SANDY SOILS OF THE SOUTHERN REGION

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

SOUTHERN

A TECHNICAL MANUAL TO IDENTIFY, EVALUATE AND MANAGE CONSTRAINTS

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Sandy soils of the southern region – a technical manual to identify, evaluate and manage constraints

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COVER: Sandy soil pit, South Australia
PHOTO: Sophie Clayton, GRDC

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Introduction

Across the southern regions of Australia, growers have been observing ‘water left behind’ after growing crops in sandy soils. This poor crop water use is due to several constraints in sandy soils that present challenges for crop production.

Soil amelioration to overcome high soil strength, water repellence and low fertility has been shown to profitably improve crop production, and efforts to better understand the situations in which to apply amelioration practices have gained strong momentum in recent years. There is the potential for the conversion of large areas of sandy soils to more productive and resilient farming systems in the southern cropping regions of Australia.

Understanding the key constraints, appropriate amelioration tools and set-ups that will best address the constraints, are critical to success. A profit–risk analysis can help growers and advisers think through the relevant components of the costs, the expected response and financial risks associated with amelioration of deep sands.

After six years of research in the southern region, this technical manual brings together our latest advice on identifying the key constraints, matching the amelioration option to the constraint identified, reviewing trial results for relevant combinations of constraint–treatment–location to estimate the likely response, and a process for evaluating the cost and likely return for a treatment.

Chapter 1: Key constraints to production on sand

Water repellence and pH extremes

KEY POINTS

- Diagnosis of soil constraints is the first critical step in predicting crop response and the economic value of management options
- Understanding where and how water repellence and acidity or alkalinity constrain crop performance will help you derive the most cost-effective management practices
- Constraint zones within a paddock can be determined relatively easily using readily accessible imagery and production data and field-based testing processes

Multiple soil constraints commonly occur on sandy soils across the southern region, especially in the low-rainfall zone. Physical and chemical constraints rarely occur in isolation, and together restrict root growth and crop water use efficiency.

Measuring constraints on sands to inform management

The extent and severity of constraints varies across sandy paddocks (especially among dune–swale landscapes) and there is substantial value in the use of zone-based diagnosis to identify:

- **Where do the constraints exist across the paddock?**
  How do constraints differ in paddocks and across the landscape?
- **How deep are the layers affected by contraints?**
  At what depths do the different constraints start and stop?
- **How severe is the constraint?**
  Is the constraint mild, moderate or severely limiting production?

There are a range of strategies that can be implemented to combat constraints, which vary in effectiveness, longevity, and cost. Field-based diagnosis is the first step to effectively determine the likely economic value of the management practices available.

Know your constraints

Two common constraints encountered in sandy soils are:

- **water repellence; and**
- **subsurface acidity (low pH) or alkalinity (high pH).**

Figure 1.1: Repellent sand grains inhibiting water droplet infiltration.

Photo: Bill Davoren, CSIRO

Water repellence

Water repellence forms when waxes from decayed organic material (for example, stubbles) coat grains of soil, making them repel water (Figure 1.1), which inhibits water entry into the soil and promotes run-off. Compared to loams or clays, sands are more prone to repellence because the soil particles are larger with a smaller surface area. This leads to patchy crop establishment and a staggered germination of weeds, reducing yield potential at the start of the season.

pH extremes

pH is a measure of the concentration of hydrogen (H+) and hydroxyl (OH-) ions in a soil solution and indicates that a soil is acidic (low pH), neutral or alkaline (high pH). pH variation through the soil profile is common. It's important to understand this variation as nutrient availability can be affected, resulting in potential plant deficiencies or toxicities (Table 1.1).

pH is commonly measured in water (using a 1:5 soil to water solution) or in calcium chloride (soil to $CaCl_2$ solution). Whilst both measures are accurate, pH results measured in water are often 0.5 to 1.0 units higher; remember this when interpreting results between years or from different laboratories. Excessive acidity (pH<5.5 in calcium chloride) typically occurs in the 5 to 15 centimetre (cm) soil layer, which can be corrected with applications of lime. Excessive alkalinity (pH>9.0) typically occurs in the subsoil below 20cm and is more difficult to manage.

