'softening' scientific knowledge, and 'hardening' local knowledge – in translating soil research and

farming knowledge-practices into a form that is comprehensible and useful for both farmers and researchers.

ARTICULATION OF THE SOIL IMPROVEMENT PROBLEM/PRIORITY

Local stakeholders and workshop participants described a range of problems relating to drainage. For example:

> … drainage is a real issue, so that's a big one, because we have a lot of winter rainfall. So getting water off paddocks is a big one. (NRM North interview 02)

> There's a range of soils types in there, but predominantly they are duplex soils or ferrosol soils in the Deloraine area. It's always opportunity to improve soil health, so whether that's improving organic matter or drainage, pugging issues, salinity issues. (NRM North interview 03)

> … the canola flats pug up pretty badly in the winter, but they're very good spring grazing, so I guess we've got different grazing techniques on that country as well, so it's (a) a diverse business and (b) probably a – I think – quite a difficult farm to manage because of its limitations – a lot of it floods. All the canola stuff floods eight to 10 times a year, so it's unusable in the winter really. (NRM North workshop participant)

WHAT HAS BEEN DONE IN THE REGION TO ADDRESS THE SOIL IMPROVEMENT PROBLEM/PRIORITY?

Participants describe numerous extension activities carried out by both NRM North and commercial agronomists to address a range of soil-related issues in the region, including drainage. Workshop participants explained how they integrate a range of technical options into their management of drainage issues. One of these techniques is aerial mapping of the terrain: "if you have an aerial picture that really pinpoints the need for drainage, where the drainage is needed, so that's valuable." (NRM North workshop participant). Drones were described as increasingly valuable in pinpointing areas needing drainage:

> They do put a drone up through an external contractor to look at a couple of paddocks every year and we try and pick out something which is a paddock that's got about five different soil types. (NRM North workshop participant)

The use of aerial mapping is an important technique for enabling farmers to build a more accurate and quantifiable picture of drainage on their farm, and to better target areas that need drainage. As such, aerial mapping provides a way of 'hardening' local soil knowledge.

Although the extent of support provided by NRM North is unclear from the data, a participant talked about the growing significance of agronomists and private extension networks in providing soils advice to farmers:

> … since we've seen the departments of ags disappear, agronomists are the main source of knowledge for most farmers these days. That and field days run by say, Southern Farming Systems or people like that. Yeah, it's really been a change in information extension I think over the last … 15, 20 years … farmers reluctantly go to a field day, (even) very well-run field days, because they know that people like me will go and we'll report back to them. We've developed this private extension network. (NRM North interview 02)

IMPLEMENTATION SUCCESSES, ADOPTION CHALLENGES, AND HOW THESE CHALLENGES CAN BE ADDRESSED

It is clear that drainage issues are well understood by participants and that farmers have experimented with a range of techniques with visible soil benefits. For example:

> … drainage actually became a real driver for the soil health because if I could get rid of the free water – what I'd call free water – that was laying on the flats during the wintertime that meant that the soil was in much better condition coming out of the winter. Although it seemed to have technically recovered by the autumn, it didn't take long to deteriorate again. It meant a different management regime that certainly that soil from the soil beds perspective that made a hell of a lot of difference. (NRM North workshop participant)

However, some describe the need for further cost-effective solutions:

> if the Soil CRC gurus can come up with cheap and practical ways of improving drainage, and improving micronutrients or just general nutrient availability to crops and pastures from the soil. (NRM North workshop participant)

A participant also highlighted the ongoing imperative to improve communication by "building relationships with the farmers", recognising the need to offer trusted advice (NRM North workshop participant). This was identified as particularly important in targeting farmers who may be less open to changing their soil management practices:

> Some of the easiest ones to deal with are the more high production areas, so they're quite open to inputs and suggestions and technologies. Then when you go to the lower rainfall areas of the north-east, they're more traditional old school, you know, three bags of single super to the acre and that's all they really want to do. (NRM North interview 04)

