



Department of  
Agriculture and Food



# Investing in sustainable agricultural resource use — reference metrics: a companion to the Report card on sustainable natural resource use in agriculture

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# 1 Introduction

This report is a companion document to the *Report card on sustainable natural resource use in agriculture* ('the report card'), published by the Department of Agriculture and Food, Western Australia (DAFWA) in 2013. The report card provides a 'health check' on the state of land and water resources in the broadacre agricultural region of Western Australia through giving a detailed summary for resource themes.

This report provides first pass state-level metrics for each resource theme. It should be used as a reference document, alongside the report card, to support discussions on investment.

Improving resource condition can translate into higher productivity for farmers, and therefore a potentially more profitable agricultural sector for WA. Resource condition can be improved through adopting certain land management practices.

Farm productivity tends to follow investment in research and development (R&D), although a time lag of 20 years or more for benefits to show is not uncommon. The benefits of increased investment in agriculture can take time to realise (Alston 2011). Timely investment decisions are therefore very important in determining the medium-term to long-term future of agriculture.

The report card focused on the following natural resource themes: soil acidity; wind erosion; water erosion; soil organic carbon (SOC); soil compaction; soil water repellence; dryland salinity; nutrient status; nutrient export; and acidification of inland waterways.

This companion report reviews each theme against a range of criteria. It includes the management options for each theme and a relative rating of the investment characteristics of each theme. It is important to note that while technically feasible management options exist for all themes, site specific application can be altered by a range of factors including season, soil type, market prices and management. In addition, the amelioration of one theme can result in the improvement or worsening of another.

## 1.1 About this report

Each chapter discusses a theme from the report card against 11 different headings and provides a table of management options. Information for each heading was prepared as follows:

- Description: A description of the theme is provided through expert interview and or reference material.
- Diagnosis: A description of how a theme can be diagnosed was developed through expert opinion and or reference material.

- Historical context of research and development in WA: This section provides an overview of R&D that has been conducted on the theme. The information has been collected through oral history and literature review.
- Estimated area of theme: Estimates (in hectares) are derived through best available soil-landscape mapping. For some themes other data is used and is referenced in the text. In general, the figures are taken from van Gool, Vernon and Runge (2008), where values are based on modelled estimates of area at risk or affected.
- Estimated state-level annual cost of lost production (on-farm): These figures, except for soil organic carbon (SOC) and phosphorus (P), are taken from Herbert (2009) and were relevant at the time of its publication. The Herbert analysis takes the value of agricultural production assuming land degradation is present and then subtracts the value of agricultural production assuming land degradation is not present. It is an estimated annual cost. Caution should be exercised when using these figures. The relativity between the figures is more important than the figures themselves.
- Estimated state-level annual off-farm costs: These costs have been estimated through literature review. In some cases, the literature provides very specific estimates for WA, in other cases literature from other locations is cited for background however it cannot be used for WA. The figures should be treated with a high degree of caution. Off-site costs between themes cannot be compared because of the differing methodologies.
- Farm level economics: An overview statement of farm-level economics is provided through literature review and expert opinion. A selection of articles is also cited. Farm-level economic analysis is site specific and can be altered by a range of factors. The papers reviewed provide information for the site(s) investigated and therefore are only relevant for these sites.
- Barriers to adoption: The lists of barriers to adoption have been collated through interview with experts and literature review. In some cases, grower surveys are cited.
- Technical feasibility: Technical feasibility is the availability and capacity of a management option to address a theme if a farmer is affected or at risk. This information was collated through expert opinion and or literature review.
- Potential for additional benefits from investment: This section outlines the additional benefits that may be gained from investing in the theme area. It uses expert opinion alone and therefore is subjective and qualitative.
- Other themes directly affected by this theme: This section identifies other themes from the report card that could become an issue if that theme is present. It was developed through expert opinion and literature review.

## 1.2 Limitations of this report

This report is a first pass at compiling a set of metrics for agricultural resource use issues. It does not:

- consider the differing spatial attributes for each theme. It considers each theme at a whole-of-state level. When reviewing the maps within the report card, it is clear that each theme is expressed differently, depending on location, and so management responses will also differ
- consider changes over time but considers the average year. Each theme is expressed differently according to a number of factors, such as climate, management practice and soil type.
- make recommendations, rank the themes or determine where the highest return on investment (ROI) can be gained. Each funder will have their own set of priorities and weightings and should obtain specific advice from appropriate professionals before making any significant decisions
- provide quantitative analysis. All measurements are qualitative (other than on-farm costs and, in some instances, off-farm costs) and based on expert opinion
- explore a wide range of stakeholder input (uses DAFWA experts only)
- provide absolute values. The values are qualitative and are provided for comparison against attributes between each theme
- explicitly characterise the different expression of themes from episodic through to incremental through to existing and requiring adaptation
- consider the implications for projected climate change
- provide detailed farm-level advice, recommendations or economic analysis for individual farms. Specific advice from appropriate professionals should be obtained before making any significant decisions.

## 2 Themes

### 2.1 Soil acidity

#### 2.1.1 Description

Soil acidification is a natural process that is accelerated by agriculture. The leaching of nitrates from fertiliser and organic matter, and the export of agricultural products from the paddock where they are produced are the primary causes.

Soil pH is the measure of soil acidity. Low pH (high acidity) in surface soil (the top 10cm) decreases the availability of nutrients and reduces biological activity, especially nitrogen fixation in legumes. Low pH in subsurface layers (10–30cm depth) causes an increase in aluminium in the soil solution, which is toxic to plant roots. The resulting poor root growth restricts access to nutrients and moisture, and lowers crop yields (Gazey, Davies & Master. 2014).

The solution is to neutralise the acidity that accumulates in the soil with agricultural lime; however, adoption of liming into farming practice has been slow and WA's agricultural soils remain undertreated overall.

#### 2.1.2 Diagnosis

Soil pH can be measured in standard diagnostic laboratory testing. On-farm testing using a hand-held probe or solutions that signify by colour also can indicate pH levels.

#### 2.1.3 Historical context of research and development in Western Australia

DAFWA has studied various aspects of soil acidification in WA over time.

In the 1930s researchers studied the use of lime to manage soil acidity in south-west dairy farms (Fitzpatrick 2009). In 1953/54 work on peaty acid sands showed the benefit of lime application along with a topdress of superphosphate and trace elements. At this time, however, the application of lime was not recommended as standard practice because soil acidity was not widespread (Fitzpatrick 2009).

Trials demonstrating the use of lime on sandy soils in the Scott River plains in 1966/67 allowed for areas of pasture to be expanded. Later, in the 1980s, lack of nodulation of clovers was found to be due to acidic soils.

In the early to mid 1990s DAFWA soil acidity research focused on aspects related nutritional changes as a result of treating acidic soil with lime. A key finding was identification of induced manganese deficiency in lupins. Since this was easily rectified, a significant barrier to liming was effectively removed.

Related research at the University of Western Australia (UWA) and CLIMA (Centre for Legumes in Mediterranean Agriculture) investigated ways to reduce the rate of acidification and to understand factors affecting the movement of lime from the surface to subsurface.



In the early 2000s an innovative project designed to demonstrate the impact of subsurface acidity by injecting lime behind deep-ripper tines established a number of sites throughout the wheatbelt. This project developed into further collaboration between DAFWA and UWA in a subsoil constraints project in which acidity remained a key element of research and development.

Soon after, natural resource management (NRM) bodies became major funders of on-ground work and a collaborative project between DAFWA and Precision SoilTech was developed to survey the extent and severity of soil acidity in the Avon River Basin and to provide advice and recommendations on the application of lime to participating growers. This very successful project was followed by another collaborative effort in the North, South West and South Coast NRM regions with funding from the Australian government.

For the past 25 years, DAFWA's main soil acidity projects included extension activities, which became known as Time to Lime and Time to Re-Lime, designed to encourage farmers to apply lime. The application of lime is now the key management option for soil acidity.

Today, the Grains Research and Development Corporation (GRDC) is funding a project to assist national coordination of soil acidity projects and to provide management support and extension to WA growers.

#### **2.1.4 Estimated area of soil acidity**

Based on project and commercial soil sampling of more than 93,000 sites carried out between 2005 and 2013, 70% of surface soils in the south-west agricultural area (13 million hectares) are more acidic than recommended. And, according to the report card, about half of subsurface soils (9.3 million hectares) are more acidic than recommended (Gazey, Andrew & Griffin 2013).

The report card confirms that the current situation is worse than earlier estimates. In 2008 van Gool, Vernon and Runge estimated that the subsurface layer on 2.3 million hectares of agricultural land was acid, 4.3 million was at high risk of becoming acid, and 5 million was at moderate risk.

#### **2.1.5 Estimated state level annual cost of lost production (on-farm)**

Lost production due to acidic soils was estimated at \$498 million (Herbert 2009). Recent soil testing suggests the land area affected is greater than used in this analysis and, therefore, the on-farm costs are likely to be higher.

#### **2.1.6 Estimated state level annual off-site costs**

Costs at this stage are mostly contained within the farming property. Off-site costs associated with soil acidity — such as decreased water use (dryland salinity), poor nutrient efficiency (excessive nutrients in waterways), poor biomass or groundcover (wind and water erosion) — are difficult to quantify.

### 2.1.7 Farm-level economics

Liming to counter soil acidity is in general a profitable activity. However, profitability varies depending upon season, the severity of acidity, soil type and the type of production involved.

Interpretation of individual trial results taken out of context and without reference to the acidity of the profile and the degree to which it is fixed can lead to erroneous conclusions especially when trying to estimate the time to recovery.

- In 2014 data from 69 long-term DAFWA trials across the wheatbelt were analysed to identify the on-farm economic benefits of liming. From 1991–2012, the average gain from liming was a 10% annual increase in yield (\$45/ha at \$250/t). If the first two years of data are removed, the gain increases to a 12% annual increase in yield (\$62/ha at \$250/t). This value is the yield benefit only and excludes the cost of amelioration. Higher responses were found when lime was combined with ripping or tillage. Individual circumstances will predict likely on-farm responses (Gazey et al. 2014b).
- Data from Dandaragan and Dalwallinu showed that cultivation to incorporate lime increased yield sufficiently in the first year to cover the cost of cultivation and part of the cost of lime. The rate of financial improvement is determined by three factors: pH needs to be below target levels; the lime needs to be mixed with the soil through some form of cultivation, and the soil fertility needs to be adequate. Incorporating the lime ameliorates subsoil acidity two to three years faster than topdressing. Mixing to the depth of low pH has immediate economic benefits (Scanlan, Brennan & Sarre 2014).
- On a property at Kellerberrin, lime sand was applied to plots in 1991 at rates of 1t/ha, 2.5t/ha and 5t/ha and again in 2001 at a rate of 1t/ha. In 2012 the plots that received 5t/ha in 1991 were yielding 0.55t/ha more than the unlimed plots. If wheat prices are \$300/t, this is an estimated benefit of \$165/ha (Leake, Leake & Gazey 2014).
- At Maya, the benefits of deep ripping and applying lime at the same time to jointly alleviate soil compaction and subsoil acidity were investigated. The combination of deep ripping to a depth of 50cm and incorporating lime had a benefit of \$159/ha over the control treatment, 3 years after treatments had been applied. There was no immediate benefit from applying surface lime alone, although there was a benefit of \$60/ha over the control from deep ripping to a depth of 50cm (Davies et al. 2009).
- A review of 28 small plot trials and 25 large-scale demonstrations established between 1994 and 1996 respectively, were managed and monitored. The sites, located across the wheatbelt stretching from Northampton, to Varley and down to Esperance, provided a consistent picture to researchers, who then developed general recommendations for farmers — namely, that the

application of lime at a rate of 1–1.5t/ha every 7–10 years will maximise overall profitability of a liming program, with higher rates for subsurface acidity and strongly acidic situations. The estimated payback period for lime is about four years (Gazey & O’Connell 2001).

- At Hyden, the application of lime at a rate of 2t/ha increased gross margins by 30%. A rate of 1t/ha increased gross margins by 21% (or \$13 to \$18/ha) per year compared to the unlimed control (Gazey & O’Connell 2000).
- A review of lime trials in Western Australia showed a 2–5 year time lag before yield responses were experienced. However benefits accumulate over time. For instance, in Wongan Hills the benefits at year zero were minus \$75/ha, at year five \$110/ha and at year ten \$250/ha. Crop selection also affects the payback period. Benefits are received earlier if the crops grown are more sensitive to acidic soils (O’Connell, 2000).
- O’Connell (1999) found the benefits of lime application outweighed the sometimes high costs of lime transport.
- At Wongan Hills, consistent yield responses were seen in all crops (with the exception of lupins) on acidic soils. Gross margins for limed soils were at least equal to, and often greater than, unlimed soils. A trial at Varley showed the cost of liming was outweighed by the benefits by Year 2 (O’Connell & Gazey 1999).

### **2.1.8 Barriers to adoption**

A number of barriers prevent growers from liming adequately (Fisher 2009):

- high upfront costs
- time lag until a return is obtained (although improved incorporation techniques can reduce the interval)
- delayed application increasing the interval before a return
- inaction not necessarily factored into budget decisions as a loss of income or as a reduction in the value of the soil resource
- mixed messages about how, when and which lime to apply
- perceived doubts about the effectiveness of lime (mostly explained by insufficient lime or insufficient time since application to allow for low pH to be ameliorated).

### **2.1.9 Technical feasibility**

Soil acidity can be overcome easily with the application of lime. Only half of the annual estimated amount of agricultural lime needed to treat acidic soils in WA was being applied in 2013 (Gazey et al. 2014a). Time lags to profitability can be reduced through incorporation techniques where appropriate for soil type. Techniques such as

deep ripping, spading and mouldboard ploughing also can make incorporation of lime at depth affordable where multiple soil constraints exist.

#### **2.1.10 Potential for additional benefits from investment**

Significant effort has been extended over the past 30 years to encourage farmers to apply lime. In the initial phases, the key message was prevention. Over time, however, the message has changed to treatment where acidity is identified as a production constraint. Whenever an extension campaign has been undertaken, there has been an increase in the amount of lime applied.

With the use of lime remaining well below that needed for appropriate management, more soils will continue to acidify to a point where acidity becomes a constraint to production. In the absence of a new extension campaign, the issue can only become more pressing. With an estimate of 74% of farmers identifying soil acidity as a 'moderate or worse' problem on their farm, and 90% of farmers considering soil acidity on their farm as 'manageable', the prospect for reduction of soil acidity through knowledge sharing is real.