How to test

Paddock diagnostic zones

Paddock diagnostic zones can be determined using:

- **Aerial imagery** in Google Earth Pro can provide an indication of soil type (for example, colour) and zone differences, such as dunes and swales. Utilise 'historical imagery' to inspect changes over time.
- **Soil proximal sensors** such as electromagnetic induction (EMI) can identify changes in soil properties, which are often strongly correlated to paddock productivity. Soil analysis is required to calibrate the EM readings with soil properties and understand the cause of variation (that is, soil texture, moisture content, salts). Learn more on precision soil mapping at SPAA.
- **Plant production measures** such as normalised difference vegetation index (NDVI) and/or grain yield and protein maps can identify production zone boundaries. Access free and current NDVI imagery at IrriSAT.

Paddock testing

Once the diagnostic zones are established (usually three to five in each paddock), there are some easy paddock testing options available to measure repellence and pH within each zone (Table 1.2). The best time to conduct these tests is in late summer or early autumn when the soil is dry.

Table 1.1: Potential impacts of low and high soil pH.

Acidity	Alkalinity
Toxic amounts of H+ stunts root growth and limits nutrient availability (particularly phosphorous), along with changes in microbial activity	Excessive alkalinity can cause plant toxicity and reduce root growth
Toxic forms of aluminium can also be released in some acid soils, exacerbating the issues above	Carbonate and bicarbonates of calcium and/or sodium accumulation can impact phosphorus and trace element availability
Lentils, faba beans and barley are more sensitive to acidity than wheat	Often co-occurs with other constraints including sodicity, salinity and/or boron toxicity

Figure 1.2: Paddock pH indicator testing. The ideal range is between 6.5 and 7.5. Acid layers will show as bright green or yellow colours. Alkaline layers will be deep purple.

Photo: Chris Davey, YP AG

More precise analysis

If water repellence and/or acidity is identified within the paddock diagnostic zones and is considered severe (Sandbox score 2, see below) careful soil sampling and accurate laboratory measurement are recommended before management options are considered – consult your agronomist.

Water repellence: Follow the instructions in Table 1.2 for collecting composite samples for the 0 to 5cm and 5 to 10cm layers, placing samples in labelled bags. Send to a laboratory (no need to dry first), requesting the molarity of ethanol droplet test (MED). Use the interpretation criteria in Table 1.3 to assign a severity score.

Acidity: The collection of soil samples for laboratory testing will depend on the position of the acid layer; 0 to 5cm, 5 to 10cm and 10 to 20cm depths are commonly recommended, although 0 to 5cm, 5 to 15cm and 15 to 25cm are also useful. Traditional 0 to 10cm sampling used for nutrient analysis may not identify acidity in the 5 to 15cm layer. Collect multiple samples from within each zone, combining the appropriate layer depths in a clean and labelled bucket. Thoroughly mix the composite samples and retain 250 grams (g) to send to a laboratory, requesting pH (calcium chloride), organic carbon and soil texture assessments.

This information will help you identify the best lime rate to treat acidity. If your soils contain aluminium, you might also request a test for this. Silver grass, sorrel and annual ryegrass are all indicators of acidity and aluminium in soils, so look out for these too.

Score results

Use the diagnostic criteria in Tables 1.3 and 1.4 to assess the severity of each constraint and assign a 'Sandbox score' for each paddock zone. You can use this information to find experimental results for sites with a similar constraint profile in the Sandbox tool, an online platform that presents results from the GRDC Sandy Soils Research Project (CSP1606-008RMX). Severe constraints need to be addressed as soon as possible, while moderate constraints should be monitored.

Table 1.2: Preparation and testing procedures to determine water repellence and pH. The soil must be dry to accurately test for repellence.

