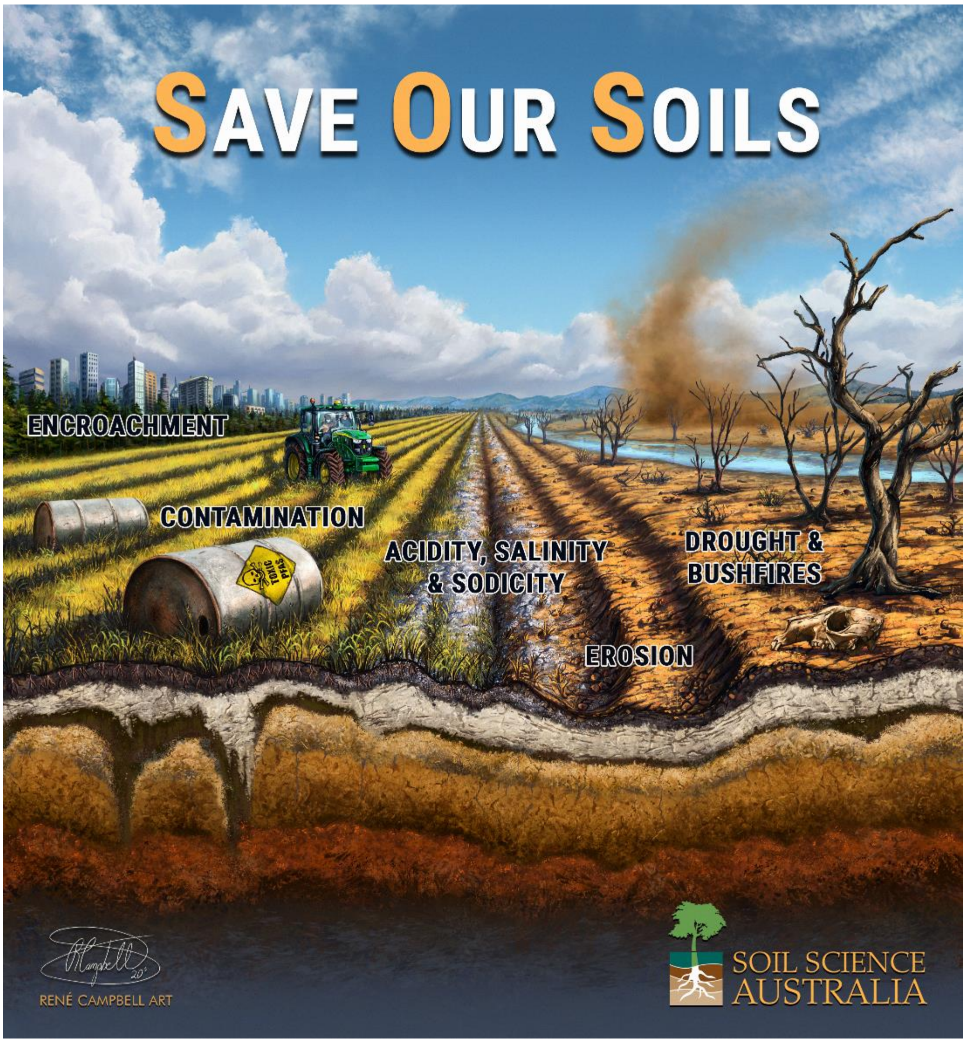

Released on World Soil Day - 5 December 2020

www.soilscienceaustralia.org.au

Soil Science Australia (2020). Save Our Soils – Supporting Document. Released on World Soil Day 5 Dec 2020. Soil Science Australia.

Enquiries should be addressed to:

Soil Science Australia Federal Office, email: office@soilscienceaustralia.org.au

VALUES AND SERVICES OF AUSTRALIAN SOILS

Soils are one of our most valuable resources in Australia, supporting our food, fibre, and water supplies. Soil underpins our agricultural production, directly contributing approximately $63 billion AUD per year to Australia's economy (Jackson et al. 2018). Soils are also an important resource for storing and filtering water. These characteristics sustain our natural environment, provide for society's needs such as for irrigation and stock watering, while also filtering contaminants from our water resources. Soil water storage also protects our towns and infrastructure by mitigating flooding.

Soil contains and directly supports the overwhelming majority of our terrestrial biodiversity, from microscopic organisms such as fungi and bacteria, to macroscopic organisms such as earthworms and wombats. These soil organisms play critical roles in important ecosystem processes including organic matter decomposition, nutrient cycling, enhancing plant nutrient uptake, carbon and nitrogen fixation from the atmosphere, and improving soil structure and aeration (Colloff 2011). Many of these ecosystem functions are vital to the long-term sustainable use of our soils.