#### **2.1.11 Other themes directly affected by this theme**

Soil acidity is complex because it affects not one or two but a confluence of themes that tend to amplify one another — water repellence, wind erosion, water erosion, loss of soil organic carbon (SOC) and increased export of phosphorus (P) due to reduced plant growth.

**Table 1: On-farm management options for soil acidity\***

Management option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/reliability	Associated benefits/drawbacks
Surface application	Lime <sup>†</sup> + cost of application (\$8–10/t/ha for lime spreading only)	Long-term benefits	Lime applied as an even coverage to the soil surface and moves through the soil profile over time	All locations	High However, this method has significant time lags while the lime moves through the soil profile	Long lag period may result in grower perceiving no or limited benefit and therefore not continuing application of lime
Shallow incorporation	Lime <sup>†</sup> + cost of application + shallow incorporation	Long-term benefits	200–300kg/ha lime incorporated at seeding to 10–12cm to maintain soil pH	All locations	High Not effective at recovering acidic soil as not enough lime is applied Reduces time of neutralisation over surface application	Availability of suitable machinery Decreased efficiency of seeding operation Possible yield decrease associated with delays to time of sowing
Surface application then deep rip	Lime <sup>†</sup> + \$40–50/ha for deep ripping.	Long-term benefits	Incorporates lime into the soil profile resulting in faster response times Modified and shallow leading tine deep rippers may do a better job of allowing limed topsoil to fall behind the ripping tines into the subsoil creating pH corrected pathways for root growth.	Deep sandy earths, pale deep sands and sandy gravels Should not be used on shallow duplex or soils with abundant rock or cemented gravel	High Shorter response times to surface application	Helps reduce soil compaction and water repellence Can increase risk of wind and water erosion
Surface application then rotary spading	Lime <sup>†</sup> + \$150/ha for spading Higher rates of lime may be needed due to greater mixing with soil. Often deep ripping is needed prior to spading at an additional cost of \$40–50/ha.	Long-term benefits	Incorporates lime into the soil profile to 30–35cm resulting in faster response times Gives a good distribution of lime	Deep sandy earths, pale deep sands and sandy gravels Avoid shallow duplex or soils with abundant rock or cemented gravel	High Shorter response times compared to surface application	Helps reduce soil compaction, water repellence and weed burden Difficulty seeding into loose soil, traffic and harvesting on soft soil. Can increase risk of wind and water erosion in the short-term
Surface application then mouldboard ploughing	Lime <sup>†</sup> + \$100–150/ha	Long-term benefits	Incorporates lime into the soil profile resulting in faster response times Buries lime with the topsoil, leaving an acidic layer of subsoil at the surface	Sandplain soils with mild to moderate subsurface acidity Use with caution on highly acidic soils	Moderate Shorter response times to surface application, but can leave acidic surface layer that will need subsequent liming	Helps with soil compaction, water repellence and weed burden Difficulty seeding into loose soil, traffic and harvesting on soft soil. Can increase risk of water and wind erosion Often requires the application of more lime to treat the acidic soil brought to the surface

\* This and other management option tables are based on Davies et al., 2012, p. 1.

† The cost of agricultural lime ranges between \$7/t and \$30/t at the pit, depending on source and location.

(continued)

**Table 1: On-farm management options for soil acidity (continued)**

Management option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/reliability	Associated benefits/drawbacks
Direct injection	Lime <sup>†</sup> + cost of direct injection (no commercial machinery exists for adequate cost comparison)	Long-term benefits	Lime is injected into the subsurface soil in seams providing ameliorated pathways for roots to grow through the acid layer.	All locations	Can be a difficult technique to master Incorrect placement retains the cost of a highly acidic subsurface soil layer as lime may end up in a clump at the base of the ripping tine with a layer of acid subsoil on top	Allows for deeper placement of lime with minimal soil disturbance compared to spading or soil inversion techniques Difficult to apply technique accurately (slow operation and not commercially available)
Precision application	Lime <sup>†</sup> + ~\$135 000 for autosteer + application method costs.	Long-term benefits	Allows for targeted application of lime. Variable application can be achieved without autosteer by identifying large management zones (often soil types) and applying rates accordingly or adding more lime to the areas that need more a few years after the initial application.	All locations	High Targeted application increases returns	Reduced soil compaction Can be used in a more general way to achieve variable application over several years without the expense of guidance equipment
Perennial pastures (esp. grasses)	Cost of establishing the grazing system \$100–150/ha	Long-term benefits	Reduces N leaching and therefore potentially reduces the acidification rate	Typically high rainfall coastal areas	Moderate but restricted application	Does not increase soil pH Reduced risk of wind and water erosion
Choosing tolerant crop and pasture species	Potential cost of new seed	Annual. Acidity remains unaddressed	Acid-tolerant crops and varieties are used	All locations	Moderate when used as an approach to maintain productivity and income stream to supplement treatment of acidic soil with lime (not a solution on its own)	Soil acidity remains untreated and the problem will continue to worsen Reduces flexibility of land use. Only acidic-tolerant species can be grown, until they too fail and soil is degraded beyond economically viable recovery

\* This and other management option tables are based on Davies et al., 2012, p. 1.

<sup>†</sup> The cost of agricultural lime ranges between \$7/t and \$30/t at the pit, depending on source and location.

## **2.2 Wind erosion**

### **2.2.1 Description**

Wind erosion occurs when soil particles are picked up by the wind and moved elsewhere (Carter & Laycock 2013). Three preconditions for wind erosion are loose soil, lack of surface vegetation, and wind strong enough to move the soil particle (Carter 2006).

### **2.2.2 Diagnosis**

Wind erosion can be diagnosed through observation. The likelihood of wind erosion can be diagnosed through the following factors:

- potential — observations of soil texture, roughness and place in the landscape
- detachment — dislodgement of vegetation and soil from livestock trampling and machinery use
- cover — estimate of percentage groundcover from living and dead plant material, gravel and stone.

### **2.2.3 Historical context of research and development in Western Australia**

Wind erosion research has been ongoing for a long time. In the 1960's there was increased interest although it was not until the 1970's that wind erosion was acknowledged as a problem. The large wind erosion event in Jerramungup in the early 1980's resulted in much attention being given to the issue in Western Australia and the dust storm in Melbourne in 1983 brought the issue to national prominence. The soil and land conservation districts were established in Western Australia in the early 1980's as a tool to help manage wind erosion (DAFWA 2014b).

By the 1980s DAFWA had become Australia's leading research body for wind erosion, a position it held for a decade or so until increasingly successful management of the risk led to reduced investment in research. Today, DAFWA monitors the risk of wind erosion through twice yearly roadside surveys, aerial photography and satellite imagery. DAFWA contributes to the New South Wales DustWatch program, which uses weather stations at Merredin and Mullewa, monitors wind speed, rainfall and atmospheric particulate concentration (DEH 2014).

### **2.2.4 Estimated area at risk of wind erosion**

In 2008, 6.4 million hectares of agricultural land in WA was estimated at risk of wind erosion — 0.02 million at extreme risk, 0.9 million at very high risk and 5.5 million at high risk (van Gool, Vernon & Runge 2008).

### **2.2.5 Estimated state level annual cost of lost production (on-farm)**

The annual cost of lost production due to wind erosion was estimated at \$71 million (Herbert 2009).

### **2.2.6 Estimated state level annual off-site costs**

There was no easily identifiable literature for off-site effects of wind erosion for WA and therefore a state level off-site cost is not provided.

Studies investigating significant wind erosion events in Australia estimated the cost of off-site effects to be 1.5 to 4.5 times the cost of on-farm damage (Williams & Young 1999; Tozer & Leys 2013).

Tozer and Leys (2013) estimated the costs to New South Wales of a significant dust storm in 2009. The study considered a range of off-site costs including retail and service including cleaning costs after the event, cessation of construction work due to occupational health and safety, air transport, cleaning, absenteeism and fire alarm call outs. On farm costs such as stock losses, loss of infrastructure and feed purchases were considered to be 2% of the cost of household cleaning.

Williams and Young (1999) investigated off-site costs of a dust storm in South Australia through six cost centres; individual households, power supply, road safety, road maintenance, cost of air travel and human health. The human health costs were mainly associated with costs of asthma such as absenteeism, impairment, disability and death. The paper also cites Husza and Piper (1986) that concluded “the off-site cost of wind erosion in New Mexico as estimated to be 50 times greater than the on-site cost of wind erosion”

However, these studies encompassed city areas and focused on low frequency, high impact events (one in 50 year events). Regional and rural areas with lower population densities may expect more frequent, lower cost events.

### **2.2.7 Farm-level economics**

The risk of wind erosion has been reducing over the last few decades, suggesting many conservation farming practices have good farm level economics. A reduction in livestock numbers since the early 1990s and extensive adoption of minimum tillage have significantly reduced the risk of wind erosion events in broadacre agriculture in WA. Caution is needed, however. Changes in stock numbers or a move away from conservation farming practices could increase wind erosion risk.

- Minimum or no-tillage reduces fuel use and has lower crop establishment costs (Padfield 2011).
- Tree windbreaks have the most benefit in dry windy years. They are unlikely to provide economic benefits where exposure to wind events is low (Sudmeyer, Bicknell & Coles 2007).
- A study at Esperance found that four or five wind erosion events are needed in the first 35 years of establishment for tree windbreaks to pay for themselves. A payback in 10 years would require at least two events. If there are no wind erosion events in the first 15 years, costs are unlikely to be recovered (Jones & Sudmeyer 2002).



- For every 1mm of topsoil lost, a subsequent 2% reduction in yield results (Leonard 1993). Removal of 4mm topsoil can translate to a 4–20% yield reduction. Assuming a yield of 1.4t/ha and a grain price of \$175/t, this translates to a loss of \$20–50/ha (Marsh 1982).
- According to the South Coast Linear Programming model, grazing pasture below the recommended level is less profitable than maintaining coverage. It can be more profitable to maintain coverage above recommended levels in some instances. Retaining pasture coverage at recommended levels has a payback of one to two years (Bathgate 1990).
- Investigations of the costs of wind erosion events in Jerramungup in 1980–81 showed the average cost per affected farm was \$140/ha. In 2012 dollars, this is equivalent to \$490/ha (Goddard, Humphry & Carter 1982).

### 2.2.8 Barriers to adoption

Some conservation agricultural practices have been adopted by the majority of broadacre growers; with minimum or no-till seeding practices reaching mature levels of adoption and exceeding 80% in all areas (D’Emden, Llewellyn & Flower 2009).

Non-adoption of practices and technologies may be due to:

- difficulty in defining the value of lost soil (Bathgate 1990)
- high cost of establishment, long payback periods and lost area of cropping for tree windbreaks
- day-to-day management of other farm issues that may involve larger losses or gains, particularly in the short term (Bathgate 1990)
- a loss of 3mm of soil or less may lead to an imperceptible loss of production. Factors such as fertiliser use, disease, weeds and season can mask much of the reduced yield due to soil loss (Williams, Tanaka & Herbel 1993).
- different degrees of tolerance. One farmer may consider a minor erosion event as acceptable; another may see any erosion as bad. One may tolerate erosion in a small area of paddock but not in a large area of the farm
- weed and trash management practices. Some farmers burn stubble, reducing surface cover and increasing the risk of erosion (D’Emden, Llewellyn & Flower 2009).
- reduced levels of minimum or no-till in an attempt to manage weeds (D’Emden, Llewellyn & Flower 2009).
- a perception that erosive events are unlikely and the impact is low, compared to the existing practice.

### **2.2.9 Technical feasibility**

DAFWA has focused on conservation farming, which means disturbing the soil as little as possible to keep a cover of crop, pasture or stubble on the ground to build organic matter and to minimise the risk of erosion.

Minimum till has significantly reduced wind erosion risk in WA and is now considered standard practice. Where this technology is applied well, low level erosion can be reduced or prevented. However, some events are either too expensive to prevent or simply defy management by landholders. For instance, consecutive low rainfall years, grasshopper or other pest incursions, and fires can leave the ground bare, increasing the risk of soil erosion. Climate change also has the potential to increase both the frequency and severity of major soil erosion events.

In WA, a low-to-moderate wind erosion risk is experienced more than every nine in 10 years. Therefore effective risk management is technically feasible.

### **2.2.10 Potential for additional benefits from investment**

About 90% of farmers have soils that have the potential to erode; however, only 5% of farmers are estimated to experience notable erosion each year. Some of this is by accident, some due to poor application of practices to reduce wind erosion risk, and some due to failure of the farming system in extreme events.

About 75% of farmers are close to full adoption of risk management practices, 20% are likely to be able to improve practices with targeted advice, and 5% are unlikely to effectively manage wind erosion (DAFWA 2013).

Overall, there is limited ability to improve adoption of wind erosion management practices in WA; however, continuation of extension activities could ensure adoption does not fall away.

### **2.2.11 Other themes directly affected by this theme**

The most susceptible soils to wind erosion – sands with very low clay content at the surface – are also susceptible to developing water repellence (DAFWA 2014c), nutrient leaching, acidification, and sub-soil compaction (Davies & Lacey 2011).

Soil movement due to wind erosion can reduce Soil Organic Carbon (SOC) and increase export of phosphorus (P). Weed seeds and soil additives such as applied lime can be moved by wind erosion. Wind erosion also can remove disease spores (pleiochaeta root rot of lupin, blackleg of canola) from the soil surface and distribute them elsewhere.

