The National Soil Research, Development and Extension Strategy

SECURING AUSTRALIA'S SOIL

For profitable industries and healthy landscapes

A strategy developed under the National Primary Industries Research, Development and Extension Framework

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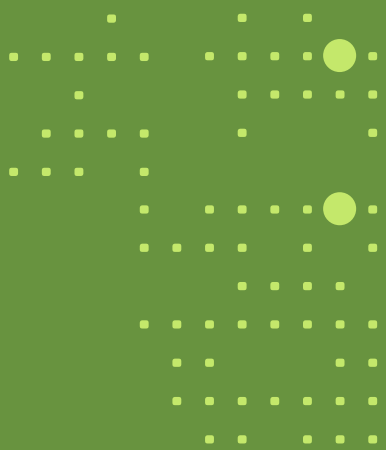


VISION	**Securing Australia's soil for profitable industries and healthy landscapes**
AIMS	• Ensure the national soil research, development and extension (RD&E) system generates and applies new knowledge to meet future challenges in soil use and management • Develop a process for national coordination and prioritisation of investment in soil RD&E to increase both effectiveness and efficiency, and commence the actions necessary to implement it • Improve the quality, availability and access to soil data and soil management information to meet user needs • Facilitate effective transfer of soil data, information and knowledge to end users • Assess future national soil RD&E capability needs and steps required to provide that capability (including education, training, people and skill development and RD&E infrastructure) • Encourage greater collaboration in developing and using physical infrastructure and human resources
GOALS	• Improve effectiveness of co-investment to generate and apply new knowledge • Improve quality, availability and access to soil data and information • Improve communication and exchange of soil knowledge • Adopt a national approach to building future skills and capacity • Collaborate on development and use of physical infrastructure
R&D STRATEGIC DIRECTIONS	• Improve soil management to increase agricultural productivity and profitability • Quantify the soil asset in space and time: mapping, modelling, monitoring and forecasting • Find solutions to manage soil/subsoil constraints • Understand soil and its role in delivering ecosystem services • Manage soil across the landscape • Harvest, verify and communicate innovations in soil management • Capture bright ideas to deliver world-class outcomes

Securing Australia's soil for profitable industries and healthy landscapes

GOALS	Improve effectiveness of co-investment to generate and apply new knowledge	Improve quality, availability and access to soil data and information	Improve communication and exchange of soil knowledge	Adopt a national approach to building future skills and capacity	Collaborate on development and use of physical infrastructure
OUTCOMES	Delivery of world-leading, innovative soil research by Australian scientists Joint identification of RD&E priorities Increased collaboration across organisations Sharing of knowledge Reduced duplication	Maps of functional properties of soils at appropriate resolutions Improved systems for monitoring change in soil properties over time Improved ability to forecast future condition of soil Improved understanding of the condition of the resource base Improved decision-making at all levels	Improved management of the soil resource by landholders Improved delivery of evidence-based information Improved knowledge exchange from researcher to farmer and back Improved knowledge of and engagement with soil experts Increased understanding of soil-related extension activities across Australia	Appropriate skills, capability and capacity to support current and future soil research, development and extension (RD&E) High quality education and training opportunities (tertiary and vocational) that meet needs of employers and soil managers Clear career pathways for soil science graduates Long-term support by industry to early career scientists (including through uptake of professional development programs)	Improved knowledge of physical infrastructure available in Australia for use in soil RD&E Collaboration, strategic investment in and development of new technology Nationally important assets (archives and field sites) protected Improved standards for collection and analysis of soil samples Improved interpretation and communication of soil test results Improved engagement with and capture of information from private laboratories
ACTIONS	Establish strategy implementation committee Establish topic-specific working groups Deliver annual soil RD&E forum Develop and review national soil RD&E priorities Facilitate networks and identify co-investment opportunities Communicate strategy activities and outcomes Monitor, evaluate, report and improve	Undertake market research of user needs for soil data and information Establish a national, cooperative approach to collection, sharing, monitoring and analysis of soil data Agree to national standards for soil data, including collection, sharing, monitoring and analysis Develop integrated national soil information system, including improved web-based delivery of soil data and information Engage effectively with public and private sectors to better capture soil information and data	Explore opportunities to use web-based technology to: • deliver credible information • communicate project level activities • establish register of expertise Improve delivery of soil information to extension providers, consultants, advisors and agribusiness professionals (e.g. through train-the-trainer type initiatives) Encourage uptake of accreditation (e.g. Certified Professional Soil Scientist) by extension providers, consultants, advisors and agribusiness professionals	Undertake national skills audit to map current and future expertise and capacity Continue developing a national soil science curriculum Develop a professional masters program in soil science Increase support for postgraduate scholarships and stipends Review existing soil related VET programs Explore development of online courses in soil science Recognise and promote training opportunities outside formal education system Encourage uptake of professional accreditation (e.g. CPSS)	Establish a dispersed national soil archive Expand inter-laboratory soil testing proficiency programs Develop national standards for collection and analysis of soil samples Consider mechanisms to capture public and private soil data and information from analytical laboratories Maintain, collaborate and communicate work conducted on long-term field sites

Summary

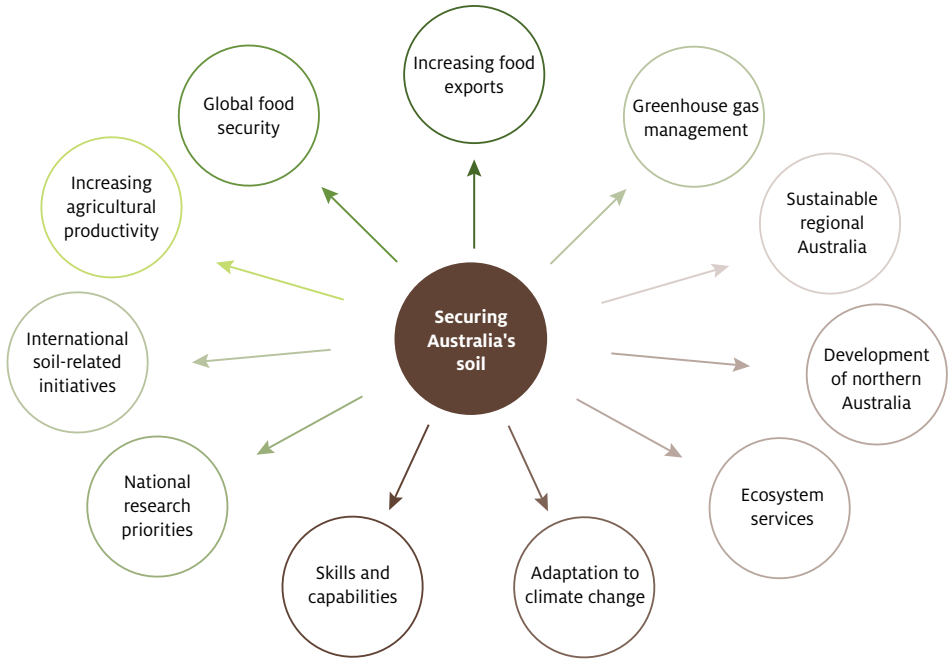
Soil is vital to our existence. It provides nutrients, water and physical support for the production of food and fibre, and the base resource for roads, homes and built infrastructure. In doing so, soil underpins our agricultural industries and supports other industries including construction engineering and mining. Soil also sustains our natural environment by cycling and storing nutrients and water, and it helps to regulate our climate by acting as a source or sink for important greenhouse gases.

But soil is a non-renewable resource (within human timescales) and Australia's soils are mostly ancient, strongly weathered and infertile by world standards. While there are areas of highly fertile soil, Australia's soil is often poorly structured and affected by salinity, sodicity, acidification and other constraints, and in some regions severely degraded by wind and water erosion. We need to understand and manage our soil if we are to increase agricultural productivity and profitability, reverse degradation and improve soil condition for present and future generations.

Despite substantial investment in soil research, development and extension (RD&E), lack of national coordination has resulted in inefficiencies, limited effectiveness and poor return on investment. Australia needs a mechanism to identify, coordinate and address national priorities across industries. Australia's first National Soil Research, Development and Extension Strategy (soil RD&E strategy) will help to ensure sustainable agricultural productivity and profitability, enabling us to provide food, fibre and forestry products to national and global markets. These and other drivers that highlight the need for a national strategy are outlined in Figure 1.

To meet growing global demand for food and continue to be a net exporter of food and fibre, valued at $30 billion annually, Australian farmers must be able to effectively manage their soil. They will need to produce more with less (land, water, inputs) while contending with a changing climate. Farmers will need access to knowledge gained through world-class RD&E. The National Committee on Soil and Terrain (NCST) predicts improvements in soil management resulting from access to up to date user-friendly soil data could generate benefits to Australia worth at least $2 billion a year by 2020 (assuming a 5 per cent to 10 per cent increase in agricultural productivity). The soil RD&E strategy will foster collaboration between more than 150 research,

FIGURE 1 Drivers for a soil research, development and extension strategy



industry and education providers and ensure coordinated delivery of soil information that meets the needs of farmers, landholders and other end users (Box 1).

BOX 1 Users of soil RD&E

- Broadacre and dryland farmers
- Tree plantation managers
- Irrigators of dairy, horticulture and high value crops
- Consultants, agronomists, agribusiness, service and extension providers (grower groups, natural resource management bodies)
- Those working in engineering, construction, mining, geology, energy
- Planners, such as natural resource management bodies, local government
- Government policy and program managers
- Researchers (university, government, private)
- Financial institutions

Soil security is vital to sustainable development. Soil security is concerned with maintaining and improving the global soil resource to produce food, fibre and fresh water and contribute to energy and climate sustainability, biodiversity and protection of the ecosystem. Australians expect production of food and fibre products to be sustainable; they want agricultural landscapes to protect biodiversity and provide high quality ecosystem services, such as clean air and water and healthy soil. Ecosystem services are essentially the benefits that humans receive from nature. Estimates suggest that ecosystem services, including those provided by soil, contribute $33 trillion annually to the world economy (Costanza et al. 1997). It is therefore essential to understand the complexity of the soil resource and to maintain and improve its integrity so that it can continue to deliver benefits for all.

Australian farmers have improved the way they manage their soil, for example, through rapid uptake of no-till farming practices since the 1980s.

More can be done to improve soil condition and halt soil degradation, particularly through improved management of soil acidity and ground cover. Those who deliver soil knowledge must be better informed to support our farmers and land managers. New tools and technology will provide farmers, consultants, policymakers, planners, researchers and other users of soil data and information with improved ability to test, map and monitor the condition of the soil resource, predict its capability and functionality, and implement better management and planning decisions.

BOX 2 Strategy goals

- Improve effectiveness of co-investment to generate and apply new knowledge
- Improve quality, availability and access to soil data and information
- Improve communication and exchange of soil knowledge
- Adopt a national approach to building future skills and capacity
- Collaborate on development and use of physical infrastructure

In 2011 it was estimated that annual investment in soil RD&E was approximately $124 million (DAFF 2011). Despite this significant annual investment there has previously been no mechanism to identify, coordinate and address national soil RD&E priorities across industries. In 2008 the NCST, supported by the former Natural Resource Management Standing Committee, commissioned Managing Australia's soils: a policy discussion paper (Campbell 2008) to consider soil resource and management issues and opportunities in Australia. In March 2012, as a result of the report and a stocktake of Australia's investment in soil RD&E (DAFF 2011), the then Primary Industries Standing Committee (PISC) endorsed development of the soil RD&E strategy.

This strategy document recognises the benefits improved understanding and management of soil will provide to agricultural productivity and profitability. It also recognises that soil provides essential ecosystem services to agriculture, the environment and the community. The strategy vision is supported by five goals (Box 2) that provide a framework for collaboration and cooperation, generation of new knowledge and provision of capability in:

- data and information
- education and training
- communication of soil knowledge
- physical infrastructure (including analytical equipment, soil archives and long-term field sites).

Extensive stakeholder consultation in 2013, including through the Advocate for Soil Health, Major General the Hon. Michael Jeffery, led to development of soil R&D strategic directions (Box 3). The strategic directions were developed to target and coordinate soil research and development efforts in the national interest, providing a framework for investment and collaboration. The strategic directions will help scientists, industries, policymakers and land managers work together to develop opportunities and overcome challenges in the laboratory and at the farm and landscape scale.

BOX 3 Soil R&D strategic directions

- Improve soil management to increase agricultural productivity and profitability
- Quantify the soil asset in space and time: mapping, modelling, monitoring and forecasting
- Find solutions to manage soil/subsoil constraints
- Understand soil and its role in delivering ecosystem services
- Manage soil across the landscape
- Harvest, verify and communicate innovations in soil management
- Capture bright ideas for world-class outcomes

Strategic directions address the strategy goal to improve effectiveness of co-investment to generate and apply new knowledge. They also align with other strategy goals by developing new tools and technology to support a proposed Australian Soil Assessment Program, and by ensuring that soil extension activities provide relevant information underpinned by sound science.

Strategy goals will support strategic directions by ensuring Australia has sufficient numbers of soil scientists with the training and expertise to address current and future challenges. The goals will help build the infrastructure to support nationally relevant soil RD&E, including analytical equipment, soil archives and long-term field sites.

The National Implementation Committee will drive the strategy, assisted by topic-specific working groups and supported by an executive officer. The committee will deliver an annual soil RD&E forum; develop and manage a national website for the soil strategy; deliver monitoring, evaluation, reporting and improvement activities; and review national soil R&D strategic directions. The strategy will align with existing sectoral and cross-sectoral strategies under the National Primary Industries Research, Development and Extension Framework and contribute to the work of the Research, Development and Extension Committee and Resource Management Committee.

The soil RD&E strategy will foster national coordination, collaboration and increased effectiveness and efficiency in Australia's soil RD&E effort. It will bring together knowledge, skills and infrastructure from across jurisdictions and organisations to address national and regional priorities, opportunities and problems. It will facilitate co-investment, reduce duplication of effort and ensure knowledge generated in one jurisdiction, region or industry can be passed on to others. The strategy will play a vital role in securing Australia's soil for profitable industries and a healthy landscape.

Contents

CHAPTER 1

Overview

1.1 Australia's soil

Terrestrial life of the Earth is ultimately dependent upon soil for its survival. Without the water, nutrients and physical support provided by soil and its biota, most plants would not exist nor the animals that depend on them, including humans. Soil is therefore an essential and precious part of life and one that is largely non-renewable in human timescales. Healthy and resilient production landscapes are fundamental to the provision of ecosystem services (Cork et al. 2012), sustainable food and fibre production, and prosperous rural and regional communities (Campbell 2008).

Australia's soils are mostly very old, strongly weathered, shallow and infertile by world standards and present many challenges to those managing them. In general, surface layers of cropped soils have a low organic matter content and are often poorly structured. Subsurface layers with high clay content occur throughout Australia, restricting drainage and root growth; and bleached layers with very low levels of nutrients impact on productivity. Many of our soils are affected by salinity, sodicity, acidification or other constraints, leading to physical and chemical limitations to crop and pasture growth and decreased production. For example, soil acidity affects two-thirds of Western Australia's wheatbelt, an area that produces half of Australia's wheat crop and 80 per cent of wheat exported, costing the farming community more than $400 million annually through lost production (Herbert 2009). While Australia has large areas of fertile cracking clays, these soils are often difficult to manage due to their physical limitations. Australia's variable climate adds to these challenges, and managing the land and soil resource effectively requires sophisticated risk management systems and a high level of expertise, adaptability and resourcefulness (Campbell 2008).

Australia's soils are a major national asset underpinning our agricultural productivity and ability to be a significant exporter of food valued at $30 billion annually (gross value of food exports) (DAFF 2013). Assets need maintenance and this applies to our soils. Australian agriculture needs to be able to increase productivity to help meet the 70 per cent rise in world food demand anticipated

by 2050 (FAO 2011). Agriculture must also manage for climate change and reduce greenhouse gas emissions. Achieving these multiple goals will depend on managing and improving the soil resource base.

State of the Environment (State of the Environment Committee 2011) and other reports have shown that soil degradation, including acidification, erosion and loss of soil carbon, will increasingly affect Australia's agriculture unless carefully managed. Assessment of soil condition for regions with cropping and/or intensively managed grazing systems (approximately 75 million hectares) showed that for:

- acidification—50 per cent of regions were in very poor or poor condition, while 95 per cent of regions showed a deterioration in soil pH
- wind and water erosion—53 per cent of regions were assessed as in poor condition, while soil cover in 11 per cent of regions was deteriorating
- soil carbon—33 per cent of regions had very poor or poor soil carbon content, while 85 per cent of regions had ongoing deterioration in soil carbon content.

Dryland salinity has also been identified as an ongoing threat, although the millennium drought may have halted its spread temporarily. Some agricultural systems continue to mine stores of soil nutrients without adequate replacement (Bell et al. 2010; State of Queensland 2012). Runoff and loss of topsoil from less-than-optimal land management practices have the potential to degrade major environmental assets, such as the Great Barrier Reef, with run-off (including sediments, nutrients and chemicals) reducing water quality into the reef lagoon.

It is likely that Australian agriculture will have to improve capture and use of soil water (from both rainfall and irrigation) and improve soil nutrition to reduce reliance on the high energy requirements for production of inorganic fertilisers. The industry will also be expected to manage soil to store more carbon and to reduce its greenhouse gas emissions, such as those associated with fertiliser use.

Australians expect production of food and fibre products to be sustainable; they want agricultural landscapes to provide high quality ecosystem services, such as clean air and water and healthy soils, and the protection of biodiversity. These challenges come together in the concept of soil security. Soil security is concerned with the maintenance and improvement of the global soil resource to produce food, fibre and fresh water and contribute to energy and climate sustainability, the maintenance of biodiversity and protection of the ecosystem (McBratney et al. 2014). Although Australia continues to produce world-class soil RD&E, the full suite of knowledge and information needed to meet these challenges and to assess progress is not currently available. Australia needs a coordinated national soil RD&E strategy.

1.2 Challenges and drivers of soil research, development and extension

1.2.1 Increasing agricultural productivity and contributing to global food security

Australia's soils underpin our agricultural productivity and the ability to be a net exporter of food. About 60 per cent (by volume) of total agricultural production (valued at more than $30 billion in 2011–12) is exported. Australia's food production systems supply most of its domestic food and contribute 1 per cent of all the food eaten in the world, feeding some 40 million people daily outside Australia (PMSEIC 2010). However, productivity growth in Australia's broadacre agriculture sector has slowed in the past decade (Lake 2012). Continued productivity growth is essential for Australian primary producers to maintain or improve our international competiveness and ensure the environmental sustainability of our production systems. Productivity growth will enable Australia to continue to meet our own food and fibre needs and to contribute to the needs of others.

1.2.2 Increasing food exports

An increasingly wealthy and mobile middle class is emerging in the Asia–Pacific Region, creating new opportunities including an increasing demand for high quality food products (Atkin & Connolly 2013). Australia should be well placed to help meet this demand. However, our ability to capitalise on this and to consistently meet market requirements will require greater focus on and demonstration of sustainable food production systems. Australian food producers must manage our natural resources, including soil, water and energy, to support productivity growth and maintain the sustainability of those natural resources.

Other drivers, particularly adapting to climate change and maintaining ecosystem services, make the tasks of maintaining food security and increasing food exports even more challenging and emphasise the need to better understand, use and manage our soil.

1.2.3 Planning for long-term sustainability in regional Australia

Around 30 per cent of Australians live in rural and regional Australia, with rural economies accounting for 17 per cent of national employment and contributing 12 per cent of gross domestic product (DAFF 2011). Effective soil RD&E will be needed to underpin decisions about land use and change in regional Australia (for example, mining and urban development), to assist with developing responses to reduced water availability (for example, in the Murray–Darling Basin) and to improve the resilience of our agricultural industries to a changing and variable climate. Most planning arrangements are determined at state and territory or local government level and officers working within these organisations will need improved soil knowledge before strategies can be implemented fully and efficiently.

1.2.4 Developing northern Australia

A goal of the Australian Government's 2030 Vision for Developing Northern Australia is to increase Australia's agricultural output and supply premium products. Northern Australia, with its proximity to the Asia–Pacific Region, could benefit from rapid population growth and increased market access. Seasonal variation between the northern and southern hemispheres could also be advantageous to the development of sustainable agriculture in northern Australia. An additional 5 million to 17 million hectares of arable soil in northern Australia may be suitable for a variety of agricultural purposes (Wilson et al. 2009). If agriculture is to be productive, profitable and sustainable in this region, the variable soil will need careful management and the application of local and world-leading soil RD&E and soil management practices. Local Indigenous communities will also need to be involved in agricultural development and in capturing and translating Indigenous knowledge of land management for broader application.

1.2.5 Managing greenhouse gases

Australian agriculture contributes 16 per cent of national greenhouse gas emissions (Department of the Environment 2013), with a further percentage from net deforestation activities likely to be associated with agriculture. Australians expect that soils will be managed to store increasing amounts of carbon (which can benefit production and reduce net emissions) and that agriculture will reduce its contributions to greenhouse gas emissions, such as those associated with fertiliser use, including nitrous oxide releases.

The potential for Australia's soils to store additional carbon is not well understood. We need more knowledge about:

- the rate at which soil can accumulate and retain carbon under different management systems
- the maximum carbon carrying capacity of soils
- the permanence of this soil carbon sink
- the potential nutrient trade-offs in storing carbon
- how to monitor changes in carbon stocks
- how to incorporate soil carbon sequestration into a national accounting scheme.

Knowledge about the cycling, availability and uptake of soil nutrients is limited; for example, we do not yet fully understand the phosphorus acquisition mechanisms of phosphorus efficient plants and

the role and ecology of soil microorganisms in making phosphorus available to crops and pastures. Strategic investment in new knowledge is needed before goals in soil carbon sequestration or nutrient use efficiency can be achieved.

1.2.6 Adapting to a changing climate

Climate (especially rainfall) and soil quality determine where agriculture and forestry can be undertaken, what can be produced and at what cost. Due to our geographical position, Australia is vulnerable to the effects of climate change. Rainfall is projected to decline in southern Australia, mainly in Victoria, southern New South Wales and south-west Western Australia. Rainfall patterns are also expected to change which, in some instances, may present opportunities for new industries to emerge. In other instances, a small decrease in rainfall may be magnified by higher evaporation rates, reducing the amount of water (effective rainfall) that is held as soil moisture and is available to meet plant water requirements. Changes in rainfall may also affect timing and rates of aquifer recharge which could lead to changes in how salt is deposited and transported across the landscape, potentially resulting in decreased agricultural productivity and a loss of viable agricultural lands.

Improving water use efficiency for dryland and irrigated agriculture would help the agriculture industry adapt to climate change and enable farmers to better plan for and manage climate risks. Factors that influence the amount of water stored in soils include surface infiltration rates and profile storage capacity; these interact with management factors such as the use of fallow and no-till practices, cover crops and other conservation farming methods. A better understanding of Australia's different soil types, their limitations and how their attributes change with climate and management practices in different regions is required to improve water use efficiency and productivity at a national scale.