	Water repellence	pH
Equipment	• Shovel • Medicine/eye dropper • Deionised water or rainwater • Sample bags and buckets	• Shovel or dig stick • pH indicator dye and powder (soil pH kit) • Tape measure
Preparation	• Carefully scrape off all organic matter and the top 2–3 millimetres (mm) of the topsoil layer at each diagnostic zone testing site • The area should be free of standing stubble (i.e. in the inter-row), weeds and plant roots	• Dig 3–5 holes to 40cm depth within each diagnostic zone to create a vertical soil profile face
Testing	**Surface testing** • Using an eye dropper, place three similar sized large droplets on the surface, dropped from the same height e.g. 20–30mm • Record the time each drop takes to infiltrate to determine repellence (see: Score results below) • Repeat three times at each diagnostic site • Consider repeating this at different depths in the soil (i.e. at the depth of sowing) **Testing 0–10cm – a composite** • Collect multiple samples from: - 0–5cm of soil – place in bucket #1 - 5–10cm of soil – place in bucket #2 • Mix each bucket thoroughly and place in labelled sample bags • If samples are wet, place the soil in a tray and allow to air dry (for example, over 1–2 warm days) • Once dry, use the eye dropper to repeat the surface testing process and record the infiltration times	• Apply pH indicator dye according to kit instructions onto the soil surface; apply the powder and let the colour develop • Once the colour reaction is complete, use the diagnostic indicator card to determine the pH • With a tape measure, identify the position of any pH changes and acid layers • You can also use a dig stick soil probe, removing an intact soil core and apply the same procedure to assess the pH change

Table 1.3: Severity of water repellence based on the time of water infiltration (a) and the lab-based assessment using the molarity of ethanol droplet test MED (b).

Sandbox score	Severity	(a) Water droplet infiltration time	(b) MED
0	Non-repellent	Water infiltrates dry soil in 5 seconds or less	0
0	Mild	Takes more than 5 to 60 seconds to infiltrate	0.2–1
1	Moderate	Takes 60 to 240 seconds to infiltrate	1.2–2.2
2	Severe	Takes more than 4 minutes to infiltrate	2.4–3.0 3.2>3.8 very severe

Table 1.4: Severity of acidity and alkalinity, as determined using pH indicator dye and a colour chart, which is roughly equivalent to the pH in water (a) and measured in a 1:5 solution of calcium chloride at the laboratory (b).

	Sandbox score	Severity	(a) pH indicator kit	(b) pH $CaCl_2$
Alkalinity	2	Severe	>9.0	>8
	1	Moderate	8.5	7.5
	0	Mild	8	7.0
	0	Neutral-Ideal	7.0	6.5
Acidity	0	Mild	6.5	6.0
	1	Moderate	6.0	5.5
	2	Severe	<5.5	<4.8

Physical soil constraints

KEY POINTS

- Sandy soils commonly have physical constraints that reduce crop root growth and exploration and water use efficiency, which ultimately reduces yield
- Hardened subsoil layers within sandy soils vary in nature and distribution through the soil profile. They are typically categorised into two forms:
  - Traffic-induced compaction (cultivation pan) – soil particles bind together tightly due to the application of external forces, such as the weight of machinery, mainly when the soil is wet
  - Natural subsurface hardening
    - *Hardsetting* – a reversible chemical process in which a hard layer forms as the soils dries out, restricting root growth, but softens on wetting
    - *Cementation – an irreversible chemical process in which salts precipitate (solidify) and cause cementing, even when wet*
- Understanding the differences between soil-hardening processes can assist with amelioration strategies and future planning

The villains of hard subsurface layers in sandy soils

The cost of subsoil constraints

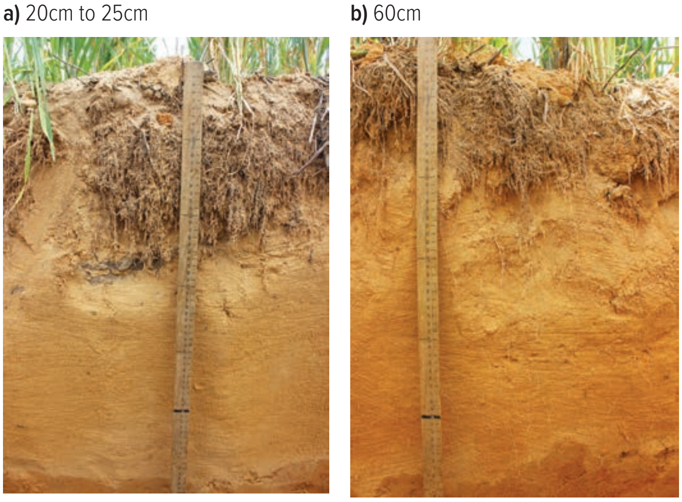
Many Australian sandy soils have hardened subsoil layers that prevent root penetration and reduce access to nutrients and water deeper in the soil profile. Agricultural production loss associated with soil compaction in Australia is estimated to cost about $850 million per year.[1]

Hardening subsoil layers

The nature and distribution of hard and/or cemented soil horizons varies. Two broad categories of natural subsurface hardening within sandy soils are typically identified.