**Table 2: On-farm management options for wind erosion**

Management option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/reliability	Associated benefits/drawbacks
Stubble retention (minimum till one option)	Standard practice	Annual	Knife point seeding, disc seeding or direct drill	All	High	Can result in increased water repellence; higher levels of organic matter; lower labour, fuel and machinery costs; reduced soil compaction
Minimise soil disturbance	Minimal (all about timing practices)	Annual	Undertake processes such as deep ripping or soil inversion at times where soil erosion risk is lowest (moist soil)	All	High	
Managing stocking rates to reflect changing capacity	Depending on quality of stock and current market prices, grower may make or lose money	Annual	Reduce stocking rates to ensure minimum cover of 50% is maintained	All	High	May need to purchase livestock when adequate groundcover Reducing grazing pressure to maintain 50% cover can make it more difficult to seed Perception of lost income due to reduced grazing
Sacrificial paddock	Lost soil nutrition from eroding paddock	Annual	Put aside one paddock where stock can be moved in high risk erosion years	Gravelly soils that are naturally resistant to wind erosion	High	Increased risk of erosion in sacrificial paddock
Feedlots	Cost of transporting animals to feedlot	Annual	Move animals to feedlots during periods of low feed availability	All	High	
Perennial pastures	Cost of establishing grazing system (\$100–150/ha)	Length of pasture phase (10+ years)	Minimum of 50% cover year round	Medium to high rainfall, typically coastal areas	High	Out-of-season feed Increase SOC
Tree windbreaks	Variable depending on size of windbreak	Several years for the trees to grow to reach maximum effectiveness, then life span of the tree	Plant trees in a location that provides maximum wind protection to the paddock	Areas highly susceptible to wind erosion	Variable (depending on height of trees and porosity, which affect effective distance of reduced wind)	Shelter belts for livestock Loss of production in root zone of trees as a result of competition Reduced soil water evaporation Reduced salinity
Fence/wall windbreaks	Expensive	Depending on materials, medium to very long term	Build a wall or solid fence	Horticulture	High (used to protect high value crops)	Expensive to install and therefore not suitable for broadacre agriculture
Soil roughening	Variable	Annual	Roughen the soil to reduce wind run	Heavy soils	Moderate	Can reduce water repellence
Applying clay clods or gravel	Expensive to transport and apply (\$300–900/ha)	10+ years	Application of clay or gravel can help to stabilise the soil	Requires nearby clay or gravel supply	Very high if sufficient amount applied	Depending on application rate, may increase clay content and overcome water repellence
Applying mulch	Expensive		Application of a layer of mulch across the top soil	Close to a supply of mulch, as delivery costs are expensive	Providing the mulch particle size is large enough that it will not be blown away, can be very good	Increase soil carbon and water-holding capacity May increase water repellence

## **2.3 Water erosion**

### **2.3.1 Description**

Water erosion is the movement of soil by water from one place to another. Any amount of soil loss from erosion in south-west Western Australia is unlikely to be sustainable. A water erosion event, once occurred, is largely irreversible (Galloway & van Gool 2013).

### **2.3.2 Diagnosis**

Water erosion is diagnosed through observation. Paddock-scale assessment of the risk is determined through in-paddock measurements of land use, topography and soil type.

### **2.3.3 Historical context of research and development in Western Australia**

In the 1950s DAFWA identified contour and interceptor banks — among other practices to manage soil condition — as key management options to counter water erosion. At this time, paddocks could be worked a number of times each season with ploughing used as a tickle, to incorporate weeds, and seed.

In the 1990s the private sector provided farmers with support and expertise in the design of contour and interceptor banks. However, installation declined later because such banks can be problematic with no-till farming and controlled traffic farming (CTF), which help to stabilise the soil and therefore reduce the risk of water erosion. Consequently, private and public sector expertise in bank design has declined.

The economic consequence of water erosion has declined over recent years, due to the adoption of minimum tillage, stubble retention and CTF in cropping practices, and a reduction in the size of the WA sheep flock and a conversion to greater cattle numbers in grazing situations. As a result, little research into water erosion has been undertaken over the past three decades. However, DAFWA continues to track and research this theme in a limited way.

### **2.3.4 Estimated area at risk of water erosion**

About 1.2 million hectares is at risk of lost production due to water erosion. In 2008 an estimated 0.2 million hectares was estimated at extreme risk of water erosion, 0.4 million hectares was at very high risk, and 0.6 million hectares was at high risk (van Gool, Vernon & Runge 2008)

### **2.3.5 Estimated state level annual cost of lost production (on-farm)**

Lost production due to water erosion was estimated at \$10.1 million annually (Herbert 2009).

### **2.3.6 Estimated state level annual off-site costs**

There was no easily identifiable literature for off-site effects of water erosion for WA and therefore a state level off-site cost is not provided.

International studies suggest that off-site costs can be double that of on-site costs (Jones et al. 2008; Lee, Southgate & Sanders 1998; Pimentel 1995).

### **2.3.7 Farm-level economics**

There is no easily identifiable on-farm literature specifically on water erosion for Western Australia. However the on-farm long term production penalties of water erosion costs are likely to be similar to that of wind erosion.

The wide spread adoption of minimum till cropping suggests a general affordability and adoptability of this practice. Controlled traffic farming (covered in more detail in soil compaction) can also be a highly economic management practice, although up-front costs can be high.

### **2.3.8 Barriers to adoption**

The majority of WA farmers have adopted conservation agricultural practices to help prevent erosion. Instances where adoption has not occurred may be due to:

- difficulty in defining the value of lost soil (Bathgate 1990)
- day-to-day management of other farm issues that may involve larger losses or gains, particularly in the short term (Bathgate 1990)
- a loss of 3mm of soil or less may lead to an imperceptible loss of production (factors such as fertiliser use can mask much of the reduced yield due to soil loss (Williams, Tanaka & Herbel 1993))
- different degrees of tolerance. One farmer may consider a minor erosion event as acceptable; another may see any erosion as bad. One may tolerate erosion in a small area of paddock but not in a large area of the farm
- high cost of entry to CTF (see 'Soil compaction')
- high cost of constructing banks, which can also make CTF difficult. The high cost often does not provide an economic return, except where waterlogging is ameliorated
- the high cost of stabilising watercourses by fencing, stock exclusion and revegetation, which is not offset by an increase in productive capacity or economic return.

### **2.3.9 Technical feasibility**

Overall most management options are technically feasible. However water erosion risk will remain where stock are present. Major rainfall events, that are projected to increase due to climate change, will increase water erosion risk.

### **2.3.10 Potential for additional benefits from investment**

Water erosion is largely well managed in WA, with farmers undertaking practices that manage for risk in most years. However, some events cannot be completely managed by land holders.

The potential for additional benefits from investment are probably limited due to the widespread adoption of effective management practices. However, continuation of extension could ensure adoption does not fall away.

### **2.3.11 Other themes directly affected by this theme**

The presence of water erosion can increase the risk of losing of soil organic carbon and increasing phosphorus export due to soil movement.

Soil compaction, soil structure decline and non-wetting can directly increase the water erosion hazard by adversely decreasing the infiltration rate of rainfall and increasing the number of run-off events which contribute to erosion.

**Table 3: On-farm management options for water erosion**

Management option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/reliability	Associated benefits/drawbacks
No-till or minimum till	Standard practice	Annual	Knife point seeding, disc seeding or direct drill	All	High	Can result in increased water repellence, higher levels of organic matter, less labour, fuel and machinery costs, reduced soil compaction
Winter and summer active components in pastures or perennial pastures Waterlogging tolerant pastures	Depends on cost of seed  Up to \$150/ha	Annual	Sow a pasture with a mix of winter and summer active species	All	High	Can help to increase SOC, reduce risk of wind erosion, increase soil biodiversity, reduce nutrient export.  Longer pasture phases can have a cost of forgone crop income
Managing stocking rates to carrying capacity	Depending on quality of stock and current market prices, grower may make or lose money	Annual	Reduce stocking rates to ensure minimum cover of 70% maintained	All	High	May need to purchase livestock when groundcover is adequate
Feedlots	Cost of transporting animals to feedlot	Annual	Move animals to feedlots during periods of low feed availability	All	High	
Sacrificial paddock	Lost soil nutrition from eroding paddock	Annual	Put aside one paddock (usually a low productivity paddock) where stock can be moved in high-risk erosion years	Paddocks that are already extremely degraded or have a greater resistance to water erosion due to soil type	High	Increased risk of erosion in sacrificial paddock
Banks	Significant costs of earth moving	10–15 years	Earth is moved to make banks according to paddock contours to slow or stop water flow	Areas with higher rainfall Steep slopes Livestock focus	Moderate	Can make CTF more difficult Slows water, but does not fix the problem Removal of banks can increase future risk of water erosion, particularly with livestock
Vegetated water courses	Cost of replanting vegetation and excluding stock	As long as vegetation remains	Plant vegetation	Watercourses at high risk of erosion that no longer have perennial vegetation	High for the water course	Increased biodiversity Reduced nutrient export
Controlled traffic farming	\$40 000 autosteer technology and equipment standardisation  \$2000–10 000 for equipment standardisation alone	Long term	Maintains soil structure and channels water along hard wheel tracks	All soils	High	Less crop damage, 3–10% reduction in inputs, 5–15% increase in crop yield, increased longevity of deep ripping, improved traction in wet conditions, less fuel used, compaction minimised
Contour tilling versus up and back	Maybe slightly higher time costs	Annual	Paddocks tilled according to contour lines	All paddocks with a gradient	Low to moderate	

## **2.4 Soil organic carbon**

### **2.4.1 Description**

Soil organic carbon (SOC), a small but vital part of all soils, is largely derived from plant and animal materials in various stages of decay, from decomposing organisms through to charcoal. Soil carbon (fertility) is concentrated at the soil surface (Griffin, Hoyle & Murphy 2013; Hoyle et al. 2013) and is linked to increased productivity (Hoyle, Baldock & Murphy 2011).

### **2.4.2 Measurement**

SOC is calculated in a laboratory by taking a soil sample from the desired depth and measuring the percentage (%) of organic carbon. However, while standard soil tests provide a SOC percentage (concentration) for a sieved soil to 2mm, they are not strictly reliable. For increased accuracy, a measure of bulk density and gravel content for the same depth of soil is helpful. These tests adjust for changes in soil mass per unit volume but they can be costly.

### **2.4.3 Historical context of research and development in Western Australia**

SOC in WA has historically been investigated for its soil health benefits, with DAFWA and UWA undertaking a significant component of this work.

At Wongan Hills in the 1960s, increased SOC levels in the top 5cm of soil were measured after seven years of legume pasture (Fitzpatrick 2009). Other research around the same time suggested that a harvest of clover seed decreased SOC and hence soil fertility (Fitzpatrick 2009). Meanwhile, work at Merredin Research Station showed no consistent trend in SOC values for land that had been under a long-term wheat pasture rotation before cultivation, during fallow and under two successive years of wheat (Fitzpatrick 2009).

The Western Australian No-Tillage Farmers Association (WANTFA) has measured soil organic carbon levels across member paddocks suggesting an increase in the percentage soil organic carbon when no-till farming practices are used. However, doubt remains that the beneficial effects are more than surface deep. Recent research suggests that although minimum till increases carbon in the top 10cm of soil, the amount of SOC to a depth of 30cm remains the same (Griffin & Hoyle, unpublished data), largely a result of less cultivation and inputs remaining on or near the surface.

In 2003 the National Carbon Accounting Scheme led by DAFWA considered changes in SOC from long-term trials and paired sites, that is, farmed soils versus native soils. The results were variable, with SOC increasing in some paired sites under agricultural production, while in others it decreased. On average, however, changes in SOC for WA soils were minimal (Griffin et al 2003).

Since this date, DAFWA and UWA have undertaken significant bodies of research within a national framework to establish a baseline for SOC under a range of different



soil and land uses in WA, to help measure the effect of management on SOC levels (Hoyle & Murphy 2006; Hoyle & Murphy 2011; Hoyle et al. 2013; Murphy et al 2014). This work identifies soil type and climate as the primary determinants of SOC in WA, with management largely considered a third level influence (Hoyle et al. 2011; Hoyle et al. 2013).

Scientific interest in SOC has been renewed over the past decade by the possibility of carbon becoming a tradeable commodity in either a voluntary or a mandatory carbon trading market. As well as focusing on potential production benefits, attention is being directed to long-term carbon storage.

#### **2.4.4 Soil organic carbon in Western Australian agricultural region over time**

The report card provides an estimate of SOC content in agricultural regions of WA that will serve as a baseline for future estimates.

It has been observed that many low-input agricultural systems in Australia have led to a gradual decline in SOC (Hoyle 2013). While trial differences have sometimes been measured between practices such as stubble management and cultivation, it is considered possible that in many of these that the 'better' practice may still be degrading SOC over time – albeit more slowly (Hoyle, unpublished; Sanderman et al. 2010). However, as mentioned above, there are studies where SOC in the top 30cm of soil for paired cleared sites showed little difference to uncleared sites on sandy surface soils, although more of the carbon in cleared sites was discovered in the surface layers (Griffin et al 2003). Some cleared sites had more carbon than the uncleared pair, possibly due to improved nutrient levels of these soils (Griffin et al 2003).

Levels of SOC in the top 10cm of agricultural soil range from around 56t C/ha in the high rainfall, lower temperature regions through to 10t C/ha for the low rainfall, high temperature areas of the south-west of WA (Griffin et al. 2013; CSIRO 2014).

#### **2.4.5 Estimated state level annual cost of lost production (on-farm)**

As SOC underpins system function rather than being a land degradation issue, this calculation is not relevant.

#### **2.4.6 Estimated state level annual off-site costs**

As SOC underpins system function rather than being a land degradation issue, this calculation is not relevant.

#### **2.4.7 Farm-level economics**

Comparatively little work has been undertaken on farm level economics for SOC in WA. The production value of SOC remains unquantified and increasing SOC for carbon trading, appears financially unattractive. The financial benefits or otherwise of encouraging farmers to increase SOC are unclear.

- A meta-analysis (Lam et al. 2013) investigated the benefits of carbon farming in Australia. They found the higher value expected to be returned from farming carbon for carbon credits from a formal scheme such as the Carbon Farming Initiative (CFI) means farmers lose less money over 10 years compared to participation in a voluntary market. However, even at \$23/t of carbon stored, farmers would lose between \$3 and \$7/ha from participation.
- On a model farm at Northam at decile 5 rainfall, the Select Your Nitrogen model was used to assess the profitability of N fertiliser. The addition of N fertiliser was only profitable when SOC was low (0.75%). At higher levels (1.75%), plants sourced a greater amount of N from the soil (Scanlan 2013).
- On a model farm at Merredin, the Agricultural Production Systems sIMulator (APSIM) and the Central Wheatbelt MIDAS were used to investigate the trade-offs between profit maximisation and SOC storage. In this study, profit was maximised at 70% cropping while SOC storage was maximised at 80% pastures. A carbon price above \$80/t would be needed to encourage farmers to farm carbon (Kragt et al. 2012).
- An overview of management practices for SOC storage shows that carbon sequestration is a slow process. At a carbon price of \$20/t, storing carbon in the soil for credits would be difficult to justify financially at a whole-of-WA level (Baldock 2009).

#### **2.4.8 Barriers to adoption**

Reasons management practices to increase SOC have not been adopted may be due to:

- lack of profitability for increasing SOC for carbon credits (Baldock 2009)
- the necessity of a long-term commitment (SOC can be readily lost and building SOC levels can take considerable time) (Hoyle 2013)
- history of failed attempts to reach objectives for carbon credits due to misinformation and unrealistic expectations for some products (Baldock 2009)
- climatic and soil type constraints (Hoyle 2013)
- other limiting factors such as wind erosion or soil acidity (Hoyle 2013)
- expectations of projected decreases in rainfall due to climate change (Hoyle 2013), less rainfall may inhibit plant growth and increase the risk of erosion.