1.2.7 Delivering high quality ecosystem services

Australians expect agricultural (and forestry) landscapes to deliver high quality ecosystem services. Many of these services are delivered from the 60 per cent of Australia's land mass that is managed for agriculture. Soil management practices have a major impact on the quality of on-site and off-site ecosystem services (Cork et al. 2012). For example, excessive drainage can cause nutrient leaching, while soil loss through wind and water erosion can reduce air and water quality. Waste minimisation and resource recovery policies are creating new challenges for soil research and development. Increasing volumes of organic and inorganic materials are being diverted from landfills for use as soil amendments after processing, with at least 5 million tonnes of such material available annually (GRDC 2010). This is creating new opportunities and risks to soil health and public health.

1.2.8 Improving research and training

Improved knowledge and management of Australia's soils is required in order to achieve the Australian Government's strategic research priorities (DIICCSRTE 2013), including lifting productivity and economic growth, managing our food and water assets, and living in a changing environment. The National Farmers' Federation and other organisations have identified the need for improved and innovative methods to exchange knowledge and for increased education and training of skilled staff to support sustainable land use and management (NFF 2012).

1.3 Linkages to international initiatives

The Global Soil Partnership, established under the Food and Agriculture Organization of the United Nations (FAO), recognises the central role of soil resources as a basis for food security and the provision of key ecosystem services. The Partnership also recognises many of the problems related to soil information and management that need to be addressed in Australia, including:

- Soil data is often fragmented, partly outdated, heterogeneous and difficult to compare, not easily accessible and does not respond well to users' needs.
- Capacity in soil knowledge is a scarce resource due to loss of expertise and skills.
- Soil RD&E is fragmented, largely the domain of soil scientists, not accessible for use by various disciplines or for decision-making and not tailored to address the problems and development agendas of today.
- Awareness of and investment in soil management are low compared with the needs of long-term sustainable soil use and management.
- Soil policy is often perceived as a second-tier priority.
- There is no international governance body to support information exchange and coordinated global action on soil management.

Australia is a member of the Intergovernmental Technical Panel on Soils, and regional partnerships are in the process of being established. The Global Soil Partnership aims to:

- promote sustainable management of soil resources for soil protection, conservation and sustainable productivity
- encourage investment, technical cooperation, policy, education awareness and extension in soil
- promote targeted soil research and development focusing on identified gaps and priorities and synergies with related productive, environmental and social development actions
- enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines
- harmonise methods, measurements and indicators for the sustainable management and protection of soil resources.

In April 2013 FAO member countries agreed to the proclamation of the International Year of Soils 2015. This will serve as a platform for raising awareness of the importance of sustainable soil management as the basis for food systems, fuel and fibre production, essential ecosystem functions and better adaptation to climate change for present and future generations. The Global Soil Partnership is involved in planning for this event.

1.4 Defining research, development and extension

Research

Australia's first soil RD&E strategy covers all aspects of research, including:

- pure basic research—experimental and theoretical work purely for the advancement of knowledge
- strategic basic research—aimed at acquiring new knowledge but directed into specified broad areas and with the expectation of practical discoveries
- applied research—original work undertaken primarily to acquire new knowledge with a specific application in view, either to determine possible uses for the findings of basic research or to determine new ways of achieving specific and predetermined objectives.

Development

Development is an adaptive activity that takes existing knowledge (often from different sources and disciplines) and applies it to resolve specific problems or difficulties in a particular setting. The knowledge may have been applied elsewhere, but needs to be tested and demonstrated in the new situation and perhaps modified in the light of experience.

Extension

Extension is the process of enabling and building capacity for change in individuals, communities and industries through communication and information flow to help develop awareness, knowledge and skills. Extension can include elements of education and training, individual and group participatory learning, and practical demonstration with learning by doing. Some people involved in developing this strategy prefer the term 'knowledge exchange' rather than 'extension', to emphasise that the flow of information (for example, between soil researchers and land managers) needs to be in both directions and iterative.

Implicit in the National Primary Industries Research, Development and Extension Framework is the concept that research relevant to Australia's soils can be undertaken anywhere in the country (and in some cases overseas). Development work is usually undertaken regionally to deal effectively with specific problems, while knowledge exchange is usually best undertaken at a local scale.

1.5 Need for the National Soil Research, Development and Extension Strategy

In the past, Australia made substantial investments in soil RD&E, particularly in the areas of nutrient deficiencies, soil erosion, acidification and subsoils hostile to plant growth. Despite recent investment in soil-related issues such as nutrient management and carbon sequestration, research investment has reduced in many of the topics that underpin good soil knowledge and management.

Campbell (2008) noted a dramatic decrease in soils expertise, a trend likely to accelerate as the current generation of senior experts approaches retirement. Downsizing in tertiary soils courses means fewer graduates and a reduced capacity to rebuild. Many of the 101 stakeholder submissions received in response to Campbell's paper supported a strategic approach to soil management in Australia, including strategic and increased investment in soil research, particularly in the areas of soil biology, soil carbon sustainability and practice change (NCST 2009).

Activity in soil RD&E has been very successful, for example, through the uptake of no-till farming practices across Australia. However, budgetary pressure and short-term funding arrangements have limited provision of a broad range of skills that will be required in the future. Other aspects of the existing national soil RD&E effort are of concern:

- Current levels of investment in soil RD&E may not be adequate to address challenges and future needs.
- There is no obvious mechanism available to ensure that national priorities for soil RD&E are identified or that investment is adequate, strategic or aligned to address these priorities.
- Many organisations fund and/or undertake soil RD&E (Chapter 3), but relatively little co-investment occurs between organisations funding activities on the same or related topics.
- Particularly for development and knowledge exchange, the more than 150 organisations involved have only a limited awareness about, or contact with, other groups undertaking similar or related work; only limited sharing of data (for example, from soil tests) or knowledge takes place.
- Links between R&D and knowledge exchange with land managers (Appendix C) are limited, except within some industry sectors, especially cross-sectoral exchanges. Current activities (for example, grant applications to Australian Government natural resource management programs) provide strong evidence of a continued demand by land managers for more information about soil and how best to manage it.
- Lack of soil data with the required attributes and scales needed to guide investment decisions is an acknowledged concern across Australia; existing data is not readily available to land managers in interpreted formats.
- Current education and training activities may not be sufficient to maintain the skills and capacity needed to address future needs and is not meeting the needs of land managers today.
- Limited knowledge exists about available and future physical infrastructure needed to support national soil RD&E or opportunities to manage, collaborate and make investment decisions more efficiently.

Increased collaboration and development of coordination mechanisms would ensure effectiveness and efficiency of the national soil RD&E effort.

In its recent note on Australia's food and fibre future (2013) the Australian Academy of Science stated that, under the states–Commonwealth government system no one agency is capable of delivering or coordinating the innovation required. The authors noted that the the National Primary Industries Research, Development and Extension Framework aims to foster collaboration and reduce inappropriate competition between Australian research agencies. These comments apply particularly to the existing soil RD&E system.

Acknowledgement of the urgent need for collaboration, coordination and education led to the development of the soil RD&E strategy. How the strategy will meet these goals is summarised in Chapter 4.

1.6 Benefits to stakeholders

The soil RD&E strategy will deliver multiple benefits for industry, policymakers, researchers, educational institutions and their students, and the employers of soil scientists and knowledge providers, including extension officers, consultants, advisors and agribusiness.

The major beneficiaries of a soil RD&E strategy are industry and the community through the work of the signatories to the National Primary Industries Research, Development and Extension Framework—namely the Australian and state governments, CSIRO, the rural R&D corporations and the universities. Through this strategy, as with the other strategies under the National Primary Industries Research, Development and Extension Framework, these agencies will achieve greater certainty, effectiveness and efficiency of investment (which includes taxpayer and industry levy funds) through coordinated and collaborative delivery aligned with an agreed strategy. This will ultimately be of benefit to industry and to society.

For industry, the soil RD&E strategy aims to deliver more efficient use of levy dollars, with R&D corporations sharing resources and collaborating on common issues. Extension officers and consultants will be more informed and will know where to access the latest information about soil research and development so they may assist farmers to better manage their farms and the soil resource. As a result, understanding of how soil functions will increase and this is likely to lead to improved soil management, increased productivity and improved delivery of ecosystem services to the community from agricultural land. Land managers will be better equipped to find and use soil information more effectively, and investment in soil RD&E and in soil information will be better aligned with industry needs.

The strategy will help policymakers make more informed decisions about land use and agricultural production based on improved availability and access to data and information. It will form the basis for developing and setting national priorities for investment and for leveraging investment with partner organisations. Increased understanding of the roles and responsibilities of different agencies will aid collaboration, reducing duplication of effort and improving efficiency and effectiveness of research and extension expenditure. This greater understanding may also improve linkages and collaboration between universities and other organisations undertaking and delivering soil RD&E.

An agreed framework for setting research priorities will help universities and researchers make better investment and resourcing decisions. It will encourage collaboration across institutions and improve linkages with government and rural R&D corporations and statutory authorities, including improved opportunities to match research to the needs of industry and the community. Communicating the results of soil research is a key component of the strategy and will result in improved pathways for disseminating the results of research to a broader audience. A national strategy will raise the profile of soil science and ensure greater recognition of the importance of this topic and its practitioners.

Educational institutions and students will benefit from improved educational opportunities for students and teachers of soil science, including the potential for collaboration across institutions to deliver higher education courses in soil science. Greater availability and access to data and information about Australia's soil will inform and underpin educational material and graduate knowledge and skills will be better aligned with the needs of employers. This will result in improved career pathways for soil science graduates and greater emphasis on soil science as a career.

For those delivering soil information to land managers, improved access to and availability of soil data and information will help them advise clients and design communication activities (for example, field days, trial sites and demonstrations). The strategy will improve linkages between farmers, extension providers and researchers to ensure that researchers match their research with the needs of users. Extension providers will be able to find the information they need and the experts to source

it. Land managers will be able to draw on reliable, up-to-date information to make informed decisions about changing their management practices.

1.7 Research, development and extension topics in the strategy

The strategy focuses on primary industries. It is part of the Primary Industries Research, Development and Extension Framework endorsed by the former Primary Industries Ministerial Council (now Agricultural Ministers Forum) and supported by the Australian, state and territory governments, CSIRO, rural R&D corporations and statutory authorities, and the Australian Council of Deans of Agriculture. These bodies represent a wide range of users of soil RD&E across the agricultural and forestry industries. Many also capture soil information and are potential providers as well as users of soil information.

The strategy also recognises the many other users of soil information, including companies, groups and individuals working in natural resource and catchment management, mining, environmental planning and road and urban construction (Appendix C).

The strategy considers current policy drivers that emphasise the importance of improving outcomes from existing investment in soil RD&E. These drivers include the growing focus on food security, climate change and the associated increase in production risk and changes in production type, and continued competition for natural resources. Specific topics included in the strategy's scope include agricultural land management, carbon sequestration science, land capability and soil degradation, soil and land inventory and monitoring, soil biology, soil chemistry and soil physics. Some topics have been excluded because they are covered sufficiently in other strategies developed under the National Primary Industries Research Development and Extension Framework or under existing initiatives such as Australia's Biodiversity Conservation Strategy and Native Vegetation framework. These topics include non-soil-related environmental impacts associated with agriculture, climate change (except where it relates directly to soil carbon, greenhouse gases or climate risk management with respect to soils) and industry – or commodity-specific RD&E.

CHAPTER 2

Consultation and development

2.1 National Soil Research, Development and Extension Strategy

In 2008 the then Primary Industries Ministerial Council initiated development of a national strategic framework for primary industries RD&E. This initiative aimed to:

- ensure alignment of Australia's RD&E capacities with future industry and community needs
- increase collaboration between funders, researchers and educators
- strengthen Australia's position in international markets
- ensure more effective and efficient RD&E to support primary industries.

In 2009 a Statement of Intent was signed by Australian, state and territory governments, rural R&D corporations and statutory authorities, and the Australian Council of Deans of Agriculture. The soil RD&E strategy reflects the support of these organisations in furthering the national framework.

Under the National Primary Industries Research, Development and Extension Framework, 14 sector strategies led by individual industries (such as grains, dairy and cotton) and eight cross-industry strategies (including climate change and water use in agriculture) will be developed. To date, 22 of these strategies have been completed and are in the process of being implemented. In March 2012 the then PISC endorsed development of the soil RD&E strategy as one of the cross-sectoral strategies. The broad aims of the strategy are to consider future soil RD&E needs common to all industry sectors and improve effectiveness and efficiency of investment in soil RD&E.

2.2 Terms of reference

Under the terms of reference, the strategy will:

- be developed in line with objectives of the National Primary Industries Research Development and Extension Framework
- identify priorities, resourcing and collaborative opportunities across funders and providers to improve efficiency and effectiveness of investment in soils RD&E

- recognise and not duplicate other sectoral and cross-sectoral RD&E strategies
- evolve as a result of consultation across a range of stakeholders involved in soils RD&E
- recognise current policy drivers and contribute to broader policy agendas, including food security, greenhouse gas management, adaptation to climate change, land use planning and competition and delivery of high quality ecosystem services
- include implementation arrangements as agreed by all parties involved in its development.

2.3 Reference group

The National Soil Research, Development and Extension Strategy Reference Group comprised representatives from:

- Australian, state and territory governments (except the Australian Capital Territory)
- research and development corporations—the Grains Research and Development Corporation (GRDC), Meat & Livestock Australia (MLA) and the Cotton Research and Development Corporation (CRDC)
- universities—the University of New England and the University of Sydney
- industry—Birchip Cropping Group, Western Australia No-Tillage Farmers Association, and Soil Science Australia/Certified Professional Soil Scientists
- research bodies—CSIRO.

The role of the reference group was to:

- provide representation across sectors to ensure agreement by relevant stakeholders involved in soils RD&E
- consult with the Agriculture Senior Officials Committee (AGSOC - formerly PISC) for feedback and endorsement and final approval from both AGSOC and the Agricultural Ministers Forum (AGMIN - formerly Standing Council on Primary Industries)
- provide knowledge and expertise during development of the strategy to ensure appropriate issues and actions were considered
- prioritise issues to be explored as the strategy developed and identify issues that required further investigation (including a process for this investigation) so that gaps in knowledge were addressed and the strategy was informed by accurate and up-to-date information
- provide ideas, options and support for implementation arrangements to ensure actions within the strategy are achievable
- provide feedback on relevant documents, including drafts of the strategy, to ensure accuracy and appropriateness in line with the National Primary Industries Research, Development and Extension Framework
- help develop a stakeholder communications and engagement plan to ensure input into the strategy development process from the broad range of stakeholders involved in soils RD&E
- provide networks and contacts to assist with consultations and seek feedback from peers and stakeholders where appropriate.

Reference group members are listed in Appendix B.

A subset of the reference group, the development team, was formed to drive development of the strategy. The team consisted of representatives from the Australian Government Department of Agriculture, CSIRO, Department of Environment and Primary Industries Victoria, University of Sydney, GRDC and, from July 2013, Department of Primary Industries New South Wales.

The role of the development team was to:

- lead the day-to-day work to develop the strategy
- take a strategic view of issues presented by the reference group, determine how these should be acted upon and examine the potential implications of those actions
- prioritise options proposed by the reference group, using cost-benefit analysis and/or available information
- formulate options for completing tasks as agreed by the reference group
- contribute to drafting of the strategy
- ensure the strategy is consistent with the National Primary Industries Research, Development and Extension Framework.

Funding to support development of the strategy was provided by GRDC; the Australian Government Department of Agriculture; CRDC; Dairy Australia;

and the Queensland, Western Australian, Tasmanian, Victorian and Northern Territory governments. The Department of Agriculture provided secretariat services to the reference group and development team, with the secretariat supporting the development of the strategy, including by the engagement of contract support where required. An external consultant was engaged to help draft papers and the strategy. The strategy document was drafted by a consultant in collaboration with the secretariat at the Department of Agriculture. The strategy reference group provided input to and feedback on drafts of the strategy, and a final draft of this document was circulated for consultation in November 2013. Feedback was received from key stakeholders in industry, government, research organisations and the private sector. The overall comment was positive and relevant feedback has been incorporated into the final strategy document.

2.4 Communication and consultation

Following each reference group meeting, a short written communiqué was provided to reference group members and to Soil Science Australia for wider distribution through their respective networks. Summaries of progress were distributed, outlining the main topics likely to be of interest to users of soil information, researchers and policymakers. An email database with more than 330 contacts was established to communicate progress and provide opportunities for stakeholders to become involved in strategy development. Members of the reference group and development team also made presentations about the strategy to stakeholders, for example, at the Soil Science Australia and New Zealand Society of Soil Science conference in Hobart in December 2012. A short questionnaire seeking views about soil RD&E and how it might be improved was distributed at this conference and responses were used to help guide development of the strategy.

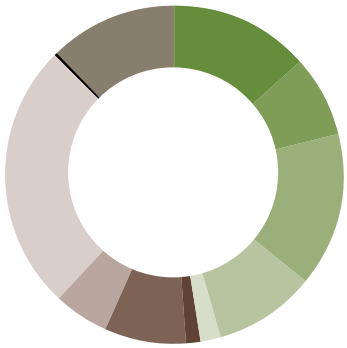
The NCST co-organised a two-day workshop in Canberra in December 2012 to inform development of a proposal for a national cooperative soil assessment program. More than 40 participants contributed to this workshop, including all members of the NCST, the recently appointed Advocate for Soil Health, rural R&D corporations and statutory authorities, consultants, modellers, industry (fertiliser companies, farmers and farmer groups), natural resource management bodies, CSIRO, National Plan for Environmental Information, Bureau of Meteorology, the Department of Agriculture and the Department of Climate Change and Energy Efficiency. The results of this workshop, and a subsequent report by the NCST, have been incorporated in the strategy (sections 3.3.2 and 4.3.2).

In considering future education and training needs, the secretariat asked postgraduate students in soil science about their future study and work expectations and intentions, with a focus on whether these scientists will remain in Australia once they graduate. Results are reported in Chapter 3.

In May 2013 the strategy secretariat surveyed organisations representing both users and providers of soil information and knowledge about the role they intended to play in future soil RD&E. They were also asked about their fields of interest and specialist skills. A wide range of people with an interest in soil RD&E (Figure 2) were also asked about their views on the current status of soil RD&E efforts, whether their needs for soil information are being met and what changes they would like to see nationally. Results from the 182 responses were used in formulating goals and activities described in chapters 4, 5 and 6.

Regional consultation workshops were held during 2013 in Bendigo (Victoria), Adelaide (South Australia), Toowoomba (Queensland), Northam (Western Australia) and Orange (New South Wales). The 108 participants were drawn from public, non-profit and private organisations: farmers, consultants and agronomists; grower group members and staff; catchment managers; soil research and knowledge exchange staff; agribusiness personnel; policymakers and planners; and people from other industries with an interest in soils, for example, road and urban construction (Figure 3).

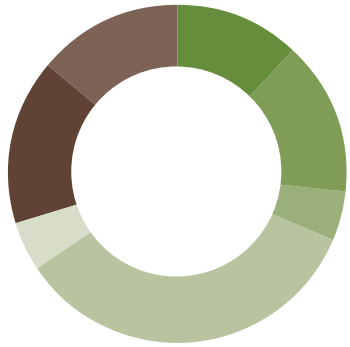
FIGURE 2 Sectors represented in the National Soil Research, Development and Extension Strategy Survey, 2013



Agricultural extension services	13%
Agricultural industry/company	8%
Education and extension	15%
Farmer or other land manager	10%
Land development planner	2%
Natural Resource Management organisation	1%
Other user of information for soil management	8%
Research scientist – other	5%
Research scientist – soils	25%
Research scientist – other	1%
Policy, government service provider	12%

Data source: Soil Research, Development and Extension Strategy Secretariat, Australian Government Department of Agriculture, 2013

FIGURE 3 Sectors represented at national consultation workshops, 2013



Consultant	12%
Extension	15%
Farmer	5%
Government	34%
Industry	5%
NRM Region	16%
Research	14%

Note: **NRM** Natural resource management region.
Data source: Soil Research, Development and Extension Strategy Secretariat, Australian Government Department of Agriculture, 2013

At each workshop, a locally based member of the reference group welcomed participants and gave an overview of strategy development. This was followed by participant discussion around the questions:

- What are your top three soil management issues?
- What information are you looking for on soil, how do you find it, is it adequate for your needs?
- How can we improve the way we communicate about soil?
- What are the current strengths of soil RD&E in Australia?
- How can Australia benefit from improved soil RD&E?
- What are the human capacity issues and opportunities?

Outcomes from these workshop discussions are summarised in Appendix D and have been incorporated into the strategy goals and actions.

2.5 Strategic directions for future research, development and extension

At a meeting in April 2013 the strategy reference group identified a need in the strategy for national strategic directions for soil R&D. These were developed following:

- consultation with leading scientists, policymakers and industry representatives
- consultation with the Advocate for Soil Health, Major General the Hon. Michael Jeffery
- the soil RD&E strategy Online Survey
- face-to-face meetings with stakeholders in Victoria, South Australia, Queensland, Western Australia and New South Wales.

Issues were collated and consolidated by the secretariat and in August 2013 a list of issues was sent to more than 330 stakeholders for ranking. Results were presented at the National Soil Research and Development Strategic Directions Forum in Canberra on 25 September 2013.

More than 50 scientists, policymakers, consultants and representatives from industry, grower groups and natural resource management regional bodies participated in the forum. Their contributions informed preparation of seven strategic directions that were then endorsed by the reference group (Section 4.4).

CHAPTER 3

Current investment and capability

This chapter describes users of information on soils and soil management—the crucial target audience whose needs this strategy aims to address. Current funding and provision of Australian soil RD&E is discussed as well as the extent to which existing investment in, and management of, soil RD&E meets the needs of users effectively and efficiently.

3.1 Meeting the needs of users of soil information

Appendix C summarises the main users of soil information and soil management knowledge in Australia, the information they need, for what purposes and how they obtain this information. Types of information sought (soil attributes, scale and frequency) varies between user groups, as do information collection methods (regional soil survey versus on-farm or satellite data). Collation, packaging and interpretation of soil data into formats that can assist management decisions is important to users but is not always available.

The ultimate test of whether users' needs for information on productive and sustainable soil management are being met by existing soil RD&E is provided by data about production levels, about the soil management practices being applied and by measured changes in environmental condition. Production indicators (such as amount of pasture or crop produced per hectare per millimetre of rainfall) provide over time an indirect assessment of the maintenance of the productive capacity of soil. Evidence that soil managers are adopting improved practices and moving toward accepted best practice in soil management would suggest that managers' needs are being addressed by the soil RD&E system and that information about improved practices and their adoption is readily available. Measured improvement in soil condition (for example, only natural rates of erosion, increased soil carbon level and maintenance of required nutrients) and in environmental indicators (such as no contamination of waterways by eroded soil or excessive lost nutrients) also provide evidence that soil management has reached, or is moving toward, sustainability requirements.

