Guidelines to managing sandy soils across low-rainfall regions of south-eastern Australia

Practical strategies to optimise productivity, profitability and environmental sustainability

Grains industry and natural resource management working together

NRM Organisations · Production & Environment Partnerships · Grains Industry

Ag Excellence Alliance

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

Cover photos: (Main image) Ben White, (Insets: From top to bottom) Evan Collis, GRDC, Stephen Davies, DAFWA

Foreword

Up to 40 per cent (4.1 million hectares) of the broadacre farming area of South Australia has soil constraints that could be overcome through the application of new advances in technology, machinery and soil management. These constraints include non-wetting sands with low fertility and low water-holding capacity and heavier soils with poorly structured subsoils.*

The agricultural production challenges surrounding sandy soils are complex and interrelated. To view any one aspect in isolation risks failing to address the challenges as a whole. Management practices that aim to increase the overall water-holding capacity the of the soil resources and water use efficiency (WUE) of the farming system will deliver substantial increases in production while delivering key environmental benefits through reduced erosion and loss of valuable soil water and nutrients out of the production system.

Guidelines to managing sandy soils across low-rainfall regions of south-eastern Australia is a collection of current local trial data and grower experience. Included in the following pages are research findings from interstate, particularly Western Australia where extensive research has been carried out and growers have had many years of practical experience managing sandy soils. This publication endeavours to equip growers and advisors with the most up-to-date information to improve soil health, structure and productivity.

Special thanks to Lou Flohr, Mick Faulkner and Jeff Braun, Agrilink Agricultural Consultants (Aust) Pty Ltd for compiling this publication and Michael Moodie, Therese McBeath, Amanda Cook, Anna Butcher, Robert Pocock and Evan Hunt for their contributions. Also thanks to Catriona Nicholls for her editorial work, and to Megan Hele for her design and layout efforts; creating a publication that is a pleasure to read and provides a lasting legacy of the *Delivering multiple benefits messages — A partnership with NRM* project.

Mark Stanley
Executive Officer, Ag Excellence Alliance

*Source: Fraser M, Davenport D, Bartel B, and Wilhelm N (2016) *Overcoming constraints on sandy soils — amelioration strategies to boost crop production* GRDC Update paper.

Ag Excellence Alliance supports farming systems groups across south-eastern Australia, and providing linkages with natural resource management regions.

GRDC are the major funders of this project

Production and Environment Partnerships

Delivering multiple benefit messages — A partnership with NRM is an innovative project, which delivered technologies to growers across southern Australia, which have increased production and profitability while addressing key natural resource issues.

Working in partnership with seven natural resource management (NRM) regions, the project brought together the expertise of the grains industry with natural resource networks in these regions to extend the uptake of new and improved farming practices.

A significant part of the project was developing and delivering four regional extension and communication projects to address high-priority regional issues around integrated weed management (IWM) and the management of sandy soils.

It is a legacy of the sandy soils management projects carried out in partnership with the Eyre Peninsula NRM region — *Improving Production and Management on the Dune Swale Systems*, and the Murray Darling Basin NRM region and Mallee CMA — *Maximising the Productivity and Sustainability of sandy soils.*

Photo: GRDC

Photo: Sam Trengove,Trengove Consulting

Photo: GRDC

Guidelines to managing sandy soils across low-rainfall regions of south-eastern Australia

These ***Guidelines to managing sandy soils across low-rainfall regions of south-eastern Australia*** have been produced as part of the ***Delivering multiple benefit messages — A partnership with NRM*** project, with funding from the Grains Research and Development Corporation (GRDC).

More details can be found at **www.agex.org.au**

Compiled by Lou Flohr Agrilink Agricultural Consultants (Aust) Pty Ltd.

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Contents

Photo: Nigel Wilhelm, SARDI

Introduction

Key facts

- Sandy soils dominate the landscape across much of the low-rainfall regions of south-eastern Australia.
- The poor water-holding capacity of many sandy soils has both agricultural and natural resource management (NRM) implications.
- Successful management requires a thorough understanding of the complex interactions between sandy soils and the agricultural systems they are required to support.

Sandy soils are a dominant feature of the soil resource base in the low- to medium-rainfall cropping zone of south-eastern Australia. The poor water-holding capacity of sands is the major factor limiting yield potential and also impacts the natural resources across these south-eastern regions.

Sandy soils are particularly vulnerable to erosion, prone to water repellence and have a poor ability to hold water and nutrients in the root zone. These soils also are inefficient accumulators of soil organic matter (SOM), which results in high rates of carbon (C) being released into the atmosphere as carbon dioxide (CO_2).

Improving the water-holding capacity of sands enables crops to better access soil moisture, boosting dry matter (DM) production and significantly increasing grain yields. This has flow-on environmental benefits. Increased crop water use reduces the amount of recharge entering perched water tables, reducing the risk of seeps developing across the landscape. Greater crop biomass increases the level of ground cover, which is essential to reducing the risk of soil erosion.

A large gap currently exists between water-limited potential yield and actual yields on sandy soils in the low-rainfall cropping regions of south-eastern Australia. This publication aims to bring together current knowledge and best-practice management strategies to address the issues limiting the productivity and sustainability of sandy soils within the context of the whole farming system.

Grower consultation

The topics covered in the following nine chapters are based on consultation with industry experts and agronomists, as well as a small-scale survey of 22 growers. Of the growers surveyed, one third were from the Eyre Peninsula and two thirds from the Mallee and Upper South East. More than half the survey respondents reported that 20–40% of their farms comprised what they considered to be 'sand'.

The single most important issue related to sandy soils, identified by survey respondents, was water repellence, followed by inadequate fertility (soil nutrition). Erosion also polled highly as a major issue on sandy soils.

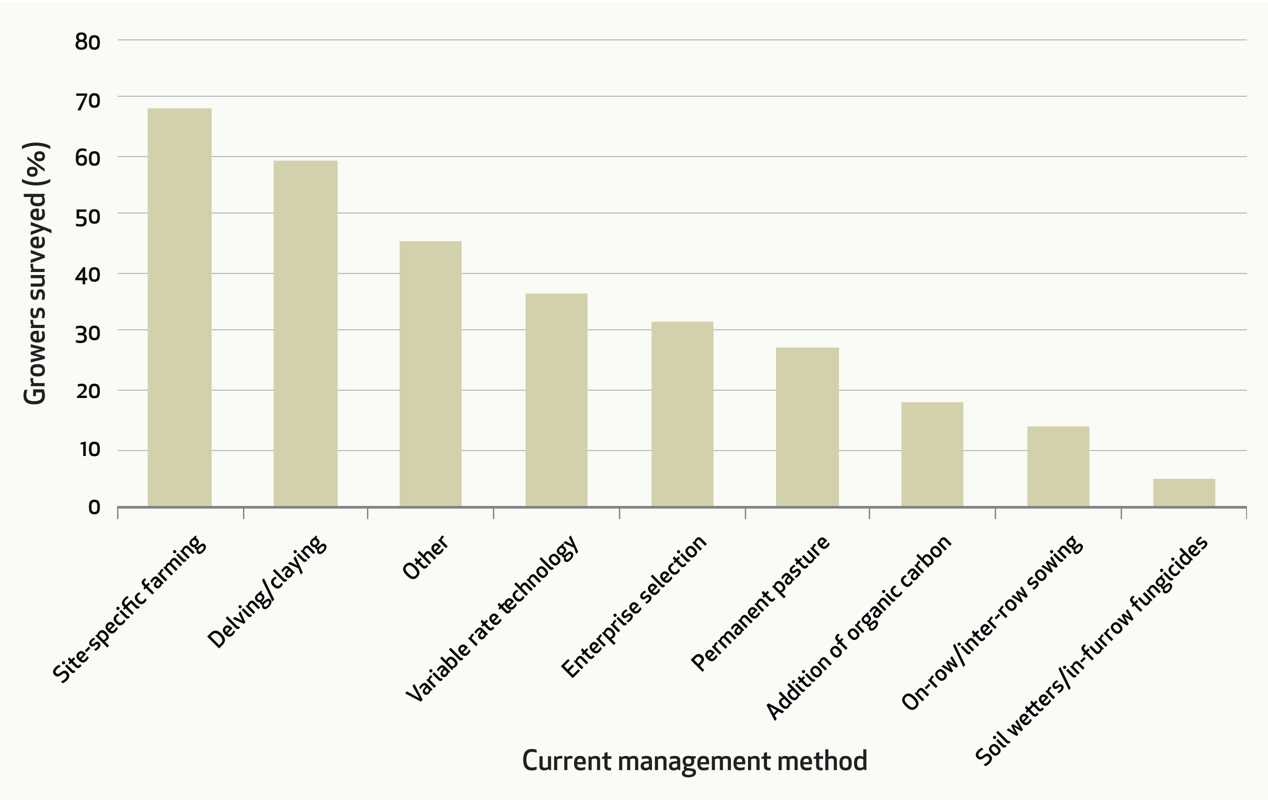
PREVIOUS PAGE: Strategies that protect fragile sands from erosion are critical for long-term sustainability and productivity. Photo: GRDC

ABOVE: Growers currently use strategies such as clay spreading and delving to lift production on sandy soils. Photo: SEPWA

Growers were asked about the strategies they employ to manage sandy soils. An overview of the range of strategies identified in the survey is outlined in Figure 1. In addition to the strategies listed in the survey, respondents identified a range of 'other' management strategies they use to improve the performance of sands, including mouldboard ploughing, delayed sowing to allow sandy soils to wet, fencing off sandy zones and sowing pastures as break crops, to name a few.

Soils are a foundational resource of every farm business and natural ecosystem. The preservation of soils is essential to sustain the profitability of farm businesses and the health and biodiversity of ecosystems. Management strategies that limit the risk of erosion, and therefore protect the soil surface from degradation, are critical to ensuring the long-term sustainability of low-rainfall farming systems for future generations.

Figure 1. Current grower practices employed to manage sandy soils across south-eastern South Australia



Source: Results of a grower survey carried out by Lou Flohr, Agrilink Agricultural Consultants (Aust) Pty Ltd during 2015

Sandy soils: an issue of size

Key facts

- Sandy soils represent about 30% of cropping soils across south-eastern Australia.
- Soils with a high sand content (and low clay content) are inherently low in fertility and their ability to store moisture.
- Management practices that boost the water-holding capacity of sandy soils will have a significant impact on crop water use efficiency (WUE) and subsequent crop and pasture productivity.

The size of the soil particle drives many of the issues associated with sands; either directly or indirectly. Sandy soils are characterised by a dominance of large, coarse particles and a low clay content (<5%).

Coarse-textured soils represent about 30% of cropping soils across the low-rainfall cropping regions of south-eastern Australia.

A typically-low clay content reduces the ability of sandy soils to physically protect organic matter (OM), resulting in its rapid decomposition and associated release of high rates of carbon (C) into the atmosphere as caron dioxide (CO_2), rather than being sequestered in the soil. This process is exacerbated by the low nutritional status of sandy soils.

Most of the challenges associated with agricultural production on sandy soils are linked to their inability to capture and store moisture. Improving the water-holding capacity of sandy soils will have associated benefits for agricultural production, including better water-use efficiency (WUE).

Water-holding capacity

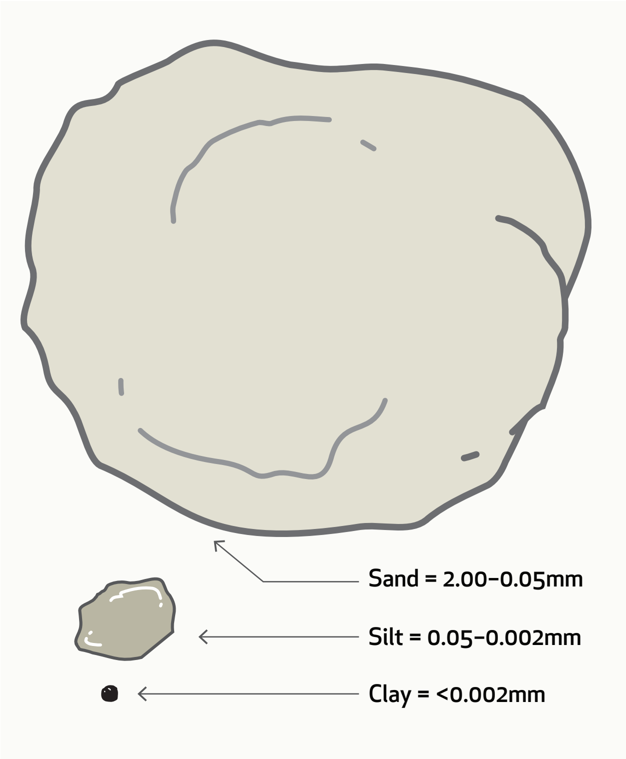
The water-holding capacity of a soil is directly related to the ratio of surface area to volume. While the surface area per grain of sand is large compared with clay, the surface area to volume ratio is far higher for clay (Figure 2).

As a result clays are better able to store rainfall as it soaks through the soil layers, while water rapidly passes through coarse-textured sands. Infiltration and drainage rates of >200mm per hour have been recorded for Mallee sands, which is at least double the rates for heavier-textured swale soils. A simulated rainfall event, equivalent to 125mm, on a Mallee sand showed that applied water had moved to a depth of 2m over four days and all of this moisture had drained below 2m after one week.

The actual speed at which water moves through the soil profile is directly related to the proportion of sand, silt and clay particles (known as soil texture). Consequently, crops in finer-textured soils (soils with a high clay content), which can capture and store water easily, do not need to root as deeply as those on coarse-textured soils (soils with a high proportion of sand) to access the same amount of water.

As a result, the opportunity to capture and store rainfall throughout the year on sandy soils is far lower than finer-

Figure 2. A comparison of sand, silt and clay particles



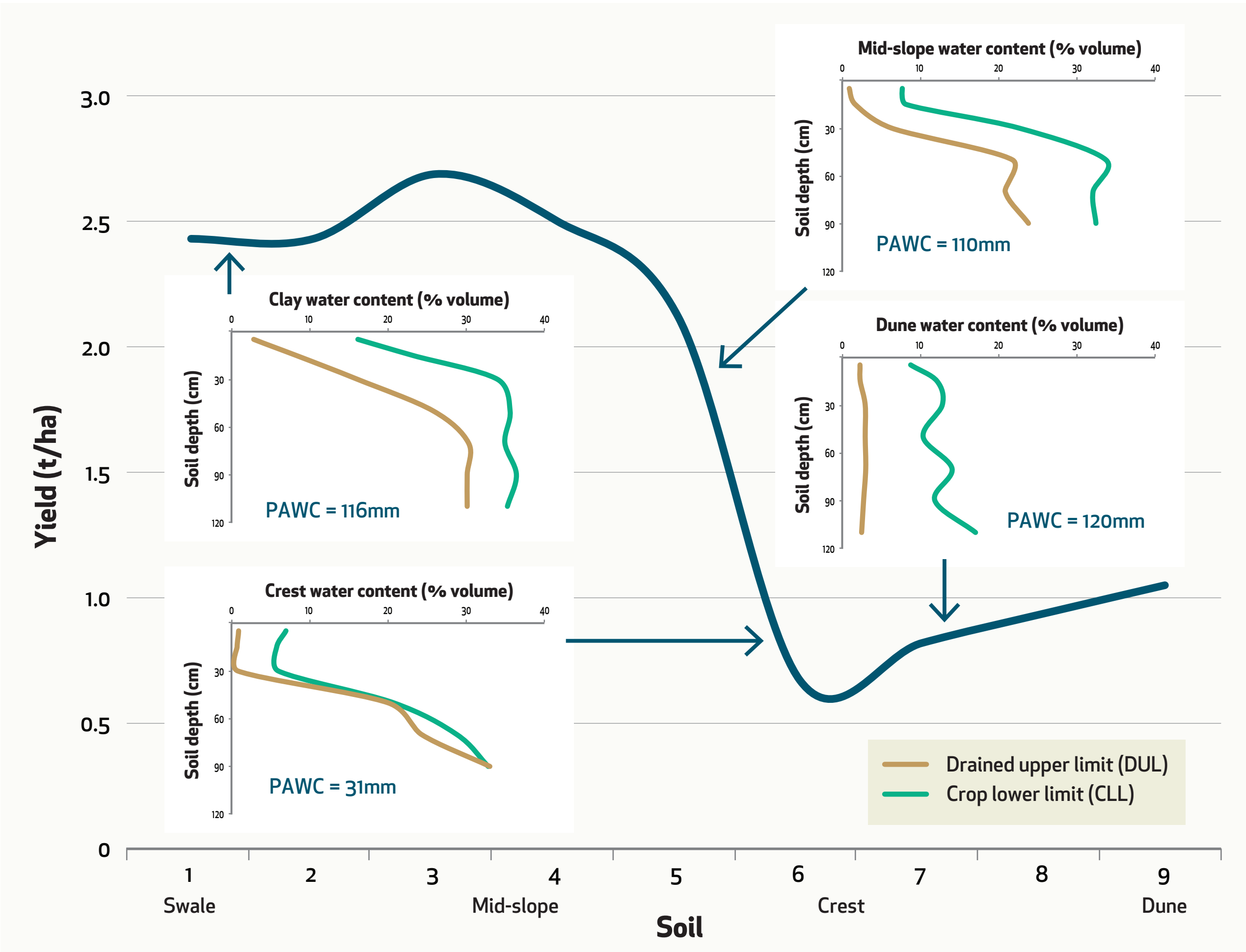
textured clay-based soils. For crops to reach their water-limited yield potential on sandy soils they require regular rainfall throughout the growing season.

Compounding the challenge of their inherently-low water-holding capacity is a bleached layer, which often occurs at variable depths within the profile of many sandy soils, restricting the roots of plants to penetrate and access moisture and nutrients at depth, further limiting the potential crop yield.

Mallee Sustainable Farming Project (MSF) data revealed that water extraction on a sandy rise was restricted to approximately 45cm at Karoonda, South Australia, whereas water extraction continued to at least 1m on the adjacent mid-slope and swale (which contained a higher proportion of clay). As a result, the potential plant-available water capacity (PAWC) for crops grown on the crest of the sandy rise was only 31mm compared with 116mm in the lower-lying swale (Figure 3). In a large rainfall event, the crest of the sand dune simply cannot store as much as the mid-slope or the swale for future crop growth.