#### **2.4.9 Technical feasibility**

While increasing SOC is technically feasible, the process would be slow, often with 5–10 years passing before a change can be measured. Farmers in WA are already adopting measures aimed at improving system productivity such as stubble retention, minimum tillage, increasing frequency of good pastures, green manures and management of soil constraints where feasible. As such they are inadvertently

supporting systems that will help maintain or increase their soil fertility and as a consequence SOC (Hoyle 2013).

Managing specifically for SOC must be weighed up against cost, benefit and feasibility. Increasing net primary productivity supports maintenance and, in some cases, incremental improvements in SOC, but it takes time.

#### **2.4.10 Potential for additional benefits from investment**

Additional investment in R&D will significantly increase our knowledge of the importance of SOC to agricultural production in WA, particularly where both the production and financial benefits and costs are investigated and quantified across different time scales.

#### **2.4.11 On-farm management options for soil organic carbon**

Management options that maintain or increase SOC include (Hoyle 2013):

- increase biomass of crops and pastures
- retain crop and pasture residues on the paddock
- add a pasture phase or perennial pasture
- manage grazing intensity
- cover crop, green manure and pasture cropping
- apply off-paddock organic amendments
- maintain low soil disturbance systems
- decrease erosion risk
- retire non-productive areas
- revegetate and destock cleared areas
- irrigate
- minimise bare fallow phases which can lead to a rapid loss of SOC.

For more detail, refer to Hoyle (2013), pp. 68–79.

#### **2.4.12 Interactions with other themes**

SOC levels can be influenced by the presence of constraints to plant growth such as soil acidity, soil compaction and salinity as well as the severity of water repellence. Significant losses also can be directly associated with wind and water erosion.

## **2.5 Soil compaction**

### **2.5.1 Description**

Soil compaction is the physical consolidation of soil that destroys structure, reduces porosity, limits water and air filtration, and increases resistance to root penetration. Compaction often results in reduced crop yield (Carter, Davies & Schoknecht 2013).

Subsurface compaction is caused by the movement of heavy machinery, with machinery sizes and loads markedly increasing over the past few decades. Surface compaction is mainly due to stock and vehicle traffic.

Natural processes, such as packing and cementation, can also result in the formation of hardpans in the soil. Naturally hard soils to depth are unlikely to respond to treatment (DAFWA 2014a).

### **2.5.2 Diagnosis**

Misdiagnosis is common and the significance of compaction is often underestimated.

No simple diagnostic test is available but indicators include (Davies & Lacey 2011):

- moist subsoil within 30–40cm of the surface in cropped areas after reasonable crops in dry finish seasons
- large, dense clods brought up by deep tillage when the soil is quite dry
- difficulty of tines in penetrating soil
- poor root growth, particularly in the 15–40cm layer
- roots tending to be confined to pores and cracks
- horizontal root growth above dense hardpan
- swollen root tips as roots try to penetrate a hardpan

Compacted layers can be detected using a hand probe in moist soil. Feel for resistance (typically between 15cm and 40cm) from a cropped soil compared with soil in native vegetation or near a fence line.

### **2.5.3 Historical context of research and development in Western Australia**

Research into subsoil compaction and deep ripping began in earnest in WA in the late 1970s. This work established the general knowledge that deep ripping of sands with more than 30cm depth could often improve grain yields by 20–30%. Deep ripping was therefore generally included in management practices on many sandplain farms, especially in the Northern Agricultural Region (NAR). That said, investigations on the northern sandplain also identified how easily recompaction can occur on deep-ripped sands.

The introduction of knockdown herbicides in the 1980s allowed for the adoption of minimum till and this, combined with heavier farm machinery, resulted in subsoil compaction becoming a serious yield constraint.

At Merredin Research Station in the 1980s, the importance of managing stock on wet soils to limit surface soil compaction was identified (Fitzpatrick 2009). Since the 1990s, attention has focused on CTF and breaking the hardpans through mechanical tillage, by deep ripping and deep working knife points.

At Mullewa in 1997, a large-scale farm trial to compare current cropping equipment with CTF was established. Over four seasons, this trial assessed and quantified the grain yield and quality benefits, input reduction and fuel-saving benefits of CTF after deep ripping of compacted sand. The results of this work, further on-farm trials and grower tours encouraged numerous WA growers to adopt CTF.

Trials have shown additional benefits from CTF over time, including increased nutrient supply from biological activity (especially soil macrobiology), reduced fertiliser needs and increased efficiency of fertiliser use.

Disadvantages may include soil become looser at the surface — introducing problems for plant anchorage and mechanical responses to seeding equipment. Firming soil by strategic rolling is being investigated for such complications. Wheel-track sinkage and erosion also occur over time and need to be addressed.

#### **2.5.4 Estimated area affected by soil compaction**

About 14 million hectares is at risk of lost production due to soil compaction.

In 2008 an estimated 6.1 million hectares was at high risk of subsoil compaction and 8 million hectares was at moderate risk (van Gool, Vernon & Runge 2008).

About 7.8 million hectares is at risk of soil structure decline. In 2008 an estimated 2.5 million hectares was at high risk and 5.3 million hectares was at moderate risk (van Gool, Vernon & Runge 2008).

#### **2.5.5 Estimated state-level annual cost of lost production (on-farm)**

The cost of lost production due to soil compaction was estimated at \$333 million for subsoil compaction and \$14.8 million for soil structure decline (Herbert 2009).

#### **2.5.6 Estimated state level annual off-site costs**

Costs are mostly contained within the farming property.

#### **2.5.7 Farm-level economics**

The adoption of CTF to prevent compaction can be financially beneficial which accounts for high levels of adoption. Deep ripping to remove hardpans can also be highly beneficial financially. Some farmers are successfully integrating mouldboard ploughing with establishing a CTF system. Once fully equipped for CTF, deep ripping can be used on soils that have received inversion tillage to loosen re-compacted soil and hardpans that were deeper than the inversion depth. The removal of hardpans will allow for greater benefits to be received from CTF.

- Using the Central Wheatbelt MIDAS at Merredin, using a wheat yield of 1.2t/ha, the payback period for CTF was estimated to be between 1.5 and 2.5 years where autosteer is already in use. When autosteer is not in use and is adopted, the time was halved due to reduced overlap. Benefits were estimated at \$36/ha (if autosteer is already in use) and \$45/ha if adopted as part of a CTF package. The optimal area of crop without CTF is 1500ha, with CTF it is 2000ha (Blackwell et al. 2013).
- Based on trials between compacted and non-compacted soils at Geraldton, the estimated cost of not controlling compaction in a 2t/ha crop was \$53/ha (Davies 2013)
- The Central Wheatbelt MIDAS showed that CTF increases farm profits, particularly in crop-dominant situations. For the standard MIDAS farm at Merredin, the difference between using and not using CTF in crops is 50% or \$76 000 annually. Benefits are primarily generated through increased grain yields and quality. The other contributor is cost savings from reduced inputs (Kingwell & Fuchsbichler 2011).
- The benefits of deep ripping and applying lime at the same time were investigated at Maya, in a trial established within a controlled traffic cropping system. The combination of deep ripping to 50cm and incorporating lime had a benefit of \$159/ha over the control three years after the treatments were applied. There was no immediate benefit with applying surface lime alone, although there was a benefit of \$60/ha over the control of deep ripping to 50cm (Davies et al. 2009).
- In another trial at Merredin, deep ripping increased gross margins by 25%, deep ripping plus nutrients by 36% and deep ripping plus nutrients plus gypsum by 67%. At Tammin, deep ripping increased gross margins by 7%, deep ripping plus nutrients by 25%, and deep ripping plus nutrients plus gypsum by 36% (Hamza & Penny 2006).
- On the Geraldton sandplains, farm modelling of CTF found an area of between 1000ha and 1500ha needs to be cropped to exceed the capital costs of the CTF system. If more costly autosteer needs to be adopted, it takes between 2500ha and 3000ha before the capital costs are exceeded (Webb et al. 2004).
- Also on the Geraldton sandplains, CTF increased canola yields by 110kg/ha, even with a poor seasonal finish. The trial showed an increased gross margin of \$30–40/ha (Blackwell 2001b).
- The costs of implementing CTF to reduce compaction are variable and in some instances can be high. The benefits of CTF are not just sustained improved yields after deep ripping but also the reduction of input costs and maintenance of the natural resource (Blackwell 2001a).

Farm-level economic analysis is very site specific and can be altered by a range of factors including season, soil type, market prices and management. The papers reviewed provide information for the site(s) investigated only. Broad generalisations should be made with caution.

### **2.5.8 Barriers to adoption**

Reasons why measures to overcome soil compaction have not been adopted may be due to:

- difficulty of diagnosis so that the problem remains unrecognised
- unaware of the cost of compaction in terms of lost productivity
- concerns about risks of deep ripping and longevity of benefits.

Reasons why adoption of CTF has not occurred may be due to (Kingwell & Fuchsbichler 2011):

- the significant number of poor years in the past decade reducing the farmer's capacity to borrow money for such expensive technology
- high capital cost weighed against uncertain yields
- more discernible entry costs than a possible benefit of, say, 7% increased yield (side-by-side comparisons on-farm are difficult)
- increased work involved in reallocating resources according to soil type or expanding the cropping area for maximum benefits
- difficulty in identifying dependable sources of information on CTF
  - concerns about weed control as header trails can concentrate weed seeds in the same place each year with CTF. Increased organic matter from straw in the header trails, if not spread evenly, may also tie up pre-emergent herbicides. Both problems can be addressed with strategic use of alternate harvesting tramlines depending on the season.

### **2.5.9 Technical feasibility**

Soil compaction can be ameliorated relatively easily by deep ripping or deep working knife points, although increasing depth of compaction may hamper complete removal of the constraint. Rapid re-compaction from subsequent traffic is an issue. Adoption of a fully matched CTF system may be more difficult at larger scales due to machinery constraints (e.g. 18m-wide seeders) and the level of investment required over a long period as equipment is replaced.

While existing options are highly appropriate for the majority of cropping areas, effective extension requires further demonstration of benefits. The benefits of removing compaction are immediate, but the benefits of prevention may take more time to accrue, especially on heavier textured soils. Overall, and particularly with good guidance systems and up-and-back seeding, the technical feasibility is good.

### **2.5.10 Potential for additional benefits from investment**

Improved diagnosis and identification of compaction has the potential to further reduce problems associated with the issue.

Effective management of compaction is lagging behind the management of some other soil constraints largely because it has gone undiagnosed. Adoption is likely to increase and better compaction management has the potential to make significant productivity gains over a very large area. Further innovation in effective amelioration of compaction is likely and may be expected to deliver additional benefits.

### **2.5.11 Other themes directly affected by this theme**

Soil compaction can increase the risk of wind and water erosion, nutrient export due to decreased plant growth, and dryland salinity.



**Table 4: On-farm management options for soil compaction**

Management option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/ reliability	Associated benefits/ drawbacks
Reduced vehicle pressure and loads	New machinery (potential cost)	Avoids treatment or extends time before treatment required	Reduces compaction – reducing pressure in tyres reduces surface compaction – reducing axle load reduces subsoil compaction and depth of compaction	All susceptible soils	High	May be feasible with small-scale multiple autonomous vehicles
Reduced traffic	New machinery to allow more than one operation on each pass (potential)	Extends time before treatment required	Reduces area compacted through fewer passes by combined treatments or wider equipment	All susceptible soils	High	Fuel savings
Controlled traffic	\$40 000 autosteer technology and equipment standardisation Cost of \$2000–\$10 000 for equipment standardisation alone	Extends time before treatment required once compaction has been removed. Allows structure of heavier textured soils to improve over time	Restricts compaction to dedicated wheel tracks	All susceptible soils	High	Less crop damage 3–10% reduction in inputs 5–15% increase in crop yield Increased longevity of deep ripping Improved traction in wet conditions Lower fuel use as wheels or tracks run on firm soil surface Increased nutrient supply from biological activity (especially soil macrobiology), reducing fertiliser needs and increasing fertiliser use efficiency Soil can become looser at the surface and introduce problems for plant anchorage and mechanical responses to seeding equipment (firming from strategic rolling is being investigated for such complications) Wheel-track sinkage and erosion over time often need to be addressed
Minimising stock grazing on wet susceptible soils	Small cost	Extends time before treatment required	Reduces surface compaction and damage to surface soil structure	All susceptible soils	High	Access to pasture restricted by soil conditions Difficulties in stock management if large areas of non-susceptible soil are unavailable
Longer pasture phases in rotation	Cost of establishing pasture phase Crop income forgone (potential)	Period of pasture	Improves soil structure and avoids subsoil compaction through less machinery	Higher rainfall coastal areas	Moderate	Increased risk of surface compaction
Deep ripping	\$40–50/ha + significant cost in time	3-4 years to at least 10 years, depending on soil characteristics and management. Benefits last much longer if combined with CTF Some sands self compact under wetting and drying	Breaks up layers of compacted soils Shallow tines or discs ahead of the deep ripping tines are important, if ripping below 30cm	Most beneficial on deep light sandy soils, although beneficial on most of WA's compacted soils	High	Soil may be more susceptible to compaction if not carefully managed Increased risk of haying off Increased risk of wind and water erosion Seeding into loosened soil more difficult Management needed to limit recompaction

**Table 4: On-farm management options for soil compaction (continued)**

Management option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/ reliability	Associated benefits/ drawbacks
Shallow ripping	\$250/tine (few \$/ha over cropping program)	Annual, if traffic is not controlled; longer if traffic is controlled	Using longer points on the seeder to dig deeper to about 15cm Can treat large area with a small change in productivity compared with deep ripping where a small area is treated for a large return	Suitable on most compacted soils	High (provided tine breakout is high enough)	Soil may be more susceptible to compaction if not carefully managed Increased risk of wind and water erosion Management needed to limit recompaction If compaction is very deep, production still will be limited by underlying compaction
Soil inversion	\$100–120/ha + significant cost in time	Lasts until recompacted through machinery movement Some sands self-compact under wetting and drying	Breaks up layers of compacted soils to a depth of 30–35cm	Deep sandy earths, pale deep sands and sandy gravels Should not be used on shallow duplex or soils with abundant rock or cemented gravel	High	Reduction of weed burden Incorporation of lime or clay or other soil amendments, although buried in layer and not mixed well Overcome soil water repellence Potential increase in wind and water erosion Difficulty of seeding into loose soil Exposure of toxic low pH soils Crusting and surface sealing if higher clay content subsoil is brought to the surface Management needed to limit recompaction and deeper compaction can remain below the ploughing depth.
Rotary spading	\$150/ha + significant cost in time	Lasts until recompaction through machinery movement  Some sands self-compact under wetting and drying	Breaks up layers of compacted soils to a depth of 25cm	Deep sandy earths, pale deep sands and sandy gravels Should not be used on shallow duplex or soils with abundant rock or cemented gravel	High	Incorporation of lime, clay or other soil amendments Reduction in weed burden Overcoming soil water repellence Increased risk of wind and water erosion Difficulty of seeding into loose soil Management needed to limit recompaction Deep compaction can remain below the depth of spading, which may need to be removed by deeper ripping.
Gypsum		Dependent on soil characteristics and management	Stabilises soil aggregation	Use on sodic soils Not effective on sand	Moderate	

## **2.6 Soil water repellence**

### **2.6.1 Description**

Water-repellent soils are unable to or are slow to absorb water, which simply pools on the surface or moves down 'preferred pathways' leaving large volumes of dry soil. Sandy soils with lower clay contents are more susceptible. The resistance to wetting is caused by the accumulation of waxy hydrophobic organic matter at the surface. Germination of plants in water repellent soil is often patchy and delayed. Incomplete wetting of the soil profile reduces the amount of plant available water that the soil can store which is an important driver of productivity and yield potential. Nutrients in dry soil are unavailable to the plant so 'dry patch' as a result of water repellence reduces nutrient availability and soil fertility (Carter et al. 2013).