On-farm practice change is monitored through the biennial Australian Bureau of Statistics (ABS) Agricultural Resource Management Survey (ARMS), which surveys 33 000 of Australia's 135 000 agricultural businesses. Results are reported at the national, state and natural resource management region levels. Data from the ABS 1995–96, 2000–01 and 2010–11 agricultural censuses (which surveyed all agricultural businesses) have been used with data from the 2007–08 and 2009–10 ARMS to track trends in practice change (Barson et al 2012a, Barson et al 2012b, Barson et al 2012c, Barson et al 2012d). Trends at the national level include:

- The percentages of farmers in the broadacre cropping, dairy, horticulture and beef cattle and sheep industries taking action to protect their soil from wind and water erosion and to help build soil carbon have increased.
- Between 13 per cent and 23 per cent of farmers in each of the reported industries were actively managing soil acidification; however, soil acidification is a long-term problem that will require an ongoing education and awareness-raising strategy.
- For broadacre cropping industries, data indicate ground cover management has improved due to better tillage and residue management practices. For the grazing industries (beef cattle, sheep and dairy) more farmers reported active monitoring of ground cover levels. Further work is needed to encourage farmers to manage to targets of 50 per cent to 70 per cent ground cover to reduce erosion risk and increase carbon storage.

The Grains Research and Development Corporation's *Farm Practices Survey 2012* (GRDC 2012) covered 1312 grain farming businesses in 2011, equivalent to around 8 per cent of the total area planted to grain crops. Survey results demonstrated encouraging trends in relation to sound soil management through practices such as:

- reduced or no tillage—60 per cent of cropped area was sown with less than 30 per cent soil disturbance
- stubble retention—44 per cent of cropped area had stubbles retained through to planting
- soil testing and nutrient budgeting—45 per cent of the cropped area was tested for nutrient status and 29 per cent of farms test soils annually.

These results show that progress is being made, although they measure the uptake of only some soil management practices and for some the uptake is increasing from a low base; for example, only 10 per cent of the area cropped in 2011 had lime applied, and in Western Australia the amount of lime being applied to cropped areas remains well below the estimated 2.5 million tonnes a year required (Fisher et al. 2012). Environmental data from sources such as the State of the Environment reports shows that we face many challenges in conserving and maintaining our soil resource.

3.2 Funders and providers

In 2011 the then Department of Agriculture, Fisheries and Forestry published *A stocktake of Australia's current investment in soils research, development and extension: a snapshot for 2010–11* (DAFF 2011). As part of the stocktake the department distributed three surveys. An extensive questionnaire was sent to 120 organisations likely to be funding and/or undertaking soils RD&E, training soil scientists and/or communicating the results of soils R&D. Consultants received a shorter questionnaire and an online survey was published on the Soil Science Australia website to collect information on the distribution of soils expertise and the demographics of those working in the field.

A classification of fields of research in soils sciences was needed to provide comparative information on levels of investment and capability available to different areas. It was decided to use the ABS Australian and New Zealand Standard Research Classification (ANZSRC), which is used to report R&D investment by government, higher education and the private sector and for the Australian Research Council's Excellence in Research in Australia reports. The standard was adapted to provide fields of interest for soil RD&E in Australia (Table 1).

Details of organisations contacted, questionnaires used and survey results were published in the stocktake report (DAFF 2011). Of the 54 responses received from organisations, 45 reported current expenditure on soil RD&E within Australia. Thirteen organisations reported their primary role to be funding of such activities, 19 were primarily providers, while 13 nominated teaching as their

TABLE 1 Soil research, development and extension fields of interest

ANZSRC group	ANZSRC field	Examples of projects in this field
Soils (0503)	Soil carbon sequestration (050301)	Multispectral imaging analysis, organic carbon and N_2O (nitrogen oxide) flux modelling, areal estimation of carbon quantities
Soils (0503)	Land capability and soil degradation (050302)	Erosion, modelling, sediment transport, sediment measurements, soil conservation, conservation measures and structures, productive potential of soils
	Soil and land inventory and monitoring	Soil and landform mapping, classification, spectral analysis, terrain analysis, geostatistics, geographic information system classification of soil and landscape, soil monitoring
Soils (0503)	Soil biology (050303)	Biodiversity (function and structure), measurement and interpretation, bio/eco-informatics, bioremediation, microbial metagenomics, biology of gas efflux phenomena, nutrient cycling, suppressive soils/plant disease resistance and susceptibility, inoculant technology, biofertilisers
Soils (0503)	Soil chemistry (050304)	Acidity, alkalinity, colloids, conditioners, enzymes, fertility, organic matter, salinity, solutions
Soils (0503)	Soil physics (050305)	Air, compaction, density, energy balance, mechanics, physical properties, porosity, strength, soil water
Soils (0503)	Soil sciences not elsewhere classified (050399)	na
Agriculture and land management (0701)	Agricultural land management (070101)	Diagnosis and management of sodicity, soil amendments such as bentonite, crop responses to tillage systems

Note: ANZSRC Australian and New Zealand Standard Research Classification field of 'Land capability and soil degradation' was expanded to address soil and land inventory and monitoring for *Australia's current investment in soils research, development and extension: a snapshot for 2010–11* (DAFF 2011).
na Not available.

primary role; several organisations reported having multiple roles. Total expenditure reported was about $124 million, of which $49 million was provided by organisations funding soil RD&E. Many providers received external funding (Table 2). Table 3 shows how this expenditure was distributed between ANZSRC fields.

Combining responses to all three surveys, together with additional information provided by Soil Science Australia, the total staff directed to soil RD&E was estimated at 847 full-time equivalents, with 39 per cent at the professional scientist level, 19 per cent soil technical support, 13 per cent extension staff, 6 per cent teaching and 24 per cent postgraduate students (Figure 4). These figures do not include private consultants or other agribusiness. Comparable data provided by Soil Science Australia in May 2013 is summarised in Figure 5.

Several observations from this stocktake stand out. Current national effort in soil RD&E is considerable, but also complex, changing and largely uncoordinated. Investment in soil RD&E in 2010–11 was estimated at $124 million a year, with funds provided by at least 32 organisations. The Soils Research, Development and Extension Working Group, which helped conduct the stocktake, noted a shift in location of soil R&D effort from state agency providers and CSIRO to the tertiary education sector. Most state agencies reported a decline in effort, apart from Victoria where there had been little change other than a

TABLE 2 Expenditure by soil research, development and extension providers, by source, 2010–11

RD&E provider	External funds ($)	Internal budget ($)	Funds provided to others ($)	Total ($)
State and territory government departments	27 379 229	20 972 705	4 093 270	52 445 204
Tertiary education institutions	38 723 053	13 314 330	50 000	52 087 383
Australian Government	7 558 000	8 236 000	na	15 794 000
Other	849 064	3 125 900	na	3 974 964
Total	74 509 346	45 648 935	4 143 270	124 301 551

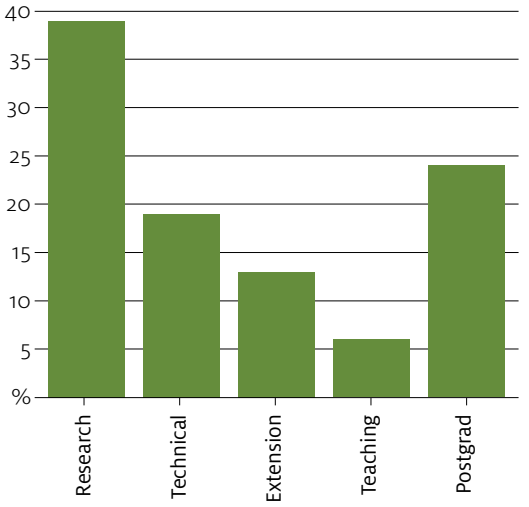
Note: RD&E Research, development and extension. **na** Not applicable.
Source: *A stocktake of Australia's current investment in soils research, development and extension: a snapshot for 2010–11* (DAFF 2011)

TABLE 3 Expenditure by research, development and extension providers, by category, 2010–11

ANZSRC field of interest	Australian Government ($m)	State and territory governments ($m)	Tertiary education institutions ($m)	Other ($m)	Total ($m)	Total (%)
Agricultural land management	1.3	4.9	10.8	1.7	18.7	15.0
Land capability and soil degradation	0.9	9.0	3.2	na	13.1	10.5
Soil and land inventory	2.7	7.8	5.6	na	16.1	13.0
Soil biology	1.3	7.6	4.8	0.7	14.4	11.6
Soil carbon sequestration	4.9	6.7	10.9	na	22.5	18.1
Soil chemistry	2.7	12.2	11.0	0.4	26.3	21.2
Soil physics	2.1	3.8	2.4	0.6	8.9	7.2
Other	na	0.4	3.3	0.6	4.3	3.5
Total	15.9	52.4	52	4	124.3	
Total (%)	12.8	42.2	41.8	3.2		100

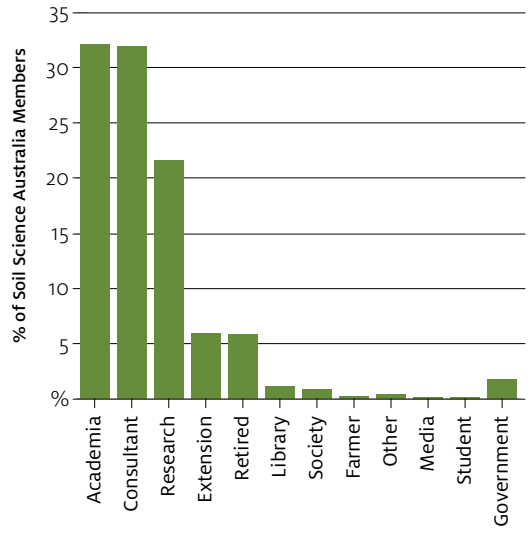
Note: ANZSRC Australian and New Zealand Standard Research Classification. **na** Not applicable.
Source: *A stocktake of Australia's current investment in soils research, development and extension: a snapshot for 2010–11* (DAFF 2011)

FIGURE 4 Soil research, development and extension activities, by staff category, 2010–11



Source: *A stocktake of Australia's current investment in soils research, development and extension: a snapshot for 2010–11* (DAFF 2011)

FIGURE 5 Occupations of Soil Science Australia members, 2010–11



Data source: Soil Science Australia

redirection from field-based land and soil survey activities to digital soil mapping activities. New South Wales, while still contributing, had halved its effort, with staff attrition often occurring in response to budget pressures. In some organisations the soil RD&E capability remained but had moved to other fields of research. For example, many of CSIRO's 78 full-time equivalent researchers were reportedly working on water research projects.

Investment in some fields of interest—for example, soil carbon sequestration and soil biology—has increased in recent years particularly in the university sector where budgets, capability and capacity are increasing and investment of their own research money is taking place. This may be a response to particular government-funded programs. What is not clear from the stocktake data is the extent to which current soil RD&E investment is targeted to national priorities or whether it is managed to maximise benefits through changed policy and practices.

More than 150 organisations are involved to some extent in the national soil RD&E effort. This includes private consultants, relevant agribusiness, industry and grower groups and natural resource management regional bodies, many of which provide advice and expertise in soil management. While some of these and their staff are probably aware of other organisations and the work they undertake (particularly in the research arena), it is equally likely that others are not. Private consultants and other groups have difficulty finding time to seek out knowledge generated by soil R&D or to integrate data from disparate sources. This represents a major disconnect between soil knowledge in the research arena and the awareness, skills and practices of land managers.

Another important observation from the stocktake was the apparent mismatch between numbers of full-time equivalent staff committed to soil R&D (most research, technical and postgraduate categories in Figure 4) and those directed to knowledge exchange (the extension category). In 2011 more than 30 per cent of Soil Science Australia members listed their occupation as consultant (Figure 5); however, it is not known how many are delivering soil information to land managers nor how many work in the mining, environmental

assessment and construction sectors. Some 60 members (5 per cent of total) listed their occupation as extension, a term traditionally associated with primary industries. It should be recognised, however, that a proportion of soil extension is delivered by agents (public and private) who have a broader range of expertise and may not be a member of a specialist society such as Soil Science Australia. The large proportion of Soil Science Australia members in academia (32 per cent), which historically does not have the same linkages with extension deliverers, may also be a contributing factor to an apparent disconnect between research and extension.

Experience from business and other fields of innovation suggests that the ratio of effort between basic research and successful application through applied research and experimental development should be around 1:10 (see, for example, expenditure data in OECD 2013). The OECD data suggests that Australia under invests in domestic soil knowledge exchange, perhaps reflecting a shift in the way R&D is disseminated, as recognised by the work of the Research, Development and Extension Committee. Whether this role has been taken up fully by the private sector is so far unknown. Private sector advisers may have limited economic incentive to provide soil knowledge relevant to sustainable resource management; if this is the case this gap will need to be addressed.

These issues are taken up further in Chapter 4.

3.3 Current situation in national soil research, development and extension

3.3.1 Coordinating investment

Administration of soil-related activities—including land management, soil monitoring and mapping, planning and delivery of extension services—are the responsibility of the states and territories, under various legislation:

- New South Wales—*Soil Conservation Act 1938* and *Catchment Management Authority Act 2003*
- Northern Territory—*Planning Act 2008, Pastoral Land Act 2011, Soil Conservation and Land Utilisation Act 2001*
- Queensland—*Soil Conservation Act 1986* and *Soil Survey Act 1929*
- South Australia—*Natural Resource Management Act 2004, Pastoral Land Management and Conservation Act 1989* and *Development Act 1993*
- Tasmania—*Environmental Management and Pollution Control Act 1994* and State Policy for the Protection of Agricultural Land 2009 under the *State Policies and Projects Act 1993*
- Victoria—*Catchment and Land Protection Act 1994*
- Western Australia—*Soil and Land Conservation Act 1945*.

There is currently no clear and agreed organisational responsibility or mandate to coordinate and deliver major national soil related outcomes. The lack of a national mechanism limits the ability of the many organisations and groups involved to jointly identify and assess national and regional priorities and ensure that adequate investment is directed to them in a coordinated and efficient manner. This, together with insufficient links between generation, delivery and application of new knowledge, reduces effectiveness and limits returns achieved by the national investment into soil RD&E.

However, the NCST through the Australian Collaborative Land Evaluation Program has pioneered a new and effective model for technical cooperation between the states, territories and Commonwealth—a model that can usefully be built upon. The National Geosciences Mapping Accord also provides an example of a model for development and operational delivery of agreed national functions that could be applied to soil-related knowledge delivery. Other examples of the type of national mandate required in soil include that of the Australian Bureau of Statistics' or the Bureau of Meteorology's responsibilities in developing a National Plan for Environmental Information. Each of these different models can be effective in accommodating the priorities of individual institutions as well as progressing national priorities.

Additionally, some excellent examples of enduring collaborations and partnerships between organisations more broadly include:

- AgriBio, Centre for AgriBioscience, a joint venture between La Trobe University and the Victorian Department of Environment and Primary Industries
- Waite Research Institute, an initiative of the University of Adelaide that comprises 12 research organisations and other bodies, including the CSIRO and the South Australian Government
- Tasmanian Institute of Agriculture, a joint venture between the University of Tasmania and the Tasmanian Government
- Queensland Alliance for Agriculture and Food Innovation, a collaboration between the University of Queensland and the Queensland Government
- CSIRO and Grains Research and Development Corporation partnerships examining tillage, water use efficiency, rhizosphere biology and root interactions
- CSIRO and Meat & Livestock Australia partnerships researching phosphorous use efficiency
- Agricultural Production Systems Research Unit, a partnership between CSIRO, the University of Queensland and the Queensland Government
- Australian involvement in the GlobalSoilMap.net consortium and newly new formed, FAO-led Global Soil Partnership.

The Australian Government delivers major investment in natural resource management, including improved soil management, through partnerships with 55 natural resource management regional bodies across Australia. Conservation Agriculture Australia (formerly the Conservation Agriculture Alliance of Australia and New Zealand) has built a network of grower groups. The network shares information on new developments in conservation agriculture and promote the benefits to the wider agricultural community.

Project-level collaborations have delivered soil RD&E products, including the Grain & Graze initiative, led by Grains Research and Development Corporation in collaboration with grower groups, universities and Australian and state governments. The Primary Industries Adaptation Research Network has established strong links between research institutions and government agencies across Australia, to share information and collaborate on multidisciplinary climate change adaptation projects, including farming systems, soil management and water use.

These are isolated examples that serve to emphasise the need for national coordination of collaboration and co-investment in soil RD&E. This would reduce duplication of effort and increase efficiency. For example, recently several rural R&D corporations and statutory authorities and agencies invested in reviews of, and research into, phosphorus fertiliser use; a shared approach, incorporating industry specific concerns, may have delivered better returns on investment for the nation.

The stocktake (DAFF 2011) of Australia's current investment in soil RD&E identified 32 organisations that fund such activities, of which 19 were primarily RD&E funders and 13 were funders and providers of soil RD&E. It is likely that other organisations and groups not included in the stocktake survey also invest their own resources, particularly in soil development and extension. This would include private consultants and agronomists, other agribusinesses, catchment bodies and non-government organisations. Although their investments may be small individually, these groups play a crucial role in providing and exchanging knowledge about soils and their management, ensuring the best return from the national investment in soil RD&E.

Most individual organisations determine their own priorities so the proportion of total investment directed to collaborative ventures is rather small. Organisations will always have their own goals and priorities, but the risk and reality of duplication and of poor targeting of investments is exacerbated by:

- absence of a mechanism to jointly identify and publicise national priorities for soil RD&E
- lack of an authorising body to promote and facilitate co-investment where organisations share priorities and to steer funding towards agreed priorities.

3.3.2 Soil data and information

The many actual and potential users of soil information in Australia often have very different data (attributes and scale) needs (Appendix C). For the purposes of this strategy, users are grouped into three broad categories:

- Organisations that directly make land use and soil management decisions, have sufficient resources to employ their own skilled soil scientists and collect soil data; they also use national sources of soil information effectively. Most require site-scale soil information at a limited number of locations, often with specific attributes measured at specific soil depths. They include corporate farms and plantation owners, construction, underground services and mining businesses and research organisations and groups.
- National, state, territory and local governments, catchment management bodies, non-government organisations and other groups that require soil information for policy, planning or program development. Some may have their own staff with expertise in soil research, knowledge and management. Those who do not will need assistance to access the relevant soil information and to interpret it to meet their needs. This type of soil information is necessary to monitor investment effectiveness (for example, in natural resource management programs), to identify emerging issues for targeted investment and for public use. This group of users requires broad scale soil data, except for monitoring and evaluation purposes where repeated site measurements may be needed.
- Individual farmers and other land managers, farm consultants and agronomists who are not soil experts and who need help obtaining and interpreting soil information to support strategic and tactical crop or pasture decisions. This group requires site-specific soil information, often at fine scale (tens of metres) with attributes of interest to them provided in an up-to-date, timely manner in an accessible format. They want to know how soil condition affects the profitability and sustainability of their farm or enterprise, and how they can improve soil condition and deal with particular soil problems. They want increased personal knowledge of soil management and proven practical and successful solutions to soil problems in their local area. Increasingly, these users are producing their own on-farm soil data through both remote and proximal soil sensing, yield maps, satellite imagery and other forms of spatial data.

Consultation undertaken and evidence collected by the NCST and others demonstrates that the current soil RD&E system does not meet the needs of all three user groups. Members of the first category largely have sufficient resources to meet their own needs for soil information, although they would benefit from greater availability of reliable, consistent and comparable regional soil data with the attributes they require. They also want ongoing access to people with knowledge and expertise in soil mapping, soil chemistry and measurement of soil characteristics and in management and restoration of problem soils.

The current RD&E system does not meet the needs of users in the second group (concerned with policy, planning and program development). The type of soil data they require is not always available at the required scale or in a format they can use; data is rarely comparable due to differences between jurisdictions in the coverage, scale and reliability of past soil data sets. This group also frequently needs assistance to collate and interpret soil data; while this expertise is sometimes available it is not clear where or how to access it. Few Australian businesses or groups are able to provide access to soil information or collate and interpret that information for this group of users.

The third category of users, individual farmers, consultants and agronomists, faces similar problems. Not only is the soil information they require generally not available at the requisite scale or with relevant attributes, in rural areas few people are available with the knowledge and expertise to collate datasets and interpret them into a form that can be used to make strategic or tactical on-farm decisions. This has been a common complaint of grain growers wishing to adopt, for example, precision agriculture technology; and research and survey findings have shown the lack of service providers in soil data and interpretation is the biggest impediment to continued adoption of precision agriculture methods. A small number

of service provider organisations or programs offering interpreted soil information do exist—for example, Soil Quality in Western Australia and a limited number of farm consultants—but these are able to assist and support only a small proportion of farmers and their consultants/agronomists.

3.3.3 Communicating and exchanging soil knowledge

There is currently a significant amount of extension type activity taking place around the country and there are many opportunities for land managers to learn about soil. Land managers want to know how to better manage their soil to improve production and profitability, reduce input costs, sequester carbon, mitigate the effects of climate change, improve resilience and protect the resource for generations to come. Many land managers also want to improve the ecosystem services delivered by their soil. But while there is a strong demand, there are some concerns about the quality of the information being delivered. Land managers and farm consultants/advisers attending strategy consultation meetings identified soil-related topics for which they sought new or additional information (Appendix D), for example, how to measure changes in soil condition, the effects of new farming systems on soil attributes and improving soil biology and nutrient cycling.

The disconnect between research, development and extension components of the national soil RD&E system has been exacerbated by a shift in the delivery of soil extension from public to private sector providers. While private agronomist and farm adviser services have expanded to provide this service, many do not have the uncommitted resources to survey, collate and repackage the knowledge produced by a large number of R&D organisations. Most research organisations are not funded to undertake extensive communication and knowledge exchange, nor do they necessarily have staff with the skills to do this effectively and efficiently.

Some of the building blocks for a more effective process of knowledge exchange are in place, for example, manuals and fact sheets about soil problems and how to manage them, decision support systems and training/workshop materials. Support for continued delivery of these has been limited; however, Australian Government funded natural resource management programs have funded soil management extension activities. Individual industries, often through their R&D corporations, have implemented successful programs for the communication and exchange of soil knowledge, including action learning and other types of skill development workshops. The rise of grower groups has provided a form of infrastructure that (with sufficient resources) enables collation and packaging of user-friendly R&D findings, as well as on-farm testing and further development of improved soil management practices. Some state and territory government agencies and natural resource management regional bodies have undertaken a similar role, albeit at a broader scale.

Under the current soil RD&E system, each research provider, development group (often grower groups) and knowledge exchange provider (a mixture of public and private) works separately in their own field of endeavour, driven by the need to make a living, publish research or demonstrate improved local farming practices. No mechanism exists to access, exchange, collate and deliver information from RD&E organisations, industry sectors or regions. The net result under the current national soil RD&E system is that the needs of land managers are not necessarily reflected in the research being undertaken, that a good deal of knowledge from within the research arena has not yet made it to application through improved soil management practices, and that there is scope for considerable duplication of effort and repeating of efforts to exchange soil knowledge.