Further research on highlighting the financial benefits of different options for addressing drainage issues, was also identified as a priority:

> I think it's more research, showing the benefits of it … putting a dollar figure to those benefits. That is the thing that will create greater and quicker adoption by people, rather than a policy and regulations and more red tape. Farmers have enough to deal with. They have enough bookkeeping. They have enough recording of information. We need to encourage them because they can see the financial benefits and the long-term sustainability benefits. (NRM North interview 03)

PRACTICAL RECOMMENDATIONS/OPTIONS FOR IMPROVING ADOPTABILITY

Existing approaches used by NRM North and independent consultants such as workshops, field days, and drive arounds provide a good foundation for encouraging adoptability of more targeted techniques for addressing drainage issues. Participants discussed use of technical tools that include mapping, drones and topographical data as part of these approaches. However, it is difficult to gauge based on the data how effective existing approaches are in enhancing adoptability. Issues to be considered by the NRM North group include:

- Communicating the benefits of current successes to encourage wider adoption of tools.
- Capitalising on existing farmer experiences to build communities of practice to develop cost-effective drainage remediation tools.

- Finding resources to access relevant scientific expertise and communicate soil research to farmers in ways that are understandable.

RIVERINE PLAINS INC (RP)

Assessing applicability of the Soil Adoptability Framework using the example of lime applications to control soil acidity

INTRODUCTION

Based on detailed analysis of qualitative data from the workshop and three interviews with RP stakeholders, lime applications to control soil acidity, including use of variable rate applications, were identified as a key priority to improve soils in the region. The narrative that follows is based on participant reports about how lime application techniques are being implemented in the region, mechanisms used for encouraging adoption, and the extent to which uptake by farmers has been successful. The narrative helps to clarify how local approaches for promoting farmer adoption of regular lime application techniques align with the researcher's Soil Adoptability Framework. This framework outlines two complementary approaches for farming systems groups – 'softening' scientific knowledge, and 'hardening' local knowledge – in translating soil research and farming knowledge-practices into a form that is comprehensible and useful for both farmers and researchers.

ARTICULATION OF THE SOIL IMPROVEMENT PROBLEM/PRIORITY

Workshop participants reported wide acceptance of the benefits, integration and use of liming practices to address soil acidity over a period of at least 20 years. For example:

> It's a known input cost in our programs. It's just how you tackle and how often you are replacing what you're taking out of the paddocks… Lime is one of the many inputs that we have to put in every year to try and improve the soils and hopefully leave them in a better place than you found them. (RP workshop participant)

However, participants identify that more systematic applications of lime amendments need to be carried out to improve acidity issues:

> …not everyone has been putting enough lime on. So we've been using blanket rates for a long time. People that happily use averages. Variable rate lime in gypsum has been bandied around but there's now new evidence that is going to show that variable rate lime could have been used more effectively maybe. (RP workshop participant)

> I'm seeing evidence that they haven't got it right yet, that we're actually getting wider variability in pH. So as we lime our acidic soils, we're getting the high end of the paddock up to between 5 and a half, six, and we've got that low end that is still down there at say 4.2 and underneath that for 4.2, the subsoil acidity that's being masked. (RP workshop participant)

WHAT HAS BEEN DONE IN THE REGION TO ADDRESS THE SOIL IMPROVEMENT PROBLEM/PRIORITY?

The RP group seeks funding to conduct local research and run field days and on-farm trials to address a range of soil-related issues in the region. However, no data was available on the

potential sources of funding. For workshop participants, field days and trials were seen as valuable in learning about, and having the opportunity to assess, soil management techniques and practices:

> they're talking about field days. We'll go and look, and if [name suppressed] has had a trial of something and it's really good because if it fails, you've still learnt … You start on a small area and you can evaluate … (RP workshop participant)

As such, RP activities appear to be oriented to both 'softening' of scientific knowledge as well as the 'hardening' of local knowledge. While it is unclear from the data the extent to which more systematic lime applications are promoted in regional extension activities, it is evident that work is being done on the ground to address soil acidity issues:

> [we have] been doing more with this soil acidity and it's really about getting people to assess, critically assess the effectiveness of their efforts to manage or improve soil pH … The standout to me has been the different levels of understanding of farmers and advisors to their soil issues. (RP interview 03)

IMPLEMENTATION SUCCESSES, ADOPTION CHALLENGES, AND HOW THESE CHALLENGES CAN BE ADDRESSED

It is clear that the farmer participants understand the significance of liming as a way of dealing with soil acidity issues. They report good results across a range of on-farm soils using precision agriculture technologies and extending that technology to address subsoil stratification pH variations:

> Some of those now have moved onto grid sampling, using variable machines. I have some that have now had their whole properties done twice. Looking at some results from those, their levels of pH … they're very even, six plus. … now started doing with them some subsoil…. But testing has been done on the ones that have had average lime programs… there's some that have done it, that vary rates now, for a number of years with two lots of grid sampling. They're across the board fairly even. One I looked at the other day, his lowest at 10 to 20 was 4.8. He had two under 5.2. So we're pretty happy with that. (RP workshop participant)

Nevertheless, participants reported challenges in implementation, including superficial applications that may not always be effective: "a lot just put on a rake, a lot just spread it over the top. It's not incorporated. Is it beneficial? Is it having a full effect or could they be doing something a bit more to give the effect? There's a few people kind of not incorporating at depth" (RP interview 01). Soil type variability was also reported as contributing to the complexity of lime applications:

> Just for a soil test here, this is a classic example of how we've cropped this year. Red soil, black soil. Red soil is 4.9. Black soil is 7. Now, we tried to spread the red part of the paddock. It's not a straight line. It's quite tricky. But we realised that we've got that sort of result, therefore why put lime on an area that's got 7 pH? (RP Workshop participant)

A broader challenge is the increasing cost of getting lime trucked in: "it is becoming more of a problem because the pits are getting further away from us" (RP workshop participant). Participants indicated that different options were being investigated to reduce the burden of freight costs. This included consideration of a manufactured, pelletised product of calcium carbonate – Calciprill – that may provide consistent applications as opposed to powdered lime. However, there was uncertainty as to the cost-effectiveness of the product:

> It's marketed as a product that you, because it is finer, you need less of it. So they can afford to charge expensively because you're going to use less of it. So ultimately, they imply that you're going to save money compared to applying blanket lime at 2.5 plus tonne per hectare. (RP Workshop participant)

A final implementation challenge raised in the research is funding constraints for the RP group and other farmer groups in the region to undertake focused and effective extension on the most effective options for addressing soil acidification:

> we don't have a lot of funding to promote the need to monitor and address soil acidification. If soil research is so expensive or investment in any soil projects – to get good data – is so expensive, it's very hard to focus our dollars as effectively as we could. (RP interview 03)

PRACTICAL RECOMMENDATIONS/OPTIONS FOR IMPROVING ADOPTABILITY

Existing approaches used by Riverine Plains Inc – such as field days and trialling – provide a good foundation for encouraging adoptability of more systematic lime application techniques. However, it is difficult to gauge from the data how promotion of more systematic lime applications are integrated into existing R,D&E approaches. While lime application is widely accepted by farmers in the region, financial pressures, including the cost of transporting lime, are key drivers that need to be recognised in influencing approaches to lime application in the region. Issues to be considered by Riverine Plains Inc include:

- Facilitating workshops where local experts discuss the benefits of more systematic lime applications.
- Building local communities of practice in which farmers who have had soil improvements from more systematic lime applications share their experiences with others.
- Finding ways to pool local resources to reduce the costs of transporting lime to the region.