However, in the absence of a bleached subsoil layer, crops growing on sandy soils can develop roots at depth, where they can extract moisture deeper in the profile. Crops on these soil types can outperform those on heavy clay soils, in seasons of low rainfall, where moisture is tightly held limiting the ability of plants to extract soil moisture.

Figure 3. A typical dune–swale system at Karoonda, SA showing the difference in plant available water capacity (PAWC) at four sites across the system



This theoretical supposition is supported by anectodal information local grower experience, where crops on sandy soils have produced higher yields during dry years compared with those grown on the swale.

The total water-holding capacity of any soil will depend on a range of factors, including water-repellence, soil OM levels, and chemical and physical subsoil constraints.

Growers can influence water-holding capacity through a range of management approaches, which are outlined in the following chapters.

Measuring soil moisture

Understanding the current water-holding capacity and soil moisture status at any given point during the growing season allows growers to develop management strategies to optimise crop production.

A range of soil moisture measuring technologies is available, including soil moisture probes.

Soil moisture probes provide a continuous reading of soil water in a visual format, allowing growers to understand what happens to soil water during the year, the rooting depth of the crop and the effects summer rain events and poor summer weed control can have on stored soil moisture.

A capacitance type probe with a data logger can cost about $5000 plus annual maintenance and a mobile network connection.

Water use efficiency

Ultimately, the opportunity to increase the productivity of sandy soils, and indeed any landscape, is to improve crop WUE. Water use efficiency is a measure of the capacity of a farming system to convert water stored in the soil and rainfall that falls throughout the growing season into plant biomass and/or grain.

The following formula provides a simple and useful way to calculate WUE for crop production efficiency:

TOP: In dry years, crops on sandy dunes can outperform those on the moisture-limited low-lying swales. Photo: Emma Leonard, GRDC

ABOVE: Soil moisture probes allows growers to better understand current soil moisture status, supporting proactive management. Photo: Alistair Lawson, GRDC

A complex challenge

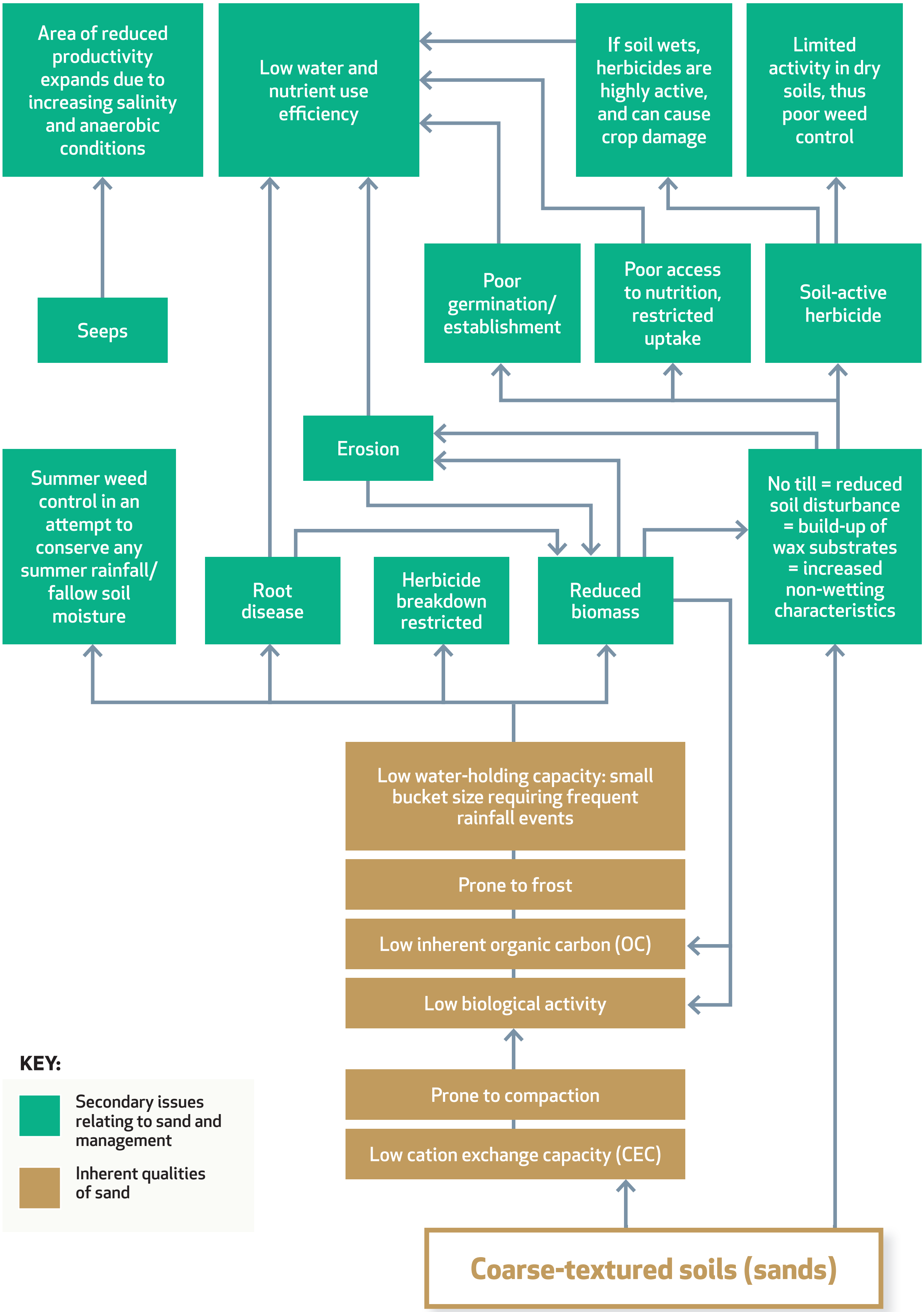
Looking at soil moisture in isolation can be misleading without understanding the complex range of factors that limit crop production.

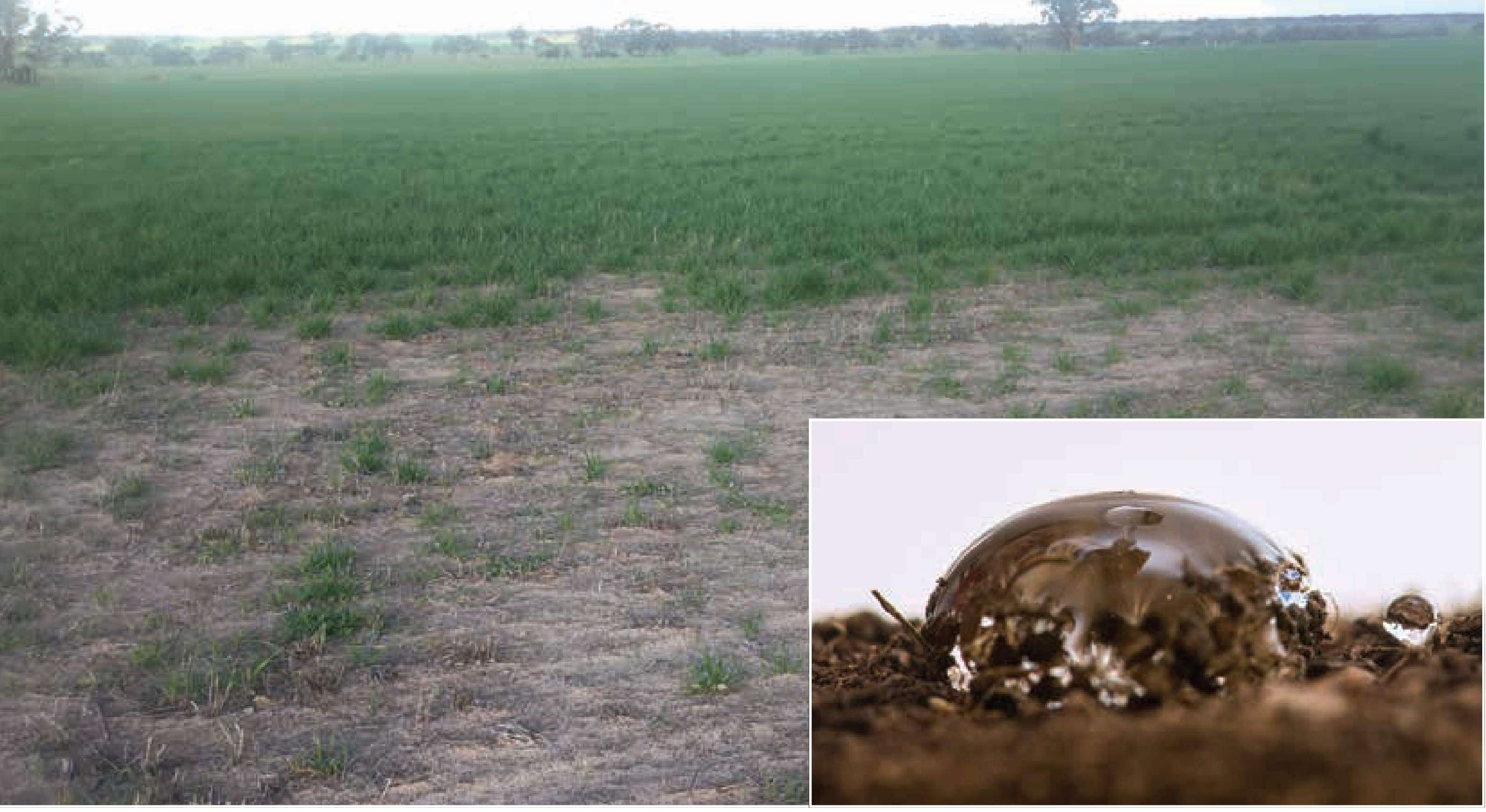
The agricultural production challenges surrounding sandy soils are complex and interrelated. Key to their management is to avoid viewing any one aspect in isolation. Doing this risks failing to address the challenges as a whole (Figure 4).

Growers can maximise productivity on sandy soils by understanding the challenges and developing a management strategy that addresses the key limiting factors, which may include: water repellence, soil fertility, weeds, pests and diseases, erosion, frost, seeps and subsurface compaction.

$$\text{Crop WUE kg/ha/mm} = \frac{\text{grain yield (t/ha)}}{\text{crop water supply (mm) — soil evaporation (mm)}}$$

Figure 4. The complexity of managing sandy soils





Managing water repellence proves critical for productivity on sandy soils

Key facts

- **Growers rate water repellence as the single biggest issue associated with sandy soils.**
- **Waxy compounds from plant matter cause water repellence in sandy soils — legumes induce greater repellence than cereal crops.**
- **A range of amelioration and mitigation strategies are available to address water repellence on sandy soils — growers need to assess which tools are likely to be most cost-effective for their situation.**

Water repellence is the key factor limiting productivity on sandy soils and it is the most difficult issue for growers to manage. More than two million hectares of farming land across South Australia alone are affected by water repellence.

While accurate figures are not available, research suggests that on average 40% of crop production is lost annually as a result of water-repellent (non-wetting) soils.

Water repellence explained

Water repellence is a natural condition, which is caused when waxy compounds from decaying plant material coat the surface of the soil particles resulting in uneven wetting of the soil.

Sandy soils (soils with less than 5% clay) are most vulnerable to water repellence due to their low surface area to volume ratio. The symptoms and severity of water repellence depend on the amount and distribution of rainfall and the land and soil temperature that determine the wetting-heating and drying (at the break of the season). The expression of water repellence varies considerably from year to year with seasonal conditions.

The amount of waxy compounds released into the soil depends upon the type and volume of organic material being broken down in the soil. This in turn determines the occurrence and impact of water repellence.

There is evidence that the breakdown of plant material from legume crop and pasture species affects the severity of water repellence. It follows that the adoption of no-till stubble retention (NTSR) systems, which result in greater levels of biomass on the soil surface, has contributed to larger volumes of waxy compounds entering the soil as stubble breaks down — further intensifying water repellence.

Interestingly, NTSR systems create both advantages and disadvantages for the development and impacts of water repellence. Surface soils under NTSR can be 1.5–40 times more repellent than soils under a conventional tillage system. On the other hand, standing stubble creates continuous and preferential pathways for water to move from the soil surface and through the profile. The reduced risk of erosion and the additional benefits of a NTSR system still make it the preferred management approach where water is the major limiting factor.

PREVIOUS PAGE: Estimates indicate that up to 40% of crop production is lost as a result of non-wetting soils. Photo: John Robertson, Agwise Services Pty Ltd (INSET): Evan Collis, Evan Collis Photography, WA

Table 1. Water infiltration test for water-repellent soils

Severity of water repellence	Time taken for water to disappear from the soil surface (seconds)
Not significant	<1
Very low	1–10
Low	10–50
Moderate	50–260
Severe	>260

Source: NSW, Department of Sustainable Natural Resources

Testing for water repellence

Water repellence is commonly limited to the topsoil. A common test for water repellence, and one that is relatively easy to conduct on farm, is the time taken for a water drop to disappear on the soil surface. The period of time taken for the drop to infiltrate the soil provides a guide on the severity of water repellence (Table 1).

Management options

There are two main options for managing water-repellent sands — amelioration and mitigation — and the most cost-effective option will depend on the scale of the issue and the suitability of options given the existing soil characteristics.

Amelioration

Amelioration strategies, such as clay spreading, clay delving or deep cultivation (exchanging subsoil with topsoil) change the properties of the surface soil and are generally expensive.

Amelioration often requires large-scale investment and carries both financial risks if unsuccessful and landscape risks, such as erosion, if poorly managed. Even considering the risks, amelioration strategies tend to be the most effective long-term options, given that, in general, a one-off capital expense can continue to deliver benefits lasting for up to 10 years.

Clay spreading

In 2000, Michelle Cann, PIRSA, estimated that 2 million hectares of land across SA was constrained by water repellence, leading to the wide adoption of clay spreading. It can provide long-lasting benefits (more than 30 years), with crop yields often doubling, when compared to the untreated area.

Spreading clay involves removing clay from the swale (lower-lying) area of the paddock and applying it to the water-repellent dune (rising) area of the paddock. Clay spreading is an option for deep sands (such as tenosols) where clay within the profile (depth dependent on the capacity of the delving equipment) cannot be accessed.

A clay content of at least 5% is required to alleviate water repellence, but an application of even 1–2% clay can reduce the effects of water repellence.

Clay spreading costs between $500 and $900/ha depending upon the clay content of the swale soil being used, the amount of clay required and the distance the clay needs to be carted from the pit to the site.

Water-repellence issues

Water repellence causes:

- staggered germination and crop establishment, and can in severe cases, completely prevent establishment
- staggered weed germination
- uneven wetting and soil moisture, reducing the efficacy of herbicides and impacting on weed control
- reduced nutrient availability, as dry conditions prevent the mineralisation and availability of nutrients
- poor crop or pasture establishment, reducing ground cover and exposing soils to the risk of erosion.

When considering clay spreading, keep in mind other constraints the clay source may have, such as a high lime content. High lime can restrict the availability of nutrients by increasing the soil pH.

It is important to thoroughly incorporate the added clay. If not effectively incorporated, the addition of clay can create new problems, such as impeded germination. The most effective tool for incorporating clay is a spader as thorough mixing can be achieved (contractor rates are approximately $150/ha).

Clay delving

Delving uses two, three or four tines (typically 20cm wide), angled at approximately 45 degrees and spaced about 1m apart, working the soil to a depth of about 60cm or more.

Delving is effective on duplex soils, where there is a contrast in texture (e.g. sodosols or chromosols). Delving breaks through the hard A–B horizon interface and redistributes the clay subsoil into the root zone.

This strategy reduces ponding of water at the A–B horizon and allows greater root penetration into the B horizon by disrupting compaction layers. After the delving process has been carried out, the paddock needs to be levelled and clay needs to be incorporated.

Deep cultivation

Diluting the non-wetting sand through the top 40cm of soil with deep cultivation is an effective way to reduce water repellence.

Options for deep cultivation include spading, one-way and mouldboard ploughing. The longevity of the impact depends on the level of mixing and the type and clay content of soil drawn into the non-wetting layer.

The major risk with any type of tillage is erosion, which needs to be considered before cultivating. Cultivating a soil when it is wet and establishing a vigorous cereal crop shortly afterwards will provide ground cover to reduce the risk of erosion. Anecdotal reports suggest wheat is better at withstanding damage from sand blasting than barley.

Grower-modified one-way plough proves cost-effective option for water-repellent sands

CASE STUDY

Ed and Evan Hunt, Wharminda, Eyre Peninsula, have avoided the high costs commonly associated with soil amelioration by modifying a one-way plough to invert their water-repellent topsoil, mixing it with wettable subsoil, while incorporating vetch as a source of biomass at the same time.

The Hunts were first introduced to the idea while visiting WA, where growers were converting one-way ploughs to mix non-wetting sands while incorporating lime.

"We decided to give it a go because it was a cheap alternative to other incorporation methods we had seen," Evan said.

"We are trialling the one-way plough to invert our non-wetting topsoils, mixing them with the more clay-rich subsoils, and are looking at using the strategy to incorporate some trace elements.

"We ploughed a small area during spring 2015 and the soil types varied from deep sand >80cm over clay back to sand 30cm over clay. In the shallower sand the plough was digging to 25–30cm. It was reaching the clay domes and bringing some clay up through the profile."

According to the Hunts the plough conversion was relatively cheap.

"We contacted AgPoint and they laser cut holes to fit the hubs on the 5 GP plough," Evan said. "There was about one day's labour involved and all up, including the cost of the plough, I would say the conversion cost about $7000–8000."

"During the conversion process we fitted 28 inch (71cm) fluted discs, so we can also use the machine for firebreaks etc."

Fine-tuning the process

Ed and Evan have found one of the downsides of the plough is only being able to work the paddock around, (i.e. not up and back). It can also be rough after ploughing and some levelling of ridges is required.

During 2016 the Hunts plan to try incorporating trace elements at depth to see if they can overcome some soil nutrient deficiencies.

"We are continuing trial work to determine whether it is a cost-effective option for reducing water repellence, but I think it will have a place in our cropping enterprise," Evan said.

For other growers looking to embark upon a similar modification the Hunts recommend buying a plough with enough lift to adapt bigger discs.

"We were limited to 28 inch (71cm) while still being able to transport it," Evan explained.