Consultations undertaken for this strategy confirmed that:

- The research community is not effectively communicating its extensive knowledge of soils and soil management to land managers, many of whom lack awareness, skills and practices necessary to improve soil management.
- Farmers need to become more involved in research, link with scientists and participate in soil RD&E so that scientists are aware of farmer needs and of the work they are doing on-farm.

- Greater focus on farming systems is needed, including the economic, productivity and social benefits of these systems to ensure improved land management practices are incorporated into farming business across all commodity sectors.
- Some excellent education and training packages and workshops have been developed, but these require either long-term funding to support continued delivery or a shift from public to private sector delivery.
- Soil information should be delivered by specialist soil scientists or advisors, consultants, agribusinesses and other professionals with a solid understanding of soil; mechanisms will be required to support these professionals.
- Individuals or organisations delivering soil information need to be aware of the expertise and activities of other organisations; this will aid effective and efficient knowledge delivery; mechanisms to support this will be required.

3.3.4 Maintaining and developing skills and capability

The stocktake of Australia's current investment in soil RD&E undertaken in 2010–11 (DAFF 2011) reported total expenditure of $124 million and around 850 full-time equivalent staff (including postgraduates). This may be an underestimate as not all of the organisations contacted by the survey responded. The stocktake did not include people with skills and expertise in soil science working in soil testing laboratories, catchment management bodies, the mining industry, road and infrastructure construction groups and businesses providing underground services. Against this potential underestimate, some organisations provided information on their full-time equivalent staff with soil qualifications, but in some cases these were not currently employed on soil-related projects due to lack of funds. More soil RD&E personnel are required to address service gaps (including a possible imbalance between research and extension) and to build and maintain skills and capacity to meet future challenges.

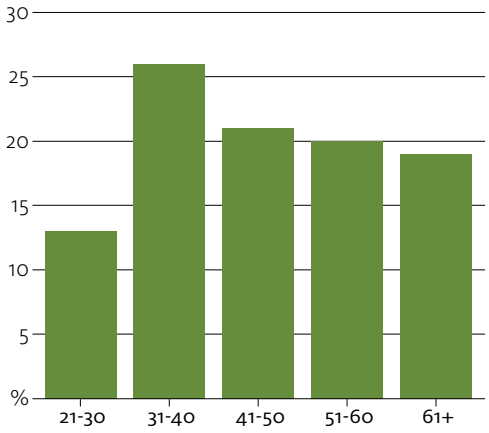
Trends in funding and effort, as reported for the stocktake, suggest that while tertiary education institutions have been able to access increased funding for soil RD&E, state and territory government agencies have faced a continuing decline in support available for activities to underpin productive and sustainable soil management. Recent attention given to adaptation and mitigation in relation to climate change and a range of associated knowledge generation programs have boosted funding for this aspect of soil RD&E. Work in soil chemistry is also robust, perhaps reflecting continued interest in nutrient management and remediation of contaminated sites. However, short-term funding increases disappear once particular programs are completed or when budget pressures take precedence.

According to Soil Science Australia membership data, the average age of a soil scientist is 44.7 years, with a median age of 43 years. This is only marginally older than the national average for individuals working in professional, scientific and technical services of 40.5 years (ABS 2011). For occupations such as secondary school teachers the national average is 44.5 years (McKenzie 2012), for lawyers 41.9 years (Hill et al. 2012) and engineers 42 years (Kapsura 2011). By contrast, the average age of farmers is 52 years, well above the national average (NFF 2012). Figure 6 shows that 13 per cent of Soil Science Australia members are in the 21 to 30 years age group and the highest proportion of soil scientists are mid-career, with 26 per cent in the 31 to 40 years age bracket.

The ageing of Australian soil scientists suggests a need for additional recruitment of, or support for, younger staff to ensure they continue in the profession, but this will only happen if employment opportunities are available. Soil Science Australia data suggests that by 2023, 380 soil scientists will be 55 years or older, 306 will be 60 years or older and 214 will be 65 years or older. This suggests that around 250 people trained in soil science will retire during the next 10 years, indicating a training requirement for at least 30 to 50 trainees a year for basic and refresher courses.

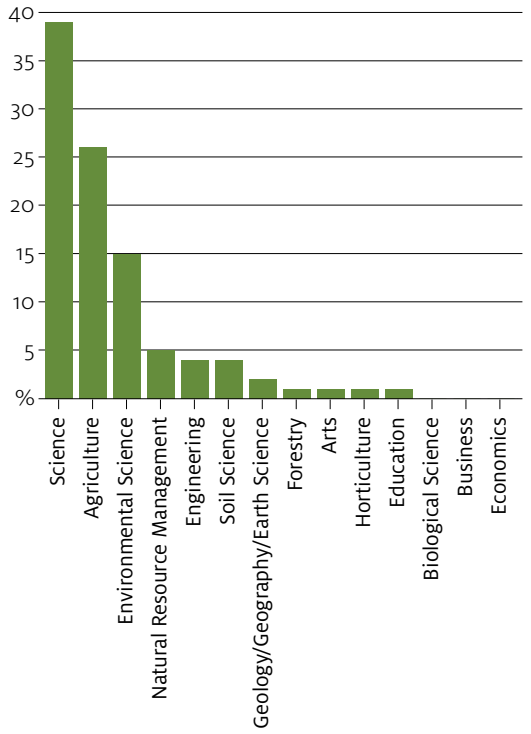
In a submission to a Senate inquiry into aspects of higher education and skills training for agriculture and agribusiness, Australia's Chief Scientist pointed

FIGURE 6 Age profile of Soil Science Australia members, 2010–11



Note: Approximately 5 per cent of Soil Science Australia members are listed as retired.
Data source: Soil Science Australia

FIGURE 7 Undergraduate degrees held by Soil Science Australia members, 2010–11



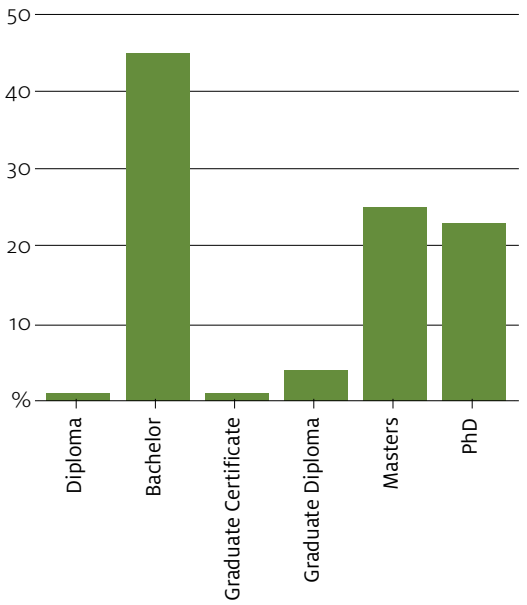
Data source: Soil Science Australia

out that a recent survey of advertisements for agricultural jobs had identified a potential demand for university graduates of around 4500 a year, more than five times the current rate of bachelor completions, a number that was itself decreasing (OCS 2012). A recent study (Field et al. 2012) examined soil science education at a national scale and made recommendations about a national approach to developing a soil science curriculum that will produce work-ready graduates with the interdisciplinary knowledge, skills and capabilities relevant to Australia's needs. However, this study was not intended to provide quantitative estimates of education or training demand or to consider needs within individual disciplines of soil science.

Degree courses in science, agriculture and environmental science provide undergraduate training for most members of Soil Science Australia. Less than 5 per cent of members have an undergraduate degree specialising in soil science (Figure 7); specialist undergraduate degrees are not available in Australia, suggesting that these members were trained overseas. Around 45 per cent of members also completed postgraduate study (Figure 8), which may provide the specialist soil science knowledge to build on non-specialist undergraduate degrees. While there are certificate and diploma courses in soil knowledge and management in Australia (Wardrop et al. 2013), they have not been widely undertaken by Soil Science Australia members (Figure 8).

A survey of 45 postgraduate students undertaken during development of the strategy shows that three-quarters intend to seek employment within Australia once their studies are completed, 50 per cent in academia/education and 37 per cent in industry/consultancy. Soil chemistry, soil carbon and soil physics were the most popular topic areas for postgraduate work.

FIGURE 8 Highest level of education of Soil Science Australia members, 2010–11



Data source: Soil Science Australia

More work is required to determine demand for undergraduate and postgraduate education in soil science and to determine whether courses, resources and facilities are adequate to meet this demand.

3.3.5 Physical infrastructure

The strategy reference group commissioned a review of the physical infrastructure that underpins soil RD&E and aspects of soil management in Australia. This was undertaken in response to the limited publicly available information about laboratories, testing equipment, soil archives and long-term field sites or experiments and where they are located. The review also collected information on the extent to which organisations/laboratories collaborate in development and use of such infrastructure; what proportion of the national infrastructure is available for soil RD&E; and whether current infrastructure is able to meet our present and future needs.

Findings from the review were published in Overview of existing physical infrastructure supporting Australia's soil research, development and extension efforts: analytical laboratories, soil archives and field research stations for soil studies (Rayment 2013). The voluntary survey distributed to public and private sector laboratories had a 55 per cent response rate (83 per cent of public sector laboratories responded but a lower proportion of the private sector). The review found that:

- Australia has about 90 active soil testing laboratories. Total expenditure is likely to exceed $50 million a year, with more than 700 full-time equivalent staff involved.
- Publicly funded organisations (government departments and universities) undertake soil testing, often to support their own R&D or for method development or calibration. However, they are now minor players in soil testing for agricultural advisory services—this has been taken up by the private sector.
- The number of soil samples analysed nationally has increased exponentially from a baseline in 1965–1966. About 531 000 samples were tested in 2012 with 87 per cent submitted for chemical testing (including for pH, nutrients, conductivity and soil carbon), while physical tests comprised 12.5 per cent and biological tests 0.5 per cent.
- Much of this testing was undertaken for agricultural advisory services, but mining, natural resource management and construction were also important generators of samples for soil testing at particular laboratories.
- Private laboratories mostly rely on others to supply soil samples for analysis, although this is changing with some now expanding their business models to provide collection, analysis, interpretation and recommendation services. Government and university laboratories were the chief custodians of specialised analytical instrumentation, mainly for biological and physical testing.
- Laboratories have limited options for physically sharing specialised items of expensive equipment because such equipment typically requires permanent, specialised installation and trained staff. Any sharing that occurs will likely be through arrangements that bring samples to the equipment rather than the reverse.

- It is likely that the private sector will progressively provide almost all routine diagnostic soil chemical tests to the Australian marketplace and offer analytical capabilities to R&D scientists on a fee-for-service basis. There is little to separate the quality of commonly performed soil test results from the public and private sectors, based on ASPAC Inter-Laboratory Proficiency Programme findings for chemical testing.
- Private laboratories reported little or no use of either near-infrared (NIR) or mid-infrared (MIR) spectral imaging technologies as surrogates for conventional soil testing, which is contrary to overseas trends. Uptake of these methods could improve soil testing in Australia, with benefits including the ability to conduct rapid testing, reduced sample preparation (less expensive), ability to predict a suite of soil attributes and to conduct tests in the field. Uptake is likely to increase with the planned production of locally relevant calibration curves, strengthened by on-site, machine learning software that can continually update NIR/MIR calibrations.
- Sharing soil test results and making them publicly available (perhaps in aggregated form) remains subject to commercial and privacy concerns, but should be addressed given the potential value of this resource.
- Much of the soil analytical equipment is being underutilised, suggesting surplus analytical capacity for soil diagnostic tests.
- Soil archives are important for developing, testing and calibrating measurement methods, for providing type specimens and for detecting changes in soil condition and attributes over time. Australia has some 16 soil archives of varying size and activity, containing more than 350 000 samples, of which Queensland has 36 per cent, New South Wales 35 per cent and the National Soil Archive, Canberra, 20 per cent. There are also regionally significant collections, such as in Victoria.
- Not all soil testing laboratories retain tested samples and the length of time and conditions under which samples are retained vary. These laboratories represent an important, uncoordinated (and short-term) soil archive resource of up to 531 000 samples annually.
- Compelling reasons for dispersed archives include: safety of infrastructure and contents from a single fire or flood; biosecurity issues; and location of samples close to where demand is likely to be (minimising access and transport charges).
- Apart from the CSIRO National Archive, the NSW facility at Yanco and the Victorian facility at Tatura, public sector soil archives in the regions seem to be struggling due to pending or planned relocations; cramped or overcrowded storage facilities; absence of assured, recurrent public funding; and limited staff dedicated to maintaining and enhancing local archive/s.
- A trend to undertake short- to mid-term soil RD&E studies on private properties is expected to increase. The best use of field stations for soil research will likely shift towards long-term studies on valued ecosystems (or cropping systems), supported by quality-assured measurements and detailed records, together with assured long-term staffing and funding.

The review demonstrates the substantial physical infrastructure and capacity developed for soil chemical, physical and biological testing and the existence of an important soil archive resource, both of which could be developed to help underpin the national soil RD&E effort.

CHAPTER 4

Future research, development and extension plan

This chapter examines how the soil RD&E strategy will work now and in the future. It builds on the identified needs of users of soil knowledge, on the stocktake of current soil RD&E investment and capability (Chapter 3) and considers factors that will affect the use and management of Australia's soils (Chapter 1). The strategy focuses on investment processes and institutional arrangements required to ensure the national soil RD&E enterprise operates more effectively. A cross-sectoral strategy is needed because the details of soil management and the RD&E required to support it are linked to other industry (for example, grains, cotton and dairy) and cross-sectoral (such as climate change and water use) strategies. A list of strategic directions is included in the strategy to inform implementation arrangements and help target and coordinate national soil R&D investment in the national interest.

4.1 Vision—Securing Australia's soil for profitable industries and healthy landscapes

Soil security is motivated by sustainable development and concerned with maintaining and improving the global and Australian soil resource to produce food, fibre and fresh water and deliver other essential ecosystem services. Soil security considers how soil contributes to agricultural productivity and profitability; energy and climate suitability; biodiversity; and the overall function of the landscape (McBratney et al. 2014). Soil underpins all terrestrial life and is therefore crucial to human existence and wellbeing, for urban as well as rural communities. It is a non-renewable resource at human timescales and prevention of its loss (for example, through erosion) or degradation (for example, through acidification) is far cheaper than remediation. Securing Australia's soil is therefore a high national priority, for both current and future generations. This understanding provides a

compelling basis for the prompt implementation of the soil RD&E strategy to improve the productivity and profitability of Australian agriculture and forestry and to protect the environment across the landscape through improved soil management.

4.2 Aims

This strategy aims to:

- ensure the national soil research, development and extension (RD&E) system generates and applies new knowledge to meet future challenges in soil use and management
- develop a process for national coordination and prioritisation of investment in soil RD&E to increase both effectiveness and efficiency, and commence the actions necessary to implement it
- improve the quality, availability and access to soil data and soil management information to meet user needs
- facilitate effective transfer of soil data, information and knowledge to end users
- assess future national soil RD&E capability needs and steps required to provide that capability (including education, training, people and skill development, RD&E infrastructure)
- encourage greater collaboration in developing and using physical infrastructure and human resources.

These aims are based around understanding what soil data, information and knowledge are needed to enable and increase productive and sustainable use of our soil by farmers and other land managers and for planning and policy, effectively and efficiently. The key to this will be improved knowledge exchange between users, researchers and developers of soil knowledge and better use of existing RD&E capacity and capabilities through improved national collaboration and coordination.

4.3 Goals

4.3.1 Improve effectiveness of co-investment to generate and apply new knowledge

Current situation

It is estimated that at least 150 organisations play some role in soil RD&E within Australia. Organisations will always have their own goals and priorities, but the risk and reality of poor targeting of investments to national priorities (low effectiveness) and of duplication (low efficiency) is exacerbated by a lack of coordination.

Why this goal is important

It is not clear that Australia is investing adequately to address the future challenges to profitable and sustainable soil use and management, while at the same time there is considerable scope to improve both the effectiveness and efficiency of existing investment. Stakeholder consultations (Appendix D) highlighted:

- topics important at a national level have not received adequate attention
- sharing of knowledge and expertise between industry sectors, organisations and regions needs to be improved
- greater effort is needed to provide timely and usable information to land managers and other users.

Increased national collaboration and co-investment between and across organisations is required to resolve these problems. This will increase effectiveness, efficiency and returns from the national investment in soil RD&E.

What the strategy aims to achieve

This strategy aims to establish a mechanism for joint identification and assessment of national priorities, for increased collaboration in soil RD&E across industry sectors, research and extension organisations and regions. It will consider the roles and obligations of different organisations (public and private) at the national, regional, local and industry level. It will also consider the need for

research across the spectrum, from cutting edge research through to robust applied information. This will lead to improved efficiency, effectiveness and appropriateness of the national soil RD&E investment and will maximise the outcomes achieved, by prioritising actions and avoiding duplication of effort.

How this will be done

The strategy proposes establishment of a national implementation committee. The committee will comprise representatives of organisations that have a major role in funding and or undertaking soil RD&E and in delivering outputs and outcomes and that have committed to allocating resources to achieve strategy goals.

The Rural Research and Development Policy Statement (Australian Government 2012) considers that rural R&D corporations and statutory authorities (RDCs) are ideally placed to use their expertise and flexible investment model to work together and bring in system participants to support implementation of cross-sectoral strategies. This role will be included in statutory funding agreements, and RDCs will be required to report on their contributions to cross-sectoral research. The Council of Rural Research and Development Corporations and Statutory Authorities will also be required to report annually on collaborative efforts, including contributions to implementation of cross-sectoral RD&E strategies. Signatories to the National Primary Industries Research, Development and Extension Framework Statement of Intent have a responsibility to contribute, while other universities and organisations with an interest in soil RD&E will likely wish to be on, and help support the activities of, the National Implementation Committee.

This committee, with executive officer support, will provide leadership to identify national soil RD&E priorities, facilitate and coordinate co-investment, help stakeholders link their priorities and activities across sectors, and ensure that networks are in place that promote collaboration and ensure effective delivery of soil data and information to all users. This core goal and its implementation are discussed further in chapters 5 and 6.

There is also scope and opportunity within the strategy to drive improvements in institutional arrangements for delivery of important national soil-related outcomes, including enabling steps such as the custodianship of nationally important soil data and information assets. As discussed in Section 3.3.1, while states and territories have Constitutional responsibility for individual jurisdictional land and soil management, there is a widely recognised need for development of a nationally supported mechanism to address cross-issue, cross-agency, multi-jurisdictional, national and international issues. The national implementation committee will examine this need and facilitate agreed organisational mandates and other institutional arrangements as necessary for better coordination and delivery of major soil-related outcomes at the national level.

4.3.2 Improve quality, availability and access to soil data and information

Current situation

The many actual and potential users of soil information in Australia have varying data needs in terms of attributes and scale. In developing this strategy, the NCST and others found that the current soil RD&E system does not meet the needs of most user groups. Some organisations have sufficient resources to meet their own needs for soil information, but others concerned with policy, planning and program development, and with monitoring long-term changes in soil condition, are not getting the information they need. The soil data they require is not always available at the required scale and is not in a ready-to-use format, and coverage, scale and reliability of past soil data sets varies markedly between jurisdictions. Individual farmers, consultants and agronomists face the same problems, with the added disadvantage that in rural areas there are few people available with the knowledge and expertise needed to collate, interpret and present different datasets in a form that can be used to make strategic or tactical on-farm decisions.

Why this goal is important

Soil information—knowledge about soils and how they are performing—is an essential national resource. It is a core input to public policy and planning in crucial areas such as climate change mitigation and adaptation, water resource management, catchment management, maintenance of agricultural productivity, conservation of biodiversity, public health and national security. Access to at least a basic level of soil information is also required by soil managers so they can make informed decisions about R&D results or improved methods of soil management suitable for their situation. Moreover, managers need soil information that shows trends in attributes and status over time. This tells them whether their practices are achieving the intended outcomes and is crucial for successful adaptive management.

A significant achievement made between 1989 and 2000 (the Decade of Landcare) was the beginning of a consistent soil and land resource survey coverage of Australia. Some states made an initial survey of their agricultural lands while others surveyed areas where land use change was occurring. A new generation of land resource specialists was trained and the level of soil knowledge in many regions improved dramatically. The infrastructure for the Australian Soil Resource Information System (ASRIS) was established and Australia started to recognise the extent of some soil problems (such as acidification) along with opportunities for new systems of land management and use. The Australian Collaborative Land Evaluation Program pioneered an effective model of technical cooperation between governments and organisations.

Investment in land resource surveys declined at the end of the Decade of Landcare. In some states this occurred when responsibilities for natural resource management were partly devolved to natural resource management regional bodies, while in other states the re-prioritisation of resources to other land management issues (such as vegetation management) reduced the effort in land resource surveys. As a result the economies of scale necessary for technical activities were lost and an unintended consequence was a dramatic slowing of the highly effective survey programs and, in some cases, a loss of skilled and experienced operators.

Information on soil resources is a prerequisite for informed decisions on land use and management. However, investment in capturing and providing this information has lagged in the past decade, especially when compared with advances made in data about water, climate and biodiversity. Soil attributes change over time with land use and management, so that past data may not be adequate for decisions today. Moreover, older sets of soil data often lack information about soil functional attributes (such as plant available water holding capacity), which is vital to modern land managers. Australian users need, but are not getting, consistent and reliable information (at local through to national levels) on the spatial distribution of soils, threats to soil function and opportunities for improving soil management and condition.

Knowledge for sustainable and productive use of soil has at its foundation:

- maps of the functional properties of soils at a resolution determined by land-use intensity
- systems for monitoring change in soil properties over time
- ability to forecast likely future condition of soils under specified systems of land management and future climates.

What the strategy aims to achieve

Australia needs to regain the momentum of the 1990s, take advantage of dramatic advances in technologies for digital soil mapping and web-based delivery of spatial information, and better utilise existing soil data and information. Lessons learnt from the recent major upgrade of Australia's water resource information systems should be applied to soils. This would include:

- completion of agreed national standards for soil data and for data collection, sharing, monitoring and analysis
- a modest long-term program of regional scale or sub-catchment scale digital soil mapping that is tightly integrated with the needs of key user groups for different soil attributes and scales, together with a complementary soil monitoring network and forecasting capability
- a survey program focusing on high priority regions where changes in land use are being,

or are likely to be, driven by one or more factors listed under Section 1.2, while at the same time balancing this with the need for a consistent and comparable national coverage

- development of new practical methods for collection and mapping of soil data on-farm, further development of statistically based soil data capture and monitoring
- improved access to and interpretation of existing soil information, including improved ICT infrastructure for web-based standardisation and delivery of soil information.