Traffic-induced compaction, also known as a cultivation pan, is a result of external forces applied to soils through farming operations (including livestock traffic), especially when the soil is wet. Root growth can be severely restricted (Figure 1.3a) and yield compromised. Soil structure is reduced through binding of soil particles, which decreases soil porosity and permeability to both air and water through the pan, in comparison to the soil horizons above and below.

Figure 1.3: Comparison of root depths: a) roots restricted to 20 to 25cm in hardened soil; b) deep ripping removed hardening, allowing roots down to 60cm (Karoonda, SA, 2021).


a) 20cm to 25cm **b)** 60cm

Photos: Bill Davoren

Natural subsurface hardening is caused by chemical processes, leading to either reversible or irreversible hardening. ***Hardsetting*** is reversible with soils becoming hard as they dry out and soft once the soil moisture increases. When looking at a soil profile, as in pictures above, the hardsetting layers cannot be indented when pressure is applied with a forefinger. Rooting depth can be extremely limited because the strength increases dramatically as the soil dries out in spring, limiting root penetration even though the soil moisture may be sufficient for root growth and water extraction. Persistence of this form of hardsetting depends on soil moisture conditions. Therefore, the severity of hardening is likely to vary within or across seasons depending on soil type and rainfall conditions.

Cementation, in contrast, is irreversible soil binding due to precipitation of chemical compounds. These cementing compounds usually come from groundwater. The degree of cementation ranges from weak (crushable between thumb and forefinger) to very strong (cannot be broken by a hammer or extreme force). Unlike hardsetting, cemented soil layers do not become soft on wetting. They can be observed even in uncleared native sandy soils, which suggests that farming practices are not necessarily the cause.

Diagnosis

Compaction and natural subsurface hardening can coexist[2], but understanding the differences can support effective management decisions.

To determine if the hardened soil layer is cemented, place a piece of a clod of dry soil (~30mm) in water for one hour. If it slakes and breaks up without agitation, it is uncemented; if not, it is cemented. The degree of cementation can range from weak to very strong.[3]

Table 1.5: Indicative characteristics of subsurface hardening (guide only).[a]

Characteristic	Traffic-induced compaction (cultivation pan)	Natural subsurface hardening	
		Wet soil	Dry soil
Bulk density (Soil weight to volume)	High	Same	Same[b]
Total porosity (Pore space between soil particles per volume of soil)	Low	High	Low
Permeability (Flow of air and water in the soil)	Low	High	Low
Soil strength when wet and drained (Force applied to the soil at the time of testing)	High	Low	High

a. Blue – characteristic is at a non-desirable indicator level;
Green – characteristic is at an acceptable indicator level.
b. Exceptions apply

Table 1.6: Testing methods and thresholds for determining subsurface hardening.[4]

	Traffic-induced compaction	Natural subsurface hardening
Test	(a) Bulk density (BD) analysis (b) Penetrometer – wet and drained soil	(a) Bulk density (BD) analysis (b) Penetrometer – range of soil water contents between field capacity and permanent wilting point.
Thresholds (rules of thumb)	(a) Where BD is ≥1.6g/cm^3 soil is regarded as compacted and root growth is restricted. Root growth is prevented when BD ≥1.85g/cm^3. (b) Where soil resistance is ≥2.5MPa measured in a wet, well-drained soil it will limit root growth.	(a) Soil hardening occurs even with BD below 1.6g/cm^3; hence cannot be a diagnostic tool. (b) Hardsetting soils will exhibit a significant increase in strength as the soil dries out, exceeding the 2.5MPa threshold. Non-hardsetting soils will not present such difference in penetration resistance when wet and dry.

AMELIORATION OPPORTUNITIES

Traffic-induced compaction

- Deep tillage practices fracturing the hardened subsoil layer have shown beneficial agronomic responses, particularly in following seasons.
- Considering the life span of deep tillage is essential, as subsequent traffic can cause soil to re-compact over time.
- Deep tillage may be required every five to 10 years to manage constraints. If the soil is prone to hardsetting, machinery traffic may not be the sole cause of hardening and deep tillage may be required more frequently.