"If we had our time again, we would probably buy the hydraulic breakout 5 GP plough, to make sure it can stay as deep as possible with higher breakout pressure."

LEFT: The Hunts fitted 71cm fluted discs to their one-way plough, which supports multiple uses.

BELOW: A converted one-way plough is proving a successful tool for inverting non-wetting sands for Ed and Evan Hunt. Photos: Evan Hunt

Spading

GRDC-funded trials carried out by DAFWA in Western Australia during 2011 showed that spading increased the average grain yields by 0.6t/ha.

Spading combines a degree of soil inversion, with soil mixing, and like mouldboard ploughing it is most suited to deep sands (tenosols). The spader lifts columns of subsoil to the surface, which improves the wetting capacity of soils, creating a number of drainage pathways for water to move into the profile. Spading costs about $150/ha (contracting rates), with effects lasting 3–7 years. It can be carried out during late autumn before sowing.

ABOVE: Mouldboard ploughing creates a total inversion of the top 30–40cm of soil. Photo: Stephen Davies, DAFWA

Spading also is an effective method for incorporating clay and/or lime, which enables these amendments to be distributed throughout the cultivated layer.

As with mouldboard ploughing (discussed below), the risk of soil erosion following spading is worth considering. Spading when the soil is wet and immediately establishing a cereal crop will minimise the risk of erosion.

Mouldboard ploughing

The mouldboard plough, which fully inverts and buries the topsoil to 30–40cm, under a layer of wettable subsoil, has been a popular tool in WA to overcome water repellence. Mouldboard ploughing is suitable for soil types such as tenosols (deep sand) or a duplex soil with a deep A horizon.

The cost of mouldboard ploughing sits around $100–120/ha (contracting rates) and the benefits can last up to seven years, with some growers reporting benefits lasting up to 10 years. The longevity of the treatment can be extended if subsoils contain low levels of clay (i.e. 5%).

In addition to improving water infiltration, recent trial work carried out by DAFWA showed that mouldboard ploughing improves nutrient availability to crops. This is due to the fact that large volumes of unmodified soil remain dry, which results in plants being unable to access nutrients. When topsoils are buried using a mouldboard plough, and sufficient rainfall is received, crop roots penetrate the soil and access nutrients from the soil solution.

During 2007, in the longest continuously-running mouldboard plough trial established in WA, by DAFWA, on a mildly-repellent tenosol, cereal grain yield benefits of 0.2–0.4t/ha were measured for five consecutive seasons after mouldboard ploughing. However, no yield response has been measured in the years where lupins and canola have been grown.

Further DAFWA trials carried out during 2007 found the biomass of annual ryegrass (*Lolium rigidum*) was reduced by 75% in a trial where lime was incorporated with mouldboard ploughing. This reduction was due to weed seed burial and increased crop competition (by addressing acidic subsoils). The burial of weed seeds as a tool to tackle herbicide resistance has been a key motivation for the uptake of mouldboard ploughing in WA and is worth bearing in mind when considering mouldboard ploughing as an amelioration strategy on water-repellent soils.

Although the benefits are substantial, mouldboard ploughing significantly increases the risk of erosion in the year of ploughing. While there is no way to completely avoid this risk it can be minimised by only ploughing the soil when it is wet and by immediately sowing a cereal cover crop.

Mitigation

Mitigation strategies focus on reducing the effects of water-repellent soils and include the application of wetting agents, on-row sowing and liming. These options are generally less expensive than amelioration strategies, but will generally only provide limited and short-term benefits.

Wetting agents

Wetting agents (or wetters) reduce the surface tension of water at the soil surface, improving the infiltration and absorption of water on repellent soils. Both on-farm experience and recent research trials are inconclusive about the benefits of using wetting agents to improve the performance of water-repellent soils and subsequent crop yields.

If considering using wetting agents, research suggests optimal performance is likely to occur using a liquid application system to apply a continuous band of wetting agent at the base of the furrow.

On-row sowing

On-rowing sowing on water-repellent soils can effectively 'harvest' water into the furrow, maximising the impact of small rainfall events, by concentrating water into the plant root-zones.

Plant residue from a previous crop can persist well into the next growing season providing preferential pathways for water to move through the soil. Therefore the row of the previous crop often has more soil moisture compared with the inter-row space, and the likelihood of crop germination is improved by sowing into this zone.

Benefits of on-row sowing are most evident early during the season and during dry years, when crop emergence can be from 2–6 times greater with on-row sowing, compared with inter-row sowing.

On-row sowing can be achieved using RTK 2cm accuracy equipment, which is widely available.

CASE STUDY

ProTrakker® improves on-row sowing accuracy

Robert Pocock, Lameroo, South Australia

Robert Pocock, Lameroo, has improved the accuracy of his on-row system with a new implement guidance system.

ProTrakker is one of several commercially-available implement guidance systems, allowing operators to more easily control tail out and drift when the implement moves in the opposite direction of the pulling vehicle.

After seeing the concept working in WA on non-wetting soils Robert noticed the water-channelling effect on his non-wetting sands was similar those he saw in WA.

"Even if we hadn't sown the paddock for a few seasons, there was always better pasture establishment in the previous furrow," Robert said. "I tried to furrow sow with RTK 2cm accuracy for three seasons with limited success due to issues such as trash flow."

Robert, with financial assistance from the *Mallee Sustainable Farming Project*, invested $8000 in a Protrakker and $10,000 for electronics with existing RTK accuracy — the Protrakker required 2cm accuracy, therefore costs to upgrade to this system would also need to be included if not existing.

According to Robert, the biggest challenge with the new system was the set-up in the first season.

"No-one else in the district has a Protrakker, so we didn't have anyone we could ask when it came to troubleshooting," Robert explained. "There was a lot of fine tuning involved on the computer."

This season Robert will set the system on 'off-sets' that will allow continuous sowing without having to nudge the sowing rig at the start of each run.

In terms of sharing his experience, Robert remind growers it's not a silver bullet for outstanding yield results but precision guidance equipment, such as the Protrakker, helps get poorer country established on marginal moisture.

"I'm happy I went with this system instead of paddle steering at this stage as it works with windrow burning and grazed stubbles," Robert said.

To enhance his system, Robert is adding a liquid wetter system to help non-wetting issues and to aid with establishing pastures and crops.

"We are trying to use the least invasive concept and avoiding clay spreading and delving to overcome our water-repellence issues," Robert said.

LEFT: Robert (left) with Southern Precision director Grant Yates (right), and local growers. Photo: Stock Journal

ABOVE: An example of sowing inter-row on a water-repellent sand (left) vs on-row sowing (right). Previous year's stubble harvested water, allowing for improved germination in the on-row crop. Photo: Bill Davoren, CSIRO

Table 2. Grower-trialled strategies to reduce the water repellence of non-wetting soils

Mitigation option	Details	Grower experience
Increased sowing speed	Sowing at speeds of 5–10km/hr with knife points allows seed to be placed directly in the water-repellent band. Increasing speeds to 10–14km/hr can throw the non-wetting soil out of the furrow.	If considering faster sowing speeds, take care not to throw soil into the adjacent row, and be aware of the risk of chemical damage associated with this practice with certain herbicides.
Alterations to soil-engaging implement	In WA, DAFWA researchers found adding wings to a knife-point or sowing boot improved grain yield by 5–20% compared with knife-points without wings.	Unlikely to be effective when soils contain rock.
Increasing sowing rate	By increasing the number of seeds/m^2, the chance of placing seed in wetting sand is increased.	Variable results.
Adjusting sowing depth to reach moisture	Growers who can easily change their sowing depth can check where the moisture is sitting, and place seed accordingly.	Lupins are notoriously hard to establish on non-wetting sands, particularly when placed in a non-wetting band. They can germinate from 50mm below the soil surface, so chasing moisture at depth could be beneficial.
Sowing in front of a rain event	Growers will 'scratch in' or place seed close to the soil surface, creating a furrow and rely on water harvesting from the inter-row. This could work well with on-row sowing.	This can be fraught with danger in the event of a heavy rain event, exposing seed and risking seed then sitting on the soil surface.

While anecdotal evidence of improved yields with on-row sowing is compelling, the experimental data is inconclusive and in some trials on-row sowing to reduced yields. This is likely to be due to the higher disease levels associated with the practice. Cereal diseases, such as Rhizoctonia, crown rot and take-all, can survive on the crowns of the previous year's crops, and by sowing the new crop in such close proximity can allow these root diseases to re-infect the new crop (see pages 24–29).

While yield benefits from on-row sowing may be inconsistent, research results indicate on-row sowing can improve weed control. A CSIRO-led trial at Karoonda, SA during 2014 found on-row sowing reduced brome grass numbers and subsequent seed set by 79% when compared with inter-row sowing. It was suggested the brome grass seeds were concentrated along the bottom of the furrow and when sown on row the following year, the crop was able to out-compete the brome grass.

Liming

Growers in WA have observed reduced water repellence with the addition of lime. Laboratory testing and field demonstrations carried out by CSIRO in WA showed the addition of lime reduced water repellence by 1–3MED units. Field experiments indicated a two-phase effect of lime application. Initially, liming caused a rapid wetting of soils following the break of season compared with the untreated controls. This was followed by a steady decline in repellence during the wet winter months, with significantly greater improvements in wettability (at least 1.5 MED units) in limed treatments compared with non-limed controls.

Trials also have found a ten-fold increase in populations of wax-degrading bacteria in limed treatments compared with control treatments. This is likely to be due to either the nutritional requirement for calcium and/or the effects of increasing the soil pH to a level, which is more favourable for microbial activity.

Trials that quantify the effects of liming on water-repellent sands have not yet been validated for SA, but assuming the soil is acidic, it is likely these effects can be replicated.

A range of other mitigation strategies used by surveyed growers is outlined briefly in Table 2.

Further information

- **Spread, Delve, Spade, Invert: A best practice guide to the addition of clay to sandy soils (GRDC, 2011)**
  https://grdc.com.au/Resources/Bookshop/2011/09/Spread-delve-spade-invert
- **Sowing strategies to improve productivity on sandy Mallee soils**
  http://www.msfp.org.au/sowing-strategies-to-improve-productivity-on-sandy-mallee-soils
- **Overcoming constraints on sandy soils – amelioration strategies to boost crop production (MSFP, 2016)**
  http://www.msfp.org.au/overcoming-constraints-on-sandy-soils-amelioration-strategies-to-boost-crop-production
- **Developing and accessing agronomic strategies for water-repellent soils (GRDC, 2012)**
  https://grdc.com.au/Research-and-Development/Major-Initiatives/Non-wetting-soils/Developing-and-assessing-agronomic-strategies-for-water-repellent-soils
- **On-row seeding as a tool for management of water-repellent sands**
  http://www.agronomy2015.com.au/papers/agronomy2015final00178.pdf


Photo: GRDC

Addressing crop nutrition proves profitable on sandy soils

Key facts

- Sandy soils are naturally low in fertility and require regular fertiliser applications to support agricultural production.
- Where required, address the factors that most limit agricultural production, such as water-repellence and subsoil compaction, before embarking on a fertiliser program.
- Variable rate technology enables targeted application of fertiliser, which is more cost-effective than blanket fertiliser applications.

Sandy soils lack natural fertility and rely heavily on regular fertiliser applications to supply the nutrients required for optimal crop production. The low fertility of sandy soils is due to a combination of low organic matter (OM) levels and poor cation exchange capacity (CEC).

While sandy soils often lack adequate nutrients to support optimal crop growth, growers often question, wisely, whether applying fertiliser will result in higher productivity, when a complex combination of factors can limit crop potential on sandy soils. Growers often are unsure whether the cost of fertiliser will be repaid in an associated increase in crop productivity.

In many cases, to maximise nutrient use efficiency, growers first need to address water repellence issues (see pages 10–15) and subsoil compaction (see pages 42-44). Unless plant roots can penetrate the soil and access nutrients dissolved in the soil solution at depth then fertiliser applications are likely to be a waste of time and money.

However, when these constraints have been addressed, a strategic fertiliser program may be the next step towards boosting productivity and profitability on sandy soils.

Maximising the returns from fertiliser inputs requires a sound understanding of current soil nutrient status, other factors that may be limiting production and the nutrients required to deliver target yields across the range of crop types being sown.

The four major nutrients required by crops are: nitrogen (N), phosphorus (P), potassium (K) and sulphur (S). Plants also require a range of 'micro' nutrients, often referred to as trace elements including: zinc (Zn), copper (Cu) and manganese (Mn).

Nitrogen management

Nitrogen is the key nutrient driving crop and pasture productivity on sandy soils and can be supplied via nitrogen fixation (via legume crops or pastures), breakdown of OM in the soil, or nitrogen fertiliser. In the nitrate (plant available) form within the soil, nitrogen is highly soluble and is prone to leaching beyond the root zone in sandy soils.

Trials carried out by Mallee Sustainable Farming (MSF) Inc during 2015 at Karoonda, South Australia revealed that 40kg/ha of nitrogen (86kg urea/ha) applied at sowing produced the highest wheat yields and protein levels on sandy soils.

The uptake of nitrogen fertiliser applied at sowing was also far greater than when applied post crop emergence (around 50% recovery when applied at sowing, compared with 30% recovery when applied at stem elongation: GS30–GS40).

Grower feedback and anecdotal evidence indicates a rate of 40kg N/ha is higher than the commonly-used rate of 15kg N/ha. However, in these trials this higher rate of nitrogen increased the average net return by $136/ha and the additional investment in fertiliser delivered a return of 80 cents per dollar invested.

Increasing fertiliser rates to ensure crops grown on deep sands have an adequate supply of nitrogen also can increase the water use efficiency (WUE) by up to 91% compared with current district practice.

Variable rate technology

Soil types across a farm and even within paddocks can be highly variable. The use of variable rate technology (VRT), in combination with soil testing and paddock history, allows growers to better apply fertiliser at rates that match both crop and soil requirements.

The advantages of VRT are supported by trials carried out on the dune–swale systems of the Mallee, SA. Figure 5 shows the cumulative gross margin from 2009–15 for different nitrogen strategies at Karoonda, SA. High rates of nitrogen on the heavy soils cause the crop to hay-off, which lead to a decrease in yield. These trial results would indicate that reducing the rates of nitrogen applied to these areas and re-allocating nitrogen to areas that are low in clay (and nitrogen) would improve yields and the return on investment in fertiliser.

ABOVE: Legumes, such as lupins, add nitrogen to the soil and offer a critical disease break between cereal crops. Photo: Ruth Sommerville, UNFS

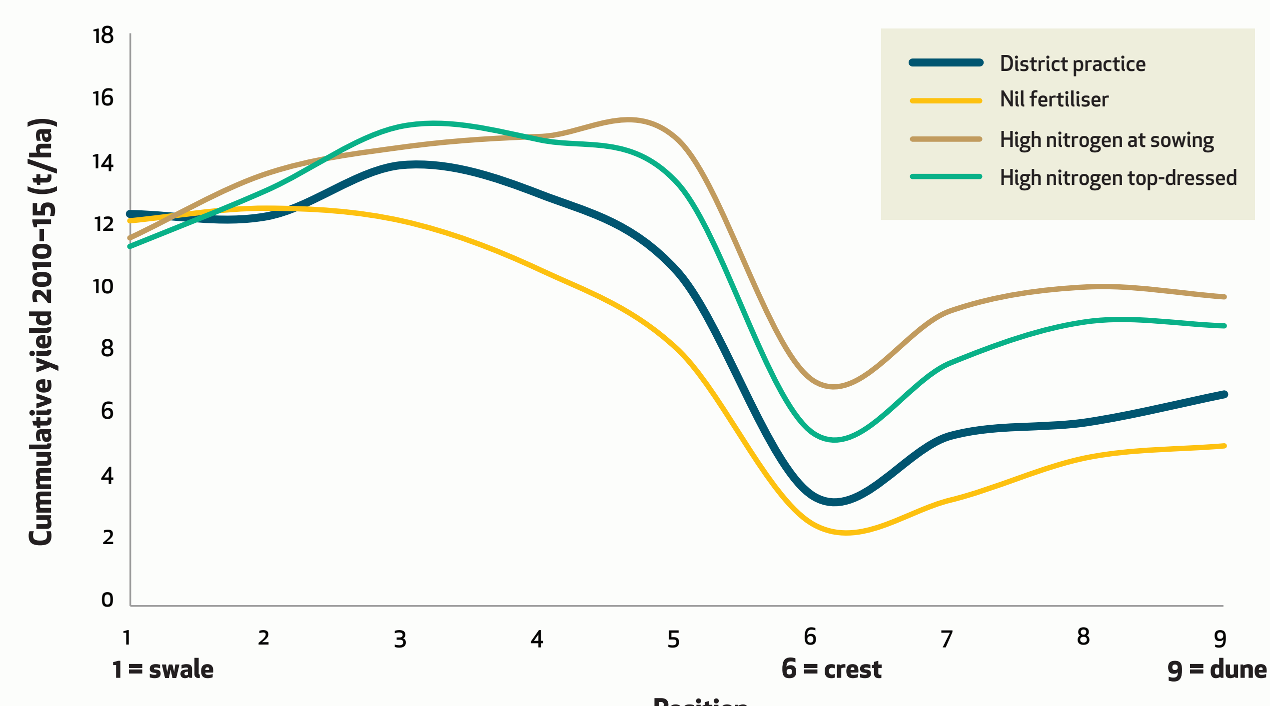
The role of legumes

Legumes play an important role in building soil nitrogen levels, as well as playing an important role in breaking the disease cycle and offering a broader range of weed control options.

When it comes to selecting a legume break crop, the best decision will depend on a range of factors. For example, in a mixed cropping and livestock system, a legume break crop may be a legume pasture, which may not have the same value in a cropping system as it does for an operation that includes livestock.

The inclusion of a non-cereal break, and even including a two-year break phase, can improve the accumulated yields of wheat by 1–2t/ha over the following two to three seasons. It can increase profitability by up to $100/ha/year for a four-year period when compared with continuous wheat.

Figure 5. Cumulative gross margin for the addition across nitrogen on a swale, mid-slope and dune system at Karoonda, SA 2009–15



Source: CSIRO, 2015

Yield Prophet – a tool to assist with nitrogen fertiliser decision making

Yield Prophet is an online production model designed to present growers with real-time information about the water and nitrogen use of their crops based on nitrogen and water measurements carried out at the start of the year.