How this will be done

The NCST reviewed the data and information aspect of the national soil RD&E effort through workshops and consultations. The committee has developed a business case for re-establishment of an Australian Soil Assessment Program (ASAP–NCST 2013), which would:

- establish a mandated cooperative national approach for collection, sharing, monitoring and analysis of soil data that will implement consistent soil data standards to support interoperability, optimise access, reduce costs, remove duplication and improve data quality
- provide strong national leadership and coordination to develop an integrated soil information system that will support government and industry programs and feed into a wider national environmental information infrastructure
- provide prioritised and statistically based soil data capture and long-term monitoring that enables identification of, and response to, high-priority uses; monitoring must be part of long-term ecological research and reporting
- engage with all stakeholders, including the private sector, to improve efficiencies, knowledge, standards, data availability and cooperation to build a trusted source for nationally consistent soil data
- further develop existing initiatives aimed at providing an infrastructure for web-based delivery of standardised soil information
- build soil information that fulfils Australia's objective of becoming a major exporter of food; take advantage of new technologies to capture and analyse soil data to build knowledge to support climate change adaptations and identify new opportunities.

The committee is developing a detailed investment plan for implementing the proposed Australian Soil Assessment Program. The plan will identify current and future priorities and resourcing, and it may include market analysis of the needs of different soil information user groups to help guide program development. The program will be considered by the soil RD&E strategy Implementation Committee (Chapter 6) when addressing the needs of different user groups for improved quality, availability and access to soil data and information. Cost-effective delivery of such an initiative will also need to be considered.

4.3.3 Improve communication and exchange of soil knowledge

Current situation

The current soil RD&E system is not meeting the needs of land managers (Appendix C). Under the current soil RD&E system, research providers, development groups (such as grower groups) and knowledge exchange providers (mostly private farm consultants and advisors) often work separately in their own field of endeavour, driven by either the need to publish, to demonstrate improved local farming practices or to make a living. No mechanism exists to access, exchange, collate and deliver information from these separate RD&E organisations, industry sectors and regions.

Why this goal is important

In order to realise the large returns possible from investment in a national system of soil RD&E, we must:

- meet the needs of Australia's land managers
- ensure knowledge is communicated and exchanged successfully
- ensure evidence-based information is used to underpin policy, planning, use and management of our soil.

Without effective knowledge exchange, informed decisions about productive and sustainable land use and management are not possible, from farmers making on-farm management decisions through to policymakers making decisions at the national level.

What the soil RD&E strategy aims to achieve

Jenkins et al. (2013) suggest that if the overriding aim is to foster greater championing of and engagement with good soil management, the strategy must look beyond the functional use of soils in agriculture and include additional functions and benefits that soils provide in landscapes and ecosystems. The larger goal for soil extension is a change in values so that soil is valued for all the important roles it plays in our ecosystems, in the same way that water and climate are valued.

A national soil knowledge exchange system must address four core themes:

- creating awareness among land managers and the wider community about the importance of soil and its management
- exchanging and building information and knowledge about soil management in all aspects of RD&E (for example, ensuring there is an ongoing dialogue from farmer to scientist to farmer and so on)
- facilitating and supporting behaviour change to improve policy, planning and soil management practice
- using tools to assess changes in soil condition as a result of management, to enable adaptive management to take place, and (at the national scale) to measure changes in awareness, skills and practice change.

How this will be done

The goal of increasing exchange and flow of knowledge between different components of the national soil RD&E system is central to this strategy. The soil RD&E strategy aims to build on current knowledge exchange networks to improve their linkages and make better use of these networks. This will be achieved by developing a national system for knowledge exchange that provides different pathways to reliable and independent information about soils and their management. This might include a web-based source of soil knowledge and diagnostic tools, education and training materials, as well as information about trials, demonstration sites and workshops. The strategy will also examine the role of Certified Professional Soil Scientist (CPSS) and other forms of accreditation, development of communities of practice or shared interest and skilling of land managers to know what questions to ask and where to look for answers. Support by strategy participants for an increased level of regional and local development, demonstration projects and education and training workshops will be sought. The soil RD&E strategy Implementation Committee will also be concerned with achieving greater engagement of R&D funders/providers with grower groups, private consultants and other agribusinesses, with greatly increased exchange of knowledge across organisations and at a national level.

Papers on soil extension and knowledge exchange (Galea et al. 2013; Jenkins et al. 2013) provide examples of activities to increase awareness, exchange knowledge, achieve behaviour change and monitor progress. Others are available from the past experience of Australian Government natural resource management programs, individual industries and government agencies, and from the wider literature on rural extension. The national implementation committee (Chapter 6) will consider in more detail the urgent need to improve knowledge exchange across industries, with work to be progressed through a knowledge-specific working group. This will include consideration of and linkages with the work of the Research, Development and Extension Committee on improving extension services.

4.3.4 Adopt a national approach to building future skills and capacity

Current situation

The stocktake of Australia's investment in soil RD&E, undertaken in 2010–11 (DAFF 2011), reported total expenditure of $124 million and around 850 full-time equivalent staff (including postgraduates). The strategy will have to address gaps and a need to build and maintain skills and capacity to meet future challenges. Work is required to determine likely demand for undergraduate and postgraduate education in soil science and whether courses, resources and facilities are adequate to meet this demand.

Why this goal is important

A national strategy for soil RD&E requires people with the skills and experience to implement it. Land managers in Australia will face a range of challenges in future and all components of RD&E will be needed to meet them. Maintaining and building skills and capacity is a particularly important goal because:

- new skills and new information will be required to meet future challenges; for example, a better understanding and management of soil biology and soil chemistry to improve nutrient supply to crops
- loss of skills and capacity from government agencies has not been completely replaced nor has it been expanded by agribusiness and grower organisations, resulting in loss of some skills and activities, as well as independence
- increased soil RD&E activity in tertiary education institutions may be put at risk by completion of current programs and budget pressures
- the demographics of Australian soil science suggest many scientists are likely to retire in the next decade and new appointments will be required
- capacity for effective knowledge exchange between land managers and people undertaking soil R&D is in urgent need of expansion.

What the strategy aims to achieve

A national skills audit is required for soil RD&E to map existing expertise and capacity against what is needed now and for the future, with a particular emphasis on how tertiary education and other education and training organisations will meet these needs. The audit will also examine availability of education and training materials (from award courses to technical workshops) and consider resources needed to deliver training to meet measured demand. Attention should be given to the need for greater interaction between soil science disciplines and related disciplines beyond soil science.

Employment opportunities, career pathways and funding sources for people with soil science expertise and skills will need to be considered, including the role of succession planning by institutions and the role of R&D funding bodies in supporting postgraduate and postdoctoral positions. A more detailed discussion of education and training needs is provided in Wardrop et al. 2013.

How this will be done

The soil RD&E strategy Implementation Committee, working with education and training providers and employers including the Australian Council of Deans of Agriculture, will examine the national education and training capability in more detail to assess potential changes over the next 10 years and to develop a more detailed soil RD&E capability development plan. The plan will consider the needs of particular industries, related sectors (especially climate and water use) and the many end users of soil information. Activities that may be implemented following this review include:

- continuing the development of a national soil science curriculum across education providers that builds the skills and knowledge in soil RD&E required to meet the needs of employers, clients and students
- establishing a professional-level masters program, delivered across institutions so that students from all universities have access to world and Australian leading expertise
- encouraging R&D corporations to invest in future soil R&D capability and capacity by funding industry-specific PhDs and postdoctoral fellowships in soil science
- improving soil knowledge and training through vocational education packages, including in-service courses (such as the Agriculture, Horticulture and Conservation Training Package Continuous Improvement Project to develop and inform future training packages)
- encouraging uptake of professional accreditation, either specific to soil or more broadly, to ensure soil knowledge exchange by suitably qualified personnel, and exploring opportunities for linkages across accreditation bodies
- coordinating and promoting training and education opportunities offered outside formal education systems and arrangements
- exploring opportunities to incorporate soil education and training into new and evolving delivery pathways, including examining the

market and need for this material and how it may connect with current and future tertiary and vocational education and training.

4.3.5 Collaborate on development and use of physical infrastructure

Current situation

Government departments and universities continue to undertake soil testing; however, they are now minor players in routine soil testing for agricultural advisory services—these have been taken up by the private sector. Australia has some 90 soil testing laboratories, with around 531 000 samples tested in 2012 (Section 3.3.5). Soil archives are important for development, testing and calibration of measurement methods and for providing type specimens and detecting change in soil condition and attributes over time. Australia has at least 16 soil archives of varying size and activity, which combined contain more than 350 000 samples.

Another important component of physical infrastructure for soil RD&E is availability of secure sites for long-term (multi-decade) field experiments. These are essential to enable assessment and comparison of gradual changes in soil attributes under different farming systems, for evaluation of the effects of climate change and of alternative adaptation strategies and for testing of innovations in soil management at practical spatial and temporal scales.

Why this goal is important

Collaborative use of physical infrastructure for soil RD&E is poorly developed in Australia. Reversing this situation could increase outputs and outcomes of the national effort and increase efficiency in resource use. For example, as diagnostic testing equipment ages and as new and more cost-effective soil tests are developed and implemented, testing laboratories will need to invest in new machines and skills. Specialisation, collaboration through sharing of samples or calibration information, and coordination of purchases could offer large cost savings providing that commercial and privacy concerns and capital replacement budgets can be managed. Joint management of a spatially distributed national soil archive with a single web access portal, and of long-term field experiments and sites, could help researchers maintain and make better use of viable working facilities at least cost and make sound business cases for future investment.

What the soil RD&E strategy aims to achieve

The soil RD&E strategy aims to implement several recommendations arising from the review of physical infrastructure:

- Of some 90 Australian soil testing laboratories fewer than 10 per cent are considered to be of international standard relative to the best in North America, South Africa and New Zealand. There is scope for broader participation in the Australasian Soil and Plant Analysis Council Inc. (ASPAC) Inter-Laboratory Proficiency Programme and for ASPAC to expand this program to include soil physical tests and eventually biological tests.
- Even the largest soil chemical testing laboratories in Australia rely heavily on instrumentation technologies, automation, laboratory equipment, building designs and methodologies developed two to four decades ago. Action is needed to stimulate the soil chemical testing sector to bring its methods up to international standards. Greater consistency in extraction methods and equipment across laboratories should also be considered (they are being considered by the NCST and ASPAC).
- No private-sector soil testing laboratory in Australia reported using infrared reflectance technology (for example, near- and mid-infrared spectroscopy) as a surrogate for soil chemical or physical tests. In contrast, the technology is in common commercial use by soil testing laboratories overseas, and some of these laboratories took in-house responsibility for instrument training/calibrations. Machine-learning software has been developed to continuously improve infrared training calibrations as new wet chemistry data comes to hand. That software is now available commercially and warrants serious consideration for wide use in Australia, as does the development of a national calibration program for near-infrared and mid-infrared spectroscopy.

- Budget pressures and downsizing have adversely affected public-sector soil testing laboratories that 10 to 20 years ago provided the foundations for the profession in Australia. Private sector laboratories have filled the gap in testing capacity but not in training and skills/capability development; the latter need urgent attention.
- The important issue of soil test result interpretations and recommendations, including processes for compiling and agreeing on appropriate soil test methodology and interpretative criteria, need further consideration at the national level. These processes should be transparent, inclusive and have a regional focus that ensures inclusion of local knowledge, Australia's soil types and preferred crops and pastures.
- Australia lacks a recognised national glasshouse testing facility for pot-trial studies of, for example, soil attributes, composts and new fertiliser formulations across soil types and plant species. Such a facility would add significant value to the individual tests (many unreported) undertaken each year.
- A dispersed (with respect to location) national soil archive should be developed, together with agreed protocols and procedures (including for data and sample sharing) and a mechanism to ensure periodic meetings to report on and coordinate the activities of individual archives. Funding for this archive, and for the associated database, needs to be secure and long term. Support could be provided through the NCST and Australian Collaborative Land Evaluation Program.
- Australia lacks a coordinated network for sharing information about and interrogating existing long-term experiments. Such a network should be developed, with consideration given to how experiments can be accessed by collaborators to address scientific questions. Consideration also needs to be given to how costs are distributed to effectively maintain these national assets.

How this will be done

It is proposed that the soil RD&E strategy Implementation Committee (Chapter 6) establish subgroups drawn from relevant organisations and practitioners to develop the recommendations on soil testing, soil archives and long-term field experimental sites, with a clear timetable for results and actions. Specific proposals will be communicated through the soil RD&E website and considered by a wider audience at annual soil RD&E forums. The committee will advise on public and private sources of funding for initiatives related to physical infrastructure for soil RD&E.

4.4 National soil research and development strategic directions

The strategic directions are the result of extensive consultation with leading scientists, policymakers and industry representatives and incorporate the work of the Advocate for Soil Health, Major General the Hon. Michael Jeffery.

Strategic directions will focus investment and provide a mechanism for stakeholders to consider where commonalities exist and to pool resources and expertise, achieving greater outcomes from soil RD&E investment. Strategic directions focus on delivering outcomes to agriculture and forestry but do not exclude investment in soil R&D outside these industries if a need is identified (for example, soil remediation of mine sites). They will help scientists, industry, policymakers and land managers collectively explore and tackle opportunities and challenges in the laboratory and at a farm and landscape scale, and improve understanding and management of Australia's soil resource.

4.4.1 Improving soil management to increase agricultural productivity and profitability

Soil is the foundation of our farming systems. Soil is complex and many factors must be managed to ensure it is fit for purpose and managed to maintain and improve agricultural productivity and profitability and the natural resource base. Whole systems thinking will promote integrated RD&E across each of the soil research fields of interest.

Examples of research and development include:

- improving nutrient use efficiency to increase productivity and prevent negative impacts (including acidification, eutrophication, leaching and greenhouse gas emissions)
- understanding and managing soil biology within the farming system
- managing soil water and improving water use efficiency
- managing soil carbon for productivity, resilience and sequestration outcomes
- understanding soil/root interactions to better manage the farming system
- understanding and improving soil management in northern Australia, including Indigenous land use of the soil landscape
- exploring how the recycling of waste products for nutrient supply could deliver sustainable and cost-effective productivity improvements.

4.4.2 Quantifying the soil asset in space and time: mapping, modelling, monitoring and forecasting

The need for improved quality, availability and access to soil data and information is a recognised strategic goal and the NCST is working to build better national systems through the strategy and more broadly. To meet this goal, RD&E is required to improve how we quantify Australia's soil asset.

Examples of strategic farm-scale research and development include:

- rapid, cheap and accurate real-time methods for soil assessment, such as proximal sensing, that can be used to better inform decision-making and monitor the soil resource from season to season
- techniques and tools to understand functional attributes of soil for improved management and productivity
- tools and systems to help landholders and advisers interpret soil test results and make informed and accurate management decisions
- innovations in precision agriculture to provide, interpret and better use soil data and information in real time.

For policymakers, planners and those working across the landscape, R&D is required to understand the condition of the soil resource at the national, regional and local level and its trend over time. Developing new tools, systems, methodology and nationally consistent protocols for soil assessment are essential to improve how we monitor and predict how production systems perform and how the landscape is changing or may change over time. Strategic research and development could include:

- advanced proximal and remote sensing, digital soil mapping and spatial modelling
- measuring and predicting the spatial distribution of soil attributes in real time
- developing methods and capability for monitoring and forecasting soil change
- developing tools to better understand the impacts on soil in a changing climate.

4.4.3 Solutions to manage soil/subsoil constraints

Soil constraints are a major challenge for land managers in Australia, from the farmer growing a crop or pasture to the engineer designing a major highway. Chemical properties (including sodicity, acidity, salinity and nutrient status), physical properties (including soil structure, porosity and compaction) and biological properties (including nutrient cycling capacity and disease suppressive soil) affect the productivity and determine the appropriate management of the soil. Soil constraints are critical and are particularly difficult and costly to remediate in the subsoil.

While knowledge exists about how to manage and remediate soil constraints, strategic RD&E is required to ensure solutions:

- are based on sound knowledge of soil types and location of constraints
- are economical and sustainable
- are practical for land managers to apply
- result in soil that is fit for purpose for the desired commodity or industry.

Overcoming soil constraints, particularly at the subsoil level, could boost productivity by expanding the root zone; it may also prevent other industries, including the construction industry, from making costly errors when constructing and repairing infrastructure such as roads and underground services. Economically viable solutions will ensure greater uptake by land managers, resulting in improved productivity and profitability.

4.4.4 Soil and its role in delivering ecosystem services

Soil delivers a range of essential ecosystem services. It provides food and fibre for all, supports plants and the millions of macro- and micro-organisms living in it. Soil supplies plants with nutrients and water, filters water against pollutants and absorbs waste. Soil plays an important role in climate regulation.

Strategic R&D is needed to improve our understanding of the ways in which soil contributes to the delivery of essential ecosystem services. Understanding the value of these services—including the value soil provides to the production of agricultural commodities or to healthy waterways and clean air—will help us manage this important asset and communicate its value to the broader community.

4.4.5 Managing soil across the landscape

Securing our food production system is a critical concern. Soil degradation leading to loss of productive agricultural land could reduce Australia's primary productivity and reduce levels of profitability and competitiveness in the international marketplace. Soil degradation can affect environmental quality and lead to increased greenhouse gas emissions, loss of biodiversity and ecosystem productivity and sedimentation of waterways and water storages. Understanding soil across the landscape will provide opportunities to manage and protect prime agricultural land and help in the sustainable development of industries, including agriculture, across northern Australia.

Research and development is required to improve our understanding of soil function, soil formation and degradation rates and processes (including wind and water erosion, acidity and salinity), as well as to develop techniques to better manage the soil resource. Research and development is required to understand land capability, including identifying and protecting prime agricultural land across the landscape, through informed planning decisions and appropriate land management.

4.4.6 Harvesting, verifying and communicating innovations in soil management

Australian farmers are highly innovative. Each season landholders and soil managers test thousands of ideas when they grow their crop, manage their livestock and provide food and fibre products. Improving links between farmers and scientists to verify techniques would improve the way we manage the soil resource.

Research and development should:

- capture and harvest innovations
- verify innovations using sound scientific methodology
- test innovations across the landscape and across industries
- communicate innovations to a broader audience to encourage uptake of improved management practices.

4.4.7 Capturing bright ideas to deliver world-class outcomes

New information, knowledge, tools or products that improve the way we understand, manage and monitor our soil may be delivered by lay practitioners or soil and other science disciplines, including engineering, nanotechnology, information and communication technology, nuclear science, medicine, chemistry, biology and physics. Australia's innovative soil scientists must be encouraged to chase big ideas, but we must also look beyond the traditional to capture potential and deliver world-class outcomes.

4.5 Relationship between strategy goals and R&D strategic directions

Strategy goals have been developed to deliver skills and capacity, tools and systems and a framework to support how soil RD&E is delivered in Australia. Strategic directions for soil R&D, on the other hand, identify nationally significant issues and opportunities for organisations to work together to improve how we understand, manage, protect and benefit from the soil resource. Strategy goals address the how while strategic directions address the what.

Strategic directions will be used to address the strategy goal improving the effectiveness of co-investment to generate and apply new knowledge. They also complement and align with other strategy goals—for example, by developing new tools and technology to support the proposed Australian Soil Assessment Program (NCST 2013) and informing soil extension activities with relevant information underpinned by sound science.

Strategy goals will support the strategic directions by ensuring there are sufficient numbers of soil scientists with the appropriate training and expertise to address current and future challenges and providing the infrastructure to support nationally relevant soil RD&E, including analytical equipment, soil archives and long-term field sites.

4.6 How the strategy will resolve existing problems

Section 1.5 describes why the soil RD&E strategy is needed and suggests improvements to the existing RD&E system. Table 4 explains how the strategy goals will help achieve these improvements.

4.7 Alignment with other primary industry research, development and extension strategies

Concerns about sustainable and profitable use and management of Australia's soil are reflected in other cross-sectoral and industry strategies developed under the Primary Industries Research, Development and Extension Framework. The soil RD&E strategy shares several objectives and priorities with those other strategies (Table 5). Examples are drawn from several existing RD&E strategies and could also apply to others.

TABLE 4 National Soil Research, Development and Extension Strategy outcomes

Areas for improvement	How goals will resolve concerns	Outcomes strategy will achieve
Investment in soil RD&E to address challenges	Goal 4.3.1, 'Improve effectiveness of co-investment to generate and apply new knowledge, will address this	• increased national focus on challenges to soil management, world-class, innovative RD&E by Australian scientists • improved planning, use and management of Australia's soil resource
Mechanism to identify and direct investment to national priorities	Strategy Implementation Committee will develop mechanism for collaborative identification of priorities and promote RD&E investment in priority areas (Goal 4.3.1)	• identify national priorities for soil R&D, enabling improved targeting and effectiveness of RD&E investments
Collaboration and co-investment between RD&E funders	Encourage co-investment; collaborative identification of priorities will increase opportunities for and promote RD&E co-investment by funders (all goals)	• joint identification of priorities and greater collaboration in sharing skills, knowledge and resources to address them • reduced duplication of effort, increased efficiency in making and managing RD&E investments
Collaboration and co-investment between RD&E providers, including understanding roles and responsibilities	Foster greater collaboration and co-investment by RD&E providers, while enabling organisations to continue to pursue their individual projects (all goals)	• joint identification of priorities and greater collaboration—sharing skills, knowledge and resources—address them • reduced duplication of effort • opportunities to share facilities, skills and expertise across disciplines, regions and organisations, leading to increased returns from investments in soil RD&E
Links between organisations involved in communicating and exchanging soil knowledge	National system for knowledge exchange will be developed to improve information flow, awareness and linkages between organisations involved (Goal 4.3.3)	• increased sharing of data and knowledge between industries, regions and organisations and reduced duplication • better targeting of investment to meet industry/ local needs based on improved understanding of existing knowledge • improved management of the soil resource
Links between soil R&D and knowledge exchange	Increase exchange of knowledge between land managers, scientists and decision-makers and within the RD&E system (Goal 4.3.3)	• increased returns from past investments in soil R&D as more land managers use results • potential for further innovations in soil management • continuing problems in soil management addressed more effectively • improved delivery of evidence-based information

Continued...

TABLE 4 National Soil Research, Development and Extension Strategy outcomes Continued

Areas for improvement	How goals will resolve concerns	Outcomes strategy will achieve
Availability of soil data for users and access to collated/ interpreted data	Improve quality, availability and access to soil data and information, starting with market analysis of user needs (Goal 4.3.2)	• maps of functional properties of soils at appropriate resolutions • systems for monitoring change in soil properties over time • improved understanding of soil condition and ability to forecast condition • improved land use and soil management decisions by planners and land managers across industries and governments
Education and training that provides skills and capacity necessary to meet challenges	Conduct a national skills audit to map existing expertise and capacity against present and future needs (Goal 4.3.4.)	• appropriate skills, capability and capacity to support soil RD&E effort • high-quality education and training that meets employer needs • clear career pathways for soil science graduates • replacement of skills and expertise lost through retirement • adequate capacity to meet soil management challenges • increased soil management knowledge and skills among land managers and advisers
Understanding and management of physical infrastructure available to soil RD&E	Promote improved soil testing methods, standards and interpretation; improve management of national soil archives and long-term experimental sites (Goal 4.3.5)	• improved knowledge of Australia's soil RD&E physical infrastructure • increased collaboration, strategic investment in and development of new technology • improved standards for collection and analysis of soil samples and interpretation and communication of results • improved engagement with and capture of information from private laboratories • protection of nationally important assets (archives and field sites)
Effectiveness and efficiency of national soil RD&E effort	Improve effectiveness and efficiency of national soil RD&E effort (all goals)	• improved returns from investments in soil RD&E

Note: **RD&E** Research, development and extension.