Our soils are also critical in global climate change mitigation as Australia's soil stores large amounts of organic carbon, storing 3.5% of the total global stocks in the 0-30 cm layer (Viscarra Rossel et al. 2014). However, native vegetation clearance and poor soil management have, and continue to result in the loss of soil organic carbon and enhanced greenhouse gas emissions (Gray et al. 2019). Capturing and retaining carbon in soil (sequestration) helps mitigate climate change and also improves soil health and productivity. Soil carbon sequestration is an accredited method under Australia's Emissions Reduction Fund (ERF). Therefore, storing carbon in soil can also produce direct economic benefits in addition to the improvements to soil function. The ability of a soil to store significant stocks of carbon is typically associated with a moist climate, fertile clay-rich soils, and a higher vegetation cover (Gray et al. 2019).

When considering all the above soil functions and services, Australia's soils provide an estimated value of $930 billion AUD per year. This number is based on analysis of McBratney et al. (2017) who determined that soil provides an average value of $121,022 AUD per square kilometre per year. Hence, the value of soils far exceeds the value of the land itself which, while by far the most valuable Australian environmental asset (making up 90% of total assets), is valued at $5.8 billion AUD (ABS 2018).

Soils are threatened by a number of degradation issues that result in large direct costs, indirect costs, and lost economic opportunity. These are described further below.

THREATS TO AUSTRALIAN SOILS

URBAN AND INDUSTRIAL ENCROACHMENT ON OUR MOST FERTILE SOILS

Urban encroachment has occurred across Australia when population growth and land values in cities and regional centres puts pressure to develop surrounding peri-urban and rural regions. These areas frequently contain high value agricultural soils. Industrial encroachment has also occurred when land becomes more economically valuable for industrial uses compared to its current use (for example, coal mining) (Williams 2015). Areas that have been encroached by urban and industrial developments are often valuable in their current state or were previously deemed unsuitable for urban development. Valuable soils include those used for agriculture, ecosystem services, and conservation(NSW EPA 2015, Metcalfe and Bui 2017). The extent to which reduction in available farmland may impact food production depends on where the loss occurs (e.g. fertile areas or extensive pastoral areas), the availability and cost of inputs (e.g. water, nutrients, energy and labour) and the socio-economics of production (e.g. loss of communities, young people, skilled labour and markets)(Millar and Roots 2012).

Historically, Australian cities were established on soils suitable for food production and near reliable water supplies. Urban expansion into the peri-urban fringe has led to sealing over of these soils with impervious surfaces (e.g. roads, pavements). It appears unlikely that these high-quality soils will ever regain their previous biological function (State of the Environment 2011 Committee 2011, Metcalfe and Bui 2017). Urban developments also affect crop yield and water regimes (Campbell 2008). Pressure to sell also affects neighbouring agricultural landholders as new occupants in the expanded urban area put pressure on growers to change or cease farming practices that cause odour, noise or dust (Metcalfe and Bui 2017). Urban encroachment causes an iterative loss of strategically valuable agricultural lands in local government areas and is a significant challenge across most states and territories (State of the Environment 2011 Committee 2011, Metcalfe and Bui 2017). Although urban encroachment occurs nation-wide, its management falls to local councils and State governments through city boundaries and state development policies. Some states have introduced legislation to protect key soil agricultural areas from urban encroachment (e.g. *Character Preservation (Barossa Valley) and (McLaren Vale) Bills 2012* in South Australia), but this is not the case for many other regions. In addition to the agricultural benefits, preventing urban encroachment into peri-urban and rural areas also yields social benefits such as recreation, biodiversity, visual amenity, flood mitigation and other ecosystem services (Metcalfe and Bui 2017).

EROSION

Soil erosion is the removal of soil particles from one place to another via the movement of wind or water. It is a natural process that is greatly enhanced by human activities; this acceleration makes it one of the greatest threats to soil function globally as soil is a non-renewable resource (ITPS 2015, Metcalfe and Bui 2017). It is a particular concern in Australia where soil formation rates are well below the global average (Bui et al. 2010, Metcalfe and Bui 2017). The loss of topsoils and exposure of subsoils results in reduced agricultural productivity and native vegetation health (WA EPA 2007). Soil erosion can also undermine infrastructure, lead to sedimentation, and contaminate water supplies and aquatic ecosystems (WA EPA 2007). Severe erosion leads to a loss of soil functional capability. The loss of organic carbon and other nutrients due to wind and water erosion are significant causes of soil condition decline over time (Tozer and Leys 2013, NSW EPA 2015).

Globally, soil water erosion transports 23 to 42 million tonnes of N and 15 to 26 million tonnes of P off agricultural land, often causing eutrophication of waterways receiving nutrient rich sediments (ITPS 2015). Replacing these nutrients, primarily through fertiliser application, costs an estimated $33-60 billion USD for N and $77-$140 billion USD for P (ITPS 2015). In catchments flowing to the Great Barrier Reef, the waters contain five times as much sediment, two times as much nitrogen and three times as much phosphorus compared to pre-development conditions (Waterhouse et al. 2017). In addition, the 2015 rate of crop yield losses per annum due to soil erosion was 0.3% (more than 10 million hectares per year). At this current rate it is predicted that a 10% loss of potential crop yield will occur by 2050 (NCST 2013, ITPS 2015). The cost of soil erosion within Australia is difficult to quantify but is undoubtedly substantial, particularly as up to 10 million hectares of land have less than 500 years until the A horizon, which is the topsoil of a soil profile and generally the most productive and valuable layer, will be lost (WA EPA 2007, Bui et al. 2010, Metcalfe and Bui 2017, Waterhouse et al. 2017). The cost of dust storms in New South Wales alone is estimated to be $9 million AUD per year (Tozer and Leys 2013).