WESTERN AUSTRALIAN NO-TILL FARMERS ASSOCIATION (WANTFA)

Assessing applicability of the Soil Adoptability Framework using the example of mechanical amelioration of water repellent soils

INTRODUCTION

Based on detailed analysis of qualitative data from the workshop and four interviews with WANTFA stakeholders, mechanical amelioration (examples are claying, deep cultivation, soil inversion) of water repellent soils (also called non-wetting soils) were identified as a key priority to improve soils in the region. The narrative that follows is based on participant reports about how mechanical amelioration techniques are being implemented in the region, mechanisms used for encouraging adoption, and the extent to which uptake by farmers has been successful. The narrative helps to clarify how local approaches for promoting farmer adoption

of mechanical amelioration techniques align with the researcher's Soil Adoptability Framework. This framework outlines two complementary approaches for farming systems groups – 'softening' scientific knowledge, and 'hardening' local knowledge – in translating soil research and farming knowledge-practices into a form that is comprehensible and useful for both farmers and researchers.

ARTICULATION OF THE SOIL IMPROVEMENT PROBLEM/PRIORITY

While soil characteristics and constraints in the regions encompassed by WANTFA are diverse, water repellent soils were identified as a particular challenge:

> The soils across our region are quite varied … Then as you get up the slopes, into the mid-slopes, these move into a lot of white sand, which is low fertility and tends to be water repellent and non-wetting, a lot of iron, like rocky outcrops, that are iron and gravel-stone based. They tend to be highly productive, but also, too, they can be inherently non-wetting too. Other soils that are what we called sandplain type soil, a deep yellow sand and very good at growing crops, now that they've got the nutritional packages right and also, after you overcome the issues with water repellency. (WANTFA interview 01)

WANTFA have been working with the State Agriculture Department "to develop strategies to combat those issues" (WANTFA interview 01). Two amelioration methods that have been used to address water repellency are mouldboard ploughing and the use of a Plozza plough:

> … mouldboard ploughing, where if there's a single issue, like water repellency, the soil can be mouldboard ploughed to about 30 centimetres deep, which inverts that top 30 centimetres of soil and buries the water repellent layer at depth. So, then you don't have water repellent soil again. Then a last main way of ameliorating soil is through the use of what's called a Plozza plough, that was developed by the Plozza brothers. That involves a modified one-way disc plough with huge discs on it that basically invert soil the same as a mouldboard plough, but with a far lower initial capital outlay and also works quite well in gravel soils, where mouldboard ploughs don't like to go. (WANTFA interview 01)

WHAT HAS BEEN DONE IN THE REGION TO ADDRESS THE SOIL IMPROVEMENT PROBLEM/PRIORITY?

WANTFA engages with its members in a variety of ways to address soil management issues. These engagement activities accord predominantly with the 'softening' of scientific knowledge detailed in the Soil Adoptability Framework. The 'softening' of scientific knowledge is evident in local research, workshops and demonstration days that aim to make scientific knowledge locally applicable and workable for farmers:

> We tend to influence through research and development adoption, more applied research. We work with farmers on their farms, predominantly. We occasionally subcontract universities or CSIRO to do modelling work or glasshouse work, but it's generally related to what we do in the field. Particularly of late, we tend to work with farmers using their equipment, using their knowledge and what they want to do, based – yes, we guide them in their – how to design trials and so on. (WANTFA interview 04)

> I think the biggest influence we've had now is … live demonstration days as well, so we also get the machinery the farmers use, be put through their paces in the paddock,

> so farmers can have a look, kick tyres, see the actual machine in operation and ask the dealers questions. That adoption – of it then, what machines do you need to do the job, is basically where we fit in. (WANTFA interview 04)

It is also evident in the use of local soil science experts: "having people like [name suppressed] in the room to talk – and an expert who can communicate with them, someone … is really good. There are some fantastic soil scientists out there, but having that middle person who can talk to the farmers in their language about their constraints, and what works and what doesn't work, and I think that's vastly important" (WANTFA interview 04).