TABLE 5 Alignment between primary industry strategies and National Soil Research, Development and Extension Strategy

Primary industry RD&E strategy	Strategy objective or priority	Alignment with National Soil Research, Development and Extension Strategy
Water Use in Agriculture RD&E Strategy (cross-sectoral)	• reduce conveyance and storage losses • more flexible irrigation strategies • optimise water use, including soil water use • facilitate information exchange between regions, across commodity groups and between researchers and end users • understand effects of climate change on surface, soil and subsurface water supplies • develop strategies for prevention and mitigation of salinity	• provide improved knowledge of soil hydraulic properties • improve soil data for irrigation scheduling and monitoring • provide soil data and training in practical on-farm methods • information exchange is a key focus of the strategy for soil knowledge and soil management effects of climate change a core driver of future soil RD&E • provide improved soil knowledge to underpin salinity mitigation strategies
Climate Change Research Strategy for Primary Industries (cross-sectoral)	• primary industries will better manage climate variability • help producers, industries and regions adapt to biophysical effects • lower emissions while maintaining productivity • improve tools for (net) emissions reporting and attribution	• provide and disseminate improved information on soil water storage • provide information and training on better soil management • work on C sequestration and reducing N_2O emissions • improved measurement of net emissions through soil RD&E
Grains Industry National RD&E Strategy	• optimise agronomic systems for each major (grain-growing) agro-ecological zone • create tools for improved seasonal decision-making, including under climate change • reduce environmental footprint and off-site impacts of grain growing • demonstrate industry environmental credentials	• provide and disseminate improved methods and knowledge of soil productive capacity • improve soil knowledge to underpin strategic and tactical decisions • help growers optimise use of chemical inputs and minimise risk of off-site losses • help growers measure improvements in soil condition
Cotton Sector National RD&E Strategy	• improve resilience, productivity and profitability across cotton value chain • reduce environmental footprint of cotton industry • improve human capability to achieve strategy priorities	• provide improved knowledge of soil productive capacity and maintaining this under climate change • help growers optimise use of chemical inputs and minimise risk of off-site losses • capability a key focus of the soil RD&E strategy for soil knowledge and soil management

Continued...

TABLE 5 Alignment between primary industry strategies and National Soil Research, Development and Extension Strategy Continued

Primary industry RD&E strategy	Strategy objective or priority	Alignment with National Soil Research, Development and Extension Strategy
Dairy Moving Forward, the National Dairy RD&E Strategy	• increase confidence to manage climate change and capacity to reduce greenhouse gas emissions • ensure long-term sustainable use of nutrients through greater understanding of nutrient pathways • improve extension of nutrient management principles and practices	• provide information on better management of soil water under climate change, R&D directed towards understanding soil carbon transformations and sequestration and reducing N_2O emissions • improve, through R&D, understanding of soil nutrient pathways and improved measurement and management of nutrients • improve knowledge exchange, such as nutrient management practices
Fishing and Aquaculture RD&E Strategy	• reduce land degradation (especially soil loss) and poor nutrient management that can contribute to water contamination • provide ecosystem services (such as water filtration and nutrient cycling), prevent habitat degradation	• help land managers optimise use of chemical inputs and minimise risk of off-site losses to aquatic environments • assist provision of ecosystem services and protect adjacent habitats through more effective RD&E to maintain/improve soil health
Forest and Wood Products Sector RD&E Strategy	• predict and manage forest water use and carbon stocks and dynamics • adapt to a changing climate • improve soil data for plantation planning and management	• provide, through targeted RD&E, data to better assess water use efficiencies and dynamics and improve measurement of soil carbon storage and flux • address need for RD&E to test and compare options for climate adaptation • provide improved data for land use planning
Horticulture National RD&E Framework	• support sustainable practices, irrigation and water use efficiency, soil health and protection and natural resources • support climate change and climate variability mitigation and adaptation • seek co-investment opportunities	• improve soil RD&E to underpin industry practices for water and nutrient use efficiency and maintenance of soil health • support work on climate adaptation and mitigation • support RD&E co-investment
Sheep Meat Production National RD&E Strategy and Beef Production National RD&E Strategy	• promote ethical and responsible custodianship of the environment, animal welfare and resources used in the production of red meat	• increase natural resource use efficiency and reduce environmental damage • increase cost efficiency and productivity (including adaptability and risk management)
Wool RD&E Strategy	• build environmentally sustainable wool enterprises	• support management systems that preserve the natural resource base • support optimal pasture productivity and grazing management
Wine Sector RD&E Strategy	• improve and reduce inputs associated with rootstock, Vinifera germplasm, clonal stock and chemicals to enhance environmental impact on vines • develop procedures and tools to measure and reduce environmental footprint	• increase water use efficiency • ensure suitability of soil to vine stock and production methods that respect biodiversity and suit changing climatic conditions

Note: **RD&E** Research, development and extension.

CHAPTER 5

Change plan

The central purpose of the soil RD&E strategy is to bring about a greater degree of national coordination and collaboration in Australia's soil RD&E effort and thereby to improve its effectiveness and efficiency. The strategy will result in greater returns on investment in soil RD&E by establishing mechanisms that bring together knowledge, skills and facilities from across jurisdictions and organisations to jointly address national and regional priorities, opportunities and problems. The strategy provides a mechanism for ranking these priorities.

The many organisations that participate in the national soil RD&E effort (Chapter 3) lack a strong coordinating mechanism. As a result, there is a risk that knowledge generated in one jurisdiction, region or industry will not pass on to others that could make good use of it and that work will be unnecessarily duplicated or repeated over time. There are many examples of this. Greater collaboration enables organisations to share the costs of expensive facilities, equipment and other infrastructure and consider whether investment in new equipment is necessary and to more readily bring together expertise from across disciplines to tackle major R&D topics. Greater coordination means better alignment of priorities and funding streams, reducing administrative load on researchers, research bodies, government and other organisations.

Funding and managing the national soil RD&E effort to achieve this purpose requires recognition of organisational roles and responsibilities and establishment of an efficient co-investment process.

5.1 Organisational roles and responsibilities

An estimated 150 organisations contribute to the national soil RD&E effort. This is a large number of contributors and, while there are likely to be jurisdictional-, regional- and industry-specific needs that must be met, it is reasonable to inquire what arrangements exist for national coordination and collaboration of effort to reduce duplication and inefficient use of resources. The short answer is: relatively little. Organisations involved in similar activities are not working together, despite funding bodies, interagency committees and professional societies providing opportunities for joint discussion

of priorities and encouraging collaboration. Consultations undertaken in developing this strategy and information from other sources (for example, DAFF 2011) show that much more could be done to better coordinate the national effort in soil RD&E and promote collaboration and sharing of knowledge, skills and resources. This will enable Australia to achieve greater returns on both past and future investment in soil RD&E.

5.1.1 Role definitions

The Research, Development and Extension Committee defined the roles of jurisdictions, agencies and organisations under the National Primary Industries Research, Development and Extension Framework as:

- major—taking a lead role by providing significant RD&E effort through maintenance of capability and leadership to deliver national R&D outcomes
- support—contributing to R&D in partnership but with the major role taken by another organisation(s)
- link—undertaking little or no R&D but instead accessing information and resources from others.

To better reflect the needs of the soil RD&E strategy, the major, support and link categories have been expanded to suit the needs of stakeholders and to include items other than R&D expenditure.

For an organisation to take a major role within an Australian and New Zealand Standard Research Classification (ANZSRC) soil RD&E field of interest, it should do most of the following:

- provide national leadership through the impact and influence of its work (for example, new published knowledge, innovations, education/training or achievement of practice change)
- have a comprehensive work scope and provide significant or internationally leading expertise within this field of interest
- produce work of national significance; for example, the work should be national in scale or focused on a particular industry/jurisdiction with outputs that are significant nationally (for example, work on acid sulfate soils)
- be a substantial investor in or provider of soil RD&E effort (suggested total resource commitment of at least $1.5 million a year for an individual field of interest)
- engage and communicate with industries, co-investors, research partners and other major, support and link organisations to determine or influence national soil RD&E priorities (including considering local and regional input)
- foster RD&E collaboration and coordination
- make new knowledge or innovations available for use by others
- support local, regional or industry-based communication and adoption of new knowledge
- intend to maintain or increase its effort in soil RD&E over the next five years.

For an organisation to take a support role within an ANZSRC soil RD&E field of interest, it should do most of the following:

- undertake high-quality RD&E in one or more specialist topics within this field of interest
- produce work that, while not national in scope or coverage, is of functional and meaningful importance to the national effort
- support investors in or providers of Australia's soil RD&E effort (total resource commitment of at least $0.5 million a year for an individual field of interest), perhaps in partnership with others
- produce work that is either jurisdiction, region or industry specific
- be able to identify the RD&E requirements of its stakeholders and engage with other organisations to determine priorities and/or influence priority setting and foster soil RD&E collaboration and coordination
- develop strong relationships with link organisations to support local, regional or industry based communication and adoption of new knowledge
- intend to at least maintain its effort in soil RD&E over the next five years.

For an organisation to take a link role within an ANZSRC soil RD&E field of interest, it should do most of the following:

- play a key role and have specialist expertise in development and extension components of the national soil RD&E effort
- provide input into the determination of national RD&E priorities with a local, regional and/or industry focus
- engage proactively with major and support organisations to foster RD&E collaboration and coordination
- actively seek and gain timely access to new knowledge and data for translation and delivery to farmers, land managers and other users of soil RD&E outputs
- develop and deliver communication, demonstration, education and/or training materials and activities
- undertake local or regionally based trials and activities to engage with and inform their target audiences
- maintain active networks with other organisations delivering RD&E knowledge and products
- take steps to be linked effectively into the national soil RD&E effort.

5.1.2 Current and future roles

In May 2013 the strategy secretariat asked 144 organisations to nominate the role they wished to play within each soil RD&E ANZSRC field of interest. The 60 organisations that responded comprised government agencies, universities, R&D corporations, natural resource management regional bodies and grower groups (Table 6; Appendix A).

This information has identified organisations likely to participate actively in delivering soil RD&E nationally and in implementing the strategy, those able to take leadership roles in particular fields of R&D or in particular locations and those likely to play a key role in knowledge exchange. This information will be used to guide strategy activities and aid collaboration. It does not lock organisations into specific activities; rather, it identifies an interest and willingness to participate.

In addition to the organisations listed in Table 6, many other organisations responded to the roles and responsibilities survey and/or contributed to the development of the strategy, including grower groups, Landcare groups and natural resource management regional bodies. These types of organisations, as well as commercial entities (agribusiness, private consultants), play an important and varied role in delivering soil RD&E. In particular, many of these organisations contribute to the exchange of information to land managers and, depending on the business model, may:

- provide one-on-one support paid for directly by the grower
- deliver broader extension activities (including distribution of communication material, forums, field days) with funding from a range of sources
- operate across soil RD&E by undertaking research and then communicating their results and the results of other research organisations to their growers and clients.

Sophisticated, farmer-driven grower groups, such as the Western Australian No-Tillage Farmers Association (and partner organisations under the Conservation Agriculture Alliance umbrella) and Birchip Cropping Group, have built partnerships with universities and other research organisations and also undertake independent research activities. To support this work, their research is delivered to growers and other users of soil information through a wide range of extension activities, including field days, trials sites, farmer networks and other communication activities.

A range of other groups and organisations also play a vital role in soil RD&E but do not necessarily fit within the matrix presented in Table 6—for example, agricultural engineers who develop equipment to implement sustainable farming practices, including tillage machinery and irrigation infrastructure. The Australian Nuclear Science and Technology Organisation develops innovation and advances in high technology with on-ground applications, such as the development of scanning technology for rapid measurement of soil composition. Additionally, while not a signatory to the National Primary Industries RD&E Framework, the ACT Government, through the Environment and Sustainable Development Directorate, undertakes a number of soil mapping exercises within the ACT.

TABLE 6 Roles and responsibilities nominated by organisations delivering soil RD&E

Field of Interest	Major	Support	Link
Agricultural land management	CSIRO, DAFWA, Vic. DEPI, NSW DPI, CSU, Monash, UAdl, UMelb, UWA, UWS	Qld DAFF, Qld DSITIA, SARDI, CRDC, Dairy Australia, GWRDC, MLA, ANU, CDU, La Trobe, QUT, SCU, UNE, USQ, USyd, UTas, UQ, UniSA	SA DEWNR, Tas. DPIPWE, NSW OEH, GRDC, Dept of Agriculture, HAL, Qld DNRM, CPSS
Land capability and soil degradation	CSIRO, Qld DSITIA, GRDC, Monash, DAFWA	Vic. DEPI, Tas. DPIPWE, Dept of Environment, NSW OEH, CRDC, MLA, ANU, CSU, QUT, USQ, USyd, UQ, UWA, UWS, UniSA	SA DEWNR, NT DLRM, GA, NSW DPI, Dairy Australia, FWPA, CDU, UTas, Dept of Agriculture, HAL, CPSS, Qld DNRM
Soil and land inventory and monitoring	CSIRO, Vic. DEPI, NSW OEH, DAFWA, UAdl, USyd, Dept of Agriculture, Qld DSITIA	NT DLRM, Tas. DPIPWE, MLA, CSU, Monash, QUT, UWA, UWS, UniSA, SA DEWNR	GA, NSW DPI (Agriculture NSW), Dairy Australia, FWPA, USQ, UTas, CPSS, Qld DNRM
Soil biology	CSIRO, Vic. DEPI, SARDI, GRDC, UAdl, UNE, UWA, UWS, UMelb	Qld DAFF, NSW DPI (Agriculture NSW), CRDC, GWRDC, MLA, ANU, CSU, Monash, QUT, SCU, USyd, UQ, Uni SA, La Trobe	DAFWA, NSW OEH, Dairy Australia, USQ, UTas, Dept of Agriculture, HAL, CPSS
Soil carbon sequestration	CSIRO, Qld DSITIA, NSW DPI (Agriculture NSW), ANU, Monash, QUT, SCU, UAdl, UMelb, UNE, USyd, UWA, UWS, Dept of Agriculture	DAFWA, Qld DAFF, Vic. DEPI, NSW OEH, CRDC, CDU, CSU, UTas, UniSA	SA DEWNR, NT DLRM, Tas. DPIPWE, GRDC, MLA, USQ, HAL, CPSS
Soil chemistry	CSIRO, Vic. DEPI, NSW DPI (Agriculture NSW), GRDC, La Trobe, Monash, SCU, UAdl, UMelb, UNE, UniSA, USyd, USQ, UQ, Qld DSITIA	DAFWA, SARDI, CRDC, MLA, ANU, CSU, QUT, UWA, UWS	NT DLRM, GA, Dairy Australia, FWPA, UTas, Dept of Agriculture, CPSS, GWRDC
Soil physics	CSIRO, GRDC, UAdl, UNE, USQ, USyd	Qld DAFF, Vic. DEPI, NSW DPI (Agriculture NSW), CRDC, CSU, QUT, UTas, UWA, UWS	DAFWA, DLRM, GA, SARDI, FWPA, UMelb, Dept of Agriculture, CPSS, Qld DSITIA, Dairy Australia
Other soil science	UniSA	Monash, DAFWA	CPSS

Note: This information is also presented in full in Appendix A.

Professional organisations play an important role in fostering R&D collaboration and coordination and communicating research across their member base. Organisations include Soil Science Australia, the peak professional body for soil scientists, Irrigation Australia and the International Erosion Control Association, the Australian Land and Groundwater Association and the Environment Institute of Australia and New Zealand. The CPSS accreditation program also plays a crucial role in promoting the importance of soil in the Australian environment and developing a cohort of scientists with the skills and knowledge to deliver high-quality soil-related advice and assessment.

The Australian Research Council is an important national investor in research through funding schemes of the National Competitive Grants Program. Funding is allocated to research projects on the basis of a competitive peer review process. The council does not allocate budgets for particular disciplines, making it impossible to predict future patterns of funding for specific areas of research; however, the council invested around $8.5 million in soil-related research in 2012.

5.2 Co-investment strategy

Under the Primary Industries RD&E Framework, RD&E capability and new knowledge are developed nationally, applied to regional issues and extended at the local level. Clearly, a large pool of stakeholders will need to collaborate if soils RD&E is to become more effective. Many stakeholders are active in only one or some aspects of the soils knowledge generation and management process, which includes basic research, applied research, experimental development and demonstration, communication and knowledge exchange and education and training.

Soil RD&E is a cross-sectoral concern that affects all jurisdictions, most rural industries and activities that include natural resource and catchment management, mining, underground services and road and urban construction. These sectors vary in the extent to which they interact with different aspects of the soil knowledge process. This has implications for the type of co-investment process or model that would best achieve the soil RD&E strategy aims.

Any co-investment strategy must contribute to increased effectiveness and efficiency of the national effort in soil RD&E. This can be achieved by:

- increasing coordination of investment and effort in topics of common interest across jurisdictions, industries, regions, fields of science and organisations
- collaborating across scientific disciplines to better address complex national issues (such as climate change, soil and water security), developing and sharing expensive or limited infrastructure (such as soil data, physical facilities and skilled personnel)
- reducing the negative effects of fragmentation of investors and providers due to, for example, varying timing or conditions of RD&E investment decisions by different organisations or duplication of effort by many separate organisations
- effectively linking R&D with all forms of knowledge exchange and with on-ground land managers and their advisers, as well as with policymakers and land use planners
- coordinating and jointly developing national soil RD&E infrastructure, including data that meets user needs and education, training and career structures that ensure that Australia will continue to have skilled personnel
- improving monitoring and evaluation of the returns from soil RD&E to ensure national needs are met.

In its statement of intent, the National Primary Industries RD&E Framework outlines what the implementation of strategies developed under the framework will achieve:

- define a set of national priorities for each sector and cross-sector to guide research investment
- identify gaps (and mechanisms to address these gaps) in national research capability on a regular basis
- establish a process to allocate resources across priority areas and ensure maintenance of national capability and effort
- establish a process for monitoring and reviewing the system's effectiveness
- establish a process for management of intellectual property and innovation to maximise benefits to Australia's primary industries

- establish a process to ensure research findings are readily available and adopted rapidly.

A co-investment process for the soil RD&E strategy would need to be capable of achieving these broad outcomes.

5.3 Co-investment model

Several basic models, or a combination of models of RD&E co-investment, could be considered. The boundaries between them are not rigid, and mixed models have been used in the past. Models range from highly proactive, with high transaction costs and (generally) high effectiveness, to more passive, with lower transaction costs and variable effectiveness. Five potential RD&E co-investment models, shown in Table 7, were considered for their potential to meet the user needs outlined above.

The Strategy Reference Group determined that model 2 offered the best mix of effectiveness and feasibility for the main components of the soil RD&E strategy. The pool of organisations for which soil RD&E is a sufficiently core issue is large enough to make model 2 feasible. The National Implementation Committee will be established to implement this model (Chapter 6) and working groups will be formed to support the committee and address strategy goals. Such a structure ensures a leadership focus to drive implementation of the strategy but provides room for all organisations to participate according to their interests and resources. Model 2 is the co-investment model that will be implemented if this strategy is formally approved by the Agricultural Ministers Forum.

It is also recognised that, within the broad remit of soil RD&E, some specific topics may be best addressed using other co-investment models. If a soil-related cooperative research centre bid is successful in the future, parts of the strategy will be integrated into the work of that centre.

TABLE 7 Five potential co-investment models for research, development and extension

Characteristics	Active management High transaction costs High effectiveness				Passive Lower costs Less effective
Models	1. Several organisations commit to work together and commit untied resources to the program, which is overseen by their representatives	2. Several organisations commit to work together and commit their resources case by case	3. One organisation takes the lead, employs a coordinator or broker to engage other organisations and to source additional or matching resources	4. Organisations establish a loose coordination group and employ a coordinator or broker to source the resources needed from or beyond members	5. A group or single organisation identifies and publishes national priorities and hopes that they will be acted on
Examples	Cooperative research centres, some Land and Water Australia programs (for example, National Dryland Salinity Program)	Pastures Australia, Healthy Soils for Sustainable Farms program	National Program for Irrigation Research and Development, Grains Research and Development Corporation strategic initiatives	Some research associations	Australian Research Council

CHAPTER 6

Implementation actions

6.1 National Soil Research, Development and Extension Strategy Implementation Committee

The strategy implementation committee will oversee implementation of the soil RD&E strategy. It will comprise representatives from organisations that play a major role in funding and/or providing soil RD&E and that have committed to contribute resources to achieve strategy goals. The committee will provide leadership to identify national priorities, facilitate co-investment, assist stakeholders to link their priorities and activities across sectors and ensure networks are in place to promote collaboration and effective delivery of soil data and information to all users.

Other participants may be sought or self-nominate as strategy implementation proceeds. The role of the National Implementation Committee will be to:

- oversee and govern strategy implementation
- implement the strategy to achieve its objectives in a timely manner
- drive increased collaboration and coordination between organisations involved in the national soil RD&E effort
- liaise with relevant national committees, including but not limited to the:
  - Research, Development and Extension Committee and Resource Management Committee
  - NCST
  - National Committee on Land Use and Management Information
  - Terrestrial Ecosystem Research Network
  - National Plan for Environmental Information
  - National Committee on Acid Sulfate Soils

- evaluate and proactively seek collaboration and co-investment to address national soil R&D strategic directions
- identify the needs of users of soil information and data and help ensure those needs are being met
- establish more effective channels for knowledge exchange between users and providers of soil information
- undertake monitoring, evaluation, reporting and improvement activities to ensure the strategy is being implemented
- oversee communication activities, including convening an annual soil RD&E forum, oversee the soil RD&E strategy website and provide electronic newsletters and other updates to stakeholders.

As indicated in the governance structure (Figure 9), working groups will be formed to support the National Implementation Committee and deliver outcomes against strategy goals. These groups will identify problems and opportunities in the national soil RD&E effort. They will harness existing arrangements—for example, through the NCST, which will oversee data, information and physical infrastructure goals. Additional working groups may be formed as required.

The Resource Management Committee (RMC) advises senior government officials on the status of agricultural lands and the activities being conducted to improve its productivity, resilience and capacity to deliver high-quality ecosystem service outcomes for the broader community. The RMC reports on relevant work being conducted by cross-sectoral strategies developed under the National Primary Industries RD&E Framework. The NCST is a national coordinating committee reporting directly to the RMC on issues outside the scope of the strategy. Issues directly relating to the strategy will be reported through the National Implementation Committee (Figure 9).