Soil erosion can be prevented by maintaining adequate groundcover, protecting soil from particle detachment and transport. Climatic variation is a major concern for erosion management because erosion risk is determined by climate and vegetation interactions. Drought, climate change, fire and severe weather events all contribute to increased erosion risk (Metcalfe and Bui 2017, WA DAF 2017, VIC EPA 2018). Conservation agricultural practices are a key preventative measure for soil erosion, and are increasing in Australia (Metcalfe and Bui 2017); however, adoption rates are low or have decreased in some key Murray-Darling Basin catchments (Metcalfe and Bui 2017). Therefore, current rates of soil erosion by water across much of Australia continues to exceed soil formation rates despite the improving trend in erosion management through improved land management practices (ITPS 2015, Metcalfe and Bui 2017).

Strategies to prevent erosion often present an opportunity to improve soil condition and therefore, soil sustainability. Promoting vegetation leads to an increase in soil organic matter, which can improve soil structure and therefore soil nutrient content and water holding capacity. A significant challenge facing erosion prevention, however, is the scale at which most prevention activities occur, This is because most prevention takes place at the landholder scale. Social and economic pressures on landholders can prevent the activities that might lead to effective erosion prevention. Another major challenge and risk for Australia is that longer dry spells due to global climate change is likely to increase the frequency of dust storm events, including in autumn-winter which are historically considered low risk seasons (Speer 2013).

ACIDIFICATION

Acidic soils occur naturally in some areas but human activities have accelerated soil acidification which is having negative consequences on agricultural production in many regions. Soil acidification affects about half of Australia's agricultural soils (c. 50 million hectares), mostly in Western Australia and New South Wales (Metcalfe and Bui 2017). In the Western Australian wheatbelt alone, between 8 and 27 million hectares are estimated to have been affected by moderate to severe soil acidity in 2001; this area is likely to have expanded (WA EPA 2007). Acidification is accompanied by major yield decreases; productivity losses in South Australia and Victoria due to acidity and acidification have been estimated at $88 and $470 million AUD per year, respectively (DEW 2018, VIC EPA 2018). This is driven by nutrient deficiencies and toxicities, changed soil biology, and accelerated nutrient leaching (Metcalfe and Bui 2017).

Agricultural acidification is caused by adding acidifying fertilizers (such as some nitrogen fertilisers) and removing alkalinity (through removing plant products or leaching). Other localised acidification can be caused by sulfide oxidation, acid deposition from industrial pollutants, and land contamination. Because the addition and leaching of nitrogen fertilisers are associated with acidification, acidification risk increases when land use changes from low nitrogen inputs to high nitrogen inputs (Eugenio et al. 2018, VIC EPA 2018). An example of this land use change is the conversion of unimproved pasture into cropping, or cropping into intensive horticulture.

Treatment of surface acidity is relatively simple in practise, although it can be expensive, and usually involves spreading or incorporating crushed limestone, or dolomite to the surface soil. Subsoil acidity is significantly more difficult and expensive to remediate and lime movement is slow when applied to surface soil. Unfortunately, liming is not occurring at a rate that will prevent further acidification (Metcalfe and Bui 2017, VIC EPA 2018). The lost opportunity in Australia associated with soil acidity for wheat production is estimated to be worth A$400 million per annum (Orton et al. 2018). As always, prevention is generally less expensive than remediation and can be achieved to an extent by managing the type, rate, and timing of fertilizers and irrigation (WA EPA 2007). Precision agriculture provides an opportunity to reduce soil acidification through improved fertiliser regimes, and also to improve the management of acidity through variable rate liming (VIC EPA 2018).

SALINISATION AND SODIFICATION

Salinisation is the accumulation of salts whereas sodification is an accumulation of sodium on cation exchange sites leading to structural decline (i.e. dispersion). Soil salinisation occurs when i) salt stored deep in the soil profile is drawn towards the surface into topsoils and subsoil by the movement of water (dryland salinity), ii) land is irrigated with saline water (irrigated salinity), or iii)f excessive amounts of fertiliser is applied (Eugenio et al. 2018). Irrigation-driven salinity is a particular issue for areas with poor drainage conditions which prevent salt removal from the profile (WA EPA 2007, ITPS 2015). Soil salinisation can negatively affect plants/crops via osmotic stress leading to a reduction of plant water intake (Rengasamy 2016).

Sodic soils can also have negative effects on plant growth as these soils disperse when salinity water (such as rainfall) is added to these soils, and hard set when dry. Dispersion is the breakdown of soil aggregates, causing individual clay particles to disperse into the soil water and surface water. Clay particles then block soil pores, leading to poor infiltration and aeration, waterlogging when wet and hardsetting when dry. Due to their poor hydraulic and structural properties, sodic soils are vulnerable to water erosion via gullying (Wong et al. 2010, Rengasamy 2016) and those gullies with sodic subsoils are particularly difficult to stabilise.