### **2.6.2 Diagnosis**

The likelihood of water repellence can be diagnosed on-farm through observations of the following factors: dry patches after rainfall; patchy emergence of crops; staggered germinations of crops, pastures and weeds; poor weed control; slow and uneven water infiltration; increased run-off and uneven maturation of crops.

Water repellence is technically diagnosed via molarity of ethanol tests, although these are neither practical nor affordable for on-farm diagnosis. Water infiltration time on dry topsoil also can be used to diagnose repellence: an infiltration time of longer than 10 seconds indicates some repellence.

### **2.6.3 Historical context of research and development in Western Australia**

DAFWA began research on soil water repellence in the mid-1970s in partnership with UWA. By the early 1980s, work on water repellence had expanded and DAFWA had developed the soil wetter 'Wettasoil' in concert with the chemical industry.

The decade after 1990 was characterised by an increased focus on encouraging farmers to identify the problem of water repellence on their properties and to determine suitable treatment. Across the wheatbelt, researchers and farmers undertook evaluations of claying, liming, furrow sowing, and blanket and banded wetting agents. The main accomplishment of this early work was the development of short-lived surfactants that helped water infiltration while having a reduced effect on nutrient leaching.

While DAFWA continues to be the main researcher and extension agency for water repellence in WA, the department is entering more partnerships with universities and other scientific bodies such as the CSIRO. Research has led to improvements in banded wetting agents through the inclusion of water-retention compounds. In broadacre farming, wetting agents are typically applied as narrow bands on the seed rows to reduce cost through lower application rates. Water and nutrient-retaining compounds are added to some formulations to reduce the leaching effect of wetting agents. Some of these newer formulations are being used as blanket applications to

the whole soil surface with the aim of improving weed emergence and control as well as crop emergence.

Continuing research involves the following aspects: the physical and chemical basis of non-wetting; modified furrow sowing; precision seeding; alternatives to one-off deep cultivation (such as mouldboard ploughing); and other innovations that could result in improved returns from treatment of water-repellent soils.

#### **2.6.4 Estimated area affected**

About 10.2 million hectares of agricultural land in WA is affected by water repellence. In 2008 an estimated 3.3 million hectares was at high risk and 6.9 million hectares was at moderate risk (van Gool, Vernon & Runge 2008).

#### **2.6.5 Estimated state level annual cost of lost production (on-farm)**

The annual on-farm cost of lost production due to water repellence was estimated at \$250 million (Herbert 2009).

#### **2.6.6 Estimated state level annual off-site costs**

Costs are mostly contained within the farming property.

#### **2.6.7 Farm-level economics**

Existing management options can provide a relative financial advantage. Options such as rotary spading or mouldboard ploughing can provide additional benefits, including weed control or lime incorporation at depth.

- Managing for water repellence on a model 5000ha farm in the NAR (assuming 75% is cropped with an annual yield of 2t/ha and a grain price of \$280/t) produces the following results. In a good year, if water repellence is addressed with claying, mouldboarding or spading, it was estimated an additional 500t of grain is produced with an additional profit of \$25 000. If mitigation options such as wetters or improved furrow sowing are used, an additional 1500t of grain is produced with a profit of \$595 000. In a poor year, claying, mouldboarding or spading provides a gain of 125t of wheat with a loss of \$70 000, and using the wetters provides 375t of grain and \$33 000 profit. It is important to have a mix of different treatment options to maximise benefits in the long term (Blackwell et al. 2014).
- At East Eradu, the cost of mouldboard ploughing is \$80/ha with a payback period of 1 year (ABC 2013).
- Banded and blanket wetting agents were assessed for a farm at Badgingarra. The use of banded wetting agents on sandy and loamy gravels at a cost of \$7–12/ha produced benefits in improved establishment and yield. However, for blanket wetting agents, the cost of \$50/ha outweighed the benefits. One farmer purchased a paired-row seeder to replace a knife point seeder and fitted winged boots. The estimated whole-farm benefit in the first year was

calculated at \$19/ha for winged boots plus pair-rowed seeder and \$15/ha for mouldboard ploughing. Scaled up, the estimated benefits are \$77 000 over the 2300ha cropping program and \$54 000 for the 450ha of mouldboard ploughing (Davies et al. 2013).

- In a clay spreading experiment at Dalyup on the south coast, five to six years was needed for cumulative profitability at the high clay application rate of 200–300t/ha to exceed the cost of treatment. After eight years, there was a benefit of \$87/ha for 300t clay/ha and \$197/ha for 200t clay/ha benefit. Lower rates of application of 50–100t/ha were less profitable than no treatment after eight years. Deep ripping combined with claying had improved benefits at lower rates of clay application, with the additional benefits lasting around three years. The discounted returns of deep ripping and clay application were between minus \$40/ha and \$100/ha. Higher rates of clay application at 200t/ha had no additional benefits (Hall et al. 2010).
- Using the Central Wheatbelt MIDAS model, the benefits of ameliorating water repellence using a treatment costing \$10/ha was investigated at Merredin. A minimum increase in lupin yield of 30% and in wheat yield of 10% is needed before expenditure could be justified. The size of the area also affects whether treatment is justified. For example, it is better to put an affected area of 100ha on a 3000ha farm into continuous pasture rather than treat. However, there were no pasture penalties of water repellence in the model (Abadi Ghadim 2000).
- Using the South Coast MIDAS model claying was found to be the most profitable option for resolving water repellence on higher yielding soils. In more intensive cropping systems, returns are faster if 100t/ha of clay (at \$100/t) is applied. On lower yielding soils, wide furrow sowing with a press wheel was more profitable. However, the size of the area affected determines whether treatment should be applied. For wide furrow sowing with a press wheel, the yield increases would need to be sufficient to cover the upfront capital cost (Kopke & Blennerhassett 2000).
- The study investigated the break-even point of applying clay at a rate of 100t/ha at cost of \$100/t over 20 years for the south coast. The more intensive the cropping system, the faster it was to get a return on investment. For a system with one year of barley to seven years of pasture, it takes between 5 and 10 years to break even. A system that has five years of crop followed by three years of pasture, takes less than five years to break even (Carter & Hetherington 1998).

### **2.6.8 Barriers to adoption**

Management options vary in their technical complexity. Some practices fit easily into existing farming systems while others require a significant change. Agronomic benefits are quickly gained where establishment is significantly improved. Risk levels

also are variable for each option. The combination of multiple management options with various agronomic impacts, coupled with a variety of affected soil types and environments, can make the decision-making process complex. Small-scale on-farm testing is useful to help determine which options are most effective.

Barriers to the adoption of soil inversion, claying and rotary spading include (Davies 2014):

- high cost
- difficulty in identifying suitable subsoil clay, shallow enough to make excavation, spreading, delving or spading viable
- claying adoption has generally been lower in the NAR than it has on the south-coast. This appears to be related to some poor results in the region due to the use of high subsoil application rates and poor incorporation. Higher temperatures and shorter seasons in the northern part of the region may make the technique less suitable given the need to minimise evaporation
- complications such as difficulty in seeding disturbed soils, the risk of wind erosion, the risk of bringing to the surface highly acidic or toxic subsoil, and the possibility of recompaction
- establishment problems on some soils that cannot be explained by seeding depth; canola is particularly affected. Interactions with pre-emergent herbicides, poor seed to soil contact, lack of soil fertility in inverted subsoil, acidic pH, lower soil temperatures, surface crusting and inverting to the surface a layer of large gravel stones have all been suggested as possible factors
- adoption of rotary spading and soil inversion, particularly in the NAR, has increased recently. Rotary spading and soil inversion cost less than claying and both have prolonged water-repellence benefits and other agronomic benefits that include weed suppression and the opportunity to incorporate soil amendments such as lime
- the adoption of mouldboard ploughing has increased in the NAR. This can be partly explained by three factors: its suitability to the region; its ability to address more than one soil and agronomic constraint, particularly control of herbicide resistant weeds, and finally the presence of some local champions in the area

Barriers to the use of wetting agents and modified seeding equipment include (Davies 2014):

- lack of confidence in the product, with the perceived effectiveness being variable both for growers and researchers. There is an ongoing need to develop and improve understanding of the technology, when and where it is most effective, and other associated opportunities

- need for annual treatment, making it another cost associated with seeding a crop
- an additional liquid system at seeding that needs to be monitored and filled, and nozzles at the back of the bar behind the press wheels can be prone to damage. Therefore some growers perceive the technology to be an additional complication at seeding
- differences in soil type and rainfall. Banded wetting agents are likely to be more viable on the loamy 'forest gravels' of the south-west where some of the other tools are less suited. The south-west has a slightly higher adoption rate due to higher and more consistent rainfall, which makes some treatments more effective. Some of the blanket applied wetting agents generally work best on specific soil types and the response can vary depending on post-application rainfall patterns.
- combined, these barriers have constrained the use of banded wetting agent adoption to less than 5% of growers in the NAR, the Central Agricultural Region (CAR) and the Southern Agricultural Region (SAR).
- underdeveloped technology. Modifying seeding equipment to improve the effectiveness of furrow sowing is a developing technology with many options still being researched. However, adoption of these technologies is increasing as manufacturers begin to provide more options for growers to modify their seeding equipment, and as support grows for narrower row spacing, and paired and ribbon seeding to increase crop competition with weeds.

The following findings also may influence the uptake of specific practices to manage water-repellent soils:

- differences in area of application can make a large difference to annual improvements in farm profit. Claying a 500ha area for a 50% yield increase may not provide as much profit as cropping an area of 6000ha with improved seeding equipment and a 10% yield increase. Amelioration options are more likely to give large production improvements (50% or more) over smaller areas while mitigation options may only provide small production improvements (10% or less) over larger areas.
- adoption rates of the different treatments depend on the scale and pattern of water repellence on the farm. For instance, all the cropping area on a farm could be water repellent, or there could be smaller patches of water repellence within a paddock. The treatment chosen depends on the scale of the problem and cost of the alternative treatments.
- multiple management options across multiple soil types and environments can complicate extension messages and the adoption decision.

### **2.6.9 Technical feasibility**

Several options exist to treat water repellence effectively, although some specific soil type interactions remain unclear. In addition, banded soil wetting agents, on-row seeding and mouldboard ploughing can be technically challenging to implement.

### **2.6.10 Potential for additional benefits from investment**

Overall, 38% of agricultural soils are at moderate-to-high risk of water repellence and growers believe the problem is getting worse. Expression of water repellence is likely to be increasing as a result of:

- smaller and less frequent break of season rainfall events
- long-term use of nil and minimum tillage with minimal soil mixing and concentration of organic matter and associated waxes at the surface
- common use of narrow knife points for seeding (narrow knife points do not grade repellent soil out of the furrow as much as winged-points)
- increased frequency of dry seeding
- higher organic matter inputs as a result of improved productivity

Nevertheless, a significant number of farmers could benefit from adoption of practices to reduce the impact of water repellence.

Water repellence has been researched for some time and recent innovations in treatment are providing benefits at relatively low cost. Existing options could be further developed, effects on associated agronomic issues could be better understood, and interactions between specific soil types could be better defined.

### **2.6.11 Other themes directly affected by this theme**

Water repellence can increase the risk of water and wind erosion, reduce SOC and increase nutrient transport primarily due to higher leaching associated with preferential and bypass flow coupled with increased erosion.