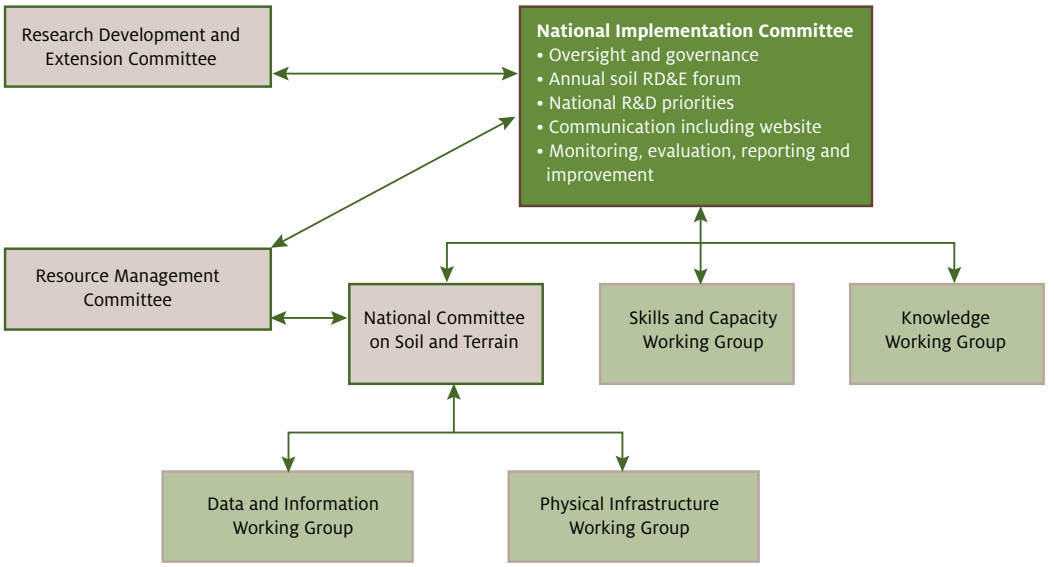
6.2 Annual soil research, development and extension forums

Annual national soil RD&E forums will assess cross-sector and regional soil RD&E priorities, consider opportunities for soil RD&E and report on achievements. Before each forum, small field-of-interest, cross-sector or regional working groups established by the strategy implementation group will develop their specific needs and priorities to present to the national forum. Other working groups will report on implementation of a national cooperative soil assessment program, education and training for those involved in soil RD&E and improved soil knowledge delivery systems. Researchers, policymakers, industry, practitioners (such as grower groups and private consultants), farmers and other stakeholders interested in soil RD&E will be invited to participate in these forums and help set the RD&E agenda. The forums could be run as part of existing soil science conferences, such as those hosted by Soil Science Australia.

6.3 Soil research, development and extension website

A website will be developed to communicate implementation, progress and outputs of the soil RD&E strategy. RD&E priorities will be reported on this website and members of the implementation committee and topic-specific working groups will be able to communicate using the website. A news function will be included on the site to regularly communicate research outcomes, events and other relevant information. Information about cross-sectoral proposals will offer opportunities for collaboration. Links to sector-specific projects will provide a snapshot of existing soil RD&E activities. This website will not create new information for dissemination but will focus on strategy-related achievements and provide links to existing initiatives (for example, the healthy soil knowledge bank, soilquality.org.au and Soil Science Australia).

FIGURE 9 Governance to support implementation of the National Soil Research, Development and Extension Strategy



Note: **RD&E** Research, development and extension.

6.4 Resourcing and executive support

It is estimated that the strategy will require an operating budget of $150 000 a year to consider goals and deliver activities such as the annual soil RD&E forum and the website. Funding to support this work will be sought from implementation committee member organisations and other interested parties. Additional funding will be sought for specific activities and projects. The implementation committee will develop a process for managing these funds and ensuring good governance.

In addition to the proposed operating budget, executive support will be required to drive the implementation of the strategy. An executive officer will provide support to the implementation committee by organising meetings, managing the annual forum and website and delivering other communication activities as required. The executive officer will play a key role in stakeholder management, including liaising with the Research, Development and Extension Committee and Resource Management Committee, linking with other sectoral and cross-sectoral strategies and encouraging collaboration and cooperation across research providers, research and development corporations and other stakeholders.

6.5 Monitoring, evaluation, reporting and improvement

The annual forum will report on the achievements of the strategy, reconsider priorities and determine areas for improvement. The success of the strategy will be reviewed every three years by organisations represented on the implementation committee. Evaluation will be publicly reported, with success measured by the extent to which strategy goals and activities have been or are being achieved. A monitoring, evaluation, reporting and improvement

plan will be developed by the implementation committee, and initial performance indicators could include:

- Achievements against implementation actions and strategy goals (Table 8).
- Implementation of a national cooperative soil assessment program, such as:
  - number of jurisdictions and organisations actively involved
  - increases in types and amounts/coverage of data available to users
- Reporting on the number of new collaborative arrangements formed as a result of the strategy, such as:
  - arrangements to address issues described under the national soil R&D strategic directions
  - joint use and availability of physical infrastructure
  - education and training opportunities, including shared use of training materials and facilities, linking of training to national competencies
  - extension/knowledge exchange arrangements.
- Monitoring of the number of research and/or extension projects that address the National Soil Research and Development Strategic Directions and consider and communicate benefits of soil management in delivering productivity and sustainability outcomes.
- Increased use of soil information and data by policymakers, researchers and farmers to better inform decision-making processes (to be tracked by website statistics and through periodic survey, data on participation at soil management training workshops and participant feedback).
- Uptake of accreditation programs (such as CPSS).
- Completion of independent evaluations by users of soil information and data of its availability and value.
- Completion of an independent evaluation of education and training in soil management and of skill development and availability of skilled personnel.
- Monitoring of investment in soil RD&E to maximise benefits.
- Evaluations conducted at the annual soil RD&E forums.
- Other measures of effective knowledge delivery, including:
  - measured change in soil management practices through national surveys and other industry-driven initiatives
  - measured changes in soil health (including reductions in dust emanating from agricultural lands, as reported through national wind erosion monitoring via DustWatch, or improvements in groundcover management).

6.6 Implementation actions and timetable

Table 8 provides an indicative timetable for achievement of the five strategy goals, from implementation in March 2014 to June 2015. It lists key organisations that will take primary responsibility for implementing actions. Other organisations and groups will also be involved.

TABLE 8 Implementation of National Soil Research, Development and Extension Strategy, 2014 and 2015

Goals and reporting requirements	Implementation actions	Organisations responsible	Dates	Measures of success
Improve effectiveness of co-investment to generate and apply new knowledge (Goal 4.3.1)	Establish National Implementation Committee	Executive officer	April 2014	Committee has met and executive support is in place.
	Establish topic-specific working groups to identify national priorities	National Implementation Committee	June 2014	At least three subgroups established and activated.
	Hold first annual soil RD&E forum	National Implementation Committee working groups	November 2014	Forum held, outputs provided to all organisations with interests in soil RD&E.
	Identify and circulate first set of national strategic directions for soil R&D to funders and providers	National Implementation Committee working groups	January 2015	First set of national soil RD&E priorities identified following forum and provided to all organisations with interests in soil RD&E.
	Develop co-investment proposals	National Implementation Committee working groups	June 2015	At least two co-investment proposals developed, support committed by at least five co-investors.
	Communicate strategy activities, facilitate soil RD&E networks	National Implementation Committee working groups	Ongoing	Regular electronic newsletter about strategy progress distributed via email and website, with a portal available for use by RD&E networks.

Continued...

TABLE 8 Implementation of National Soil Research, Development and Extension Strategy, 2014 and 2015 Continued

Goals and reporting requirements	Implementation actions	Organisations responsible	Dates	Measures of success
Improve quality, availability and access to soil data and information (Goal 4.3.2)	Undertake market research of user needs for soil data	National Implementation Committee NCST, other organisations	June 2014	User needs collated and results published.
	Agree on national standards for soil data and data collection, sharing, monitoring and analysis	NCST, other organisations	October 2014	Agreed set of national standards published and in use by organisations.
	Develop integrated national soil information system	CSIRO Terrestrial Ecosystem Research Network other organisations	October 2014	Structure of an integrated system that meets identified user needs established and being populated with data.
	Establish cooperative national approach for collection, sharing, monitoring and analysis of soil data	NCST, other organisations	October 2014	National cooperative program established with long-term funding commitments.
	Engage public and private sectors to better capture and make available soil information	NCST, other organisations	January 2015	Protocols for access to and storage of public and private soil information under active discussion.
Improve communication and exchange of soil knowledge (Goal 4.3.3)	Conduct market research of user needs and preferred sources of soil information	Knowledge Exchange Working Group, user groups	June 2014	Results collated and published.
	Establish and update soil RD&E website	National Implementation Committee, Knowledge Exchange Working Group	June 2014	Website established and funding secured for its continued management and maintenance.
	Develop national system for knowledge exchange	National Implementation Committee, Knowledge Exchange Working Group	January 2015	Proposals discussed at annual soil RD&E forum, establishment of national system commenced based on agreed action plan and funding

Continued...

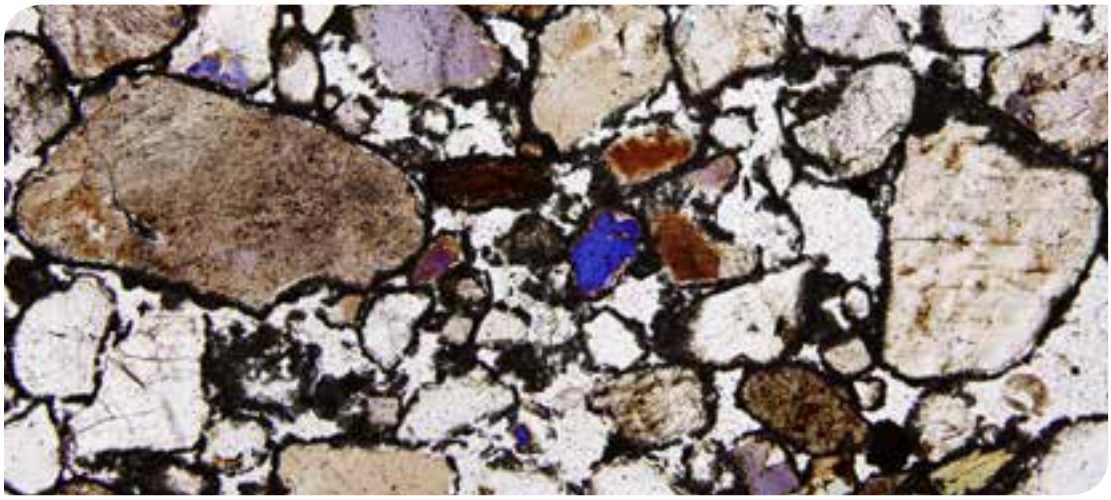
TABLE 8 Implementation of National Soil Research, Development and Extension Strategy, 2014 and 2015 Continued

Goals and reporting requirements	Implementation actions	Organisations responsible	Dates	Measures of success
Adopt a national approach to building future skills and capacity (Goal 4.3.4)	Conduct national skills audit to map existing expertise and capacity against what is needed	National Implementation Committee Skills and Capacity Working Group Australian Council of Deans of Agriculture/Environment, agribusiness, other organisations	October 2014	Audit published, results considered by tertiary education and other training bodies, commitments to additional training courses and places made public
	Develop professional masters program in soil science	National Implementation Committee Skills and Capacity Working Group, education and training organisations RD&E and providers agribusinesses	January 2015	Program under development
	Develop plan to improve employment opportunities, career pathways and funding sources for soil RD&E staff	National Implementation Committee Skills and Capacity Working Group RD&E funders and providers agribusiness	June 2015	RD&E funders and providers and other employers have considered age profile of soil RD&E staff and need for succession planning Improved career pathways established
	Complete national soil science curriculum that meets employer and land manager needs	National Implementation Committee Skills and Capacity Working Group education and training organisations RD&E funders and providers agribusiness	June 2015	Integrated and accredited soil science curriculum available nationally at different levels—for example, degree, award, vocational and refresher—and by different modes of study
	Review vocational education and training programs relevant to soil science and soil management and expand if required	National Implementation Committee Skills and Capacity Working Group, education and training organisations RD&E funders and providers agribusiness	June 2015	Up-to-date and expanded vocational education and training programs of study available

Continued...

TABLE 8 Implementation of National Soil Research, Development and Extension Strategy, 2014 and 2015 Continued

Goals and reporting requirements	Implementation actions	Organisations responsible	Dates	Measures of success
Collaborate on development and use of physical infrastructure (Goal 4.3.5)	Expand inter-laboratory soil testing proficiency programs and consistent regional interpretations for test results	National Implementation Committee Australasian Soil and Plant Analysis Council agribusiness	December 2014	Expanded program of proficiency testing established by Australasian Soil and Plant Analysis Council, regional panels have developed standards for interpretation of soil test results
	Establish national standards for collection, analysis, interpretation and communication of soil tests	National Implementation Committee Australasian Soil and Plant Analysis Council agribusiness	January 2015	Agreed protocols and testing manual developed and being implemented by soil-testing organisations
	Establish a dispersed national soil archive	National Implementation Committee Physical Infrastructure Working Group	June 2015	Focus sites for the dispersed national soil archive agreed and long-term funding secured
Strategy Monitoring, Evaluation, Reporting and Improvement program	Establish benchmarks against which progress in implementing the strategy and achievement of its goals can be assessed	National Implementation Committee	August 2014	Proposed key performance indicators identified and benchmark data collected. Indicators and benchmarks presented to the 2014 annual forum and amended as required; further data presented at subsequent forums and made publicly available.



Appendixes

Appendix A: Proposed roles and responsibilities

In May 2013, the soil RD&E strategy secretariat asked 144 organisations to nominate the role they wished to play within each Australian and New Zealand Standard Research Classification (ANZSRC) soil science field of interest. The 60 organisations that responded comprised government agencies, universities, R&D corporations, natural resource management regional bodies and grower groups. Responses for each ANZSRC field of interest are shown below.

Agricultural land management

- **Major role:** CSIRO, Department of Agriculture and Food (WA), Department of Environment and Primary Industries (Vic.), Department of Primary Industries (NSW), Charles Sturt University, Monash University, University of Adelaide, University of Melbourne, University of Western Australia, University of Western Sydney
- **Support role:** Australian National University, Charles Darwin University, Cotton Research and Development Corporation, Dairy Australia, Department of Agriculture, Fisheries and Forestry (Qld), Department of Science, Information Technology, Innovation and the Arts (Qld), Grape and Wine Research and Development Corporation, La Trobe University, Meat & Livestock Australia, Queensland University of Technology, South Australian Research and Development Institute, Southern Cross University, University of New England, University of Queensland, University of Southern Queensland, University of Sydney, University of Tasmania, University of South Australia.
- **Link role:** Department of Agriculture, Department of Environment, Water and Natural Resources (SA), Department of Primary Industries, Parks, Water and Environment (Tas.), Grains Research and Development Corporation, Horticulture Australia, Office of Environment and Heritage (NSW), Department of Natural Resources and Mines (Qld), Certified Professional Soil Scientist.

Land capability and soil degradation

- **Major role:** CSIRO, Department of Science, Information Technology, Innovation and the Arts (Qld), Grains Research and Development Corporation, Monash University, Department of Agriculture and Food (WA).
- **Support role:** Australian National University, Charles Sturt University, Cotton Research and Development Corporation, Department of Environment, Department of Environment and Primary Industries (Vic.), Department of Primary Industries, Parks, Water and Environment (Tas.), Meat & Livestock Australia, Office of Environment and Heritage (NSW), Queensland University of Technology, University of Queensland, University of Southern Queensland, University of Sydney, University of South Australia, University of Western Australia, University of Western Sydney.
- **Link role:** Charles Darwin University, Dairy Australia, Department of Agriculture, Department of Environment, Water and Natural Resources (SA), Department of Land Resource Management (NT), Department of Primary Industries (NSW), Forest and Wood Products Australia, Geoscience Australia, Horticulture Australia, University of Tasmania, Certified Professional Soil Scientist, Department of Natural Resources and Mines (Qld).

Soil and land inventory and monitoring

- **Major role:** CSIRO, Department of Agriculture, Department of Environment and Primary Industries (Vic.), Office of Environment and Heritage (NSW), University of Adelaide, University of Sydney, Department of Agriculture and Food (WA), Department of Science, Information Technology, Innovation and the Arts (Qld).
- **Support role:** Charles Sturt University, Department of Land Resource Management (NT), Department of Primary Industries, Parks, Water and Environment (Tas.), Meat & Livestock Australia, Monash University, Queensland University of Technology, University of South Australia, University of Western Australia, University of Western Sydney, Department of Environment, Water and Natural Resources (SA).
- **Link role:** Dairy Australia, Forest and Wood Products Australia, Geoscience Australia, Department of Primary Industries (NSW), University of Southern Queensland, University of Tasmania, Certified Professional Soil Scientist, Department of Natural Resources and Mines (Qld).

Soil biology

- **Major role:** CSIRO, Department of Environment and Primary Industries (Vic.), Grains Research and Development Corporation, South Australian Research and Development Institute, University of Adelaide, University of New England, University of Western Australia, University of Western Sydney, University of Melbourne.
- **Support role:** Australian National University, Charles Sturt University, Cotton Research and Development Corporation, Department of Agriculture, Fisheries and Forestry (Qld), Department of Primary Industries (NSW), Grape and Wine Research and Development Corporation, Meat & Livestock Australia, Monash University, Queensland University of Technology, Southern Cross University, University of Sydney, University of Queensland, University of South Australia, La Trobe University.
- **Link role:** Dairy Australia, Department of Agriculture, Department of Agriculture and Food (WA), Horticulture Australia, Office of Environment and Heritage (NSW), University of Southern Queensland, University of Tasmania, Certified Professional Soil Scientist.

Soil carbon sequestration

- **Major role:** Australian National University, CSIRO, Department of Agriculture, Department of Primary Industries (NSW), Department of Science, Information Technology, Innovation and the Arts (Qld), Monash University, Queensland University of Technology, Southern Cross University, University of Adelaide, University of Melbourne, University of New England, University of Western Australia, University of Sydney, University of Western Sydney, Department of Agriculture.
- **Support role:** Charles Darwin University, Charles Sturt University, Cotton Research and Development Corporation, Department of Agriculture and Food (WA), Department of Agriculture, Fisheries and Forestry (Qld), Department of Environment and Primary Industries (Vic.), Office of Environment and Heritage (NSW), University of Tasmania, Certified Professional Soil Scientist, University of South Australia.

- **Link role:** Department of Environment, Water and Natural Resources (SA), Department of Land Resource Management (NT), Department of Primary Industries, Parks, Water and Environment (Tas.), Grains Research and Development Corporation, Horticulture Australia, Meat & Livestock Australia, University of Southern Queensland, Certified Professional Soil Scientist.

Soil chemistry

- **Major role:** CSIRO, Department of Environment and Primary Industries (Vic.), Department of Primary Industries (NSW), Grains Research and Development Corporation, La Trobe University, Monash University, Southern Cross University, University of Adelaide, University of Melbourne, University of New England, University of South Australia, University of Southern Queensland, University of Queensland, University of Sydney, Department of Science, Information Technology, Innovation and the Arts (Qld).
- **Support role:** Australian National University, Charles Sturt University, Cotton Research and Development Corporation, Meat & Livestock Australia, Queensland University of Technology, South Australian Research and Development Institute, Department of Agriculture and Food (WA), University of Western Australia, University of Western Sydney.
- **Link role:** Dairy Australia, Department of Agriculture, Department of Land Resource Management (NT), Forest and Wood Products Australia, Geoscience Australia, University of Tasmania, Certified Professional Soil Scientist, Grape and Wine Research and Development Corporation.

Soil physics

- **Major role:** CSIRO, Grains Research and Development Corporation, University of Adelaide, University of New England, University of Southern Queensland, University of Sydney.
- **Support role:** Charles Sturt University, Cotton Research and Development Corporation, Department of Agriculture, Fisheries and Forestry (Qld), Department of Environment and Primary Industries (Vic.), Department of Primary Industries (NSW), Queensland University of Technology, University of Western Australia, vUniversity of Tasmania, University of Western Sydney.
- **Link role:** Department of Agriculture, Department of Agriculture and Food (WA), Department of Land Resource Management (NT), Forest and Wood Products Australia, Geoscience Australia, South Australian Research and Development Institute, University of Melbourne, Certified Professional Soil Scientist, Dairy Australia, Department of Science, Information Technology, Innovation and the Arts (Qld).

Other soil sciences

- **Major role:** University of South Australia.
- **Support role:** Monash University, Department of Agriculture and Food (WA).
- **Link role:** Certified Professional Soil Scientist.