WANTFA also engages in the 'hardening' of local knowledge through the 'de-risking' of technology:

> … our role really is to bring that new innovation in and evaluate it and put it forward so then farmers can come and have a look at it and the risks, the process I take is what I call de-risking. So, where something's new, it comes in, its full of risk/ it's too risky to adopt. So, then we go about a series of trials to understand more about what the particular problem, or the particular solution, or innovation could be. Then during that process, we inherently lower the risk, because we're learning more and more about this new innovation. (WANTFA interview 01)

While extension and engagement activities appear to be effective in encouraging farmer engagement with mechanical amelioration techniques, this is helped significantly according to one participant by the fact that non-wetting soils are already widely recognised by farmers as a production problem that needs to be addressed, and that farmers are already adopting innovative approaches to soil improvement:

> It's generally easier because farmers have got a massive issue with it. So, they've kind of identified the issue in a way, they know it's a problem. How easy those challenges get adopted … starts off as a physical problem, and then … to give people social licence … to then go ahead and do something quite dramatic and drastic to their soil, which is what they're doing now. (WANTFA interview 04)

> If you look at soil amelioration in particular, and their adoptability … it's all been created as thought out by farmers … It's funny in this field. It's very rarely have I seen examples where the science comes first for the next big step. We're all looking for that next big idea, but quite often, it comes from the farmer first. Because they see the issues all day, or the problems all day. Some of these guys are probably the best engineers going around. Not all of them have got degrees in it, but their engineering knowledge and skill and invention capability is huge. (WANTFA interview 04)

In addition, farmers in the regions served by WANTFA are viewed as having a culture that is conducive to adoption of new soil improvement practices:

> the culture around the growers tends to make them quite readily keen on adopting new practices, facing challenges and constraints. They tend to have had some quite strong grower groups historically and to an extent ongoing. (WANTFA interview 03)

IMPLEMENTATION SUCCESSES, ADOPTION CHALLENGES, AND HOW THESE CHALLENGES CAN BE ADDRESSED

While farmer adoption of techniques for amelioration of non-wetting soil was reported as having improved in recent years, further integration of these techniques into management of the whole farm was judged to be the next step:

> … there's been a lot, a lot of work done in the last five, 10 years in all the amelioration practices, a lot of soil management. The knowledge is out there, but the next step is how do we optimise it over the whole farm, and within paddocks? I think that's where we can make the biggest inroad from now on … I think farmers have a good understanding of most of the constraints, but understanding how to manage them, 'horses for courses', which paddocks you can do which – and also how you manage that paddock afterwards. Because basically, you've altered the soil profile, which alters your farm management - your nutritional management, in particular, how do you manage your paddock after you've basically transformed it. (WANTFA interview 04)

Promoting adoption in pasture systems was also identified as a key priority:

> … the cropping people have taken on the soil amelioration, but that's where the research was initially focused and now we're only just starting to look at soil amelioration in a pasture system and how they can improve pasture productivity, as it has for crop production. (WANTFA interview 01)

In terms of ongoing challenges, rainfall variability between regions was reported as a key influence on adoptability of mechanical amelioration:

> It does vary a bit across the state, and the attitudes towards rainfall zones as well… so that really high rainfall guys, yes, they probably get away with a lot more. So they can't see the value in doing a lot of amelioration, because … they get the rainfall, and they get the high productivity. So, it's a risk/ reward. The low-rainfall, really poor soil types get a big risk but big reward, and they've seen that time and time again. (WANTFA interview 04)

A further challenge raised by workshop participants include farmers' financial capacity:

> some farmers are better equipped financially to be able to do all this amelioration work to try and improve their soils and others aren't. The ones that aren't financially in a position to do it tend to hold off a little bit on that stuff or perhaps dabble in it in a limited manner just trying it out. (WANTFA workshop participant)

PRACTICAL RECOMMENDATIONS/OPTIONS FOR IMPROVING ADOPTABILITY

Existing approaches used by WANTFA – such as field days, mechanical machinery demonstration days and use of scientific expertise – provide a strong foundation for encouraging adoptability of soil amelioration techniques to address water repellency issues. What is clear from the research data is that while mechanical amelioration is widely accepted by farmers in the region, financial pressures, including machinery costs are key drivers that need to be recognised in influencing adoptability in the region. Issues to be considered by WANTFA include:

- Resourcing of local experts who are able to translate research on mechanisms for addressing water repellency into a format that is understandable by farmers and locally workable.
- Capitalising on existing farmer experiences to build communities of practice to develop credible and cost-effective methods for addressing water repellency.