The movement of salt into the root zone in areas affected by dryland salinity is driven by rising water tables. This is often caused by a change in the vegetation from deep-rooted perennial species to shallow rooted annual species. This land use change allows groundwater to rise close to the surface (approx. 1.5 m depth), before capillary action and evaporation draws the water and associated saltto the soil surface (Rengasamy 2016). It may be several decades before this process is detected and local geology, topography and groundwater aquifer characteristics also play an important role in the interactions with rising groundwater (WA EPA 2007). The loss of deep rooted perennial species continues in Australia through both natural (fire, drought) and human induced pathways (disease, urban development, native vegetation clearing), furthering the spread of salinisation into susceptible areas (WA EPA 2007, Rengasamy 2016). Although drought decreases the number of deep rooted perennial plants, it can also have a positive effect on salinisation rates by decreasing groundwater recharge (WA EPA 2007, Campbell 2008).

Salinisation and sodification are widespread issues in Australia. Although no accurate and recent statistics are available, it is estimated that about 16% of Australia's total cropping area is affected by dryland salinity.This area is expected to increase from 5.7 million hectares to 17 million hectares by 2050 (ITPS 2015, Rengasamy 2016, Metcalfe and Bui 2017). Approximately 75% of areas affected by dryland salinity in Australia occurs in Western Australia. This includes about 1.1 million hectares of land in South West Western Australia and over 14,000 hectares of land is lost to land salinisation (WA EPA 2007). About 40% of the Swan Coastal Plain (Western Australia) is at risk of salinisation (WA EPA 2007). The extent of soil salinisation in Victoria is currently unknown as it has not been mapped since the Millennium Drought (VIC EPA 2018). Although there are no recent estimates, it was estimated that salinity costs to water, infrastructure and agricultural land within the Murray-Darling Basin were $305 million AUD per year (Campbell 2008). The lost opportunity associated with soil sodicity and salinity for wheat production is estimated to be worth A$1,300 million and A$200 million per annum respectively (Orton et al. 2018).

CONTAMINATION

Soil contamination occurs when a pollutant is present at higher than background concentrations and is causing, or has the potential to cause, adverse effects on society or the environment (WA EPA 2007, ITPS 2015). These contaminants may adhere to soil particles, air or water and their transport can lead to both on-site and offsite issues (WA EPA 2007). The effects of soil contamination depend on soil properties such as clay content, organic matter content and pH, as these properties control their mobility, bioavailability, and residence time (Eugenio et al. 2018). Severe contamination degrades the ecosystem services provided by soil and reduces agricultural production capacity by limiting the end market opportunities of contaminated produce (Eugenio et al. 2018).

Contaminated sites are usually associated with past industrial or agricultural land uses where inadequate action was taken to prevent contamination (WA EPA 2007). The discovery of contaminated land in or near residential areas causes significant community concern and distress (WA EPA 2007). For example, per-and poly-fluoroalkyl substances (PFAS) have been receiving increasing attention due to their discovery in a number of sites slated for development of large infrastructure projects (VIC EPA 2018). Severe contamination can render land uninhabitable and significantly constrain land use options over the mid to long term (WA EPA 2007, ITPS 2015). As such, the economic costs of contaminated land generally outweigh the costs of remediation. Furthermore, rural sites can prove more difficult to remediate without external support due to their low land values (WA EPA 2007, NSW EPA 2015). Even though legacy sites continue to exist, managing soil contamination is improving in Australia due to improved regulation and remediation of contamination producing activities and contaminated sites (ITPS 2015).

Unfortunately, soil contamination continues to occur and actions that landholders take to improve one aspect of their business can have negative effects on other aspects. For example, pesticide and herbicide use is increasing in production systems, particularly in association with the adoption of no-till and minimum-till cropping (WA EPA 2007). These contaminants can cause significant public concerns (ITPS 2015). Increased soil contamination puts food safety and food security at risk. Agricultural contaminants usually involve build-up, leaching or transport of agricultural chemicals, including fertilisers (WA EPA 2007). Accidental release of contaminants also occurs, often due to inappropriate storage, transport, or handling while deliberate dumping of wastes due to economic pressures are also sources of environmental contamination (WA EPA 2007). Inappropriate mine management or closure is frequently associated with contamination of soil and water. These sites are likely to remain unsuitable for other uses without extensive rehabilitation (WA EPA 2007, ITPS 2015). Contamination of land and water resources, regardless of intent, often causes conflict between the landholders affected (Fergusson 2017, Metcalfe and Bui 2017).