High soil strength

Measuring soil strength with a penetrometer

High soil strength can be caused by compaction and/or hardsetting, and can severely limit root penetration, preventing access to moisture and nutrients at depth.

A cone penetrometer is a relatively simple tool to measure soil strength. It measures the force required to insert a standard cone into the soil, reported as either kilopascals (kPa) or megapascals (1MPa = 1000kPa).

Follow the method outlined in Table 1.7 below to measure soil strength and use the diagnostic criteria in Table 1.8 to assess the severity and assign a 'Sandbox score' for each diagnostic zone in the paddock.

Soil strength is strongly correlated to soil moisture, with root penetration decreasing as the soil dries out. So, it is important that penetrometer measurements are taken when the soil profile is uniformly wet (see Table 1.7). If the subsoil is dry, it will give an erroneously high reading.

Soil pits

High soil strength may also be detected by inspecting open soil pits, with the degree of soil consolidation and lack of roots indicating soil physical constraints. When digging the pit with a spade, layers with high strength will feel more dense and stronger than the soil above or below it. Observations of root growth and soil moisture at depth can also be useful, particularly if the pit is dug in late winter or spring.

Push rods

A cheaper alternative to a penetrometer is a push rod. These are typically made from 8 to 10mm steel rod sharpened to a point on one end and a cross-piece handle on the other end. The rod is pushed into the soil like the penetrometer, and hard layers are sensed by the user. Unlike penetrometers the push rod does not provide a quantified measure of the soil strength and the likelihood of impairing root growth. However, they are useful for comparing soil types, paddock zones, wheel tracks and tillage treatments.

Figure 1.4: Root growth is impeded in this sandy soil at Coomandook, SA, due to high soil strength below 20cm.

Photo: M Fraser

Table 1.7: Testing methods to measure hard or compacted soil layers using a penetrometer.

Equipment	• Hydraulic cone penetrometer
Preparation	• Identify distinct paddock diagnostic zones within the paddock of interest (typically three to five) using yield maps, aerial imagery or soil sensing technologies (for example, EM38) **Wet conditions** • Ideally, conduct assessments when the soil profile is uniformly wet (but not saturated), typically in the winter months **Dry conditions** If part of the soil profile is dry it needs to be wet up in 3-5 areas in each diagnostic zone using the following procedure: • Prepare a large bucket or tub with many 2mm holes in the bottom • Trim any standing stubble back to ground level, being careful not to disturb the root system. Place a piece of coarse cloth on the ground, place the bucket on top, and backfill around the base of the bucket with soil • Completely fill the bucket with water and allow to drain, leaving for a day before testing • After using the penetrometer, dig down to the testing depth to check that the wetting was uniform through the profile
Testing	• Insert the penetrometer into the soil at a steady speed of about 3cm per second • Note the depth where the penetration resistance (PR) reaches 1.5MPa and 2.5MPa • Continue to insert the penetrometer and note the maximum PR, and the depth at which it occurs • Repeat several times in the surrounding area to gauge the average depths and severity • Repeat in 3 to 5 locations within each diagnostic zone • Compare readings to un-trafficked areas, such as along fencelines or in native vegetation, and avoid wheel tracks and headlands • Note: penetrometers are unsuitable for use in soils with more than 10–15 per cent gravel

Table 1.8: Severity of penetration resistance, as measured using a hydraulic cone penetrometer in wet soil.

Sandbox score	Severity	Penetration resistance (MPa)	Degree of consolidation	[1]Effect on root growth
0	Not compacted	<0.50	Loose	Not affected
0	Mild	0.50–1.5	Medium	Root growth on some cereal plants restricted
1	Moderate	1.50–2.50	Dense	Root growth on most plants starts to be restricted
2	Severe	2.50–3.50	Very dense	Root growth restricted to existing pores or weak planes
2	Extreme	>3.50	Extremely dense	Significant compaction present. Root growth virtually stops

[1]Adapted from Hazelton and Murphy (2016).

Nutrition

KEY POINTS

- Nutrient supply is a common and important limitation to crop production in sandy soils
- Understanding the extent and severity of nutrient constraints through soil and plant analysis is the first step in working out which nutrients, and how much, need to be added to achieve yield potential
- Knowing your yield potential, especially if other constraints have been ameliorated, allows you to benchmark the performance of crops and consider the yield gap that might be closed
- Meeting the crop's nitrogen (N) requirement (and other nutrients) is essential to close the yield gap and extract the most profit from soil amelioration

Crop nutrition for sandy soils

Sandy soils are often infertile and nutrient deficient because they are highly weathered, low in carbon and have a poor ability to retain and cycle nutrients. Amelioration of soil constraints such as high soil strength, water repellence or acidity increases the yield potential of crops, but the crop's increased nutritional requirements need to be met to realise the new yield potential.