Yield prophet can generate reports and assist management decisions, such as fertiliser applications and time of sowing. The modelling tool also can forecast yield based on historic yield data for a particular area, generate time of sowing reports, match inputs with the yield potential of a given crop, and manage scenarios based on weather forecasts.

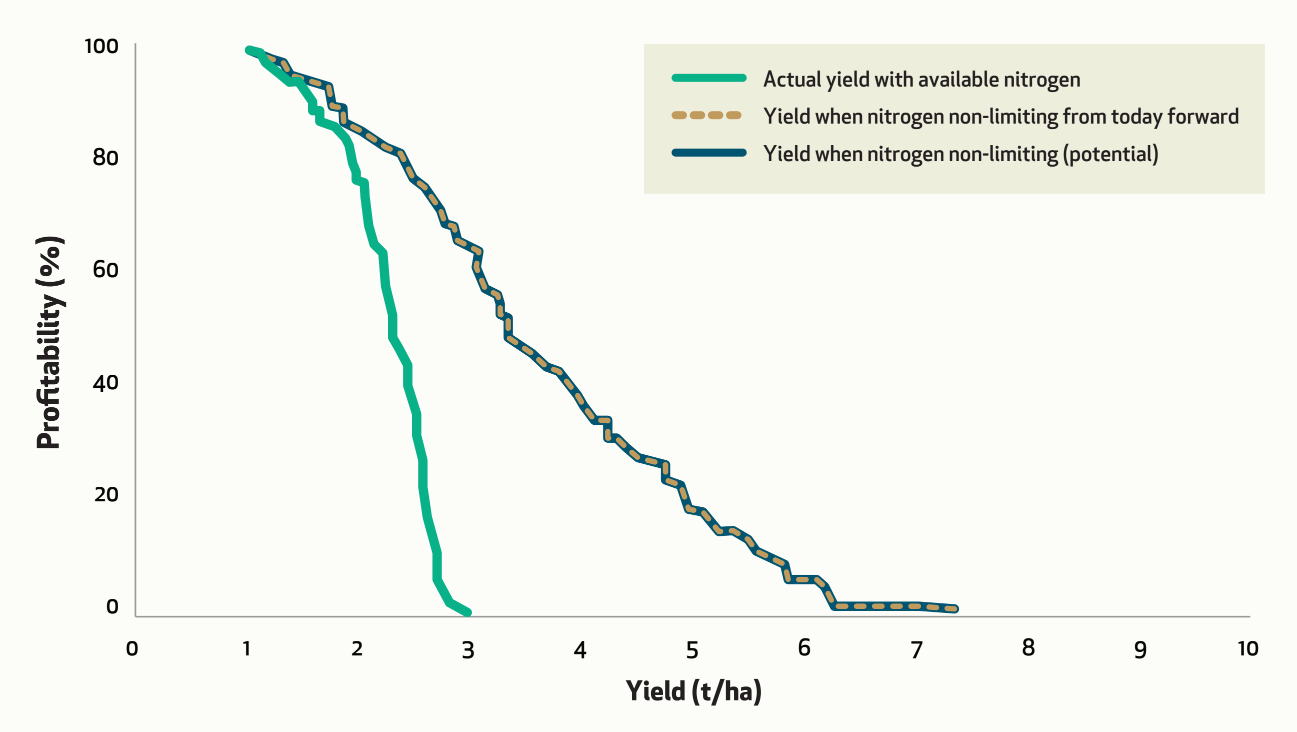
Figure 6 shows an output from Yield Prophet on 16 July, 2014 for Lameroo, SA. Based on this information, in a decile 5 (average) rainfall year, with current available nitrogen, the crop yield potential for this site is 2.2t/ha. However, when nitrogen is non-limiting, there is the potential to increase yield by an additional 1t/ha.

From this output, the decision to top-dress nitrogen may seem straight forward, however it is unlikely applying the amount of nitrogen needed to be 'non-limiting' would be economic. The decision to apply additional nitrogen needs to be weighed against other factors including seasonal forecast (i.e. La Niña or El Niño), historic nitrogen applications from previous seasons and other climatic risks such as frost.

Yield prophet sures up 'gut feeling' and is a useful support tool for nitrogen decision making.

Cost per paddock is around $170 per paddock, plus costs for soil testing.

Figure 6. A report from Yield Prophet displaying current yield potential against yield potential with nitrogen non-limiting



Although it has been repeatedly demonstrated that including break crops provides rotational benefits and increase the profitability of farm businesses, break crops are not widely grown in low-rainfall districts. Less than 10% of the cropping area in the SA-Victorian Mallee was sown to non-cereals during 2010. The major challenge is to develop suitable broadleaf crop types and specific agronomy technologies that are adapted to sandy soils in low-rainfall districts. However, despite these challenges, the longer-term benefits and value of including break crops in a rotation is worth considering.

Trace element and nitrogen interactions

Trace element deficiencies are often associated with a deficiency in nitrogen. Correcting these deficiencies is important for maximising the return on dollars invested in fertiliser inputs.

Trial work conducted at Karoonda by SARDI during 2013 showed the addition of nitrogen and trace elements (copper, manganese and zinc) increased yields by 77% compared with the no fertiliser treatments and yields were 40% higher than nitrogen (urea) only treatments.

Phosphorous management

Phosphorus is relatively immobile and when applied as fertiliser any phosphorus that is excess to crop requirements remains available for the following crop, assuming it is not tied up due to acidic or alkaline soil conditions. Although in extreme cases, phosphorus can be leached from a coarse sand.

Because it is relatively immobile, phosphorous testing is easily carried out with a 0–10cm soil test.

Phosphorus is commonly applied based on the amount removed by the crop in the previous year. This approach is appropriate if soil phosphorus reserves are adequate.

Many soils have accumulated phosphorus over time because rates of phosphorus applied as fertiliser have been relatively high compared with the amounts removed by crop production. In this case, the soil is no longer responsive to an application of phosphorus and the replacement strategy can be employed.

Adopting a replacement strategy for a phosphorus-responsive deep sand can result in under-fertilisation. These soils tend to lack the ability to build nutrition due to leaching. The highly alkaline nature often associated with phosphorus-responsive deep sands can result in low nutrient availability. If the soils also are water repellent, the soil remains dry, and plants cannot access nutrients.

Based on CSIRO trials carried out at Karoonda, SA an application of a minimum of 5kg/ha of phosphorus is required to avoid deficiency.

To determine the potential for a response to the application of phosphorus fertiliser, leave a strip of crop where no phosphorus fertiliser is applied at sowing. If crop growth and subsequent yield from this nil-phosphorus treatment strip is less than the surrounding phosphorus treatment, the soil and crop are likely to respond to additional phosphorus fertiliser.

As discussed in *Row spacing, inter-row sowing and phosphorus*, (GRDC, 2010) wider row spacing increases the concentration of phosphorus in each row, allowing higher yields to be achieved with lower phosphorus rates compared with narrow row spacings.

Sulphur management

There is growing concern about sulphur deficiency on sandy soils. As a result some agronomists are recommending top-dressing with sulphate of ammonia (SOA), as opposed to urea (to address nitrogen deficiency).

Sulphur deficiency can be confused with nitrogen deficiency as physical crop symptoms are similar. Therefore, it is important to use soil or plant nutrient analyses to measure the availability of sulphur to diagnose any deficiency. This will ensure the maximum value can be extracted from the investment in fertiliser.

CSIRO trial work at Karoonda, SA during 2015 (Figure 7) found additional nitrogen applied to canola produced higher yields compared with the addition of sulphur. This is particularly interesting given canola is considered to be a crop with a high sulphur requirement and sulphur in the top 10cm, and at depth, were below the critical values.

The most cost effective and efficient long-term option for correcting a sulphur deficiency is to apply gypsum before sowing. A rate of 500kg/ha of gypsum equates to approximately 85kg/ha of sulphur, which will supply adequate sulphur for several years given about 2kg of sulphur is removed per tonne (wheat) of grain produced.

Recent trials indicate more barley crops grown on sandy soils in the SA Mallee responded to nitrogen than sulphur. Only one out of four sites was sulphur responsive, despite sulphur levels at these sites being below the critical value for sulphur (4–6mg/kg) in the top 0–10cm of soil. Crops treated with SOA yielded more than crops treated with gypsum and urea. This would, suggest the importance of looking deeper (i.e 0–40cm or 0–60cm) when soil testing for sulphur.

Nitrogen remains the main nutrient driving crop growth. If concerned about the lack of response to nitrogen applications look further than sulphur alone, as there may be other underlying nutritional limitations including trace elements.

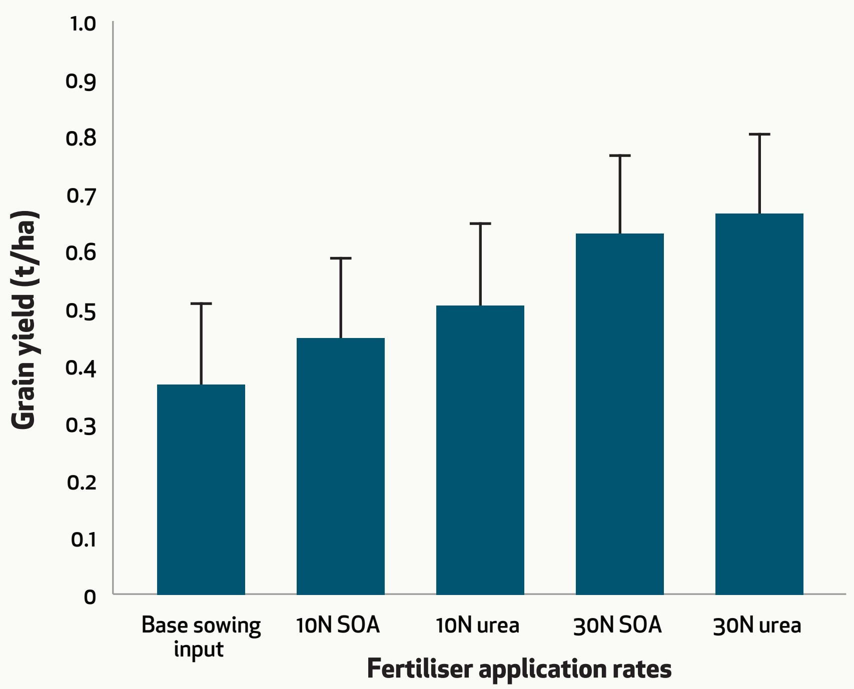
Sulphur can leach in a similar way to nitrogen, and while crops may appear deficient early in the season, this deficiency may be overcome later in the season as the root system develops and the roots can extract sulphur at depth..

Potassium management

Most soils across south-eastern Australia's agricultural regions are abundant in potassium, although low potassium levels have been found in isolated cases on the deep sands in the southern Mallee and south-east regions and parts of Mt Lofty ranges and Kangaroo Island. Almost all potassium deficiencies occur on sandy, light-textured soils.

As hay production expands potassium deficiency may become an increasing problem, as up to 10 times the amount of potassium is removed in hay compared with grain.

Figure 7. Canola grain yield on a dune site in response to urea and SOA applied at the eight-leaf growth stage



P=0.05, LSD= 0.14 t/ha with LSD represented by the error bars

ABOVE: Carrying out regular soil tests to measure and monitor nutrient levels will ensure fertiliser applications meet the demands of the crop without over-fertilising. Photo: Matt McCallum, McAg Consulting

Before applying potassium fertiliser it is first important to establish if there is a potassium deficiency using deep soil and tissue testing. If a deficiency is detected, an application of muriate of potash is the most cost-effective strategy. Best results have seen when muriate of potash is banded at a rate of 50–100kg K/ha below the seed at sowing, however effects will vary depending on current soil potassium levels.

In situations where soil tests show potassium to be below the critical value, it is assumed an application would give an economic response. However, trial results have been variable and often the cost of the potassium fertiliser is greater than the value of the additional yield.

Trace element management

The accuracy of soil testing to determine trace element levels is variable. Exercise caution when developing micronutrient strategies based on soil test results in isolation. A far more accurate option to detect a micronutrient deficiency is with a plant tissue test.

Zinc: Zinc deficiency is widespread on sandy soils across the south-eastern Australian cropping zone, with 80% of SA's agricultural lands potentially zinc responsive.

Options for applying zinc include:

- ***Soil application via spraying:*** Spray applications of zinc pre-sowing can correct deficiencies if the product is incorporated at a rate of 2kg Zn/ha. A single application at these rates can be expected to last 5–10 years if adequate distribution occurs following application.
- ***Foliar application:*** Zinc can be applied as a foliar spray, every year, or second year, at a rate of 200–330g Zn/ha for cereals. Beware of some product claims and always read the label carefully to see how much zinc will actually be being applied given the recommended rate.
- ***Granular fertilisers:*** Combining zinc with other nutrients on a granular fertiliser can be an effective option, as long as zinc is applied to every fertiliser granule. This can be done on farm by coating high analysis fertiliser with zinc oxide at a rate of 1.4kg/ha (1kg Zn/ha). Avoid granular zinc-blended fertilisers as they often have poor distribution, even if used annually.

  Note: Canola is a an efficient and effective scavenger of zinc in the soil due to its tap root, and may not require additional zinc. Confirming adequate zinc levels with a tissue test will confirm if a zinc application is required.

Manganese: Manganese deficiency is usually isolated to deep siliceous sands and, more recently, sands that have been ameliorated with clay with a high lime content. Foliar applications are the best option for rectifying a manganese deficiency. Soil applications of manganese are not recommended, particularly when soils are alkaline as the manganese quickly becomes tied up and unavailable to plants.

A rate of 4kg/ha (930g Mn/kg) of manganese sulphate will correct most manganese deficiencies

Check product labels for amount of manganese being applied.

Copper: Wheat grown on deep siliceous sands, calcereous sand, sand over clay and soils with ironstone granules on the Eyre Peninsula and Murray Mallee of SA require copper fertiliser applications every 5–10 years. High rates of nitrogen fertiliser can induce copper deficiency, and this is worth considering when planning application rates.

Options for applying copper include:

- ***Soil application via spraying:*** Spray applications of copper pre-sowing at a rate of 1kg Cu/ha followed by full incorporation usually supply sufficient copper for crop production for a number of years.
- ***Foliar application:*** Foliar applications of copper during the vegetative stages of crop growth are inexpensive and effective. In severe situations, a second spray before pollen formation may be required. A trial on the Eyre Peninsula on a copper-deficient crop produced yield increases from 0.7t/ha to 3t/ha with two applications of 90g Cu/ha (copper sulphate at 360g/ha): at early stem elongation and then prior to pollen formation.

Soil organic carbon and nutrition

Soil and crop nutrients are inextricably linked with soil organic carbon (SOC) levels. Historically, much of the low-rainfall environment has been dominated by a two-year rotation of medic pasture followed by a wheat or barley crop. In this system, the medic pasture phase fixed and supplied nitrogen required by the subsequent cereal crops. Over time growers have shifted to a more continuous cropping system and reduced livestock numbers.

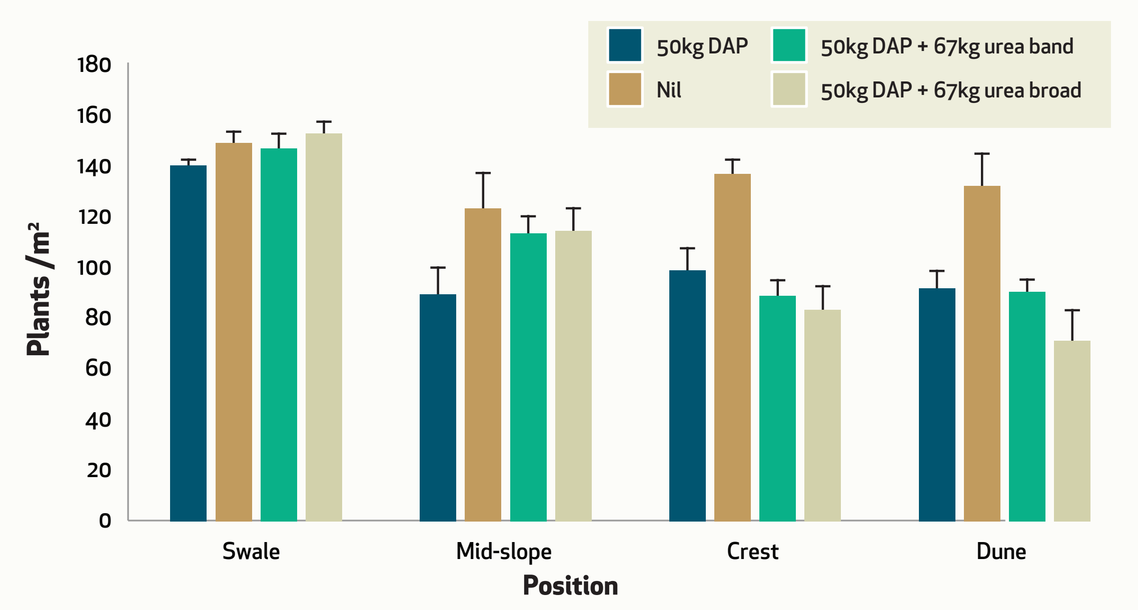
If a random paddock was selected in the low-rainfall zone and a nutrient audit was carried out to calculate nutrition applied, nutrient fixed and nutrient removed or lost, it would be likely that more nutrients have been removed than applied, particularly in the case of nitrogen. In other words, during the past 20 years or so, paddocks have been mined of some key nutrients. For phosphorus the simple strategy of replacing what is removed can be applied relatively easily. However, this is not the case with nitrogen.

Fertiliser management tips

- Soil testing for trace elements is paramount for getting the most out of your fertiliser budget.
- A standard benchmark from the FM500 performance summit is for fertiliser costs to be 12% or less of total farm income.
- Increasing the proportion of legumes in the crop rotation can increase the supply of organic nitrogen.
- Numerous trials have confirmed that variable rate technology is a useful tool to enable nitrogen fertiliser to be applied where it will have the greatest economic impact.
- Regular soil testing is required to measure and monitor nutrient levels and ensure fertiliser applications will meet the demands of the crop.
- Supplying adequate crop nutrition at or before sowing improves nutrient use efficiency. While post-emergent nitrogen applications can assist in managing risk, the opportunities and conditions are often limited. High rates at sowing are the most economical option. Beware of applying too much fertiliser at sowing on sandy soils, particularly when dry. Severe reductions in plant numbers can occur from either ammonia toxicity (high nitrogen content fertiliser) or osmotic effect where moisture is drawn to the fertiliser and away from the seed.