CLIMATE CHANGE, DROUGHT AND BUSHFIRES

The combination of Australia's climate, landscape and soils mean that only about 10% of the land is suitable for crops and improved pasture (Orton et al. 2018). Australia is also vulnerable to climate change, and in particular to changes in rainfall. Rainfall is projected to decline in southern Australia where a large proportion of our agricultural areas are located (DAFF 2014). Small decreases in rainfall can be exacerbated by increased evaporation rates and increasing aridity can also reduce soil structural stability and increase salt accumulation (DAFF 2014, Rengasamy 2016). As such, improving water use efficiency and increasing sustainable use of Australia's soil are key requirements for climate change adaptation (DAFF 2014). Soil management itself also contributes to climate change as poor soil management potentially releases large greenhouse gas emissions whereas conservation soil management can prevent the release or sequester carbon (Campbell 2008).

Climate change will exacerbate existing pressures and impacts. These pressures include shorter growing seasons, increased heat stress, increase in the frequency and magnitude of extreme events, and a decrease in water availability (Burdon et al. 2017, Metcalfe and Bui 2017). Exacerbating existing pressures is likely to lead to an increase in soil degradation from processes such as erosion (both wind and water), salinisation and sodification from irrigation waters, and organic matter breakdown. It is likely that some production systems will become economically unviable in some regions as climate change is likely to reduce the global production of key commodities. Australia is projected to be one of the most adversely affected countries due to climate change and may suffer declines of up to 79% in export commodities by 2050 (Campbell 2008).

Climate change adaptation will be vital for the sustainable management of Australia's soil resources as it increases the risk of carbon losses, erosion, and desertification, salinisation, and natural disasters such as severe droughts and floods (Campbell 2008, ITPS 2015). The frequency and severity of droughts is increasing in many parts of Australia due to climate change. Soil in wetlands and peatlands will be particularly affected by droughts via issues such as drying, compaction, salinisation, sodification, and acidification (Stirling et al. 2020). In addition, increasing energy costs will affect landholder management options (Campbell 2008). Climate change effects are disproportionately felt by large landholders and low socio-economic groups, further affecting landholder capacity to address changing conditions (Metcalfe and Bui 2017).

The unprecedented bushfires in late 2019 to early 2020 also had major impacts on soils in large areas of south-eastern Australia (Soil Science Australia 2020, Australian Academy of Sciences 2020).

OPPORTUNITIES

CARBON SEQUESTRATION TO MITIGATE CLIMATE CHANGE

Agriculture is a significant greenhouse gas (GHG) emissions sector in the Australian economy, releasing 13.1% of Australia's GHG emissions during the last accounting quarter (DEE 2018b). However, GHG emissions from agriculture have decreased slightly since 1990, with most of the change driven by livestock management (DEE 2018b). While Australia has a framework for carbon sequestration in agricultural systems via the Emissions Reduction Fund (ERF) method for 'measurement of soil carbon sequestration in agricultural systems' (Commonwealth of Australia 2013, DEE 2018a), few projects have successfully enacted this method due to a number of economic and administrative constraints (Burke 2016).

Australia also has a number of physical constraints to soil carbon sequestration. Many Australian soils have naturally low carbon contents (i.e. arid soils) or are often water limited (Minasny et al. 2017, Gray et al. 2019) which limits organic carbon accumulation. The largest losses of soil carbon due to agricultural management have occurred under conventional cropping with stubble burning, with >50% of carbon lost in the top 10 cm (Luo et al. 2010). This is similar to the global average of almost half of the soil carbon lost due to agricultural activities (Paustian et al. 2000). There is an opportunity, therefore, for substantial sequestration of carbon emissions through global agricultural best practice and a small opportunity for increased soil carbon sequestration in Australian agricultural areas.

Recently the Commonwealth Government has announced soil carbon as a priority low emissions technology along with the goal to reduce soil carbon measurement costs to less than $3 per hectare (DISER 2020). The increased focus and investment by government in this area is welcomed and should stimulate a large amount of opportunities in this area.

SOIL SUSTAINABILITY AND SECURITY

Soil is a non-renewable resource and needs to be managed in a sustainable manner (Bui et al. 2010). As such, soil sustainability should be focused on the management and conservation of the natural resource base, and the orientation of technological and institutional change to ensure continued satisfaction of human needs for present and future generations (United Nations 1998). Sustainable management is difficult, however, if human activities place substantial demands on soil resilience, often leading to a decline in soil function and productivity over time (e.g. from poor agricultural practises) (Bennett and Cattle 2013). There are a number of soil characteristics that indicate soil condition, such as (Metcalfe and Bui 2017):

- organic carbon and nutrient content,
- pH and acidification trends,
- soil structure and porosity,
- topsoil thickness, and
- salinity.

Historically, poor soils management has led to significant losses in soil carbon, nutrients and organic matter and subsequent declines in soil structure, and increased acidity and salinity (Bui et al. 2010, Metcalfe and Bui 2017). The prevention of soil degradation is therefore, an important land management goal to ensure soil sustainability (Bui et al. 2010).