The key considerations when assessing nutrient status of sandy soils are:

- **What are the limiting nutrients?** The most common limiting nutrient in sandy soils is nitrogen (N), but there can also be deficiencies of phosphorus (P), potassium (K), sulfur (S), zinc (Zn), copper (Cu), manganese (Mn) and molybdenum (Mo). The methods available to identify which nutrients are limiting include soil and plant testing and in-crop test strips.
- **Where are the constraints?** Like other constraints, it is critical to understand how nutritional deficiencies vary across soil types within the paddock (for example, dunes, mid-slopes and flats). Collect 0 to 10cm soil samples from strategic diagnostic zones and send to an accredited laboratory for analysis. Where tillage has been used to treat physical and chemical constraints, collect soil samples after amelioration to determine the impact of dilution and/or mixing of the nutrient-rich topsoil.
- **How severe is the constraint?** The severity of the deficiency, as indicated by soil and plant tests, will inform the amount of fertiliser required to correct it. See Table 1.9 for a generalised guide of soil test thresholds for sandy soils. Use these diagnostic criteria to assess the severity of nutritional constraints and assign a Sandbox score for each paddock diagnostic zone. Alternatively, consult your agronomist.

Addressing deficiencies

When deciding how best to address nutrient deficiencies after amelioration, it is important to know the new yield potential you are targeting. Crop yield potential is largely driven by rainfall and can be calculated using long-term average rainfall records. According to Sadras and Angus (2006) the potential yield for wheat is:

- **Potential yield (kilograms per hectare (kg/ha))**
  = 22 × (crop water use – 60) *1.12

The crop water use is estimated as the growing season rainfall (April to October mm) plus 0.25 x summer rainfall (December to March mm). The 1.12 multiplier assumes that the grain yield is reported at 12 per cent moisture content (Hunt and Kirkegaard, 2012).

Figure 1.5: Scepter⦶ wheat, sown 24 May 2022, with district practice fertiliser applied (left) and with an additional 55kg/ha of nitrogen applied up to GS30.

Photos: M Fraser

Table 1.9: Guidelines of nutrient limitations based on critical values for laboratory soil tests for nitrogen, phosphorus, sulfur, potassium, zinc and copper.

Sandbox score	Severity	N kg/ha per tonne (t) target yield	mg/kg Colwell P	mg/kg KCl-S	mg/kg Colwell K	mg/kg DTPA Zn	mg/kg DTPA Cu
0	Sufficient	>40	>18	>4.1	>49	>0.27	>0.23
1	Marginal	20–40	14–18	2.3–4.1	31–49	0.13–0.27	0.16–0.23
2	Deficient	<20	<13	<2.2	<30	<0.12	<0.15

[1] Soil test thresholds for N, P, K, S are derived from https://bfdc.com.au/interrogator/frontpage.vm and for Zn and Cu from Peverill et al. (1999). Note that soil testing for manganese and molybdenum availability do not have reliable thresholds.

Table 1.10: Estimates of yield potential, attainable yield, and nitrogen (N) requirement for attainable yield based on long-term rainfall at sites in SA and Victoria. Examples of actual and yield gaps are also included.

Site	Yield potential (t/ha)	Attainable yield (t/ha)	Total N requirement for attainable yield (kg/ha)	[A] Actual yield (t/ha)	Yield gap (t/ha)
Buckleboo	3.1	2.5	100	1.4	1.1
Bute	5.6	4.5	180	3.6	0.9
Koolonong	3.2	2.6	104	1.3	1.3
Murlong	4.5	3.6	144	0.4	3.2
Pinnaroo	4.0	3.2	128	1.9	1.3
Sherwood	7.4	6.0	240	0.9	5.0

[A] Yield specific to the constrained sand, not the whole paddock.

The profitability of commercial crops is usually optimised at about 80 per cent of the yield potential (Hochman et al., 2012). This is because the cost of extra inputs to achieve the last 20 per cent of yield exceeds the value of the grain. So, the yield potential needs to be multiplied by 0.8 to determine the attainable or target yield.