Figure 8 shows that even at low rates on the crest and dune soils (i.e. 50kg DAP), crop establishment can be reduced. The cause for reduced establishment in Figure 8 is likely to be from osmotic stress, where moisture is drawn away from the germinating grain. The amount of fertiliser that can be applied with the seed at sowing depends on row spacing, soil type and seed bed utilisation. Refer to the 'Further Reading' section to determine what is safe in your system.

Figure 8. Effect of fertiliser across four zones at Karoonda in the Southern Mallee



Note: It is likely osmotic stress is the cause of reduced plant numbers in both the dune and crest zones

The nitrogen content of a soil is highly dependent on the amount of SOC contained within that soil. SOC is a large and complex molecule that provides the basic food source to microbes. Microbes breakdown the SOC, releasing (mineralising) nutrients that can then be taken up by plants. If nutrients are not removed then this system would be in an equilibrium and the mineralisation process slows. When nutrients are removed, this drives the further breakdown of SOC, and over time this SOC pool is slowly eroded.

When the historical farming system of south-eastern Australia shifted from a medic–wheat system to continuous cropping, the number of legumes within the system reduced, increasing the reliance on the SOC nitrogen pool and supplementary fertiliser to meet crop nitrogen requirements. Due to the higher demands for nutrition with continuous cropping, the system is relying heavily on the SOC pool to supply crop nitrogen, resulting in the erosion of this pool. The reduced SOC pool in the soil results in lower microbial activity and a lower capacity to mineralise nitrogen.

The drawdown on soil organic nitrogen reserves from SOC needs to be balanced, particularly where nitrogen inputs are low, in order to halt the depletion of these organic reserves in fragile sands.

When organic nitrogen reserves become exhausted it is particularly difficult and expensive to re-build nitrogen levels in a low-rainfall environment, because ultimately, the environment will dictate organic carbon, and therefore, chemical and biological fertility. While no-till farming practices will slow organic carbon depletion, any increase is somewhat restricted by rainfall.

ABOVE: Numerous trials investigating the incorporation of organic matter, such as chicken manure, have seen productivity benefits emerge. Photo: Evan Collis, GRDC

Deep placement of nutrients

Growers are often frustrated at the amount of unused moisture in sandy soils at harvest, which represents a lost opportunity for achieving the yield potential. Generally, crop growth is in fact limited by poor soil fertility at depth and not inadequate soil moisture.

In many sands an infertile layer can occur anywhere from 10cm through to 40cm beneath the soil surface. Roots require a combination of moisture and nutrition to exert the energy to grow deeper in the profile, and in the absence of one or the other, roots tend not to reach these infertile layers. The rooting depth of crops is substantially reduced, and subsequent performance is impacted.

Numerous trials have investigated the viability of the deep placement of fertiliser into these 'nutritional deserts. Results have been mixed and remain inconclusive.

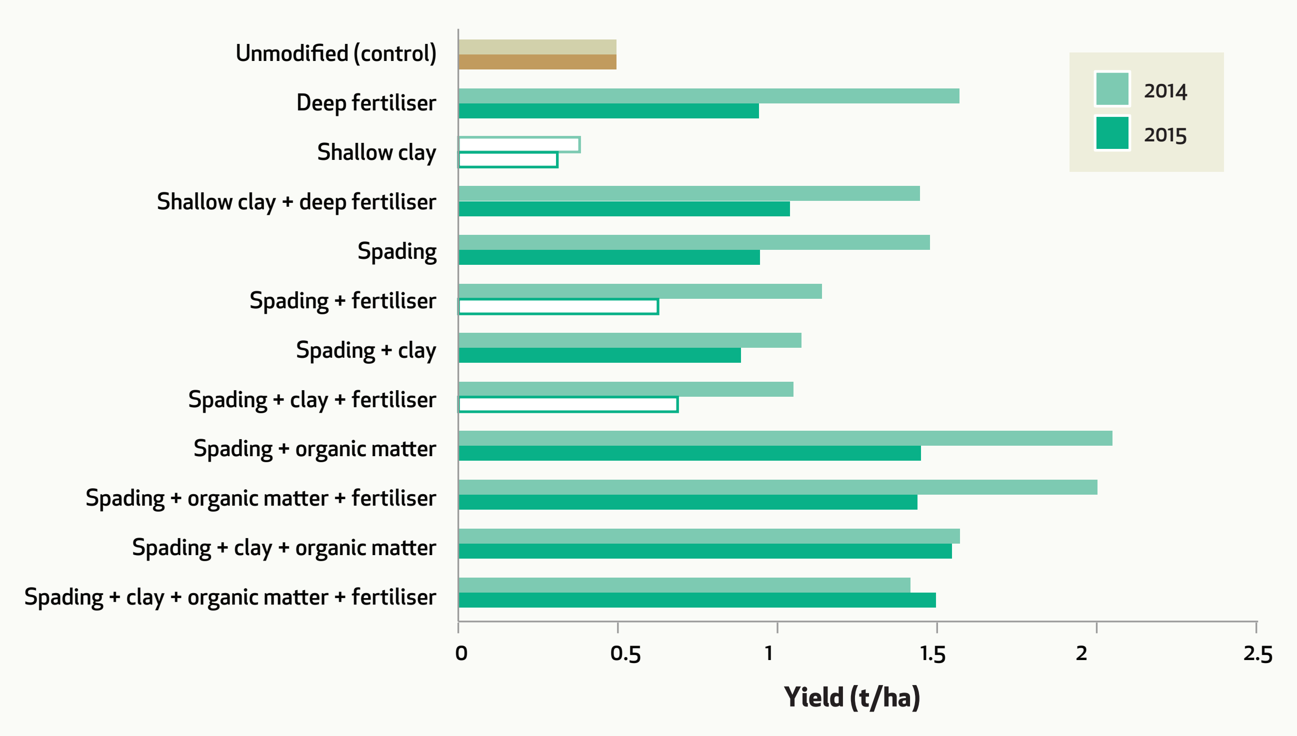
The PIRSA 'New Horizons' program continues to assess the effects and cost-benefit of incorporating organic matter and nutrients to depth across a range of treatments to address the issue of the bleached A2 horizon.

Trials in this program have found:

- Crop productivity on infertile sandy soils can be greatly improved by incorporating organic matter deep into the soil (>30 cm).
- In some cases, crop yields are further boosted by incorporating clay and/or fertiliser to depth.
- Two years of recent research shows the best soil modification treatments can increase crop yields by 70–200 %, even in season of below-average rainfall.
- Treatments that address multiple constraints in these soils provide greater benefit than those addressing an individual issue.
- Crop yields are reduced when clay is poorly incorporated into the soil (Figure 9).

This is a 'proof-of-concept' trial and the application of treatments in the trial would not be economical on a broadacre scale, given even the moderately-priced treatments start from around $500/ha, and in some cases the cost of treatments are even more than the value of the land itself.

Figure 9. Comparison of wheat yield at the New Horizons site, Karoonda, SA (2014 and 2015)



Note: Solid bars denote significance. The clay rate used at this site was 600t/ha, and the organic matter source was lucerne pellets at 10t/ha. The delivery of fertiliser was using commercial fertilisers, surface applied and spaded or deep banded to 20–40cm. The unmodified treatment was district practice, and were provided with fertiliser to match the crops likely potential.

Further information

- Closing Mallee yield gaps using nutrition and break crops at Karoonda (CSIRO, 2015) http://www.msfp.org.au/wp-content/uploads/2014-Karoonda-FD-Booklet.pdf
- Low risk strategies for low-rainfall canola (CSIRO, 2015) https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-117-Optimising-canola-profitability/Low-risk-strategies-for-low-rainfall-canola
- Mallee Crop Sequencing Project (Mallee Sustainable Farming Project, 2013) http://www.msfp.org.au/wp-content/uploads/2013-Karoonda-FD-Booklet.pdf
- Deep placement of nutrients — Few excuses left not to recommend it (Minnipa Ag Centre, 2004)
- The value of break crops in low rainfall farming systems, (Mallee Sustainable Farming Project, 2016) https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/The-value-of-break-crops-in-low-rainfall-farming-systems-and-which-ones-perform-the-best
- 2013 Barley Agronomy Update (SARDI 2013) http://www.msfp.org.au/wp-content/uploads/2013-Karoonda-FD-Booklet.pdf
- Match nitrogen to soil type to lift crop profits (CSIRO, 2013) (GRDC, Ground Cover supplement March–April, 2013) https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS103/Match-nitrogen-to-soil-type-to-lift-crop-profits
- New Horizons — the next revolution in agriculture (PIRSA,2015) http://pir.sa.gov.au/major_programs/new_horizons
- Do we need to revisit potassium? (GRDC Updates, 2014) https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Do-we-need-to-revisit-potassium
- Fertiliser Toxicity- Fact Sheet, GRDC https://grdc.com.au/Resources/Factsheets/2011/05/Fertiliser-Toxicity
- Row spacing, inter-row sowing and phosphorus, (GRDC, 2010) https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/ROW-SPACING-INTER-ROW-SOWING-AND-PHOSPHORUS

Proactive approach reduces risk of soil-borne root diseases

Key facts

- Growing non-cereal break crops reduces the inoculum levels of all four major cereal root diseases.
- Fungicides are available to reduce disease levels, but are expensive and can vary in their ability to control disease.
- Investing in effective summer weed control will pay dividends by reducing soil-borne root disease and conserving soil moisture.

The cost of soil-borne cereal root diseases is most significant in the cereal-dominated rotations of the low-rainfall zone. Introducing a non-cereal break crop or pasture phase can reduce disease risk and provide other whole-system benefits.

Soil-borne root diseases are particularly severe on sandy soils due to suppressed root growth and fewer microsites to protect soil biota (organisms) — a consequence of low organic matter (OM) levels, low fertility and poor water-holding capacity. Under dry conditions, the activity of beneficial soil microbes also is reduced, which in turn enables the well-adapted pathogens to thrive and increase in numbers.

The most common soil-borne diseases affecting crops in the low-rainfall areas of south-eastern Australia include rhizoctonia bare patch (*Rhizoctonia solani AG-8*) cereal cyst nematode (CCN), take-all and crown rot.

Understanding the level and types of disease currently infecting individual paddocks is the first step to developing an effective disease-management strategy.

A Predicta-B® test is a DNA-based soil test that identifies which soil-borne pathogens pose a significant risk to broadacre crops leading up to sowing. This useful tool enables growers to assess and then plan and implement strategies to manage the risk of a range of root diseases.

Rhizoctonia bare patch (*Rhizoctonia solani AG-8*)

Rhizoctonia bare patch is a fungal pathogen that can affect plant roots at any stage of growth, increasing in severity under cool, dry conditions.

Plants affected by the *Rhizoctonia solani AG8* fungal pathogen are usually stunted and sometimes appear purple in colour. If plant roots are severely infected, the root cortex (core) will be eaten away and the stele (central root cylinder) will break, leaving characteristic brown 'spear tips'.

PREVIOUS PAGE: Clearly-defined bare patches or areas of stunted growth are a symptom of cereal root disease. (INSET): Plants severely infected with Rhizoctonia will show clear signs of roots damage. Photo: Sjaan Davey, SARDI

ABOVE: A crop rotation that introduces non-cereal crops can significantly reduce soil disease pathogen incidence. Photo: Alan McKay, SARDI

Bare patches appear in affected crops from an early growth stage and form sharply-defined areas of stunted plants, caused by the primary root infection.

The impact of Rhizoctonia has declined with the adoption of no-till farming, summer weed control and more timely sowing into warmer soils.

Crown root infection, from Rhizoctonia, tends to be seen more often, which can be more serious, as the crown roots play an important role in accessing moisture deep in the soil profile late during the season, driving grain filling.

Rhizoctonia can be particularly severe in sandy soils, in cereal-on-cereal rotations, or where there is poor grass weed control during break crops or pasture fallows. The disease also varies in its behaviour under different crop types, inoculum levels and summer rainfall conditions (Figure 10).

Canola and legume crops will reduce inoculum levels, with canola having the greatest beneficial impact. Inoculum levels will also decrease following all crops over summer, with levels dropping more following a wet summer.

Management options

There is a range of management options available to control Rhizoctonia, each with varying degrees of efficacy.

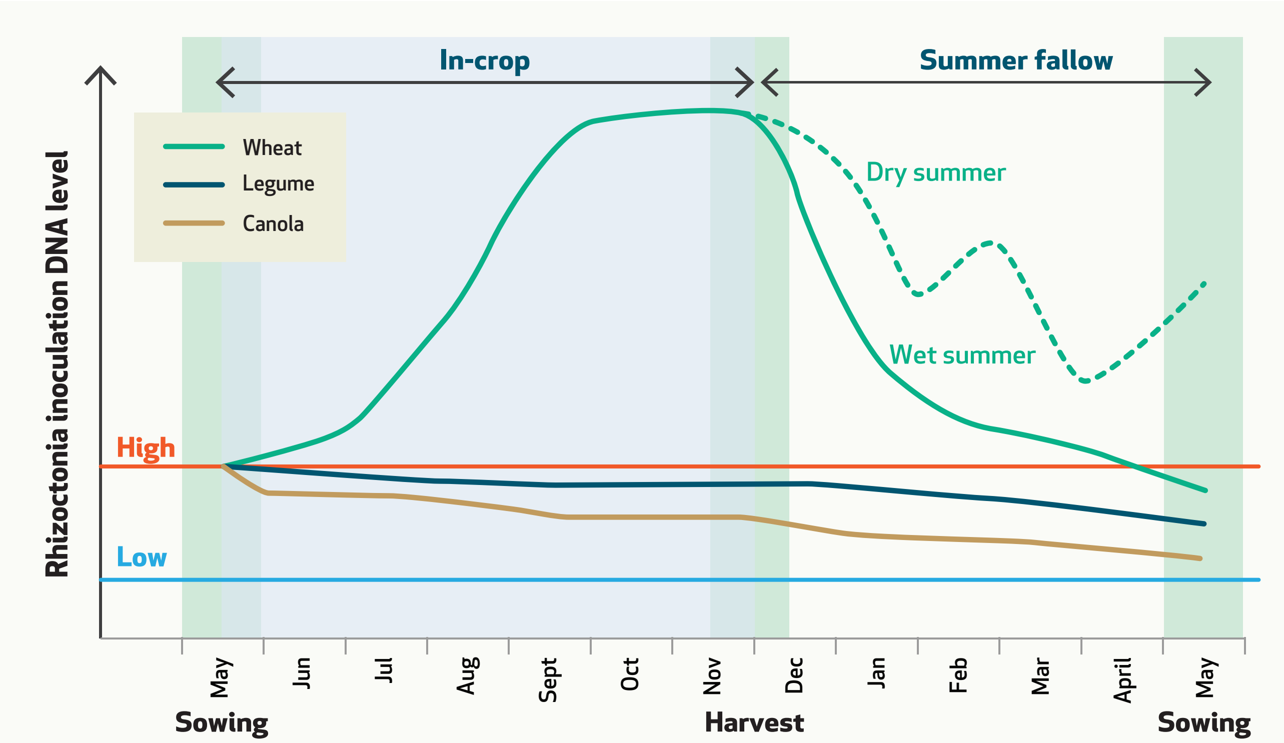
Non-host break crop

The best and most reliable way to control Rhizoctonia is to include non-cereal break crops in the rotation. However, the number of reliable and profitable break crop options that can adequately protect the sandy soils in low-rainfall environments from erosion is limited.

Canola, chickpeas, field peas, vetch and legume pasture breaks can increase wheat yields by 9–47% compared with cereals or other grassy phases.

Canola usually provides a one-year disease break and is by far the best option for reducing Rhizoctonia inoculum, due to its biofumigation properties. Legumes also provide a disease break and can provide a number of additional benefits, including a supply of organic nitrogen (N). Legumes are not as efficient at extracting moisture from the soil profile compared with canola and cereals, and therefore residual soil moisture is often left in the profile for subsequent crops.

Figure 10. The impact of crop type and summer rainfall on Rhizoctonia inoculum levels



Source: *Tips and tactics Rhizonctonia, Southern Region* (GRDC)

CASE STUDY

Serradella break crop offers multiple benefits

Colin and Anna Butcher, Brookton, Western Australia

Colin and Anna Butcher have been growing Margurita French serradella (*Ornithopus sativus*) for a number of years, to reduce soil-borne diseases, increase soil nitrogen levels and fill feed gaps in their livestock operation. The inclusion of this hardy annual legume has enhanced the profitability and sustainability of their farming system through lower input costs (fertiliser and fodder) and increased soil fertility and feed.

The Butchers achieve additional savings by harvesting their serradella crop, saving the seed and sowing again during February the following year. The semi-hard-seeded nature of the seed reduces the risk of germination with summer rainfall, but breaks down sufficiently to allow germination following the autumn break.

"Serradella suits our acidic sands and fits in well with our livestock operation," Anna explained. "We often are short of feed during autumn and our summer-sowing approach allows us to fill feed gaps and avoid supplementary feeding."

According to Colin and Anna, serradella grows relatively well on sand, and the loamy soils across their farm, although regeneration appears to be better on their heavier soil types.

"Originally we grew serradella to provide nitrogen for our cropping phase, but livestock love it, and we have been able to increase our stocking rates and grow our sheep enterprise as a result," Anna said.

ABOVE: Summer-sown Margurita French serradella, 25 February, 2013 (left) compared with autumn-sown serradella, sown on 31 May, 2013 (right). Photo: Colin and Anna Butcher.

Establishment program

Colin and Anna establish their serradella with a sowing rate of 20kg/ha during February.

"The seed is grown on-farm and harvested with a conventional header," Anna explained. "We use the canola settings on our air-seeder to sow the crop and sow at the same depth as canola.

"It takes time for the dormancy of the seed to break down, so it doesn't germinate until about March.

"We avoid sowing into weedy paddocks, which can compete with the serradella — if we do have a weed infestation during the growing season, we treat the serradella as a brown manure crop.