Sustainable land management can only occur when the land's capability is understood and managed within that capability (NSW EPA 2015). However, our understanding of soils continues to be patchy even though soils and their interactions underpin our agricultural and horticultural production systems (Burdon et al. 2017). While appropriate land management is vital for the sustainable use of soils, economic pressures can drive landholders into unsustainable production habits or prevent landholders from choosing more sustainable methods (NSW EPA 2015). These economic conflicts occur because systems that maximise yearly income are often not the same systems that maximise soil longevity (Bennett and Cattle 2013). Therefore, sustainable soil management requires approaches where long term soil condition is a core consideration (Campbell 2008).

A vital component of sustainable soil management and agricultural best practice is the availability of accurate and relevant soil information for landholders. In addition to the data generated by industry, research and the government, landholders themselves generate data during their activities. Soil information is primarily in the form of geographical information systems (i.e. spatial data and mapping) and is hosted amongst a large number of agencies, often in an inaccessible format which prevents efficient access and collaboration of interested parties. An important gap in Australia's data infrastructure is that a single entity for the collection and curation of soils data does not exist.

Rather than a single-dimensional land assessment approach, such as land capability mapping of soil and landscape biophysical features, the Soil Security concept includes consideration of other allied soil facets, including societal connections, education, policy, legislation, current land use, condition, and the economic and environmental value of our soils (McBratney et al. 2014, Soil Science Australia 2018). Soil Security does not simply identify discrete soils, rather, quantifies additional factors which could result in soil becoming unsustainable, or not secure. In quantifying this, it provides a framework for realising the potential for improved productivity, function, and ecosystem services. In this way, Soil Security is a broader concept than soil health, condition or quality.

Our food production in Australia is underpinned by the soil resource. Food exports are a significant sector in the Australian economy and indefinitely producing national and global food supplies will only be possible in agricultural systems that are managed sustainably (Orton et al. 2018). In this sector, industry driven sustainability goals are potentially an important driver in improving soil sustainability (VIC EPA 2018). However, it is important to realise that land that cannot be managed sustainably while being economically viable indicates that that land use is unsuitable for the capabilities of the site (Campbell 2008). Although both industry and individual landholders are responsible for enacting sustainability measures, governments also have a responsibility to support sustainable management through the provision of soil resources, community awareness, professional support, incentives, investment, and extension (Campbell 2008). Governments also have a responsibility to discourage unsustainable management by preventing inappropriate projects, and by maintaining regulations and compliance capabilities (Campbell 2008). The Soil Security principles and framework provide a good opportunity to do this in an integrated way.

PRIORITIES FOR ACTION

The recommendations below are drawn from the Soil Science Australia 2019 Expert Panel Survey. This survey was administered by Soil Science Australia and included 48 responses from 75 invited members wherein members were chosen to reflect a range of career histories and progress. The recommendations were reviewed in 2020 following substantial progress in addressing several of the recommended actions.

ADOPT A NATIONAL INTEGRATED APPROACH TO SOIL MANAGEMENT

National level strategic planning:

- Continued development, consultation and subsequent adoption of the National Soils Strategy by all State and Territory Governments.
- Implement the National Soils Strategy including creation of a publicly funded entity (e.g. a National Soils Bureau) with the aim to improve conservation, monitoring, management and the productive capacity of Australia's soils in an integrated manner across Government and Industry sectors.
- Integrate environmental and agricultural priorities in all landscape decision-making processes.

- Develop long term strategies for achieving national soil security.

INCREASE INVESTMENT, ADVOCACY AND COMMUNICATION ON SOILS

Increase investment in soils research, development and extension (RD&E):

- Increase the priority and certainty of current soil research funding initiatives.
- Increase investment in soils research - soil is a national research priority but currently receives on average <$1.3million total Australian Research Council funding per year.
- Invest in Soil Science Australia training and capacity building programs.
- Increase research into the effects of climate change, drought and bushfires on soils.
- Improve support resourcing for preventative actions against soil degradation.
- Improve resourcing and infrastructure for contamination management and remediation.

Improve dialogue between landholders, industry, government, education and research:

- Improve collaborations between research and other stakeholders.
- Improve strategic planning between government and other stakeholders.
- Improve engagement with already developed soil policies.
- Develop improved tools to deliver soils information to stakeholders to meet their needs.
- Encourage realistic expectations of land capability; support landholder actions to change land use to align with those expectations.
- Encourage consumer cultural change to better align with sustainable soil systems.

Improve extension on the value of soils and soil conservation:

- Provide support for preventative measures against soil degradation.
- Provide support for mitigating actions and adaptation for climate change, including soil carbon sequestration.
- Develop and release community fact sheets on soil issues, solutions, and opportunities. Raise public awareness of the value of soils.

IMPROVE SOIL INFORMATION SYSTEMS TO SUPPORT SUSTAINABLE LAND MANAGEMENT

National Soil Information Framework:

- Continue to scope and refine the business case for the development of a National Soils Information Framework to enable they nationally integrated production, storage, and communication of soils data and information.
- Invest in and implement the NSIS.
- Facilitate improved data sharing and communication between the States and Territories
- Increase community soils awareness.
- Provide opportunities for open access soil data
- Establish a National Soil Monitoring Network with long term monitoring sites to accurately measure changes in soil condition over time

Agricultural best management practise:

- Improve farming systems management to prevent soil degradation (e.g. including strategically locating agriculture, stock management, preserving soil organic matter, preventing the inappropriate storage and use of irrigation water).
- Encouraging soil testing to promote best nutrient application practices.
- Encourage chemical handling certification to prevent agricultural contamination.