**Table 5: On-farm management options for soil water repellence**

Management option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/reliability	Associated benefits/drawbacks
Improved furrow sowing	Cost of winged points or boots, press wheels	Short term (months)	Grading of repellent soil into ridges Water harvesting Reduced flow of repellent soil into the furrow	All locations (most effective on deep sands, sandy duplex and sandy gravel soils) but some seeding systems are less suitable for heavier textured or rocky soils which do not exhibit repellence.	Good	Water harvesting Potential nutrient leaching from higher water infiltration Excellent for establishment of perennial grass pastures in the NAR
Banded wetting agent	\$10–12/ha/year New press wheels may be needed	Short term (months)	Aids water penetration into furrow base Can reduce yield by increased leaching and reduced water retention in topsoil	All locations and soil types	Low to good, depending on season, effective application and timing of application in relation to rainfall	Water harvesting Some formulations have water- and nutrient retention compounds Potential nutrient leaching from higher water infiltration unless retention compounds are included in the formulation
Blanket wetting agent +/- water adsorber	Typically \$25–50/ha/yr, depending on rate	Short term (1–2 years)	Aids water penetration and retention in topsoil	Forest loamy gravels and firmer soils with some clay content with current formulations	Low to good, depending on season and soil type	Can help weed management through uniform germination
Precision seeding (on-row)	Possibly disc openers or coulters and more precise autosteer	Ongoing	Water entry via remnant root pathways	All soil types but best on higher rainfall, longer season areas	Good	Improved crop establishment and increased SOC Requires effective stubble handling
Rotary spading	\$150/ha; often deep ripping is needed before spading at a cost of \$40-50/ha.	3–7 years	Soil heterogeneity from subsoil seams lifted by spades to the surface provides pathways for water entry	Deep sandy earths, pale deep sands, deep sandy duplexes and sandy gravels Not suitable for soils with abundant rock or cemented gravel Caution for soil inversion with a mouldboard or square plough of sandy earths with very acidic subsoils or shallow duplex soils where too much clay can be brought to the surface	High on suitable soils	Incorporation of lime, clay or other soil amendments Reduction in some broadleaf weeds but grass weeds can be stimulated. Improved herbicide efficacy Difficulty of seeding into loose soil High short-term erosion risk
Soil inversion (mouldboard plough)	\$100–120/ha	Up to 10 years or more	Inversion of wettable subsoil layer to the surface	Deep sandy earths, pale deep sands, deep sandy duplexes and sandy gravels Not suitable for soils with abundant rock or cemented gravel Caution for soil inversion with a mouldboard or square plough of sandy earths with very acidic subsoils or shallow duplex soils where too much clay can be brought to the surface	High on suitable soils	Reduction of weed burden Incorporation of lime, clay or other soil amendments Greatly increased risk of wind and water erosion in the short term until adequate soil cover is established Reduced herbicide use and increased efficacy Difficulty of seeding into loose soil Recompaction Exposure of toxic low pH subsoils
Clay spreading or clay delving	\$300–900/ha	Decades (some studies show benefits last for 30–40 years)	Higher soil surface area and clay content masks repellence	Pale deep sands, sandy duplexes and sandy gravels Not suited to warm shorter season environments due to competition for water and higher evaporative losses as a result of higher clay content	Excellent but only feasible where clays are suitable and shallow or where clay can be sourced nearby for spreading on deep sandy soils	Improper incorporation can seal the surface and increase water run-off and evaporative losses Water shortages during grain fill (haying off) Some subsoils can be highly alkaline and have significant levels of potassium, sulphur and other nutrients which can benefit crops. Some subsoils can have toxic levels of salt and boron or have high phosphorus retention
Perennial fodder shrubs, pastures or trees	Cost of establishment (perennial pastures \$100–150/ha)	For as long as the option remains in place	Establishes a perennial system that is less susceptible to water repellence once established	Soils (typically deep sandy clays) more susceptible to water repellence	High, although initial establishment can be challenging (especially on pale deep sands and poorer yellow deep sands)	Very effective control of wind and water erosion Effective and profitable use of perennial pastures would require good stock management Productivity gains largely driven by growth associated with summer rainfall

## **2.7 Dryland salinity**

### **2.7.1 Description**

Dryland salinity is the movement of salt to the land surface with rising groundwater. It occurs on land that is cleared of native vegetation and it causes the most widespread damage. Watertables rise as shallow-rooted crops and pastures replace deep-rooted perennials, bringing to the surface naturally stored salt. This salt accumulation at the surface reduces plant growth (Simons, George & Raper 2013).

In areas affected by dryland salinity, plant growth also may be affected by waterlogging. A highly antagonistic interaction between salinity and waterlogging affects the growth of most crop and pasture plants (Barrett-Lennard 2003; Barrett-Lennard & Shabala 2013).

Dryland salinity differs from 'transient' salinity which may result in crop losses in areas with moderate subsoil salinity but which have no shallow watertable influence.

### **2.7.2 Diagnosis**

Dryland salinity can be diagnosed on-farm by observing changes in growth and yield or in changes in composition of plant species, for instance, the loss of salt-sensitive species and their replacement with barley grass or samphire. There may be soil surface expression with a crust of salt and watertables will generally be less than 2m deep. These symptoms often are most obvious in low-lying parts of the landscape.

Salinity can be measured in the field by electromagnetic induction (i.e. using an EM38) or in the laboratory with a simple test using an Electrical Conductivity (EC) meter. Dryland salinity also may also be associated with other chemical changes in the soil such as elevated sodicity and micronutrient toxicities (e.g. boron).

### **2.7.3 Historical context of research and development in Western Australia**

Dryland salinity first came to public attention in the late 1890s when water supplies for Perth came under pressure. Regional water supplies were in many cases inadequate and, in some situations, were becoming saline. By the late 1930s, bituminised catchments were being suggested as a way to increase run-off and reduce salinisation of public water supplies. But dryland salinity was not recognised as a significant issue for agricultural land management until the 1940s (Bennett & McPherson 2002).

By the mid-1950s, the problem had become so severe that DAFWA was considered to have too few staff to provide farmers with advice. By now, the department was investigating many aspects of dryland salinity including: the entry of water into soil on salt patches and adjacent grass areas; water usage and soil moisture changes under various options such as crop, pasture or fallow; the occurrence of watertables where salt was a problem; and the relationship of dryland salinity to flooding and water movement from higher land (Bennett & McPherson 2002).

In 1956 the first salt land survey was published (Bennett & McPherson 2002). In the 1960s DAFWA and the CSIRO investigated options for saltland revegetation. Puccinella, Wimmera ryegrass, saltbush, bluebush and samphire were identified as potential salt-resilient fodder species.

By the late 1960s more than 70 dryland salinity demonstration sites had been established across the agricultural area of WA. The sites served as both an R&D tool with many insights on how to optimise pasture establishment gained, and as a demonstration tool to farmers who were able to see the potential benefits of revegetating saline land (Fitzpatrick 2009). The pace of work picked up and by 1970, 478 different plants had been identified as salt tolerant (Fitzpatrick 2009).

Interceptor banks (to divert surface water) were being discussed in the late 1970s as a potential option for managing salt-affected land, demonstration banks having been installed on Harry Wittington's farm at Brookton in the mid-1960s. Ultimately, trials showed that the banks (commonly referred to as WISALT banks) had little or no effect on salinity (Fitzpatrick 2009; Beresford et al. 2001), although they did appear in some cases to decrease the severity of waterlogging, and therefore the adverse interaction between salt and waterlogging.

Salinity also had become a public health issue after high salt levels were recorded in the regional integrated water supply system supplied by Wellington Dam (Beresford et al. 2001).

By the early 1980s, salinity had been categorically identified as one of the major environmental threats facing agricultural land. Significant political and financial attention shifted to salinity resulting in a substantial expansion of DAFWA's hydrological capacity and investigations.

Hydrological work during this period covered baseline data collection, mapping and groundwater modelling to improve understanding and enable advice to farmers faced with a growing number of proponents (groups or individuals) offering management options.

R&D focused on preventing the spread of salinity and, where possible, reclaiming affected land. Engineering options (such as pumps, siphons and deep drains); perennial pastures; inland aquaculture; profitably using salt-affected land; and commercial tree crops were all investigated and audited. Concurrent physiological studies demonstrated the importance of the interaction between salinity and waterlogging on plant growth and ion relations, and provided a plausible explanation for the effects that interceptor banks had on productivity in some situations.

In the late 1990s the focus shifted again, this time from prevention to adaptation. Modelling showed that significant increases in water use would be needed to manage and prevent salinity. Small plantings of commercial trees or deep-rooted perennials alone (often required on up to 10 times the area affected) were not going to be able to manage salinity (George & Bennett 2004) and a substantial increase in

capacity in the research areas of saltland agronomy and plant physiology was acquired.

Dryland salinity continued to be considered an issue requiring government attention through until about 2005, with research focused on plant-based options that allowed for the profitable use of saline-affected land. The \$1.4 billion National Action Plan for Salinity and Water Quality and CRC for Plant-Based Options for Dryland Salinity ('CRC Salinity') and subsequently the Future Farm Industries (FFI) CRC undertook considerable work.

The FFI CRC investigated better methods for assessing the severity of saltland based on analyses of indicator plants, the selection of superior lines of old man saltbush (with higher nutritive value and greater acceptability by sheep), development of messina (an annual pasture legume with superior salt and waterlogging tolerance), and the value of saltland revegetation in decreasing salt run-off. The development of the Saltland Genie website ([www.saltlandgenie.com](http://www.saltlandgenie.com)), which makes information available to farmers, is an important legacy of this period.

In later years, public funding was provided to protect significant public assets from dryland salinity.

Since the mid-2000s, however, work in salinity has been scaled back. This is due in part to a perception that climate change would stop the continuing encroachment of salinity and in part because it was considered that most management options have been identified; and further system development and adoption remained as the major impediments to implementation.

To date, climate change has neither allowed farmers to reclaim salt-affected land nor prevented the spread of salinity and, while it may have slowed the rate of expansion, seasonal variability and the carryover effects of clearing, will see encroachment for decades to come.

#### **2.7.4 Estimated area affected by dryland salinity**

More than one million hectares of agricultural land in the south-west of WA is severely affected by salt. About 2.8 – 4.5 million hectares have a high salinity hazard (Simons, George & Raper 2013).

#### **2.7.5 Estimated state level annual cost of lost production (on-farm)**

The annual cost of lost production of currently saline land was estimated at \$344 million (Herbert 2009). The Australian Dryland Salinity Assessment (2000) estimated the opportunity cost to agricultural land as \$80 million with a possible range of \$80–261 million. The total state level benefit of successfully managing salinity is estimated at \$667 million (George et al. 2005).

#### **2.7.6 Estimated state level annual off-site costs**

The total off-site costs of salinity are estimated to exceed on-farm costs (Simons, George & Raper 2013). In the Australian Dryland Salinity Assessment (2000), annual

off-site costs were estimated to be \$5 million for rural towns, \$505 million for roads repair and maintenance, \$11 million for railways repairs and maintenance, and \$63 million as an imputed cost of protecting 10% of affected areas of vegetation. This totals \$584 million, although the true cost is likely to be higher. For instance, the range given for the cost of protecting 10% of vegetation alone was between \$63 million and \$626 million. Other environmental costs are not included in this estimate.

The Salinity Investment Framework estimates the total cost of maintenance of salt-damaged rail and roads alone at \$22 million annually. If the area deemed at risk of salinity becomes affected; this sum increases to more than \$177 million (George et al. 2005).

Rising watertables that accompany dryland salinity also increase discharge into waterways. Such watertables often have a low pH, producing acidification of waterways, which also has a high off-farm environmental cost, especially when combined with discharge from engineering management options if water from drains is disposed of inappropriately (refer to acidification of inland waterways in the report card).

### **2.7.7 Farm-level economics**

About half of WA's salt-affected land is capable of supporting saltland pastures. The balance of the area is too severely affected for productive use and recovery would be cost prohibitive.

Sheep grazing on saltbushes should be provided with additional energy supplements such as hay, grain or high-quality annual understorey plants. Studies show that other options, such as commercial forestry and engineering solutions, are unlikely to be profitable.

Salt-tolerant crops on mildly affected saltland may allow for continued profitable cropping, although profits will likely be lower.

### **Overall**

A review of economic studies investigating options for salinity management and a series of case studies were undertaken to determine which options were most cost-effective (Kingwell 2003). The findings include:

- lucerne can be a profitable inclusion in farming systems.
- on the whole, no tree options are readily available.
- on-farm economic justification of drains is not strong.
- where land is already saline, the incorporation of saline pastures may be profitable.
- deep-rooted perennials boost farm profit, improve water management and, in some cases, remove or decrease the rate of spread of salinity.

### **Commercial farm forestry**

- In the Warren–Tone catchment, the net benefit of forestry over agriculture in a 500mm rainfall zone is \$339/ha and in a 700mm rainfall zone is \$369/ha. However, when the off-site benefits of water and costs of salinity are removed to isolate the on-farm benefit, the difference is about the same for the 500mm rainfall zone and for the 700mm rainfall zone at \$50/ha (George et al. 2012).
- The study used both the Eastern Wheatbelt (Merredin) and the Great Southern (Kojonup) MIDAS models to investigate the co-benefits of managing salinity with trees and gaining carbon credits. It found a carbon price of \$66/t would be needed for the Eastern Wheatbelt and \$45/t for the Great Southern for growing trees to be competitive against existing land uses. The inclusion of a salinity benefit reduced the required carbon price to \$61t and \$40/t respectively. The salinity management benefit is therefore small (Flugge & Abadi 2006).

### **Engineering options**

- Deep drains discharging into natural watercourses are the most cost-effective form of drain; however, they can incur unacceptable off-site environmental costs in the long term, unless supplemented with other control measures such as evaporation basins. Open, deep arterial drains are more expensive than levied banks due to the amount of earthworks required. Subcatchment evaporation basins are expensive. For low-cost options with medium-to-high benefits, such drains will likely break even. However, if medium costs and low benefits are assumed, the costs outweigh the benefits. Again, if disposal or treatment of the water is included, the costs outweigh the benefits (Ali & Filmer 2008).
- An analysis was undertaken using the STEP economic model into the profitability of using drains to manage salinity on a model farm in the Northern Wheatbelt. It is unlikely the use of drains to manage salinity will prove a financially viable option (Abrahams et al. 2004).

### **Productive use of saline land**

- Using the Central Wheatbelt MIDAS (Merredin), the benefits of fencing off saltland pastures to allow regeneration of native species compared to fencing and improving the pasture was investigated. Fencing alone has a benefit of \$15/ha. The additional benefit from improved pastures is small. If production is decreased by 10%, all benefits of fencing are eroded (Bathgate & Byrne 2007).
- A case study of a livestock farm in Lake Grace compared the profitability on untreated saline land with treated saline land. The 1800ha farm had 800ha of saline-affected land. The gross margin for untreated saline land is \$24/ha, and for treated land is \$76/ha (Land, Water and Wool 2004).

### **Perennial plant options**

- Economic Analyses using MIDAS modelling showed that improving the nutritive value (NV) of saltland pastures is much more important to the profitability of adoption than increasing biomass production (O’Connell et al. 2006).
- The paper shows that on-farm economics of using perennials compared to existing land uses are variable, and the appropriate policy response can only be targeted when other issues, such as responsiveness of the groundwater system to vegetation, potential input of salt from groundwater and the supply of fresh run-off, are taken into account (Ridley & Pannell 2005).
- Compared with infrastructure and biodiversity, agricultural land has relatively low value. Where profitable plant-based options are available, they should be used. Where they don’t exist, R&D should be undertaken to find a profitable alternative land use. Positive or neutral off-site and on-farm benefits to engineering options can be used if other options are not available (Ridley & Pannell 2005).

#### **2.7.8 Barriers to adoption**

Barriers to the productive use of saline land include (Bicknell 2012):

- costs of establishment
- low returns on investment.

Barriers to the adoption of perennial plant options to prevent salinisation include (Bicknell 2012):

- low profitability
- compatibility of the options with the current farming system
- forgone income from cropping
- establishment risk and costs
- lack of profitable low rainfall species and systems
- limited effect on watertables and recharge as a result of area sown.

Barriers to the adoption of commercial farm forestry include (Bicknell 2012):

- high establishment costs
- deferred payback times
- uncertain markets and unstable prices for wood
- concerns around separating land ownership from tree ownership
- need to learn new skills
- perceived social impacts

- lack of impact until area planted is greater than area at risk, or requires protection.