"We fertilise the paddock in autumn with a pasture/potash fertiliser, and before germination, or as close as possible, we apply imazethapyr (i.e. Spinnaker®) to suppress broadleaf weeds."

Challenging old habits

Colin and Anna have found it difficult to get out of the mind set of applying additional nitrogen fertiliser to their subsequent crops.

"Because the nitrogen supplied by the serradella is in an organic form, it becomes available when it rains, meeting the crop demand," Anna said.

"The other challenge has been adjusting to the summer sowing of serradella, although it allows us to get our grain crops sown on time."

In the lead-up to sowing Anna warns other growers not to apply sulfonylurea (SU) herbicides (e.g. Ally®) or clopyralid (e.g. Lontrel®) herbicides as they severely affect the ability of the serradella to grow and nodulate.

*Note: Serradella is well suited to the Butcher's acid sands, however growers with more alkaline soils could achieve similar benefits with a range of clovers, such as bladder clover (*Trifolium spumosum*), which are more suited to alkaline conditions.*

Further information — Serradella

- Butchers back summer-sown serradella (GRDC Ground Cover, December 2014): http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-113-NovDec-2014/Butchers-back-summer-sown-serradella
- Summer-sown serradellas deliver nitrogen benefits (GRDC, November 2014): http://www.grdc.com.au/Media-Centre/Media-News/West/2014/11/Summer-sown-serradellas-deliver-nitrogen-benefits

Fallow

A well-managed 12-month weed-free fallow can reduce Rhizoctonia innoculum levels in the soil. However, Rhizoctonia can survive on dead plant material and levels are likely to spike quickly when sown back to a cereal. Ensure the paddock is adequately covered and not over-grazed to reduce the erosion risk.

Mitigation options

Adequate nitrogen, phosphorous (P) and zinc (Zn) nutrition and reducing the use of SU herbicides, which prune root growth, can reduce the impact of Rhizoctonia.

In a direct-drilled system, a depth-modified seeder, which disturbs the soil 50mm beneath the seedbed while sowing at the correct depth, will provide sufficient soil disturbance to reduce damage caused by this disease. Low soil disturbance sowing systems, such as disc systems, can increase the risk of Rhizoctonia due to reduced disturbance of the Rhizoctonia hyphae (branching filaments) network.

Summer weed control

Research has previously shown that $5.57 is returned for every $1 invested in summer weed control per hectare through conserved moisture, improved water use efficiency (WUE) and reduced soil disease. NSW DPI research and development cropping agronomist Colin McMaster suggests this figure is more likely to be $8 in return for every $1 spent per hectare on summer weed control, and goes on to suggest the practice essentially 'buys you a spring'. Research carried out by CSIRO has shown that if summer weeds are not controlled, Rhizoctonia can reduce grain yield of barley by up to 40%.

Timely sowing

Rapid early root growth can significantly reduce the severity of Rhizoctonia — the impact on cereals is greater for slow-growing roots. In dry, cold seasons, and particularly where subsoils are compacted, root development slows and Rhizoctonia is likely to be a greater problem. A trial carried out near Lameroo, SA in 2015 showed that earlier sowing (into warmer soils) was more effective than fungicide treatments for improved crop growth.

Fungicides

During recent times penflufen-based products (e.g. EverGol Prime®) have been released as seed treatments, and were recently registered as in-furrow treatments.

Seed treatment has failed to produce consistent results, although a significant improvement (5%) in barley yields has been observed in numerous trials carried out by SARDI when fungicide was applied in-furrow during 2013.

Sedaxane-containing products (e.g. Vibrance® seed treatment, and fertiliser treatments and in-furrow products containing azosystrobin and metalaxyl-M (e.g. Uniform®) are also available to control Rhizoctonia.

In-furrow applications have produced the best, and most consistent results in trials over a number of seasons. An initial trial conducted by SARDI at Geranium, SA during 2010 found a combination of fungicides applied via split streams on the soil surface and in-furrow below the seed produced a 0.51t/ha yield response in a knife point and rippled coulter sown treatment.

Data from 2011–13 trials found that Vibrance in wheat, and EverGol Prime in barley produced an average yield increase

ABOVE: CCN cysts attached to a cereal root system at flowering. Photo: John Fisher, University of Adelaide

of 5%, but yield responses were variable and dependent on spring rainfall. Yield increased when the seed treatment was used in conjunction with Uniform® in-furrow, at a cost of approximately $24/ha.

The cost of machinery modifications to include a liquid delivery system and the cost of these fungicide products require additional investment and need to be carefully considered in low-rainfall environments.

Cereal cyst nematode/eelworm (*Heterodera avenae*)

Cereal cyst nematodes (CCN) — also referred to as eel worms — are tiny parasitic worms, which infect the roots of cereal crops, causing plants to produce a mass of small lateral roots at the feeding site. Root expansion is reduced, limiting nutrient and water uptake.

Symptoms of CCN infestation include plant stunting and yellowing, which often gives the crop a 'patchy' appearance. The presence of CCN can be established by inspecting the primary roots and looking for abnormal branching and knotting. Symptoms can be confirmed at flowering by the presence of small (1–2 mm in diameter) white 'cysts' attached to the roots.

Cereal cyst nematodes survive between susceptible cereal crops as eggs inside the protective cysts. Each year approximately 85% of cysts hatch after the autumn break, while the remaining 15% remain dormant until the following season. This dormancy mechanism means it takes at least two years of break crops (this includes resistant varieties, non-cereals or fallow) to control CCN.

Cereal cyst nematodes have a narrow host range, limited to cereals and some grass weeds. Susceptible cereals and wild oats are the most important hosts. Annual ryegrass, brome and barley grass are poor hosts. Wheat and barley varieties differ in their susceptibility to CCN.

Management options

The impact of CCN has reduced in recent years, due to newer varieties having adequate resistance to these soil-borne parasites. Continued management will ensure this disease is kept at relatively low levels.

The most effective tool available to manage CCN is to grow resistant cereal varieties or other non-host crops (e.g. legumes and canola). Refer to crop variety guides to determine the resistance of individual cereal varieties.

ABOVE LEFT: *Take-all causes premature maturation of susceptible cereal crops. Photo: Marg Evans, SARDI*

ABOVE RIGHT: *Blackening symptoms of take-all may extend to the stem sheath Photo: Marg Evans, SARDI*

ABOVE: *The take-all fungus infects the roots of the crop, restricting water and nutrient up-take. Photo: David Roget, SARDI*

Take-all (*Gaeumannomyces graminis*)

Take-all is a disease caused by the fungal pathogen, that affects a plant's ability to transport nutrients, by blocking the water-conducting tissue in the plant, restricting water uptake and causing premature maturation.

One of the most characteristic symptoms of take-all is blackening of the crop roots. The take-all fungus infects the centre of the root. In severely infected plants the blackening may extend to the stem base under the leaf sheath.

The second-most characteristic symptom of take-all is 'white heads' occurring in patches within a crop. In a severe outbreak the entire crop may be affected. The white heads contain pinched grains or no grains at all. Low soil moisture during October and November increases the occurrence of deadheads.

The host range of take-all is confined to grass species and includes wheat, barley, triticale, barley grass, brome grass, silver grass and annual ryegrass. Oats are generally not considered a host, however there is a strain of take-all that can affect oats and other cereals.

Management options

Managing take-all effectively is imperative to avoid late-season losses.

Non-host break crops

Grow crops that do not host CCN (oilseeds, legumes and oats). Barley is the preferred cereal option given it is less susceptible to take-all than wheat

Inter-row sowing

Take-all can only survive in the root and tiller bases of previously-infected crops. Inter-row sowing will reduce the risk of infection in the following crop.

Fungicides

The use of flutriafol (i.e. Impact®) either in furrow or with fertiliser can reduce the level of infection of take-all, but is generally only effective in severe circumstances (i.e. where there has been a long history of growing continuous cereals). Products containing fluquinconazole (Jockey Stayer® or Quantum Pro®) at the higher label rates will provide some suppression of this disease.

Burning

A strategic burn of badly-infected paddocks can reduce inoculum levels, however it is important to consider the consequences of a burn (e.g. increased risk of erosion).

ABOVE LEFT: Scattered 'dead heads' caused by crown rot.
ABOVE: Honey-brown and pink colouring caused by crown rot infection
Photos: Marg Evans, SARDI

Crown rot (*Fusarium pseudograminearum*)

Crown rot is similar to take-all, whereby water uptake in affected plants is poorly transported from the roots to the growing tips. A honey-brown discoloration of the crown, lower leaf sheaths and tillers at the base of the plant is a classic symptom of crown rot. Affected plants are frequently stunted and produce fewer tillers, and symptoms can extend up the stem, where the fungus may form pink spore masses at the nodes. By comparison, plant roots and crowns infected with take-all are distinctly black in colour.

Severe infections will cause plants to die prematurely and deadheads or whiteheads are produced. The deadheads are either empty or partially filled with pinched grain. Affected plants may be scattered across a paddock or occur in patches.

Yield losses are greatest during dry years, especially when moisture stress occurs after flowering. The fungus can survive for up to two years on infected cereal stubble, from previous cereal plants, volunteer plants or grass weeds. Crown rot can cause serious yield losses in durum wheat varieties, and to a lesser extent in bread wheats, barley, and oats. Other host plants include wild oats, canary grass (phalaris), wheat grass, brome grass, barley grass, winter grass and annual ryegrass.

Management options

Non-host break crops

Rotations that include non-susceptible crops will reduce the severity of crown rot. A two-year break with a pulse, oilseed crop or fallow will reduce crown rot in the following wheat or barley crop.

Disease-tolerant varieties

A number of cereal varieties offer some tolerance to crown rot — check current variety guidelines.

Burning

Stubble retention, or slower decomposition of stubble, can increase the severity of crown rot. Burning infected crowns reduce the amount on inoculum and therefore the risk of future infection.

Inter-row sowing

Similar to take-all, inter-row sowing will provide spatial separation from infected stubbles.

Further information

- The Rhizoctonia Risk Tool http://eparf.com.au/research-project/rhizoctonia-risk-tool/
- Upper North Farming Systems Stubble Management guidelines: Break crop options (UNFS, 2106)
- Upper North Farming Systems Stubble Management guidelines: Crown rot (UNFS, 2106)
- Upper North Farming Systems Stubble Management guidelines: Inter-row sowing (UNFS, 2106)
- Tips and Tactics: Rhizoctonia: Western Region, (2016), GRDC GrowNote https://grdc.com.au/Resources/Factsheets/2016/02/Rhizoctonia
- Unkovich M (2014) A review of the potential constraints to crop production on sandy soils in low rainfall south-eastern Australia and priorities for research: A report for the GRDC Low Rainfall Zone Regional Cropping Solutions Network http://www.msfp.org.au/wp-content/uploads/A-review-of-the-potential-constraints-to-crop-production-on-sandy-soils-in-low-rainfall-SA.pdf
- Gupta V, Kroker S, Davoren B, McBeath T, McKay A, Ophel-Keller K, Llewellyn R and Roget D (2013) *Summer weed control benefits Rhizoctonia disease management in cereal crops*. In 'Research Compendium 2012, Mallee Sustainable Farming Project'. http://www.msfp.org.au

Effective weed control essential for long-term productivity

Key facts

- Effective weed control will reduce competition for limited moisture and nutrients on sandy soils.
- Use a combination of chemical and non-chemical strategies to control weeds.
- Understand the attributes of important weed species to ensure control strategies are effective.
- Address the full range of factors that limit crop production (e.g. water repellence, subsoil compaction and low soil fertility), to maximise crop competition and weed control.

Weeds can thrive in sandy soils if control measures are ineffective. Low organic matter (OM), organic carbon (OC) and clay contents combined with potential non-wetting characteristics and poor water-holding capacity can see crops suffer, while certain weeds proliferate.

Large yield losses can occur on sandy soils where weeds are poorly controlled due to the competition for limited resources (i.e. moisture and nutrients). Sub-optimal crop yields, combined with expensive chemical control measures, can result in a significant loss of income. Brome grass (*Bromus* spp.) alone is estimated to cost $19.7M annually across the GRDC Southern Region.

Understanding the specific challenges of controlling weeds on sandy soils, including which weed species are more adapted to these soils, and identifying cost-effective long-term control strategies will increase both profitability and sustainability (Table 3).

There are four specific issues that contribute to poor herbicide efficacy and weed control on sandy soils:

- **Low water-holding capacity** — Rainfall events move water and soluble herbicide products faster and deeper through sandy soils compared with clay soils, which can damage crops, reducing their ability to compete with weeds. Low levels of plant-available water within the soil profile also can cause significant moisture stress in shallow-rooted annual crops, while deep-rooted weed species, such as skeleton weed, can thrive.
- **High percentage of sand** — The low clay content of sandy soils means there are less binding sites for herbicide molecules as they move through the soil profile. The consequence is that a great amount of the active ingredient of a herbicide is available to control weeds, but exacerbates the risk of herbicide damage to the crop. This is particularly a problem where product selectivity is narrow and herbicide safety is derived from the physical separation of the crop seed and the herbicide.
- **Low organic matter** — Low OM levels present a similar challenge to the low clay content of a sandy soil — herbicides are less able to bind to particles within soil, which increases the potential for crop damage. Low OM levels also indirectly affect weed control as poor growth reduces the ability of crops to compete with weeds, due to low fertility and reduced potential for mineralisation.
- **Water repellence** — Water-repellent soils can restrict the emergence of weeds at sowing (reducing the efficacy of non-selective pre-sowing knockdown herbicide applications). Staggered weed and crop germination, and dry pockets of soils, can result in significant herbicide damage to crops when the soil 'wets up' and enables rapid uptake of product.

Management options

As with all weed species, preventing seed set over a number of consecutive seasons is necessary to reduce weed populations. Employ a range of strategies to avoid or delay herbicide resistance. Do not rely solely on herbicides, or a single group of herbicides, and remember "if it works, don't keep using it".

Table 3. Key weeds species, their impact and characteristics

Weed name	Impact	Characteristics allowing proliferation
Brome grass (*Bromus spp.*)	▪ Highly competitive on sand ▪ Root disease host	▪ High level of seed dormancy ▪ Prolific seed set under ideal conditions ▪ Few selective herbicide control options ▪ Has developed resistance to a number of key herbicide chemistries ▪ Can be difficult to remove from crop seed resulting in weed seed dispersal via sowing operation
Silver grass (*Vulpia spp.*)	▪ Well adapted to sandy soils ▪ Allopathic effect of grass residue can reduce emergence of subsequent crop or pasture ▪ Root disease host ▪ Potential for livestock skin contamination and carcase downgrades	▪ Control options vary in effectiveness and are often expensive
Wild radish (*Raphanus raphanistrum*)	▪ Well adapted to growing on sandy soil ▪ Toxic effect on retained crop seed if stored for extended periods ▪ Rapidly develops resistance to many key herbicide control groups ▪ Highly competitive ▪ Rapid growth, especially at northern latitudes (long daylight hours)	▪ Possesses a tap root, which can extract moisture from deep in the profile and penetrate compacted sandy soils better than cereal plants ▪ Extremely hard seeded, resulting in seed bank recruitment over a number of seasons following seed set. This also results in a number of germinations in the crop in any one season. ▪ Ability to set seed 12 months of the year
Skeleton weed (*Chondrilla juncea L.*)	▪ Very competitive in high numbers ▪ Can be expensive to control long term ▪ Prolific seed set when not controlled before or during harvest ▪ Potential to cause quality downgrades where green material is harvested with crop	▪ Perennial species extremely well-adapted to low-fertility sands due to tap root system and perennial nature (able to utilise out-of-season rainfall) ▪ Can grow and persists in low-rainfall environments due to extensive root system
Afghan (*Citrullus lanatus*) and paddy melons (*Cucumis myriocarpus*)	▪ Well adapted to sandy soils ▪ Problematic to sowing operation when larger in size due to fibrous runners ▪ Aggressive user of summer rainfall and mineralised nitrogen	▪ Very efficient at using water, enabling extremely effective moisture conversion to biomass ▪ Extremely long seed bank dormancy (>10 years) — multiple germinations across season utilising out-of-season rainfall

- Aim to stop all seed set. Use a range of weed seed control strategies, such as narrow windrow burning, chaff carts, chaff decks, seed destructors, hay cutting, weed wiping and spray topping.
- Grow a diverse range of crops and/or pastures in the rotation to allow a broader variety of control strategies to be used. Diverse crop and pasture rotations support a wider range of herbicide options and groups can be used and rotated, which is important for delaying the development of resistance.
- Utilise autonomous spot spraying control technology, such as WeedSeeker® and WEEDit® to identify and target weeds or patches with high rates of herbicide. A targeted approach can improve cost-effectiveness of control and is most applicable for summer-active species, such as skeleton weed.
- Control in-crop weeds, including those that escape control and have a staggered germination, with an effective selective herbicide, or a non-selective control measure (e.g. crop topping).
- Test weeds for herbicide resistance. It is essential to know which products will still effectively control weeds to develop a workable herbicide rotation strategy.
- Encourage crop competition (density and growth) by applying adequate nutrition, ameliorating hostile soil conditions, reducing row spacing and increasing sowing rates towards the upper level of district recommendations.

Further information

- **Guidelines to managing key weed species across low-rainfall regions of south-eastern Australia (Ag Excellence Alliance, 2016)**
  http://agex.org.au
- **Impact of weeds on Australian grain production, GRDC, 2016**
  https://grdc.com.au/ImpactOfWeeds
- **Hitting the right target — what are our most costly weeds? (GRDC Update Papers, 2015)**
  https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Hitting-the-right-target
- **Weed resistance testing:**
  http://www.plantscienceconsulting.com.au/#
- **GRDC Integrated Weed Management (IWM) hub**
  http://www.grdc.com.au/Resources/IWMhub
- **Australian Herbicide Resistance Initiative**
  http://ahri.uwa.edu.au
- **Weed Seed Wizard**
  https://www.agric.wa.gov.au/weed-seed-wizard-0
- **WeedSmart**
  http://www.weedsmart.org.au

Photo: Lou Flohr, Agrilink Agricultural Consultants

Limiting the risk of erosion is key to managing sandy soils

Key facts

- Maintaining anchored ground cover at 30–50% will prevent soil erosion on sandy soils.
- Containment feeding of sheep can help maintain adequate ground cover and reduce the risk of erosion during dry periods.
- Delayed sowing, sowing across last year's rows and on-row sowing can assist crop and pasture establishment ,which will help reduce erosion on water-repellent sands.