Improve development controls to protect soils:

- Prevent soil degradation through meaningful design and implementation of infrastructure and development.
- Increase local level strategic planning to prevent soil contamination and encroachment of urban and industrial landuse on prime agricultural soil.
- Review land clearing and development guidelines and enable effective enforcement.
- Encourage whole landscape management for weeds and pest species.

Government capability:

- Improve governmental flexibility to respond to short term challenges.
- Support the development of soil best practice management plans.
- Promote soil stewardship with landholders.
- Support innovative ideas and new adaptive management strategies.
- Increase capacity to provide accurate technical soil advice on agricultural, environmental and planning issues

FOCUS ON PROFESSIONAL ACCREDITATION, EDUCATION AND TRAINING IN SOILS

Education and training:

- Embed capacity building and training in the National Soils Strategy
- Support soils education programs in schools and tertiary institutions via expanding the Soil Science Australia "Soils in Schools" program.
- Invest in soils training and/or employ more professional soil scientists in natural resource management organisations.
- Ensure soil science expertise developed through tertiary education programs is not lost by developing stable and reliable career pathways in soil science

Accreditation to maintain standards in soil professionals:

- Mandate the use of Certified Professional Soil Scientists (CPSS) for all major government and industry projects involving soils.
- Develop a framework to recognise and support other non-CPSS soil professionals.

REFERENCES

ABS. 2018. 4655.0 - Australian Environmental-Economic Accounts, 2018. Australian Bureau of Statistics.

Australian Academy of Sciences (2020). Soil conditions after bushfires; bushfire expert brief. July 2020 https://www.science.org.au/files/userfiles/support/evidence/2020/soil-condition-after-bushfires.pdf

Bennett, J., and S. R. Cattle. 2013. Adoption of soil health improvement strategies by Australian farmers: I. Attitudes, management and extension implications. The Journal of Agricultural Education and Extension 19:407-426.

Bui, E. N., G. Hancock, A. Chappell, and L. J. Gregory. 2010. Evaluation of tolerable erosion rates andtime to critical topsoil loss in Australia. CSIRO, Canberra.

Burdon, J., T. J. Higgins, J. Pratley, R. Leigh, B. Gibson, A. McNeill, R. Gleadow, S. Powles, B. Gillanders, B. Woods, and S. Hatcher. 2017. Grow. Make. Prosper. The decadal plan for Australian Agricultural Sciences 2017-26. Australian Academy of Sciences.

Burke, P. J. 2016. Undermined by adverse selection: Australia's direct action abatement subsidies. Economic Papers: A journal of applied economics and policy 35:216-229.

Campbell, A. 2008. Managing Australia's soils - a policy discussion paper. Prepared for the National Committee on Soil and Terrain (NCST) through the Natural Resource Management Ministerial Council (NRMMC).

Colloff, M. 2011. The role of soil biodiversity in providing ecosystem services. Report prepared for the Australian Government Department of Sustainability, Environment, Water, Population and Communities on behalf of the State of the Environment 2011 Committee. DSEWPaC, Canberra.

Commonwealth of Australia. 2013. Emissions Reduction Fund green paper.

DAFF. 2014. The National Soil Research, Development and Extension Strategy, securing Australia's soil, for profitable industries and healthy landscapes. Canberra.

DEE. 2018a. Measurement of soil carbon sequestration in agricultural systems. Commonwealth of Australia - Department of Environment and Energy.

DEE. 2018b. Quarterly Update of Australia's National Greenhouse Gas Inventory: September 2018 Incorporating emissions from the NEM up to December 2018. Commonwealth of Australia Department of Environment and Energy, Canberra.

DEW. 2018. Tracking changes in South Australia's environment - 41 trend and condition report cards. Government of South Australia Department of Environment and Water, Adelaide.

DISER (2020). Technology Investment Roadmap: First Low Emissions Technology Statement – 2020. Department of Industry, Science, Energy and Resources, Australian Government. https://www.industry.gov.au/data-and-publications/technology-investment-roadmap-first-low-emissions-technology-statement-2020

Eugenio, N. R., M. McLaughlin, and D. Pennock. 2018. Soil pollution - a hidden reality. Food and Agriculture Organization of the United Nations, Rome.

Fergusson, L. 2017. Anthrosols and Technosols: the Anthropogenic Signature of Contaminated Soils and Sediments in Australia. Water, Air, and Soil Pollution 228.

Gray, J., Karunaratne, S., Bishop, T., Wilson, B., and Veeragathipillai, M. (2019). Driving factors of soil organic carbon fractions over New South Wales, Australia. Geoderma. 353. 213-226.