Barriers to the adoption of engineering options include (Bicknell 2012):

- significant planning, management, regulation
- variability of effectiveness
- off-site impacts from the highly saline or acid groundwater, or both
- effects of highly saline or acid groundwater, or both, on downstream neighbours or the environment
- prohibitive expense to treat or manage the groundwater
- governance and long-term commitment to maintain.

### **2.7.9 Technical feasibility**

It is technically feasible to locally recover land from salinity in most areas. However, options that are reliable, simple to implement and economically viable are limited. Options to gain productivity from saline land exist, although they can be expensive to implement relative to other on-farm decisions.

#### **2.7.10 Potential for additional benefits from investment**

Saltland agronomy and plants that allow for profitable use of saline land have the most potential. Further work to improve the nutritive value and productivity of saltland pastures could be expected to increase whole farm profitability. For instance, in August 2014 Australia's first high nutritive value saltbush species was released. Much salt-affected land remains untreated so some reasonable gains may be expected from continued RD&E in this area.

It also should be noted that while the recent dry period has slowed the rate of encroachment, dryland salinity continues to expand and will increase its rate of spread if wetter periods are experienced again. Between 2.8 million and 4.5 million hectares in the agricultural regions of WA are still developing shallow watertables, and this land is predominantly in highly productive valley floors. Retaining some productivity on this land would require further investigation and implementation of potential options, including high water-use systems and surface water management to reduce flooding risk and improve saltland crops and pastures. Surface water management is likely to be far cheaper to implement than soil drainage.

Research to increase productivity from soils prone to transient salinity, rather than dryland salinity, may provide reasonable gains. These soils occur in the eastern and northern wheatbelt of WA. They are all generally cropped and are considered least productive in dry years. It is hypothesised that the salt accumulated in the subsoils restricts growth in these years due to its comparatively higher concentration in the soil solution when soils dry.



### **2.7.11 Other themes directly affected by this theme**

The change to the water balance due to clearing results in decreased evapotranspiration (water loss) and increased recharge run-off and storage. Bare ground causes wind erosion; increased run-off causes water erosion. Shallow-rooted crops allow leaching of nutrients. Saline land results in an increased risk of wind and water erosion and, if untreated, up to a 10-fold increase in wash-off of nutrients and salts.

**Table 6: On-farm management options for dryland salinity**

Management Option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/reliability	Associated benefits/drawbacks
Productive use of saline land	Cost of enterprise	As long as the option remains in place	Using saline-affected areas for potentially profitable options such as feed (e.g. saltbush) for livestock or carbon farming	Marginal areas around saline areas	Reliable, if established in the right areas	Dryland salinity is not resolved, but can reduce spread or rate of spread Reduces risk of waterlogging, wind and water erosion
Perennial plant options to prevent salinisation	Cost of establishment (\$100-150/ha) Lost income from cropping on land allocated to perennials Income from perennials is driven by the profitability of the livestock enterprise. It is at best marginally profitable	Benefits retained for as long as perennials remain	Planting deep-rooted perennials can increase water use and reduce groundwater recharge	Medium- to high-rainfall areas Areas adjacent to saline land	Only protects the land on which it is located Little benefit to surrounds	Dryland salinity is not resolved Encroachment is slowed where perennials are planted Reduces risk of waterlogging, wind and water erosion
Farm forestry	Cost of trees and maintenance of trees	Benefits are retained while trees are in place	Planting trees for commercial forestry and/or carbon sequestration	Areas of relatively fresh groundwater, transmissive localised aquifers, and slopes greater than 4%	Only protects the land on which it is located Little benefit to surrounds	Diversified income Stabilisation of soil Livestock husbandry Potentially improved water quality Reduced waterlogging Carbon sequestration
Engineering solutions	High cost of engineering works	Benefits are retained while drains are in place			Low to moderate Limited benefits beyond the drain	Off-site impacts of drained water (often highly acidic or high in toxic metals)
Salt-tolerant crops	Cost of new seed	Annual	Allows for continued profitable cropping	Mildly affected saline areas	Low to moderate	Does not address the problem
Retirement of salt-affected land	Cost of fence (\$3500/km at contract rates)	Benefits are retained while land is excluded	Area is fenced and natural regeneration allowed to occur	Most successful when topsoil remains	High Regenerates well if fenced off and stock excluded	Reduces land degradation from salt accumulation Less salt washes downstream Reduced risk of wind and water erosion Increased biodiversity In the long term, can provide grazing land

## **2.8 Phosphorus – nutrient status and export**

### **2.8.1 Description**

Phosphorus (P) is an important nutrient for plant growth; without it, plants grow poorly or not at all. WA soils have historically been poor in P. However more recently, soil-testing programs have shown that a high proportion of agricultural soils of the south-west contain more than sufficient P due to annual re-application of fertiliser. This in turn contributes to a greater risk of off-site effects through nutrient export (Weaver & Summer 2013) and represents an economic opportunity to save money from P applications and use these funds more productively.

### **2.8.2 Diagnosis**

Phosphorus is part of the standard laboratory soil test for agricultural soils. The presence of P in waterways is tested through monitoring and laboratory nutrient testing.

### **2.8.3 Historical context of research and development in Western Australia**

Nutrient management has been the subject of a widespread intervention and extension program in WA from the late 1970s onwards. Considerable resources were used to define productivity responses to fertilisers in the 1980s and these were converted to a range of decision tools that, in some cases, continue to be used in extension today. Some of this information, however, is in need of review due to changes in farming practices and conditions and interactions with other factors. Phosphorus applications in high rainfall areas also were identified to have resulted in P in run-off, causing problems of water quality downstream.

### **2.8.4 Estimated area affected by phosphorous**

In the south-west agricultural area, on average, pasture soils contain 1.3 times as much P as is required for optimal production, and arable soils in the wheatbelt contain 1.6 times optimal levels (Weaver & Summers 2013) assuming no other constraints.

About 2.4 million hectares of agricultural land is at risk of P export. In 2008, 0.4 million hectares was estimated at extreme risk, 1.1 million hectares at very high risk and 0.9 million hectares at high risk of P export (van Gool, Vernon & Runge 2008).

### **2.8.5 Estimated state level annual on-farm cost of over application**

Assuming there are no other production constraints, the estimated annual value of over application of P is \$400 million (Weaver & Summers 2013). This figure will decline if fertilisation strategies are based on evidence from soil testing, and other constraints are addressed.

The findings of the Joint Government and Fertiliser Industry Working Party (2007) if scaled up for the whole south west of WA, gives a value of \$405 million.

### 2.8.6 Estimated state level annual off-site costs

The annual off-site costs of P export in the Peel–Harvey estuary and waterways were estimated at \$361 million (Peel–Harvey Catchment Council 2014). An estimated cost of eutrophication from agriculture in the south-west has not been derived.

### 2.8.7 Farm-level economics

Whole-farm nutrient mapping and targeted fertiliser application can be a cost-effective strategy to reduce excess P in the soil. In many instances, there is excess P in the soil and therefore P applications can be reduced. This will free up funds for use on other farm productivity constraints.

Phosphorus transport into waterways is a greater problem in high rainfall areas. A range of on-farm options is available to reduce P movement into waterways but, in many cases, the options have a lower economic benefit to the farmer compared to existing practice and therefore have not been sufficiently adopted.

- Phosphorus is often applied on areas that don't need it. An example is given where a P program costs \$33 000 for a farm, and yet based on soil testing only \$4 400 of P was needed. The unnecessary application of P is costing the farmer \$28 600. It is suggested that lime or potassium (K) could be applied to overcome soil acidity or K deficiency in many paddocks, providing yield benefits over the application of P. Some paddocks also may need sulphur (S) (Summers and Weaver 2013).
- A review of practices to reduce P transport was undertaken in Weaver et al. (2012). It showed that perennial pastures, fertiliser management and soil amendment all had positive cost benefits for farmers, with riparian buffers having a negative cost benefit. Fertiliser management and soil amendment were the most effective at reducing P transport.
- A model 400ha farm on the Swan Coastal Plain was used to investigate the benefits and costs of improved P management and low water soluble P. The case studies showed that improving P management by applying it to areas in need rather than across the whole farm gave benefits of around \$10 000. Where fertiliser management practices were implemented without understanding soil requirements, the loss incurred was \$11 000 (Joint Government and Fertiliser Industry Working Party 2007) which is a difference of \$21 000 between the two management strategies.
- The most widely adopted and subsidised practice for landholders to reduce nutrient transport is the use of riparian buffers, a vegetated area near a stream that partially protects the stream from the impact of adjacent land uses. However, they work much less effectively on sandy soils. In WA, published research has suggested buffers do not reduce P transport on sandy soils where leaching and soluble P forms dominate (McKergow et al. 2003, McKergow et al. 2006ab, Weaver and Summers 2014). Other practices that

have been shown to reduce P transport, such as soil amendment and testing, have not been adopted to levels to make noticeable water quality improvements (Weaver et al. 2012).

- It is not profitable to apply P to the soil unless the crop or pasture needs it (Bolland 2010).

### **2.8.8 Barriers to adoption**

Barriers to evidenced based application of on-farm fertilisers include:

- long-term habits of applying P (Weaver & Summers 2013)
- perceived high financial and time costs associated with soil testing
- vested interests of recommendation by fertiliser companies.

Barriers to on-farm adoption of management strategies to prevent of off-farm P transport include:

- often significant costs incurred by individual farmers to change to lower nutrient transport practices compared with the cost to degraded waterways
- lower profits from some management practices to reduce nutrient transport compared with existing practices
- cost of some practices aiming solely to reduce P loss can be greater than production benefits accrued by the farmer

### **2.8.9 Technical feasibility**

Reducing the application rate of P is technically feasible because soil testing is readily available. However, consistent interpretation of results and consideration of offsite impacts requires training for all sectors involved in recommending fertilisers.

Soil amendment is feasible and requires further R&D to increase understanding, acceptance and adoption. The focus needs to move from problematic (but effective) by-products such as IronManGypsum®, Alkaloam®, LaBC®, to soil amendment with clay to improve nutrient management and reduce off-site impacts.

For off-farm issues, farmers have little incentive to implement management options that have no productive benefit to them, although there are a range of technically feasible options available.

### **2.8.10 Potential for additional benefits from investment**

There is potentially limited benefit from additional work regarding on-farm P management or banking. However, work on off-site effects has focused primarily on the Peel–Harvey catchment. Additional investment could increase the understanding of other catchments affected by nutrient loads.

Research into other areas aiming to reduce nutrient movement such as claying or the use of P by grass-based pastures compared to legumes could provide a greater suite of tools for on-farm management of off-site issues.

#### **2.8.11 Other themes directly affected by this theme**

Phosphorus banking and export in themselves are unlikely to increase the risk of another theme from the report card developing. However, amelioration of water-repellent soils has a positive interaction with improved P retention. Application of clay for water repellence improves P retention of soil, and application of wetting agents and clays increases the soil contact between dissolved P and the soil, potentially increasing P retention. Liming soil to reduce acidity can increase the availability of P in the soil and can reduce the need for P application. Measures to reduce erosion also may reduce P loss at sites where sloping clay soils carry P on clay particles to waterways.

**Table 7: On-farm management options for phosphorus – nutrient status and export**

Management Option	Approximate cost	Longevity	Mechanism	Suitable locations and soils	Likelihood of success/reliability	Associated benefits/drawbacks
Use soil tests to inform decisions	Based on a 30-paddock farm, ~ \$2500–3100 for the 1st year to develop whole farm nutrient maps	Annual	Provides a map of soil nutrient status Whole-farm nutrient mapping Optimise soil P levels on-farm, minimising off-farm P flow.	All	High	Allows for identification and treatment of other nutrient deficiencies or excesses
Effective fertiliser use	\$10/ha	Annual	Applying optimal fertiliser rates Accurate placement Split applications Not applying when heavy rains forecast Optimise soil P levels on-farm, minimising off-farm P flow	All locations	Moderate	Reduces cost to farmer Increases productivity
Use perennial pastures to increase water use and reduce erosion	\$100–150/ha for establishment	Annual	Deeper rooted perennials use more water and have lower P requirements	Medium- to high-rainfall areas Particularly areas prone to rapid run-off	Moderate	Can increase productivity, depending on farm However, likely to be less profitable than cropping
Vegetated buffers near waterways	Up to \$6000/km	Long term	Buffers reduce the off-farm nutrient load entering streams Vegetated buffers remove P attached to eroded soil	Areas close to streams	Low for sandy soils Moderate for hill slopes, draining loam and clay soils	Increased biodiversity Reduced sediment Increased aesthetics Increased farm value
Soil amendment (Alkaloam or clay)	\$70–280/ha	A long time (at least 10 years for nutrient retention and water repellence and many more for moisture retention)	Reduce movement of P off-farm An alkaline residue from bauxite processing with significant P retention properties Reduces P loss by 30–60% Claying is likely to have similar effects as well as improved soil wetting but at higher application rates than Alkaloam	Areas where dissolved P from farming moves into waterways and areas that are water repellent Usually higher rainfall sandy soils	High for sandy soils	Rapidly increased soil pH Increased plant growth Reduced non-wetting Improved water-holding capacity of the soil May need to increase rates of P application
Improve stock management around feedlots and sheds	\$75–100 per source	Annual	Management of manure and high P source areas on the farm	All	High	Improved animal health

### 3 Methodology

This report provides an overview of each theme against the criteria providing evidence for the ratings presented in Table 8. The characteristics explored through this exercise are the adoptability of management practices for each theme, the potential for additional benefits from investment, and the magnitude of the theme with respect to cost and area affected or at risk.

The ratings have been prepared using a panel of scientists from DAFWA to provide expert opinion on ratings for each theme. The magnitude and extent of the themes were defined using available published data. They are 'best estimates', given the knowledge and understanding at the time the report was prepared. The basis for calculating ratings is that they provide an indication of relativity between each theme. Understanding how the ratings were derived through reading the methodology will enhance interpretation of Table 8. It should be kept in mind that the ratings are high level, qualitative and consider only broadacre agriculture in the south-west of WA.

It is recommended those using information in this report also read the relevant theme chapters in the report card and consider other issues such as:

- identifying an appropriate investment decision framework
- determining the appropriate level of detail for costs and benefits suited to the level of the project investment.
- other issues affecting the natural resource base or other identified outcomes that are not covered in this report or the report card
- the whole system, as there are interactions between themes and management practices
- investigating and assessing the full range of options to manage the issue
- the possibility of unintended costs and benefits

#### 3.1 Adoptability of management practices

A significant body of published work identifies the factors that affect the adoption of innovation by farmers. A range of issues — including personal, economic and cultural factors — affects the adoption of one particular management practice over another. Characteristics of the practice, such as its relative advantage and trialability — also will affect adoption (Pannell et al. 2006).