The difference between your actual yield and the attainable yield is termed the ‘yield gap’. This gap is caused by soil constraints as well as weeds, pests, diseases and suboptimal agronomy.

Ameliorated sands have fewer constraints, greater potential and attainable yields, and a higher N requirement compared to the site before amelioration.

Of course, crop yield potential depends on seasonal conditions, especially rainfall. Potential and attainable yields can be estimated before sowing using long-term average rainfall data (Table 1.10), but these need to be reviewed during the season to inform post-emergent N applications.

Nitrogen requirement

The nitrogen (N) requirement or demand for a cereal crop at 11% protein is usually estimated as;

- N requirement (kg/ha)
  = attainable yield (kg/ha) x 40.

This N demand can be met from the mineral N pool in the soil at the start of the season (that is, ammonium and nitrate tests), from mineralisation during the growing season (that is, the release of N from soil organic matter), and from fertiliser or other N-containing amendments (for example, composts, manures and so on). Further information on estimating your N requirement is available from Unkovich et al. (2020).

An estimate of the N requirement for the attainable yield at key sandy soils sites is shown in Table 1.10. This scenario represents all the yield gap being closed. It is possible that an amelioration treatment will initially allow the crop roots to access nutrients in deeper layers (for example, leached N) and the fertiliser requirement does not change. However, with sustained increases in yield, the crop will eventually require a higher level of inputs. Where the amelioration does not reliably close all the yield gap, the attainable yield and associated N requirement should be recalculated.

Selecting the best management options to manage your constraint

Opportunities to treat sandy soil constraints to increase crop production can broadly be categorised into mitigation and amelioration approaches.

Mitigation approaches: These are generally lower-cost, annual strategies that aim to minimise the impact of a particular soil constraint on crop water use. Management tools include seeding and furrow design, soil openers, fertiliser form and placement, wetting agents and fungicides. These practices are expected to increase access to water in the soil but have little long-lasting impact on the soil’s long-term ability to supply water to crops.

Amelioration approaches: These are higher-intervention, higher-cost strategies that aim to have greater, longer-lasting impact, through changing multiple properties of the soil profile. Management tools include strategic deep tillage, with or without the addition of clay, organic matter or fertilisers of various forms.

These practices can be expected to change both the amount of water a soil can hold and the timing of water supply to the crop, thereby increasing the amount of water available to plants and lifting the yield potential.

The major constraints encountered on sandy soils in the southern region, along with a summary of the different treatment options, available are presented in Table 1.11.

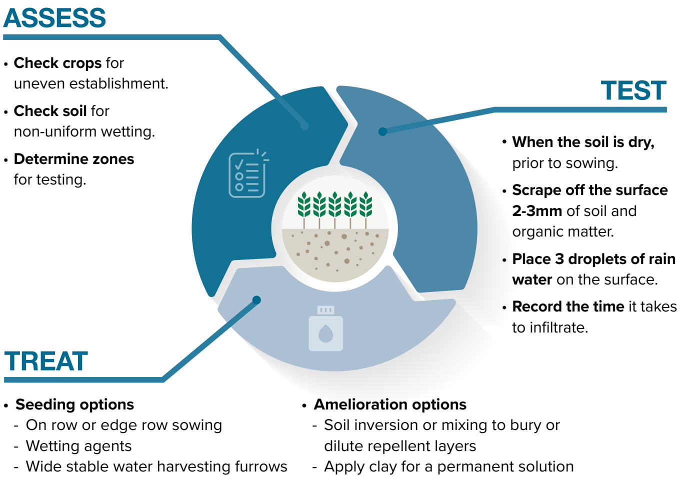
In Chapter 2 we will focus on ‘Mitigation or seeding-based approaches’. In Chapter 3 we will examine ‘Amelioration approaches using deep tillage’.

Table 1.11: Summary of sandy soil constraints and the mitigation and amelioration options for their treatment.