The risk of erosion on sandy soils is relatively high compared with other soil types. This is a consequence of the poor water-holding capacity and inherently low nutrient levels of these soils, which restricts productivity, including limited plant growth and biomass to protect these soils from erosion.

A lack of organic matter (OM), low water-holding capacity and low clay content mean sandy soils tend not to aggregate (hold together) making these soils susceptible to wind and water erosion.

Erosion results in the loss of top-soil, which contains essential nutrients. According to the Agricultural Bureau research booklet *Better soils mean better business*, the loss of 1mm of soil equates to approximately 14t/ha of soil, which represents a loss of an 10kg/ha of nitrogen (N) and 2kg/ha of phosphorus (P) during a erosion event.

In low-rainfall environments it can take 100 years to form 1mm of topsoil. Erosion can cause topsoil to be lost in a matter of minutes.

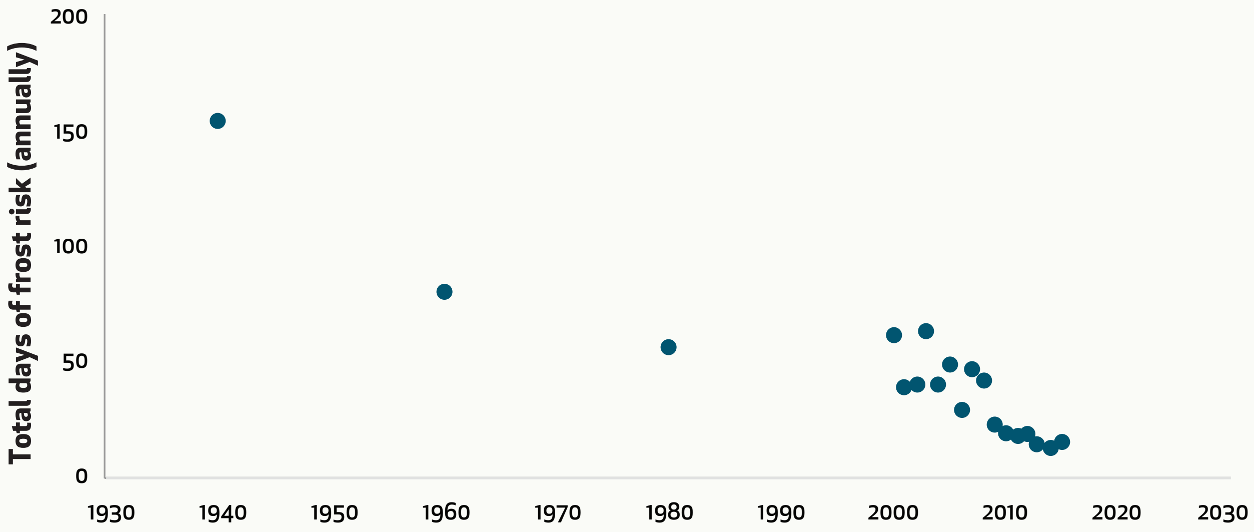
Impact of no-till

The adoption of no-till stubble retention (NTSR) systems has significantly reduced erosion, particularly across low-rainfall districts, where maintaining ground cover is challenging (Figure 11). Despite improved farming practices, erosion remains a major issue for sandy soils in low-rainfall environments.

A survey carried out by the Bureau of Rural Sciences (BRS), Canberra, during 2009 , found "erosion was rated as widespread on sandy soils across the Mallee system in New South Wales, Victoria and South Australia and in some of these areas it was rated severe". The results of the grower survey carried out as part of the *Delivering multiple benefits messages — A partnership with NRM* project supported the BRS findings, indicating erosion remains a major concern for growers across the low-rainfall region of south-eastern Australia.

Poor crop establishment on sandy soils, as a result of rapid drying or water repellence, increases the susceptibility of soils to wind erosion. Delaying sowing until the soil has 'wet up' is a strategy to improve establishment. Alternatively, on-row sowing or sowing across last year's rows on a slight angle can improve establishment on water-repellent sands.

Figure 11. Estimated erosion risk on South Australian agricultural land (average days per year)



Source: Tim Herrmann, *Department of Environment, Water and Natural Resources (DEWNR)*

Figure 12. Visual representation of 50% ground cover across two different stubble treatments

Standing stubble

Chained or rolled stubble

Photos: Mallee Sustainable Farming

Managing erosion risk

Wind erosion occurs on bare soils when the wind velocity is greater than 20–30km/hr. If the surface of a bare soil is disturbed by stock or cultivation, then a wind speed as low as 5km/hr can cause the soil to move, and when the soil starts to move, it will continue to move.

Sandy soils with 50% anchored ground cover (vegetation) will not blow. Figure 12 provides a visual indication of 50% ground cover under two different stubble treatments.

The amount, anchorage, type and characteristics of stubble residue is critical. For example, lupin stubble is more coarse and bulky than cereal stubble. Grain legume stubbles decompose rapidly and can blow away more easily than cereal stubbles. The risk of erosion on the coarse-textured (dune) soils of the Mallee and Central and Upper Eyre Peninsula following a grain legume crop, such as field peas, is high.

Managing grazing to maintain adequate ground cover is paramount to avoiding erosion. Containment feeding of livestock during high-risk periods, will ensure ground cover is retained, reducing the extent and risk of erosion.

Further information

- A review of the potential constraints to crop production on sandy soils in low rainfall south-eastern Australia and priorities for research, (GRDC, 2014) http://www.msfp.org.au/wp-content/uploads/A-review-of-the-potential-constraints-to-crop-production-on-sandy-soils-in-low-rainfall-SA.pdf
- Stubble Management: A guide for Mallee Farmers, Mallee Sustainable Farming Project, 2013 http://www.msfp.org.au/publications/msf-stubble-guide
- MSF Farm Talks: Estimating Ground Cover for Erosion Control on Low Rainfall Grazed Land http://www.msfp.org.au/farmtalk-29-estimating-groundcover-for-erosion-control-on-low-rainfall-grazed-land

Photo: Ben Biddulph, DAFWA

Sandy soils increase risk of frost damage

Key facts

- Crops grown on sandy soils can be more prone to frost damage— white sands are more frost prone than darker-coloured sands.
- Sands are less able to store water near the surface, which is important for producing radiated heat, reducing frost risk.
- Stubble reflects light and has extremely low bulk density, resulting in lower temperatures and greater frost risk.
- Changes to colour, density and texture of sandy soils can reduce frost impacts. Clay delving or spreading, rolling and the use of dark soil amendments can reduce frost risk.

Severe frost damage on light-coloured, coarse-textured soils can severely limit crop yields and quality. Losses due to frost are more frequent when late-winter and spring conditions are dry.

Frost can damage crops and pastures across south-eastern Australia. Pasture production losses due to frost are generally lower than those for crops, as most common pasture species are better able to recover from damage incurred during vegetative stages.

Cereal crops have a wide window of susceptibility to spring frost, which can damage stems, heads, spikelets or flower parts. Developing grain can also be affected by frost.

Crop losses cause significant economic impacts, as most of the cost of production has been spent by the time frost damage occurs.

Why sands are vulnerable

Sandy soils are particularly prone to frost because of their low bulk density, low water-holding capacity, reflective surfaces and relatively low nutritive status compared with other soil types.

Soil heats as it absorbs energy from the sun (solar energy), warming the air near the soil surface. The higher the soil water content, the more heat the soil absorbs, which increases the amount of warm air at the soil surface. At night the soil radiates (releases) heat at a faster rate than air, which means the temperature at the soil surface drops more quickly than the air above. Crop or other organic matter (OM) surfaces also radiate heat quickly and are colder than the air surrounding them. Water forms dew on these cooler surfaces and the dew freezes, resulting in a frost.

The total surface area of sand is low compared with finer-textured soils, which means less water is held on the surfaces of soil particles. With less water, these sandy soils have a lower capacity to release radiant heat, and are more prone to frost.

Water inside and between plant cells also freezes, causing cells to dehydrate, which can result in tissue death. The water between cells probably freezes near 0°C, but within cells there are solutes that act as antifreeze and there may be no freezing until lower temperatures are reached.

Plant tissue can recover after a frost event, but recovery depends on the severity of the frost event and how quickly the temperature increases following the event. Interestingly, warm weather following a frost makes it more difficult for a plant to recover.

Managing frost risk

Bulk density

Sandy soils naturally have a low bulk density, and sowing loosens the soil above the depth of the sowing implement, reducing the bulk density even more. A low-density sandy soil holds less water than a high-density soil because water evaporates and drains more readily. Rolling the soil after sowing will compact the surface layer, improving water retention, at or near the surface. This soil water absorbs more solar energy, which increases the potential to release some of this energy as heat to the atmosphere during the night.

Soil texture

Fine-textured soils (e.g. clay) have a much larger surface area to volume ratio and the total pore space in a given volume of soil is much lower than coarse-textured soils, such as sands. This directly impacts the soil water-holding characteristics of a soil. The increase in soil surface area means there is more water at the surface and the reduced pore spaces means less water is lost to drainage and evaporation. The application of clay to sand acts to both increase the surface area and reduce pore space (see pages 11–12 for more information on amelioration with clay).

Soil colour

Light-coloured soils reflect more solar radiation than dark-coloured soils. The principle is the same as wearing light-coloured clothing on a hot day compared with dark-coloured clothing. When light is reflected so is much of the energy it contains, resulting in reduced heating of the material itself.

Red or black sands absorb more solar energy than white sands. Part of the impact of claying to increase soil and re-radiated heat is due to the darker nature of the clay itself. It is not economical to change soil colour just to slightly change the temperature dynamics, but it can be a partial justification for spreading or delving clay.

Soil nutrient status

Recent research offers little evidence of a direct correlation between nutrient status and frost damage. It had been thought that copper-deficient plants are more prone to frost damage, but this may just be that the symptoms are similar. Even if there is a correlation, recent GRDC research has indicated there is no response to copper (Cu) in plants with sufficient levels when exposed to frost.

There has been limited recent research indicating that low potassium (K) levels may lead to plants being more susceptible to frost. It appears these protection responses kick in somewhere between 50 and 100ppm soil potassium. Applying additional potassium to crops where soil potassium levels are already adequate, which is likely across much of South Australia's cropping regions, is unlikely to offer any additional frost protection, or to be cost effective. However, some sandy soils are low in potassium and an application of potassium may be warranted to reduce frost risk and improve grain yield. Always carry out a soil test before developing a fertiliser program.

ABOVE: Variation in frost damage during grain filling four days after frost. Centre is a healthy grain. Photo Mick Faulkner, Agrilink Agricultural Consultants

High nitrogen (N) status is linked to greater frost damage and increased financial loss. There is evidence that nitrogen-rich crops are more frost prone than nitrogen-deficient crops. The interactions are complex and not completely understood.

Cold air drainage and topography

Cold air is denser than warm air and, being heavier, it descends. Generally, cold air will pool at the base of a slope. As it moves, the air is still segregating and the coldest parts descend at each point, which may coincide with the top of a crop canopy or soil. It is not uncommon to have up to 5°C difference in temperature across a vertical column of just 1.2m.

When cold air drains, the pool of displacement may be intense at the base of a slope and not the lowest point in the paddock. It is not uncommon to observe frost damage emanating from the base of a slope and extending back up the slope, while lower parts of the paddock remain relatively unaffected.

ABOVE: Frost damage can be found at the base of a slope, extending back up the slope, while lower parts of the paddock are relatively unaffected. Photo: Megan Hele

Cold air above light-coloured sands can be much colder than the air lying above adjacent areas where soils are darker because the areas with lighter soils cannot store as much heat. This can occur even if light-coloured sands are upslope from the base or the lowest point.

At the same time cold air is descending, heat continues to be lost by radiation across the landscape, until the sun rises and starts to heat the atmosphere, plants and soil surfaces.

There are no frost mitigation strategies growers can employ to eliminate frost on a broadacre scale. Creating air mixing is only possible over small areas because the amount of air that can be moved by fans or heaters is limited and is not effective across the wider landscape. Some of the practices used by horticulturalists are simply not possible, practical or affordable on a large, farm scale.

Changing soil characteristics

Trials carried out by SARDI in SA across a number of seasons found the amount and intensity of frost damage could be influenced by delving or spreading clay on sandy soils or by rolling after sowing. It must be stressed that these tactics only produced minor changes in temperature at vulnerable parts of a crop during spring frosts.

Stubble management

Retaining stubble lowers the soil temperature and contributes to lower re-radiation of heat. Recent research carried out by DAFWA during 2015 suggests stubble loads greater than 1t/ha could increase the impact of frost in low-rainfall environments and greater than 3t/ha in medium-rainfall environments.

It has been suggested that in extremely high-yielding environments, where stubble loads exceed 5t/ha, the crop canopy has a greater influence on frost impact than stubble load.

Stubble that is fully incorporated has little effect on the impact of frost other than by reducing the overall bulk density of the soil. Rolling could be an advantage where stubble is incorporated.

Removing stubble is desirable for frost mitigation, but the impact on erosion risk, crop establishment and nutritional status may outweigh the advantages.

Whole-farm risk management

Frost risk is best managed on a farm-by-farm basis and requires a whole-farm approach. Avoiding frost damage by having plants at less vulnerable stages of growth (e.g. by delaying sowing) is possible, but for winter cereals delaying sowing and maturity can lead to severe yield losses where there is a hot dry finish to the growing season. The optimum sowing time for a crop and variety is a balance between minimising the risks of both frost and heat and maximising plant available water and minimising drought stress.

Growing less-susceptible crops, such as oats and barley, can reduce losses from frost compared with wheat. Pulses generally perform poorly on sandy soils and are highly vulnerable to frost damage, but may be useful on small, targeted areas. Pasture growth can be slowed by frost but will recover if there is sufficient soil moisture in the profile.

Best practice frost management tips

Frost management tips

- Cropping sandy soils entails a greater risk of frost damage and white sands are higher risk than darker sands. In some cases frost risk can be associated with topography and soil type.
- Knowing where frost occurs regularly across the farming landscape can allow growers to develop frost maps, which build a picture of potential risk. Maps can be based on previous experience, checking and recording when frost damage occurs and verifying yield maps.
- Monitoring temperature can indicate whether conditions have been met that could cause frost damage but does not guarantee frost damage has occurred.
- Delving or spreading clay has been shown to reduce frost damage on white sandy soils, but this approach needs to be considered as part of an overall soil amelioration program.
- Rolling sandy soils after sowing or after emergence can reduce frost damage by compacting the soil, increasing water retention.
- The combined risk of frost with areas of inherent poor crop performance, can make cropping on some sandy soils a poor return on investment and other land uses may be lower risk and more profitable.
- Applying nutrients (e.g. potassium) to reduce frost, unless a nutrient is deficient, is unlikely to provide a benefit.
- Incorporating stubble can reduce the impacts of frost compared with standing stubble, but may increase the risk of erosion, chemical damage and poor crop establishment.

ABOVE: Standing stubble can increase the risk of frost, but the combined benefits of retaining standing stubble can outweigh these risks. Photo: GRDC

Further information

- Managing frost risk: a guide for southern Australian grains (SARDI and GRDC, 2007)
https://grdc.com.au/uploads/documents/GRDC_FS_Frost.pdf
- Cereals — Frost Identification: The back pocket guide (GRDC, 2000)
https://grdc.com.au/Resources/Bookshop/2012/01/Cereals-Frost-Identification-The-Back-Pocket-Guide-GRDC416
- Frost — Ground Cover Supplement (GRDC, 2014)
https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109
- Managing Frost Minimising Damage — GRDC Farmer Advice
https://grdc.com.au/uploads/documents/frost.pdf

Utilise rainfall to limit the risk of local seeps

Key facts

- Seeps result when unused water moves through the dune–swale landscape to a low-lying discharge site.
- Maximising crop water use efficiency (WUE) is the key to preventing and managing seeps.
- Establishing perennial pastures on sandy crests will optimise year-round rainfall utilisation, preventing water loss through the soil profile.

Farming systems and management practices that maximise plant water use will limit seeps from developing. Localised seeps and salinity can occur within a matter of seasons and render low-lying productive areas within a paddock unable to support any plant growth.

Growers in the Southern Mallee region of South Australia first noticed seeps developing during the early 2000s. Areas that were historically the best-performing zones of a paddock were slowly becoming waterlogged and salt levels were increasing. Eventually trafficability was affected and crops could no longer be established in these zones.

What are seeps?

Seeps occur when unused rainfall drains through a vulnerable landscape, meets an impermeable subsoil layer and discharges at the sand–clay interface (see Figure 13).

Seeps are typically seen in dune–swale landscapes under annual cropping systems, where the catchment area is a coarse sandy soil, often with poor water-holding capacity.

Rainfall penetrates the soil surface rapidly, collecting salts and nutrients as it moves through the profile.

At depth these soils have a non-continuous, impenetrable clay layer. Water pools at this sand–clay interface, and moves laterally across the clay. Over time, and with subsequent rainfall events, this water eventually discharges at the base of the catchment site.

Water recharge is greatest during a summer fallow, which aims to conserve summer rainfall for the following winter crop.

During the growing season annual crops and pastures intercept and use a proportion of the rainfall. However, due to the rapid movement of water through the sandy soils, recharge still occurs, albeit at a lower rate than during a fallow.

When the accumulated recharge evaporates, salts remain, leaving a semi-permanent to permanent scald area at the discharge site.

Farming system influences

Modern farming systems and practices have, in part, contributed to the occurrence of localised seeps. A shift to continuous annual cropping, a reduction in perennial species and effective summer weed control are likely to be contributing factors.

PREVIOUS PAGE: Continuous annual cropping, a reduction in perennial species and effective summer weed control are likely to be contributing to the development of seeps.

ABOVE: Seeps occur when unused rainfall drains through the landscape and discharges at the sand–clay interface.

Photos: Lou Flohr, Agrilink Agricultural Consultants

The effective control of summer weeds across landscapes dominated by large areas of sandy dunes, relative to swales, with underlying low permeability are potential situations that cause localised seeps to occur.

Water-repellent sands with low inherent fertility also both directly and indirectly contribute to the development of a seep.