APPENDIX B ADOPTABILITY FRAMEWORK

Step 1 Identify the soil management challenge / priority

		Completed by farming group
What is the soil improvement challenge or priority that needs to be addressed?		
Is the definition of the challenge/priority widely agreed upon among local farming networks (e.g., farmers, farming groups, agronomists)?	Yes – move to Step 2 No – Could a shared definition be developed, OR ; is there a group that can support ongoing development and adoption?	

Step 2 Identify how the soil management challenge / priority should be addressed

		Completed by farming group
What innovations have been proposed to address the soil improvement challenge and/or priority?		
Is the soil improvement innovation recognised as an effective way of addressing the challenge and/or priority? Have similar innovations been used successfully in the past?	Yes – move to Step 3. No – Can more than one innovation be advanced simultaneously? Which are deemed valuable and which are seen as fringe? Is there a risk that current fringe innovations may be neglected despite having value?	

Step 3 Identify drivers of adoptability influencing local capacity to address the challenge / priority

Drivers	Questions to determine main adoptability drivers	Completed by farming group
Personal / family	Is the soil improvement innovation compatible with the attitude, values, skill, knowledge and experience of farmers?	
Cost-benefit / financial	Does the soil improvement innovation have a clear financial benefit for farmers?	
	Can it be trialled easily and/or cost-effectively?	
Farm system	Does the soil improvement innovation fit within actual farming systems?	
	Is it feasible and practical in the context of biophysical, economic and social constraints?	
Local network	Is sufficient local support, advice and resources available to assist farmers with trialling and implementation of the soil improvement innovation?	
Socio-cultural	Does the proposed soil improvement innovation align with accepted cultural understandings of good farming, social licence, and care for the land?	
Institutional / policy	Does the proposed soil improvement innovation link to broader R,D&E or soil/farm policy priorities?	
	In what ways is external expertise utilised and managed?	
	To what extent is local knowledge valued by external experts?	
Market	Are there market or commercial incentives for farmers to engage with and implement the proposed soil improvement innovation?	

Step 4 Identify interventions for addressing adoptability challenges

Drivers marked in red and orange in Step 3	Recommended R,D and E approach to improve adoptability – completed by farming group in consultation with social researchers	Questions to consider in implementing R,D&E approach – completed by farming group in consultation with social researchers
'Hardening' local knowledge [drivers in this category to be determined by participants]		
'Softening' scientific and institutional knowledge [drivers in this category to be determined by participants]		

APPENDIX C EXAMPLE OF COMPLETED ADOPTABILITY FRAMEWORK FOLLOWING SECOND ROUND OF WORKSHOPS

Sections added or edited by farming group participants are marked in blue.

Step 1 Identify the soil management challenge / opportunity

		Completed by farming group
What is the soil improvement challenge or opportunity that needs to be addressed?		*Soil erosion*
Why is the soil improvement challenge or opportunity an issue?		*Fragile soils widespread in region. Exacerbated by farm financial pressures and climatic influences such as drought.*
Is the definition of the challenge/opportunity widely agreed upon among local farming networks (e.g. farmers, farming groups, agronomists)?	Yes – move to Step 2 No – Could a shared definition be developed, OR; is there a group that can support ongoing development and adoption?	*Acceptance that soil erosion is a widespread problem that affects productivity.*

Step 2 Identify how the soil management challenge / opportunity should be addressed