Management practices that have greater benefits to the farmer than the existing system tend to be adopted more quickly and to greater extent (Pannell et al. 2006).

In Kuehne et al. (2011), the characteristics of an innovation are brought into a framework to develop a tool that predicts the adoptability of an agricultural innovation. The theory divides the issues that influence adoption into four categories.



Figure 1: The attributes of an innovation that influence adoption (Kuehne et al 2011, p. 7)

<b>Quadrant 1</b> <b>Population-specific influences on the ability to learn the innovation</b>	<b>Quadrant 3</b> <b>Relative advantage for the population</b>
<b>Quadrant 2</b> Learnability characteristics of the innovation	<b>Quadrant 4</b> Relative advantage of the innovation

Quadrants 1 and 2 influence how quickly the innovation is adopted, and quadrants 3 and 4 influence how long it takes for an innovation to be adopted and to what extent. Kuehne et al. (2011) take the theory and develop a tool called ADOPT (Adoption and Diffusion Outcome Prediction Tool), allowing users to identify the extent of adoption and the time taken until peak adoption is reached for an innovation. The tool is not used in this report due to its specificity to any new innovation and the level of social detail required.

However, the framework discussed in Kuehne et al. (2011) is used to develop broad criteria to assess adoptability of management options for each of the themes. The management practices are considered as a whole rather than individually.

Adoptability is explored through the criteria of farm-level economics, non-economic barriers to adoption, and technical feasibility. These criteria reveal characteristics according to the relative advantage of the management practices (farm-level economics and technical feasibility), and the learnability characteristics of the management practices (non-economic barriers to adoption). These are innovation-specific characteristics rather than how the innovation is perceived in general.

Due to time constraints social data information for the population perception quadrants 1 and 3 were not investigated. Only the attributes of the innovation itself are explored.

The panel was asked to rate each theme against each criteria and against the following characteristics: farm level economics, technical feasibility and non-economic barriers to adoption, explained in more detail below under each sub-heading. The approach was informed by the work of the Salinity Investment Framework for Agriculture (George et al. 2005, pp. 8–9).

**3.1.1 Farm-level economics**

Farm-level economics are driven by a range of factors including season, soil type, market prices and management and are therefore only approximations or indicators of on-farm costs or benefits. In general, however, some practices will be profitable for around 10% of affected farmers, whereas others might be profitable for 75% of

affected farmers. This criterion (farm-level economics) provides a qualitative assessment of the profitability of management practices for affected or at-risk farmers.

Each theme chapter provides an overview statement of farm economics and cites a selection of articles.

The questions considered were:

- Are the management options affordable?
- Do the practices offer a relative financial advantage over the existing system?
- What is the lag period until economic benefits are returned?
- For what proportion of affected or at risk farmers are the practices financially advantageous?
- What are the costs of inaction?

Numbers were assigned as follows according to the likely profitability of the practice for a proportion of farmers:

na	not available
1	Profitable for <10% of farmers
2	Profitable for 10–25% of farmers
3	Profitable for 25–50% of farmers
4	Profitable for 50–75% of farmers
5	Profitable for >75% of farmers

### **3.1.2 Technical feasibility**

Technical feasibility refers to the availability and capacity of management options to address the theme if the farmer is affected or at risk.

The questions considered were:

- Are available management options available and appropriate for different agricultural soil zones?
- Will implementation of land management practices lead to changes within a reasonable period?
- Has the practice been demonstrated as effective?

Numbers were assigned as follows according to the likely adoption of the practice:

na	not available
1	Very low (0.1)
2	Low (0.175)
3	Moderate (0.375)
4	Good (0.625)
5	Excellent (>0.75)

### 3.1.3 Non-economic barriers to adoption

Barriers to adoption are those issues that can stop the adoption of management practices that will manage the identified theme if the farmer is affected or at risk.

The questions considered were:

- Are the management options easily adopted (advice, support, regulations, existing skills, complexity of options)?
- Do the management practices easily fit into the current farming system?
- Do the practices have a high level of risk?
- What is the lag period until agronomic benefits are returned?

Numbers were assigned as follows according to the severity of barriers to adoption of the practice:

na	not available
1	very high barriers to adoption
2	high barriers to adoption
3	moderate barriers to adoption
4	low barriers to adoption
5	very low barriers to adoption

## 3.2 Potential for additional benefits from investment

Investors aim to maximise benefits for each dollar spent and to achieve efficient outcomes. For an investment to be considered, benefits should exceed costs.

The most effective economic tool to compare projects is a benefit–cost analysis (BCA) that gives a benefit–cost ratio (BCR) (Pannell 2008). Those with the highest BCR should be funded.

However, the scope of the themes raised within the report card makes the task of identifying projects with a good BCR extremely complex. Within each theme, a range of different projects could be funded with a range of different potential BCRs.

According to Pannell (2008), the BCR of a project is affected by:

- size of a project. If it is too small, some benefits may not be fully realised; if it is too big there may be diminishing marginal returns
- location or focus area of a project. Some areas are more affected by an environmental issue than others
- ability of the proposed project to affect the issue. In areas where only one constraint exists, the opportunity to improve production and environmental outcomes is greater than where multiple constraints need to be addressed
- providers of information. Available information can be used to determine funding but those providing the information into the analysis can either overestimate or underestimate costs and benefits

- type of project being undertaken. For instance, a project may include one or a mix of activities. In some instances, a decision to undertake no action could provide the best benefits
- length of time before a benefit is realised. It is recommended the period of analysis should not exceed 20 years.

Given the large range of potential projects and the complexity of analysis, it was considered not feasible to analyse the overall BCR for investment against each theme for this companion report.

In the absence of this information, the panel members were asked to estimate the potential for additional benefits from investment. This approach is both subjective and qualitative.

This criterion (potential for additional benefits from investment) considers each theme from a whole-of-state level. However, it should be noted that there could be multiple themes and multiple constraints present at any one time on any one piece of land. The presence of multiple constraints can influence the BCR of a project on a site and the order of treatment.

When determining where to invest, it is important to consider what benefits would be generated from additional investment from a funding body.

The questions considered were:

- Have adoption levels changed over time? Is it likely they will increase in the future?
- Is there a need or are there opportunities to develop innovations?

Numbers were assigned as follows according to the prospects of adoption:

na	not available
1	Very low
2	Low
3	Moderate
4	Good
5	Excellent

### **3.3 Extent and magnitude of the theme**

The extent to and magnitude of the theme was developed primarily through reviewing published papers and in some cases with expert opinion.

#### **3.3.1 Estimated state level on-farm costs**

The values used for on-farm costs are the opportunity costs of land degradation as defined by Herbert (2009) except in the case of SOC and P. P values were determined through other methodologies as outlined in the theme chapter. A value

for SOC is not provided as it underpins systems function rather than being a land degradation issue.

The Herbert report aims to identify the total cost of untreated land degradation in WA's South-West Agriculture Region. The values have not been updated for this document as for the majority of themes the estimates of extent and severity have not altered since the original Herbert work.

The analysis is undertaken by taking the value of agricultural production assuming land degradation is present and then subtracting the value of agricultural production assuming land degradation is not present. Each issue is analysed in isolation. The cost presented is a maximum, and provides only an indication of loss rather than actual loss. The relative differences between the values are more important than the values themselves. The analysis allows for comparison between the different forms of degradation.

Conclusions should, however, be cautious, bearing in mind that:

- The opportunity costs are maximums (and the methodology assumes each issue is the only one present).
- The opportunity costs are a snapshot in time (and no costs are attributed to future risks).
- No account is taken of the possibilities and costs of amelioration.
- Estimates used for the south-west region are ABARE benchmarks, while the other regions use Planfarm benchmarks.
- Opportunity costs are for agricultural production only.
- Production values are presented as 'operating surplus' (gross receipts minus operating expenses).
- Values are based on modelled estimates of area at risk/affected from van Gool, Vernon and Runge (2008) rather than actuals.

Numbers were assigned as follows according to the estimated cost of treatment:

na	not available
1	Very low (< \$50 million)
2	Low (\$50–200 million)
3	Moderate (\$200–350 million)
4	High (\$350–500 million)
5	Very high (>\$500 million)

### **3.3.2 Estimated state level off-farm costs**

Some of the issues identified in the report card incur off-site costs. Estimates of these costs have been identified through literature review where possible.

Numbers were assigned as follows according to estimated cost of projected off-farm investment figures:

- na not available
- 1 Very low (<\$50 million)
- 2 Low (\$50–200 million)
- 3 Moderate (\$200–350 million)
- 4 High (\$350–500 million)
- 5 Very high (>\$500 million)

### **3.3.3 Estimated area at moderate or higher risk, or area affected**

Areas affected or at risk have been estimated using soil type and landform data (van Gool, Vernon & Runge 2008). These figures also underpin the Herbert (2009) estimates for state level on-farm costs. Numbers were assigned as follows to show areas affected or at risk:

- na not available
- 1 <5% land is affected or at risk
- 2 5–15% land is affected or at risk
- 3 15–25% land is affected or at risk
- 4 25–35% land is affected or at risk
- 5 >35% land is affected or at risk

## 4 Results

### 4.1 Interpreting the results

Supporting information for the numbers in the table can be found under each theme chapter.

Although it may be tempting to add up the numbers in Table 8 and use these totals to rank the themes, we strongly advise against it. Investors will have different weightings for each criterion and may choose different criteria for decision making and assessment.

Table 8 allows for comparison between themes, as well as within themes. However, comparisons should be made with caution given the qualitative nature of the information provided.

It should be noted that the ratings in Table 8 are made at a state level. When reviewing the maps within the report card, it is clear that each theme is expressed differently, depending on location. Therefore, the ratings in Table 8 could change if an assessment was undertaken at a more localised level.

In addition, Table 8 considers each theme in isolation, but there could be multiple themes present at any one time on any one piece of land. The presence of multiple constraints can influence the BCR of a project as well as the order in which each theme is treated.

#### 4.1.1 Adoptability

From an on-farm perspective, all themes (except dryland salinity) have moderate to excellent adoptability.

Comparisons within a theme may show a lower score in one criterion compared to the others. The lower score may highlight an area where adoption is being constrained by a barrier and where further work could be undertaken. For instance, soil acidity has high technical feasibility and very good farm-level economics, but moderate non-economic barriers to adoption. Therefore, if investing in this theme a funder may consider identifying and reducing non-economic barriers to adoption.

However, it should be noted the assessment criteria do not investigate the human dimension of adoption. Adoptability of a practice is also reliant on these aspects.

**Table 8: Consensus expert opinion of each report card theme rated against the criteria**

Report card Theme	Criteria						
	Farm-level economics	Non-economic barriers to adoption	Technical feasibility	Potential for additional benefits from increased investment	Annual state level on-farm costs (est.)	Annual state level off-farm costs (est.)	Area affected/at risk
	Summary definition of numbers in table (each end of range)						
	1 Profitable for few 5 Profitable for most	1 Very high 5 Very low	1 Very low 5 Excellent	1 Very low 5 Excellent	1 Very low 5 Very high	1 Very low 5 Very high	1 small area 5 large area
Soil acidity	4	3	5	4	4	na	5 (affected)
Wind erosion	4	4	4	2	2	na	4 (at risk)
Water erosion	3	3	4	2	1	na	2 (at risk)
Soil organic carbon (SOC)	SOC not ranked as, unlike other themes, it is not a form of natural resource degradation or lost production outcome						
Soil compaction	3	3	4	4	3	na	5 (at risk)
Soil water repellence	3	3	4	4	3	na	5 (at risk)
Dryland salinity (current)	2	3	4	3	4	5	2 (affected)
Dryland salinity (future)	na	2	3	4	5 (if realised)	5 (if realised)	3 (affected and at risk)
Phosphorus status	4	4	4	4	4 <sup>†</sup>	na	5 (affected)
Phosphorus export	3	4	4	4	na	na	2 (at risk)

<sup>†</sup>This figure is estimated using a different methodology from the other values in this criterion. Comparison between the other themes within the same criterion should therefore be done with caution.



### **4.1.2 Potential for additional benefits from investment**

A low score against this criterion does not indicate investment in the area is not warranted; it indicates that a lower return on that investment may be expected if it is made.

According to the panel, the potential for additional benefits from investment for all themes is positive. Some are lower because of the already high uptake of management practices to reduce the risk or area affected. For instance, conservation agriculture practices have become standard practice in WA over the past two decades, significantly reducing the risk of wind erosion and the number and severity of wind erosion events.

When comparing soil acidity to an option such as wind erosion, the potential for additional investment is comparatively high, so it appears the more attractive option. However, as noted under the chapter on wind erosion, stopping all investment in wind erosion activities, particularly extension, could result in the issue falling from the attention of farmers and subsequently increase the risk of significant wind erosion events occurring in the future.

It should be kept in mind that individual projects will have their own BCR's that are dependent on a range of factors determined at a finer level (refer to Section 9.2).

### **4.1.3 Extent and magnitude of the themes**

The magnitude of on-farm costs is indicative of total lost production from the present constraint. It is not indicative of how easily an issue may be resolved, or the value that may be returned if the issue is resolved. Salinity is a good example. Salinity has a high on-farm cost, but the cost of recovery is often too high to evoke action. Consequently, adaptation or containment are generally the two most feasible options. Both of these will likely have a lower return than production from the land if it were unaffected. Therefore, even where action is undertaken, an opportunity cost will still be present, taking into account the lost production from the land if it were not saline.

When looking at the extent and magnitude of the themes, salinity also presents an interesting comparison to P status. Both have a relatively high on-farm cost, although the area affected by salinity is much smaller than the area affected by P status. The cost to farmers of losing one hectare to salinity is extremely high, yet over-application of P has a lower per hectare cost but occurs over a much greater area.

Themes with high off-farm costs and low on-farm costs may not have the required level of adoption needed to resolve the off-farm issues, depending on the cost of the management practice and the on-farm benefit returned. If action is taken on-farm with many of the benefits accrued off-farm and there is no or minimal advantage to the farmer, under-adoption is likely.

## **5 Conclusion**

The information in this report is presented at a state level, and therefore provides high level guidance. It is intended to be read in conjunction with the report card which gives a detailed summary of the trends for natural resource themes, which are considered the highest priority for the state. The metrics and ratings provided are a starting point or reference for discussion regarding investment decision making.

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