Appendix B: National Soil Research, Development and Extension Strategy Reference Group and other contributors

CHAIR: Mr Ian Thompson, Department of Agriculture

Member	Organisation
Mr Ian Thompson	Department of Agriculture
Dr Martin Blumenthal	Grains Research and Development Corporation
Dr Michael Crawford	Department of Environment and Primary Industries, Victoria
Dr Hamish Cresswell	CSIRO Land and Water
Mrs DeAnne Ferrier	Birchip Cropping Group
Mr Jason Hill (replacing Dr Samantha Fox)	Department of Land Resource Management, Northern Territory
Dr Ian Hollingsworth	Horizon Environmental, Soil Survey and Evaluation, Soil Science Australia and Certified Professional Soil Scientist Representative
Dr Georgina Kelly (replacing Dr Peter Slavich)	Department of Primary Industries, New South Wales
Dr Paul Lawrence	Department of Science, Information Technology, Innovation and the Arts, Queensland
Dr Terry Longhurst (replacing Dr Felice Driver)	Meat & Livestock Australia
Professor Simon Maddocks	South Australian Research and Development Institute
Professor Alex McBratney	University of Sydney
Dr Matthew McNee	Western Australian No-Tillage Farmers Association
Mr Noel Schoknecht	Department of Agriculture and Food, Western Australia
Mr Peter Voller	Department of Primary Industries, Parks, Water and Environment, Tasmania
Mr Allan Williams	Cotton Research and Development Corporation
Professor Iain Young	University of New England, Australian Council of Deans of Agriculture
Development Team	
Dr Michele Barson	Department of Agriculture
Dr Martin Blumenthal	Grains Research and Development Corporation
Dr Michael Crawford	Department of Environment and Primary Industries
Dr Hamish Cresswell	CSIRO Land and Water
Dr Georgina Kelly (from July 2013)	NSW Department of Primary Industries
Strategy consultant	
Dr Phil Price	Mackellar Consulting Group P/L
Strategy secretariat	
Ms Caroline Wardrop	Department of Agriculture
Dr Adrienne Ryan	Department of Agriculture

Note: Some reference group members are also members of Soil Science Australia

APPENDIX C: Users of soil information and knowledge

User groups	Key stakeholders	Soil information used or sought	How soil information is used	Current sources of soil information
Broadacre dryland farmers: croppers and those with sown pastures	Farmers Farmer groups Industry bodies Farm consultants Rural R&D corporations and statutory authorities Agribusiness Other service providers Individuals	• soil types and suitability for particular uses at farm or paddock scale • depth, texture, PAWC at harvest and sowing • nutrient levels (N, P, K, S and micronutrients) • presence and level of disease organisms • constraints to production such as compaction, salinity (transient and dryland), sodicity, low or high pH, presence of toxic elements, difficult textures, acid sulfate soils • presence and abundance of beneficial and detrimental macro and micro soil biota	• plan cropping or pasture renewal strategies and programs matched to farm or paddock land capability • estimate yield probabilities based on plant available water at sowing and seasonal conditions • assist in sowing decisions, varieties used and levels of inputs (especially nutrients) • improve in-season agronomic decisions and use of inputs • underpin precision agriculture including variable rate technology • plan and monitor soil improvement programs • compare local and regional production and financial performance • value land and property	• general knowledge of regional soils from survey data and experience • personal on-farm experience managing individual paddocks • on-farm measurements undertaken in person or by specialist service provider, often using precision agriculture technology, farm records • data from soil or plant testing services, including fertiliser suppliers • soil properties inferred from yield maps, normalised difference vegetation index imagery or other spatial datasets, including water and nitrogen use efficiency • provided by farm consultant or agronomist, grower group or other agribusiness

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APPENDIX C: Users of soil information and knowledge Continued

User groups	Key stakeholders	Soil information used or sought	How soil information is used	Current sources of soil information
Tree plantation managers: forestry and horticultural crops, private and public	Project designers Project managers Individual farmers Farmer/forestry groups Industry bodies Farm consultants Rural R&D corporations and statutory authorities Agribusiness Other service providers	• soil types and suitability for particular plantation crops • depth, texture, plant available water capacity and nutrient levels (N, P, K, S and micronutrients) • presence of disease organisms • constraints to production such as compaction, salinity (transient and dryland), sodicity, low or high pH, presence of toxic elements, difficult textures, acid sulfate soils • presence and abundance of beneficial and detrimental macro and micro soil biota	• ensure land capability meets long-term plantation crop or short-term horticultural crop requirements • assist decisions about soil treatment, including input levels (especially nutrients) before crop/pasture establishment • improve in-season agronomic decisions and use of inputs • underpin precision agriculture including variable rate technology • plan and monitor soil improvement programs, including subsequent crop rotations • identify sites where risk of soil degradation (for example, hillslope erosion in forestry plantations) is high and manage sites to minimise risk • compare local and regional production and financial performance	• general knowledge of regional soils from survey data and experience • on-site measurements undertaken in person or by specialist service provider, often using precision agriculture technology • data from soil or plant testing services, including fertiliser suppliers • provided by farm/plantation consultant or agronomist or other agribusiness • spatial information through remote sensing—for example, MODIS and LiDAR

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APPENDIX C: Users of soil information and knowledge Continued

User groups	Key stakeholders	Soil information used or sought	How soil information is used	Current sources of soil information
Growers undertaking irrigated production of food or fibre, including many horticultural crops	Individual farmers Farmer groups Industry bodies Farm consultants Rural R&D corporations and statutory authorities Agribusiness Other service providers	• soil types and suitability for irrigated production at farm or paddock scale • soil suitability for land forming, bed layout and intended types of irrigation (flood, furrow, spray or drip) • depth, texture, bulk density, infiltration and drainage characteristics, drained upper limit, crop lower limit, plant available water capacity, required leaching fraction • nutrient levels (N, P, K, S and micronutrients) • constraints to production such as compaction, salinity (transient and dryland), sodicity, low or high pH, presence of toxic elements, difficult textures, acid sulfate soils • presence and abundance of beneficial and detrimental macro and micro soil biota	• plan and establish efficient irrigation layout, including storages, channels and drains, bays and beds, slopes and row lengths • assist in sowing decisions based on plant available water, crop types, varieties and levels of inputs (especially nutrients) • improve in-season agronomic decisions and use of inputs • plan irrigation activities based on plant available water and (deep) drainage characteristics • underpin precision agriculture including variable rate technology • plan and monitor soil improvement programs • better management of soils at known risk of degradation or with inherent constraints to production • compare local and regional production and financial performance • value land and property	• general knowledge of regional soils from survey data and experience • detailed on-farm measurements undertaken in person or by specialist service provider, often using precision agriculture technology • data from soil or plant testing services, including fertiliser suppliers • soil properties inferred from yield maps, normalised difference vegetation index imagery and other spatial data, including water and nitrogen use efficiency • provided by farm consultant or agronomist, grower group or other agribusiness

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APPENDIX C: Users of soil information and knowledge Continued

User groups	Key stakeholders	Soil information used or sought	How soil information is used	Current sources of soil information
Rural consultants, farm and plantation agronomists, agribusiness and service providers, other private and public knowledge exchange (extension) staff, such as grower groups, Landcare groups	Grower groups Landcare and related groups Agribusiness and other service providers Industry bodies Rural R&D corporations and statutory authorities	• soil data that enables provision of contracted services to clients, including farm and site plans, land use/cropping strategies, data collection/collation/ interpretation and in-season agronomy • soil types and suitability for particular uses at farm or paddock scale • soil depth and water characteristics, plant available water and water capacity at harvest and sowing • nutrient levels (N, P, K, S and micronutrients) • presence and level of disease organisms • constraints to production such as compaction, salinity (transient and dryland), sodicity, low or high pH, presence of toxic elements, difficult textures, acid sulfate soils • presence and abundance of beneficial and detrimental macro and micro soil biota	• plan production strategies and programs matched to farm or paddock land capability • estimate yield probabilities and assist in sowing decisions on crop types, varieties and levels of inputs (especially nutrients) • improve in-season agronomic decisions and use of inputs • underpin precision agriculture including variable rate technology • plan and monitor soil improvement programs, provide advice to individuals or groups or plan and evaluate projects • compare local and regional production and financial performance	• general knowledge of regional soils from survey data and experience • organisational data collection and records • on-farm measurements undertaken in person or by specialist service provider, often using precision agriculture technology • data from soil or plant testing services, including fertiliser suppliers • farm records and soil properties inferred from yield maps, normalised difference vegetation index imagery or other spatial datasets, including water and nitrogen use efficiency

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APPENDIX C: Users of soil information and knowledge Continued

User groups	Key stakeholders	Soil information used or sought	How soil information is used	Current sources of soil information
Construction managers (roads, buildings, other infrastructure, underground cables or pipelines), mining and energy geologists and engineers	Individual businesses Service providers	• soil attributes that affect erosion, stability and load-bearing capacity or indicate source rocks, below-surface structures and past geomorphology • depth and texture, hydraulic properties, mineral composition, in situ age, erosivity • conductivity at different depths • salinity (transient and dryland), sodicity, low or high pH, presence of toxic elements, acid sulfate soils • geochemical and geotechnical data for soils at proposed development sites	• test soil suitability for construction or mining development and whether soil layers need to be ameliorated, removed or stockpiled • determine subsurface geology and potential for commercial minerals • plan remediation and/or rehabilitation following construction • test for actual or potential contamination • assess changes to soil composition related to mining or construction activities	• detailed on-site measurements undertaken in-house or by specialist service provider • remotely sensed data on geology and mineral composition (may be proprietary and not publicly available)
Catchment management bodies, local government	Catchment Management Authority/ Catchment management bodies Australian Local Government Association and local governments Natural resource management program managers	• mapped location of different soil types, their land use capabilities and condition • risk factors affecting soil loss, degradation and contamination • changes in key attributes affecting land use capabilities • depth, texture, plant available water capacity, nutrient levels, constraints to production such as compaction, salinity (transient and dryland), sodicity, low or high pH, presence of toxic elements, acid sulfate soils, contaminants	• plan land use and monitor effects of current land use and management • monitor and report on catchment health • prioritise type and location of catchment management objectives and programs	• general knowledge of regional soils from survey data and experience • organisational data collection and records, including repeat spatial measurements of key attributes • on-farm measurements and data from soil or plant testing services where available • spatial information through remote sensing, such as MODIS and LiDAR, used to infer soil properties

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APPENDIX C: Users of soil information and knowledge Continued

User groups	Key stakeholders	Soil information used or sought	How soil information is used	Current sources of soil information
State, territory and Australian Government policy and program managers	Government departments and agencies	• broadscale maps of soil properties that affect land use capability and sustainable management • broader policy development such as policies for national food security and adaptation to climate change • functional properties to drive policy development—for example, potential for soil to store carbon	• develop, implement and evaluate land use guidelines • monitor effects of land use and management and develop rehabilitation strategies where required • provide scientific basis for policy development and for development and evaluation of rural assistance, sustainability and climate change mitigation and adaptation programs	• soil survey and land use and management data at regional scale, including repeat data to monitor change in soil condition and capabilities • spatial information through remote sensing, such as MODIS and LiDAR
Researchers, including universities, government and private research organisations (for example, fertiliser and chemical companies)	Research organisations and teams Rural R&D corporations and statutory authorities Government agencies CSIRO Universities Agribusiness	• soil types and suitability for particular uses for R&D, demonstration and knowledge exchange at farm or paddock scale • depth, texture, plant available water and water capacity at harvest and sowing • nutrient levels (N, P, K, S and micronutrients) • presence and level of disease organisms • constraints to production such as compaction, salinity (transient and dryland), sodicity, low or high pH, presence of toxic elements, difficult textures, acid sulfate soils • presence and abundance of beneficial and detrimental macro and micro soil biota	• identify sites suitable for basic, strategic and applied R&D, testing and demonstrations or for knowledge exchange activities • measure and evaluate changes in soil condition and attributes due to treatments applied	• general knowledge of regional soils from survey data and experience • farmers' personal experiences managing individual paddocks on the farm • on-farm measurements undertaken in person or by specialist service provider • data from soil or plant testing services, including fertiliser suppliers • soil properties inferred from yield maps, normalised difference vegetation index imagery or other spatial datasets, including water and nitrogen use efficiency • provided by farm consultant or agronomist, grower group or other agribusiness

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APPENDIX C: Users of soil information and knowledge Continued

User groups	Key stakeholders	Soil information used or sought	How soil information is used	Current sources of soil information
Financial institutions	Domestic banks Other lending institutions Agribusiness Farmers and farmer groups Industry bodies	• mapped location of different soil types, their land use capabilities and condition • risk factors affecting soil loss, degradation and contamination • changes in key attributes affecting land use capabilities • depth, texture, plant available water capacity, nutrient levels, constraints to production such as compaction, salinity (transient and dryland), sodicity, low or high pH, presence of toxic elements, acid sulfate soils, contaminants	• assess productive potential of individual properties to determine intrinsic capital value and underpin lending decisions • assess changes in property condition and capital value over time as part of loan management decisions	• general knowledge of regional soils from survey data and experience • organisational data collection and records, including repeat spatial measurements of key attributes • on-farm measurements and data from soil or plant testing services where available • spatial information through remote sensing, such as MODIS and LiDAR, to infer soil properties

Note: R&D Research and development.

Appendix D: Summary of consultation meeting discussions

Regional consultation workshops were held during 2013 in Bendigo (Victoria), Adelaide (South Australia), Toowoomba (Queensland), Northam (Western Australia) and Orange (New South Wales). The 108 participants were drawn from public, non-profit and private organisations: farmers, consultants and agronomists, grower group members and staff, catchment managers, soil research and knowledge exchange staff, agribusiness personnel, policymakers and planners, and people from other industries with an interest in soils—for example, road and urban construction.

A summary of the key issues raised at these workshops is presented in four categories: soil management issues (including where current information doesn't meet requirements), soil data and information, communication and extension and other issues.

Soil management issues

- Soil constraints
  - sodicity
  - salinity
  - acidity
  - acid sulfate
  - compaction
  - boron
  - magnesium
  - water holding capacity
  - nutrition
  - non-wetting
  - related to infrastructure and mining
- Managing farming systems
  - soil, nutrient, plant interactions
  - chemical, physical and biological interactions
  - limiting factors
  - resilience
  - revise recommendation for new farming systems (for example no-till)
- Pests and diseases
- Soil health = fit for purpose
- Water/soil interactions
  - efficiency
  - water cycling
  - water holding capacity/water retention
  - surface drainage
  - plant available water capacity and plant available water at sowing
- Nutrient management
  - efficiency
  - uptake by plants
  - nitrates
  - gases
  - leaching
  - bound
  - contribution to acidity
  - biological/chemical interactions
  - micronutrients
  - supply and demand down the soil profile
- Soil structure
  - influence on productivity
  - root zone management
  - compaction
- Perverse outcomes of management decisions
  - salinity
  - acidity
  - nutrient run-off
  - soil degradation
  - nutrient leaching
- Long-term trials
  - impact of change—positive/negative
  - different production methods
  - techniques
  - interventions
- Soil degradation
  - cause
  - rehabilitation
  - costs versus benefits, private versus public

- Impact of flood/natural disasters
  - degradation
  - compaction
  - nutrient loss/leaching
- Soil carbon and organic matter
  - impact on product
  - impact on climate change
  - mulch
  - biochar
- Soil biology
  - species—good/bad
  - functionality
  - impact on productivity positive/negative
  - interactions with chemistry
  - impact on soil structure
- Ameliorants
  - characteristics
  - mode of function
  - implications—positive/negative
  - cost versus benefit
- Soil/agronomy interactions
  - how roots function within the soil
  - how roots take up nutrients and water
  - how these interactions could be improved
- Analytical methods and techniques
  - rapid assessment
  - improved accuracy
  - improved efficiency
  - improved ease of use
- Chemicals
  - efficiency
  - impact on the environment
  - impact on soil fertility
- Organics
  - role of soil in organic farming systems

Soil data and information

- Soil mapping
  - What condition is our soil at the paddock, regional and national scales?
  - Why did we start mapping 50 years ago? Why did we stop 10 years ago?
  - Australian Soil Resource Information System and soil survey work carried out in the 1950s and 60s continue to be are invaluable but are landholders capable of using this information?
  - New technology—for example, digital soil mapping—is trying to use old data but information is not good enough
  - Maps created in North America are listed as a benchmark—what do they offer, how are they used and what does the information deliver?
  - What scale(s) is required by land managers and planners or for policy?
- Require capability and capacity to monitor, manage and forecast soil condition over time
  - At the farm scale—teaching farmers or their consultants to do this themselves
  - At a regional scale to inform land use planning?
  - At a national scale to inform land use, climate change, sustainability or food security policy
- Diagnostics, interpretation, provision of recommendations and subsequent monitoring must be conducted if soil testing is to deliver real, measurable benefits. Requires a level of skill by the farmer or the consultant. What is the knowledge base?
- What is the audience for a national program?
  - Geoscience Australia—mining
  - Bureau of Meteorology—water trading
  - Soil data is needed for land use planning, protection and management
- Current site data is not consistent or comprehensive—collection, testing and quality are variable. A need exists for consistent, national soil sampling and storage standards and guidelines
  - How should we collect a sample?
  - What is the minimum dataset?
  - What will inform the whole industry?
  - Validation across regions
  - Information in a standard form
  - Benchmarks across regions
  - Accreditation

  - Ethics
  - Knowledge of variances
- Enduring systems to link coordinate information
  - National cooperative soil assessment program
  - Information needs to be able to be interrogated
  - Do we have capability to record what we are doing and where it has been done (can we take advantage of the Atlas of Living Australia infrastructure?)
- Potential for crowd sourcing data but how to get it right?
  - What is the incentive for provision of private data?
  - How can we ensure accuracy and consistency of data?
  - Queensland Government is doing trials on capturing private data—explore this.
  - Could legislation be introduced to enforce collection of private data, as was done for water markets? What is the trigger? What is the public benefit?
- Farmers need information about their farm
- What information do data support tools require? For example, do they require yield maps?
- Is resolution and existing data good enough?
- Is there potential to improve tools? How could individual farm maps be fed into tools like Yield Prophet?

Communications and extension

- Why is information not hitting the ground?
  - Need for better sharing of research and capability, capacity and funding to support interpreting research
  - Feedback mechanisms—researcher to farmer to researcher and how to include policymakers?
- How do we move from anecdotal evidence to evidence underpinned by science?
  - Managing/avoiding snake oils
  - Evidence-based decisions, not emotive communications
- How do we package what we already know?
  - Relevance and potential financial benefit
  - Timeliness
  - Refresher
- Do we need to develop better tools?
  - Develop tools that help farmers interpret their soil data and information; understanding leads to uptake and change
  - Provide support to farmers so they gain the skills to use tools effectively
  - Provide more confidence to growers to make decisions to benefit next crop—nitrogen storage, availability, inputs, yield potential
  - Use new technology, facilitate interaction
  - Capture information across the country
- How should information be presented?
  - Understand the audience—choose the appropriate communication style
  - Understand the base level of knowledge before delivering information
  - Have options to address an issue/problem
  - Understand motivations and values of the audience
  - Take advantage of innovative farmers
  - Use hands-on training—for example, with own soil samples
- Is there a need to improve general soil science literacy?
  - Concern those disseminating the information do not have knowledge or access to scientists to improve flow of information
  - Is there a need for a better understanding of soil nomenclature?
  - Do our farmers/consultants have skills to match information (such as data and technology) to make the best management decision?
  - Do farmers understand that soil operates in a system, that it is a living organism?
- Are we making the right links between industries/organisations?
  - Rural R&D corporations and statutory authorities

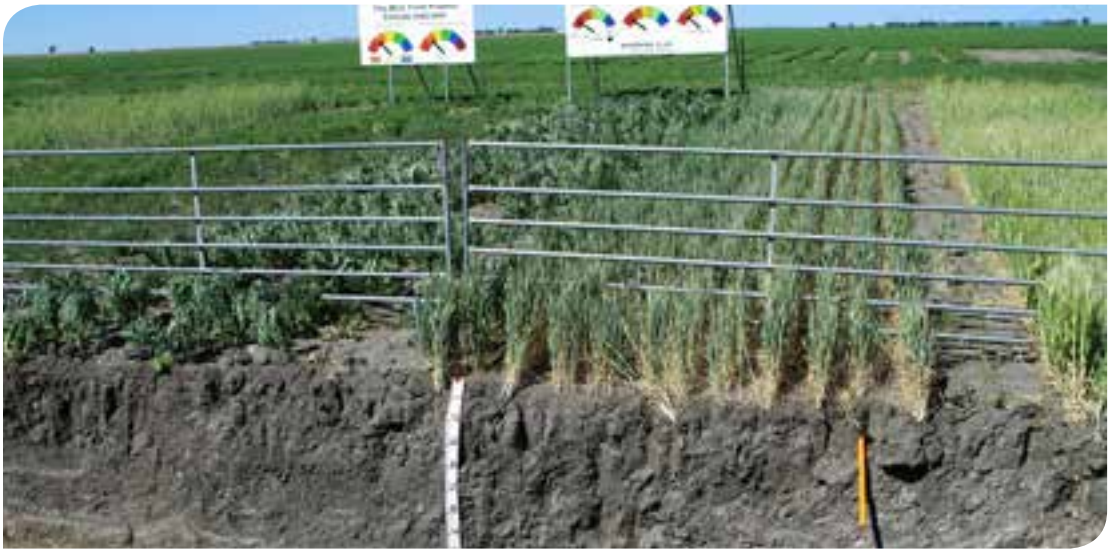
  - International organisations (Crawford Fund, Australian Government international aid programs, Australian Centre for International Agricultural Research, other)
  - Mining, infrastructure, planning
- How do we avoid reinventing the wheel?
  - Incorporate soil information into what is already being delivered by industry—for example, agronomy and grazing management
- Could we build a network of experts?
  - Networks are formed in an ad hoc manner; a credible source may be known and engaged by chance or word of mouth
  - Develop a list of available expertise so groups and organisations use experts more efficiently and effectively
- How do we improve the capture and sharing of information?
  - Must capture details on, for example, projects, trial sites and demonstration
  - Ensure information from these extension activities is available across the country
- Who will deliver extension services into the future?
  - A challenge across agriculture; what might the market provide?
  - Limited training available to teach people how to be good extension officers
- How can we get better sharing of ideas?
  - Disconnect between organic and conventional—how can knowledge be shared?
- Do we need better economic modelling to support science?
  - financially feasible options
  - understand implications if management intervention made/not made (this can also relate to environmental costs).

Other

- Education and training
  - Private consultants—do they have the training to understand complexity of soil management?
  - Infrastructure, mining and planning require education on soil chemistry and physics
  - Diagnostics—skills to match information (such as data and technology) to management decisions
  - Are our farmers skilled to make use of better information and data? Can they transform this into knowledge?
  - Growing level of interest by farm consultants in understanding how soil works—possible audience for professional masters or Soil Science Australia Certified Professional Soil Scientist program
  - What is the level of training? How can farmers and consultants gain quality education to improve their understanding of soil formally?
  - Improve farmers' and consultants' capacity to map soil and plan/action/make recommendations
  - Certified professional soil scientists and core competency test to gain accreditation.
- Have we moved too far toward applied research?
- Performance, value and management of soil asset vital
- Future planning/forecasting—what will be the issues in five, 10 or 20 years?
- Need to build capability and capacity for farmers to undertake large-scale, on-farm trials. Action on the Ground has been delivered in this way.

ACRONYMS AND ABBREVIATIONS

AGMIN	Agricultural Ministers Forum
AGSOC	Agriculture Senior Officials Committee
ANU	Australian National University
ASPAC	Australasian Soil and Plant Analysis Council
CDU	Charles Darwin University
CPSS	Certified Professional Soil Scientist
CRDC	Cotton Research and Development Corporation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSU	Charles Sturt University
DAFWA	Department of Agriculture and Food Western Australia
DEPI	Department of Environment and Primary Industries (Victoria)
DEWNR	Department of Environment, Water and Natural Resources (South Australia)
DLRM	Department of Land Resource Management (Northern Territory)
DPI	Department of Primary Industries (NSW)
DPIPWE	Department of Primary Industries, Parks, Water and Environment (Tasmania)
DSITIA	Department of Science, Information Technology, Innovation and the Arts (Queensland)
FWPA	Forest and Wood Products Australia
GA	Geoscience Australia
GRDC	Grains Research and Development Corporation
GWRDC	Grape and Wine Research and Development Corporation
HAL	Horticulture Australia Limited
LiDAR	Light detection and ranging
MLA	Meat & Livestock Australia
MODIS	Moderate resolution imaging spectroradiometer
NCST	National Committee on Soil and Terrain
OEH	Office of Environment and Heritage (NSW)
PAWC	Plant available water/capacity
PISC	Primary Industries Standing Committee
QUT	Queensland University of Technology
RMC	Resource Management Committee
SCU	Southern Cross University
UAdl	University of Adelaide
UMelb	University of Melbourne
UNE	University of New England
UniSA	University of South Australia
UQ	University of Queensland
USQ	University of Southern Queensland
USyd	University of Sydney
UTas	University of Tasmania
UWS	University of Western Sydney



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