ITPS. 2015. Status of the world's soil resources technical summary. FAO - Intergovernmental Technical Panel on Soils, Italy.

Jackson, T., K. Zammit, and S. Hatfield-Dodds. 2018. Snapshot of Australian Agriculture. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Luo, Z., E. Wang, and O. J. Sun. 2010. Soil carbon change and its responses to agricultural practices in Australian agro-ecosystems: A review and synthesis. Geoderma 155:211-223.

McBratney, A., Field, D.J., Koch, A. (2014). The dimensions of soil security, Geoderma 213, 203-213.

McBratney, A., C. Morgan, and L. Jarrett. 2017. The value of soil's contributions to ecosystem services. Page 227 *in* D. Field, C. Morgan, and A. McBratney, editors. Global Soil Security, Progress in Soil Science. Springer International Publishing Switzerland.

Metcalfe, D. J., and E. N. Bui. 2017. Australia state of the environment 2016: land. Australian Government Department of the Environment and Energy, Canberra.

Millar, J., and Roots, J, 2012. Changes in Australian agriculture and land use: implications for future food security, International Journal of Agricultural Sustainability, 10:1, 25-39.

Minasny, B., B. P. Malone, A. B. McBratney, D. A. Angers, D. Arrouays, A. Chambers, V. Chaplot, Z. S. Chen, K. Cheng, B. S. Das, D. J. Field, A. Gimona, C. B. Hedley, S. Y. Hong, B. Mandal, B. P. Marchant, M.

Martin, B. G. McConkey, V. L. Mulder, S. O'Rourke, A. C. Richer-de-Forges, I. Odeh, J. Padarian, K. Paustian, G. Pan, L. Poggio, I. Savin, V. Stolbovoy, U. Stockmann, Y. Sulaeman, C. C. Tsui, T. G. Vågen, B. van Wesemael, and L. Winowiecki. 2017. Soil carbon 4 per mille. Geoderma 292:59-86.

NCST. 2013. Establishing the Australian Soil Assessment Program (ASAP).

NSW EPA. 2015. New South Wales State of the Environment 2015. New South Wales Environment Protection Authority, Sydney.

Orton, T., T. Mallawaarachchi, M. Pringle, N. Menzies, R. Dalal, P. Kopittke, R. Searle, Z. Hochman, and Y. Dang. 2018. Quantifying the economic impact of soil constraints on Australian agriculture: A case study of wheat. Land Degradation and Development 29:3866-3875.

Paustian, K., J. Six, and E. T. Elliott. 2000. Management options for reducing CO2 emissions from agricultural soils [J]. Biogeochemistry 25:430-440.

Rengasamy, P. 2016. Salt-affected soils in Australia. GRDC, Adelaide.

Soil Science Australia. Fire and Soil: Supporting bushfire impacted communities and soil ecosystems. https://www.soilscienceaustralia.org.au/about/2020-fire-and-soil/

Speer, M.S. 2013. Dust storm frequency and impact over Eastern Australia determined by state of Pacific climate system, Weather and Climate Extremes, Volume 2, 16-21.

State of the Environment Committee. 2011. Australia state of the environment 2011. Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities. DSEWPaC, Canberra.

Stirling, E. , Fitzpatrick, R.W., Mosley, L.M. (2020). Drought effects on wet soils in inland wetlands and peatlands, Earth-Science Reviews 210, 103387.

Tozer, P., and J. Leys. 2013. Dust storms - What do they really cost? Rangeland Journal 35:131-142.

UNFCCC. 2019. Paris Agreement - Status of Ratification. United Nations Framework Convention on Climate Change.

United Nations. 1998. Kyoto Protocol to the United Nations framework convention on climate change. Page 21.

United Nations. 2015. Paris Agreement. Page 16.

VIC EPA. 2018. Victorian State of the Environment 2018 scientific assessments. Authorised by the Commissioner for Environmental Sustainability, Melbourne.

Viscarra Rossel, R., R. Webster, E. Bui, and J. Baldock. 2014. Baseline map of organic carbon in Australian soil to support national carbon accounting and monitoring under climate change. Global Change Biology 20:2953-2970.

WA DAF. 2017. Report card on sustainable natural resource use in the rangelands: status and trend in the pastoral rangelands of Western Australia. Department of Agriculture and Food, Western Australia, Perth.

WA EPA. 2007. State of the Environment Report: Western Australia 2007. Perth.

Waterhouse, J., B. Schaffelke, R. Bartley, R. Eberhard, J. Brodie, M. Star, P. Thorburn, J. Rolfe, M. Ronan, B. Taylor, and F. Kroon. 2017. 2017 scientific consensus statement - land use impacts on gret Barrier Reef water quality and ecosystem condition. Queensland.

Williams, J. 2015. Soils governance in Australia: challenges of cooperative federalism. International Journal of Rural Law and Policy Special edition 1:12.

Wong, V. N. L., R. S. B. Greene, R. C. Dalal, and B. W. Murphy. 2010. Soil carbon dynamics in saline and sodic soils: A review. Soil Use and Management 26:2-11.