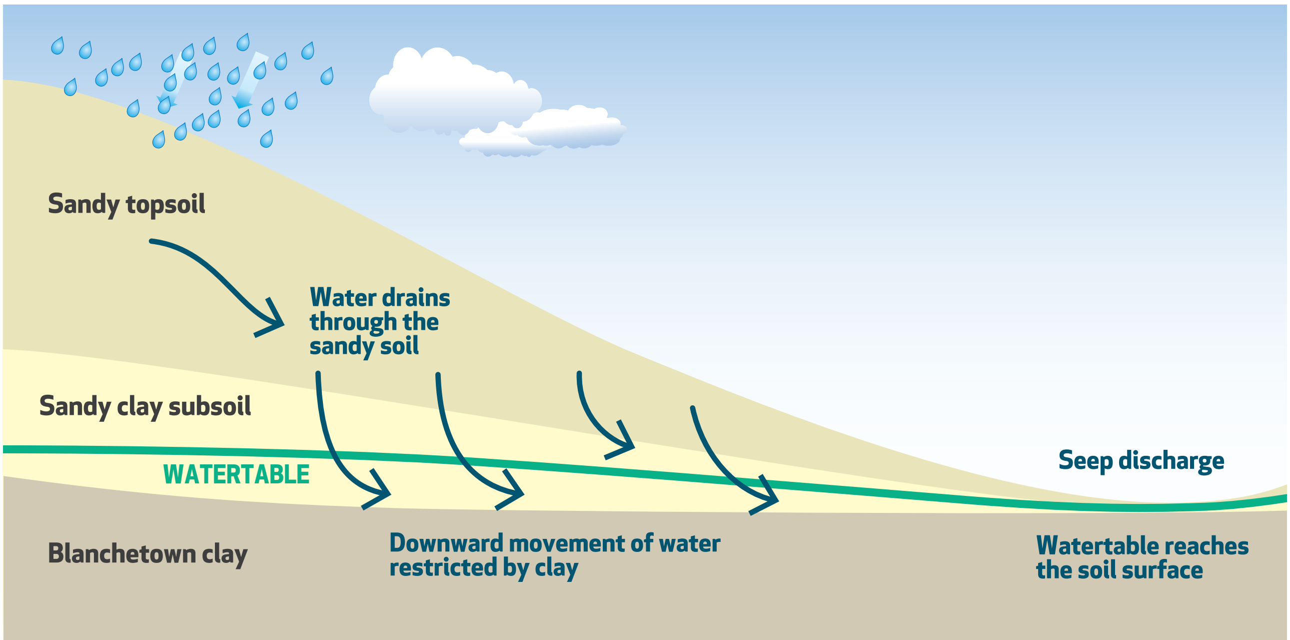
Seeps versus widespread salinity

It is important to distinguish the difference between the development of isolated, local seeps and salinity associated with a rise in groundwater levels across the region or catchment.

Seeps involve a local water system, which occurs close to the surface, they are not associated with the deeper groundwater basin, which in most cases is 40–60m deep.

It is the horizontal movement of water through the landscape, rather than a rising and falling water table that characterises a localised seep.

Figure 13. How seeps develop in a dune–swale landscape



Water drains through a sandy topsoil and sandy-clay subsoil before further downward movement of water is restricted by a Blanchetown clay layer, resulting in a perched watertable. In the lower-lying swale area, the perched watertable reaches the surface, resulting in the formation of a seep discharge area.

ABOVE: Sowing salt tolerant perennial species, such as messina (top), lucerne (above left) and tall wheatgrass (above right) will ensure water is used throughout the year. Photos: FFICRC and Catriona Nicholls

Farming system impacts

The major challenges surrounding seeps are the impacts at the discharge sites, including:

- persistent waterlogging, which can reduce trafficability for sowing and crop or pasture management activities, and limits crop and pasture options and production
- elevated soil salinity levels, which further limit crop and pasture and productivity
- poor plant growth and therefore the subsequent lack of ground cover, and evaporation, which causes salt to accumulate at the soil surface
- a bare soil surface, which is then exposed to wind or water erosion.

If the discharge or scald area is eroded, the loss of topsoil can result in a more-or-less permanent blow out, which creates an areas of permanently unproductive land.

Management strategies

The key to managing seeps is to act quickly. The faster a seep is identified and managed, the easier rehabilitation will be. Long-term degraded sites take considerably more effort (and money) to restore.

Appropriate strategies will depend on the current and potential enterprise mix and resources available. A summary of possible approaches is listed above in Table 4.

Table 4. Management options for seeps

Stage of detection	Possible symptoms	Hydraulic processes	Suitable management options
Early detection	High productivity at base or mid-slope of sandy catchment area. Small bare patches starting to appear. Trafficability not compromised.	Fresh water being discharged into the site, but site not rising to the soil surface.	Stop recharge from occurring. Take catchment area out of annual cropping and sow a perennial species, such as lucerne. After water has been used by the perennial species, the area can be re-sown to annual crops. This process may need to be repeated, as its likely to recur.
Intermediate detection	Small bare patches in discharge area from prolonged waterlogging. Some salt crusting around bare patches. Strong growth around bare patch. Boggy to drive through.	Water accumulation at the soil–clay interface has reached maximum potential, water starts to seep out of mid-slope or swale.	Stop recharge from occurring. Cover discharge site to stop evaporation — possibly with straw and consider sowing salt-tolerant perennial species, such as Puccinella and tall wheat grass. Take catchment area out of annual cropping, and sow a perennial species, such as lucerne. Consider planting shrubs and/or trees above the discharge site in conjunction with perennial species.
Late detection	Large bare patches, waterlogged, salt crusted, and can no longer drive on the affected area.	The recharge has been feeding into the discharge site for some time, expanding the area. Evaporation has occurred, increasing the salt content of the soil. It is likely to take 10 or more years before regaining productivity.	Stop recharge from occurring. Cover discharge site to stop evaporation — possibly with straw and consider with salt-tolerant perennial species, such as Puccinella and tall wheat grass. Take catchment area out of annual cropping, and sow a perennial species, such as lucerne. Plant shrubs and/or trees above the discharge site in conjunction with perennial pasture species. Damage may not be reversible.

Spading chicken manure — a novel idea for managing seeps

The ultimate goal when managing seeps is to use the water where it falls. During 2015, local agronomic consultant Chris McDonough suggested ameliorating water-repellent sandy soils, with low water-holding capacity, a bleached A2 horizon and poor nutrient status at Wynarka, SA with chicken manure sourced from local sheds.

At the Wynarka site, a large proof-of-concept demonstration was set up during 2015 on a site with a severe seep in the swale zone. Chicken manure was spaded into the soil profile to a depth of about 40cm. Three rates of chicken manure were used: 0, 6 and 9t/ha (Table 5).

The addition of chicken manure reduced water repellence and improved the fertility of the bleached A2 horizon and water-holding capacity of the topsoil.

The spading treatment without chicken manure incorporated, produced a 28% yield increase in barley. This would suggest the mixing process involved with spading reduced water repellence, increased nutrient availability through re-distributed nutrients within the horizons and stimulated mineralisation. It may also indicate the spading reduced the effects of subsoil compaction.

Replicated trials conducted by Sam Trengove, Trengove Consulting, at Bute, SA during 2015 investigated the effects of deep ripping, the deep placement of chicken manure or equivalent fertiliser (40–50cm applied with deep ripper) and surface applications of chicken manure or equivalent nutrients in fertilisers.

The deep ripping treatment without additional fertiliser or manure produced a 55% increase in yield, suggesting a possible hard pan at this site, or nutrient response from increased mineralisation from the soil disturbance.

The yields produced when chicken manure was placed at depth with a deep ripping machine can be seen in Table 6.

Results from both the proof-of-concept demonstration at Wynarka and replicated trial at Bute indicate crop yields drop above a certain quantity of applied manure. This is likely to be due to high levels of nitrogen (N) in the profile, resulting in strong early-season, using available soil water, but 'haying off' later in the season, due to low residual plant-available water. On-going trial work will clarify the optimal levels of manure to support maximum crop yields.

The above data suggests that improving the nutrient levels and water-holding capacity of a poor soil will improve crop growth through better water capture and water use efficiency (WUE). This is important information for the ongoing management of seeps. With improved water use, comes reduced loss of water deep into the profile hence less recharge entering the seep discharge point.

Table 6. Yield data from manure and deep ripping trial at Bute, SA, 2015

Treatment	Yield (t/ha)
Control	1.79
0t/ha manure, deep ripping	2.78
5t/ha manure, deep ripping	2.92
20t/ha manure, deep ripping	2.28

F pr 0.006, LSD (0.05) 0.65t

The least significant difference (LSD) gives an indication of the treatment difference that could occur by chance. The size of the LSD can be used to compare treatment results and values must differ by more than this value for the difference to be significantly different.

Table 5. Result from chicken manure demonstration at Wynarka, SA, 2015

Modification	Unmodified	Spading — no manure	Spading + 6t/ha chicken manure	Spading + 9t/ha chicken manure
Average grain yield (t/ha)	1.55	2.17	3.29	3.30
Gross income @ $220/t wheat ($/ha)	$342	$478	$725	$726
Additional income above the control ($/ha)	—	$136	$383	$384
Cost of modification ($/ha)	—	$100	$310	$415
Net return after first year ($/ha)	—	$36	$73	-$31

Further information

- *Mallee seeps*, NRM Fact Sheet http://www.naturalresources.sa.gov.au/samurraydarlingbasin/publications/mallee-seeps
- *Soak management: 2015 GRDC Updates*, Adelaide Proceedings https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Dune-discharge-seepage-areas-in-the-South-Australian-landscape

Subsurface compaction limits crop potential on sandy soils

Key facts

- Anecdotal evidence suggests widespread compaction occurs on sands in low-rainfall areas.
- Restricting root growth reduces leaf area and the plant's ability to capture resources (nutrients and sunlight).
- Deep ripping can improve yields by more than 40% and benefits can last for many years.
- Controlled traffic farming (CTF) can extend the benefits of deep ripping.

Subsurface compaction can severely limit production, especially on sands, where natural packing can occur. Restricting root growth prevents crop access to critical resources, such as water and nutrients.

Subsurface (or subsoil) compaction describes the rearrangement of soil particles and total pore space as a result of applied stresses.

The main cause of subsurface compaction, particularly on sands, is wheeled vehicular traffic — especially heavy dual-axle tractors.

Subsurface compaction can be broken down into two main types:

1. **plough pans:** more common on heavier-textured soils (i.e. clays and loams)
2. **traffic pans:** more common on lighter-textured soils (i.e. sands).

Plough pans

Plough pans can be characterised by an abrupt boundary between the tilled and compacted soil layers and there are often signs of smearing on the surface of the compacted layer. The depth of a plough plan in the soil profile depends on how deep the soil-engaging equipment penetrates the soil profile.

This type of compaction is caused by repeatedly tilling the soil at the same depth for many years. As tines wear, this can smear and compact the soil immediately below their operating depth.

Traffic pans

Traffic pans are layers of high strength in the subsoil caused by traffic compressing the soil over time. This type of compaction lies deeper in the soil profile than plough pans, with the layer of maximum strength often occuring at 10–40cm.

Soil compaction induced by wheeled traffic is typically apparent at around 15cm below the soil surface, but can be deeper in sandy soils.

Other sources of compaction

Livestock can also cause short-term subsurface compaction. Research carried out by the CSIRO indicates soil pressure from sheep hooves can be as great, or greater than, that applied by tractors given the pressure is applied to a relatively smaller

PREVIOUS PAGE: Subsurface compaction is common on sandy soils and limits the ability of plants to access water and nutrients critical for optimal growth. Photo: DAFWA

RIGHT: The severity of compaction from heavy machinery can be compounded when soil is wet. Photo: Brad Collis, GRDC

surface area. However, compaction caused by sheep is often restricted to a narrow band across the soil surface, is limited to a depth of 5–10cm and is readily penetrated by normal tined sowing implements (Figure 14).

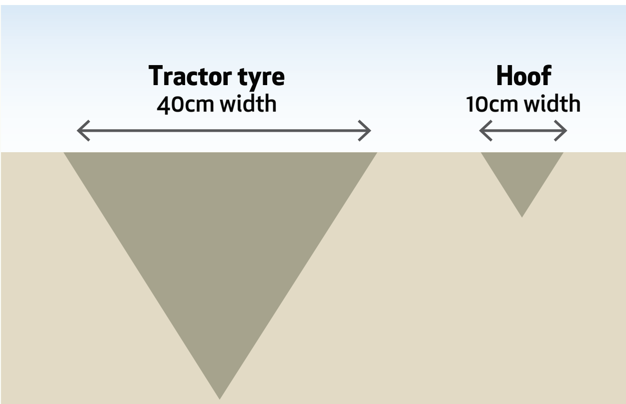
Some Mallee sands have a natural tendency to form impenetrable layers just below the soil surface. A natural sorting and movement of soil particles whereby fine sands, clays and silts settle further from the soil surface over time causes these soils to become compacted. Similar to compaction caused by livestock, this natural form of compaction can be penetrated by a tined implement at a regular sowing depth.

Measuring soil compaction

Penetration resistance is an empirical measure of the degree of compaction. Penetration resistance can be measured using a penetrometer, which measures the force needed to push a rod through the soil when a soil is at field capacity (i.e. approximately 24 hours after a soaking rain).

Researchers from Charles Sturt University, New South Wales found that root growth is typically impeded at a resistance of 1.5MPa, severely restricted at 2.5MPa and root growth ceases at 5MPa.

Figure 14. Traffic-related compaction versus livestock compaction



The width of the applied pressure from livestock is less than vehicle traffic so the depth of influence is shallower at the same contact pressure.

Source: Australian Grain (March–April 2010)

High-soil strength restricts root growth, with the effects exacerbated in drier soils — roots cannot grow beyond the wetting front in high-strength soils.

In the absence of a penetrometer, growers can identify compaction by observing the relative force required to dig a hole with a shovel.

Plant growth can also be an indicator of compaction, given compaction limits growth, often leading to stunted crops.

Responses of crop types to soil compaction

Restricting root growth to a shallow zone restricts plant access and uptake of water and nutrients. A corresponding reduction in leaf area can impede the ability of a plant to capture energy from sunlight.

Field experiments indicate that roots of cereal and grass species, such as wheat and barley, are less able to penetrate compacted soil layers than broadleaf species, such as legumes and brassicas.

Continuous cropping with cereals, can exacerbate the impact of compaction as cereal roots are less likely to produce useful root channels.

Root thickness, not root density, is the key property that allows a plant to penetrate hard soil layers. Given the roots of broadleaf species are relatively thicker than cereals and grasses, and thus more able to effectively penetrate compacted soils, they could alleviate compaction if grown after cereal crops.

Managing compaction

Ameliorating subsurface compaction using deep tillage (ripping) can result in spectacular yield responses.

Multiple trials have shown that in ripped soils, plants can extract more soil water at depth. Trials carried out by CSIRO at Loxton and Caliph, SA during 2005 measured wheat yield increases of up to 43% in response to ripping and responses were still evident in the second-year crop after ripping.

Deep ripping can deliver additional benefits including: the breaking up of hard pans, reduced water repellence by re-distributing wax-coated sand particles through the soil profile, and improved mineralisation rates, increasing the plant availability of nutrients during the growing season.

The legacy of ripping will depend on the frequency of re-wetting of the soil profile and the relative dependence of the crop on soil water located at depth. A SARDI research team

Tips for deep ripping

Tips for deep ripping

- **Timing** — Deep ripping carried out immediately after sowing, before the emergence of a cereal crop, will limit issues of trafficability following ripping. Some growers have experimented with ripping before sowing, but have found it reduces trafficability, which is challenging for paddock preparation and sowing .
- **Recompaction** — Ripped soil is more prone to re-compaction. Avoid unnecessary traffic following ripping.
- **Depth** — Ripping depth should be 1.5 times the disturbed depth of standard sowing equipment.
- **Residual effect** — The effects of ripping on responsive soils generally lasts for up to three years, but occasionally the benefits can continue for up to eight years. Generally, half the initial yield response could be expected over the subsequent two years.
- **Reliability** — Deep ripping is a reliable tactic for managing the compaction of sandy soils and enables roots to access soil water stored deeper in the profile, which is particularly important when there is a dry finish to the season.

RIGHT: Photo: GRDC

at Minnipa, SA found the effects of deep ripping were only apparent and most significant for 1–3 years. Responses will be most evident in those seasons when deep soil water is critical to yield.

Controlled traffic farming

The benefits of deep ripping can be prolonged if traffic is confined to one set of tram lines for every operation across the paddock — also know as controlled traffic farming (CTF).

Trials and experiences that compared (uncontrolled) conventional and CTF between 1997 and 2003 from Western Australia showed a yield increase of 10% in wheat along with an improvement of grain quality under a CTF system.

Controlled traffic farming CTF also creates opportunities for novel weed control options, such as inter-row spraying using precision agriculture (PA) technology.

Tips for controlled traffic farming

Tips for controlled traffic farming

- A 3:1 ratio between sprayer and sowing equipment width, based on wheel spacing configurations of major machinery manufacturers and grower experience, is the most economically-convenient option.
- While it is best practice is to have all equipment on tramlines, the priorities are sowing, spraying and top-dressing (spreading) rigs. It would be ideal to have the harvester also set up on tramlines, but given harvest usually occurs when the soil is relatively dry, the risk of compaction is less during harvest.
- Tracked vehicles provide better traction on permanent tramlines than those with single wheels.

Further information

- *Deep ripping Fact sheet*, GRDC (2009) https://grdc.com.au/uploads/documents/GRDC_DeepRipping_6pp_.pdf
- Ripping benefits quickly negated by wheel traffic, Ground Cover, GRDC (2015) https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-118-Soil-constraints/Ripping-benefits-quickly-negated-by-wheel-traffic
- 20 Questions You May Ask About Controlled Traffic in Western Australia:Paul Blackwell, DAFWA http://www.liebegroup.org.au/wp-content/uploads/2013/07/Questions-you-may-ask-about-Controlled-Traffic-farming-in-WA-v-3.pdf
- *Controlled Traffic Farming Fact Sheet*, GRDC, 2013 https://grdc.com.au/~/media/Documents/Resources/.../GRDCFSCTFhigh-respdf.pdf

www.agex.org.au

Grains industry and natural resource management working together