		Completed by farming group
What innovations have been proposed to address the soil improvement challenge and/or opportunity?		*Soil erosion mitigation using ground cover techniques, such as cover crops or retained crop residue.*
What are the mechanisms used for promoting farmer adoption of this innovation?		*Trialling of ground cover techniques through local research centre. Use of fact sheets, newsletters and field days to communicate results to farmers.* *Incentives for using ground cover techniques.*
In what ways is the soil improvement innovation recognised as an effective or necessary way of addressing the challenge and/or priority? Have similar innovations been used successfully in the past?	There is widespread agreement on the effectiveness or necessity of the soil innovation in addressing the challenge/opportunity – move to Step 3. There are doubts or disagreement over the extent to which the soil innovation is effective or needed – revisit the first and second rows of Step 2.	*Wide use and acceptance of benefits of minimum and no-till practices. Promotion of ground cover techniques now widely recognised as a priority in further improving soil management, especially in areas with light or fragile soils. Soil cover recognised by farmers as beneficial in storing water and in avoiding negative social labelling associated with eroded, dusty paddocks.*

Step 3 Identify drivers of adoptability influencing local capacity to address the challenge / opportunity

Drivers	Questions to determine main adoptability drivers	Completed by farming group
Personal / family	Is the soil improvement innovation compatible with farmers' attitudes, motivations and values?	*Compatible with farmers' sense of care for the land and their motivation to improve soil productivity.*
	Is the innovation compatible with farmers' skills and knowledge?	*Ground cover techniques used in the region – especially stubble retention – for two decades.*
	Is the innovation compatible and consistent with farmers' experiences?	*Builds on widespread acceptance and use of minimum and no-till practices in the region.*
Socio-cultural	Does the proposed soil improvement innovation align with accepted cultural understandings of good farming, social licence, and care for the land?	*Use of ground cover techniques – especially stubble retention – widely accepted in the region.*
Farm system	Does the soil improvement innovation fit within actual farming systems?	*Geographical diversity a challenge. Ground cover techniques not necessarily appropriate or relevant to all farming systems across the region.*
	Is it feasible and practical in the context of biophysical, economic and social constraints?	*Feasibility and practicality influenced by regional variations in soil types and rainfall. Seasonally high stubble loads can mean that burning is viewed as the only option for farmers.*
Support networks	Is sufficient local support, advice and resources available to assist farmers with trialling and implementation of the soil improvement innovation? Is it necessary to go outside of existing networks?	*Strong emphasis on trialling, field days, and peer learning, especially through local research centre.*
Cost-benefit / financial	Does the soil improvement innovation have a clear financial/yield benefit for farmers?	*Unclear from the data.*
	Are there clear benefits to the farmer in adopting this innovation?	*Unclear from the data.*
	Can the innovation be implemented easily and/or cost-effectively?	*Unclear from the data.*
	Is implementation of the innovation financially feasible in the context of climatic/biophysical variability?	*Feasibility influenced by regional variations in soil types and rainfall. Seasonally high stubble loads can mean that burning is viewed as the only option for farmers.*
Market	Are there market, commercial or government incentives or signals for farmers to implement the proposed soil improvement innovation?	*No current market incentives or price signals for adoption of ground cover techniques.*
Institutional / policy	Does the proposed soil improvement innovation link to broader R,D&E or soil/farm policy priorities?	*Links to broader R,D&E priorities of improving ground cover through cover crops and crop residue retention.*
	In what ways is external expertise utilised and managed?	*External expertise utilised, but challenges in attracting expertise to the region due to distance from main centres.*
	To what extent is local knowledge, know-how and current practices valued by external experts?	*Farming knowledge generally valued, but the main challenge is translating research into a language that farmers understand.*

Step 4 Identify interventions for addressing adoptability challenges

Drivers marked in red and orange in Step 3	Recommended R,D and E approach to improve adoptability – completed by farming group in consultation with social researchers	Questions to consider in implementing R,D&E approach – completed by farming group in consultation with social researchers
'Hardening' local knowledge		
Cost-benefit / financial	• Important area, but difficult to provide recommendations based on the data.	

Drivers marked in red and orange in Step 3	Recommended R,D and E approach to improve adoptability – completed by farming group in consultation with social researchers	Questions to consider in implementing R,D&E approach – completed by farming group in consultation with social researchers
Farm system	• Build regional communities of practice for trialling soil erosion mitigation techniques that are suited to local soil types and rainfall.	• What regional communities of practice already exist, and do they have the knowledge, skills and resources for trialling different soil erosion mitigation techniques? • Is there agreement on the soil erosion mitigation techniques that are likely to be most effective/suitable for different regions and soil types?
Market	• Explore ways in which the Soil CRC and other funding agencies can invest in research to develop standards, certification or market-based incentives for good soil management.	• What types of market instruments are likely to be most practical and useable? • Is there local agreement on what comprises 'good' soil management and the best indicators for assessing or measuring it?
'Softening' scientific and institutional knowledge		
Institutional	• Explore ways in which the Soil CRC and other funding agencies can provide support in accessing relevant scientific expertise, and in communicating soil research in ways that are understandable and useful to farmers.	• In what ways can local soil expertise be supported and developed to help address the challenges of accessing external expertise? • What resources are needed to improve communication of soil research to farmers in a form that they understand and can use?

APPENDIX D CRITERIA FOR ADOPTABILITY DEVELOPED IN SOIL CRC SCOPING STUDY 1.2.02

Focus of implementation and adoption	Key adoption drivers/influences	Conditions / criteria that need to be met for an innovation/practice to be adoptable
Characteristics of the innovation/ practice	Relative advantage	The innovation/practice shows strong likelihood of: • Reducing short-term costs and increasing yields and/or output prices. • Reducing or having no net impact on business risks.
	Compatibility	The innovation/practice is largely compatible with producers' existing approaches, farming methods, and machinery, and the overall farming system.
	Complexity	The practice is relatively straightforward to understand. Technical assistance is readily available to assist the producer in implementing the innovation/practice and making it workable on-farm.
	Observability	The results and benefits of the innovation/practice are visible and can be observed distinctly from other practices.
	Trialability	The innovation/practice can be adapted, changed or modified by the producer to a certain extent so that it is more easily integrated into the existing farming system.
Characteristics of the producer and their socio-cultural context	Producer goals and values	The practice/innovation is consistent with producers' financial, environmental/ conservation, family and lifestyle values and goals.
	Social networks	The practice/innovation is compatible with accepted ideas, knowledge and sources of advice within producers' broader social networks.
	Producers' local knowledge	The practice/innovation allows for the integration of producers' existing local knowledge and expertise.
	Personal circumstances	The practice/innovation is consistent with producers' family and financial circumstances.
	Trust	The practice/innovation, and those who develop and promote it, are viewed by producers as credible and trustworthy.
	Cultural norms on 'good' farming	The practice/innovation is consistent with local norms and accepted cultural scripts on what constitutes 'good' farming and being a 'good' farmer.

Focus of implementation and adoption	Key adoption drivers/influences	Conditions / criteria that need to be met for an innovation/practice to be adoptable
Characteristics of the knowledge and power relations that frame how the innovation/practice is developed and promoted	Legitimate process	Innovations/practices are co-produced through appropriate engagement among stakeholders (e.g., scientists, government and/or industry representatives and end users/landholders).
	Technological lock-in	The innovation/practice being promoted does not undermine producer autonomy and flexibility or lock them into practices or technological packages that are difficult to dis-adopt.
	Transparency	Honesty about funding and commitments and aims of different stakeholders ensures reciprocal benefit through transparency.
	Risk and uncertainty	Potential risks, uncertainties and externalities (e.g., potential for adverse consequences of adoption) are highlighted in ways that allow producers to evaluate practices/innovations and learn accordingly.
	Institutional design	Governance of projects are set up to ensure an appropriate balance between accountability and efficiency.