Constraint	Mitigation options		Amelioration options			
	Wetting agent	Seeder based	Amendments	Strategic tillage options		
				Ripping	Mixing	Inversion
Water repellence	✓	✓	Clay	x	✓	✓
Acidity	x	x	Lime Alkaline clay	Inclusion	✓	✓
Low nutrient fertility	x	✓	Fertiliser package Organic amendment Clay	Inclusion	✓	x
High soil strength	x	x	Organic amendment	✓	✓	✓

A summary of the process for managing the key sandy soil constraints that we have discussed in this manual are described in Figure 1.6-1.9.

Figure 1.6: Management of water repellance.



ASSESS

- **Check crops** for uneven establishment.
- **Check soil** for non-uniform wetting.
- **Determine zones** for testing.

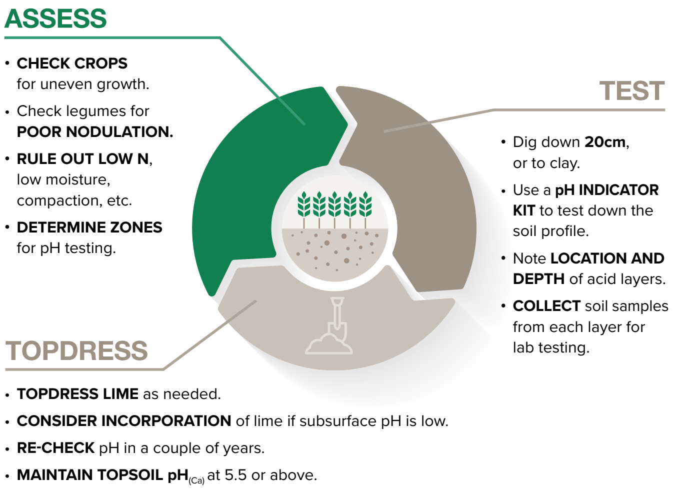
TEST

- **When the soil is dry,** prior to sowing.
- **Scrape off the surface 2-3mm** of soil and organic matter.
- **Place 3 droplets of rain water** on the surface.
- **Record the time** it takes to infiltrate.

TREAT

- **Seeding options**
  - On row or edge row sowing
  - Wetting agents
  - Wide stable water harvesting furrows
- **Amelioration options**
  - Soil inversion or mixing to bury or dilute repellent layers
  - Apply clay for a permanent solution

Figure 1.7: Management of acid soils.



ASSESS

- **CHECK CROPS** for uneven growth.
- Check legumes for **POOR NODULATION.**
- **RULE OUT LOW N,** low moisture, compaction, etc.
- **DETERMINE ZONES** for pH testing.

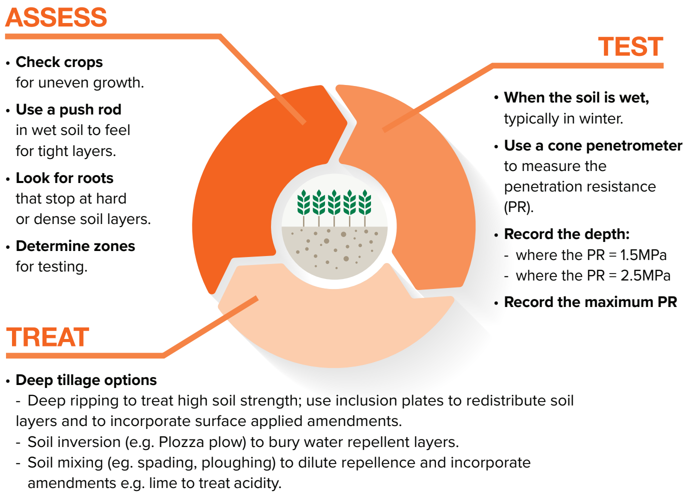
TEST

- Dig down **20cm,** or to clay.
- Use a **pH INDICATOR KIT** to test down the soil profile.
- Note **LOCATION AND DEPTH** of acid layers.
- **COLLECT** soil samples from each layer for lab testing.

TOPDRESS

- **TOPDRESS LIME** as needed.
- **CONSIDER INCORPORATION** of lime if subsurface pH is low.
- **RE-CHECK** pH in a couple of years.
- **MAINTAIN TOPSOIL** $\mathbf{pH_{(Ca)}}$ at 5.5 or above.

Figure 1.8: Management of high soil strength.



ASSESS

- **Check crops** for uneven growth.
- **Use a push rod** in wet soil to feel for tight layers.
- **Look for roots** that stop at hard or dense soil layers.
- **Determine zones** for testing.

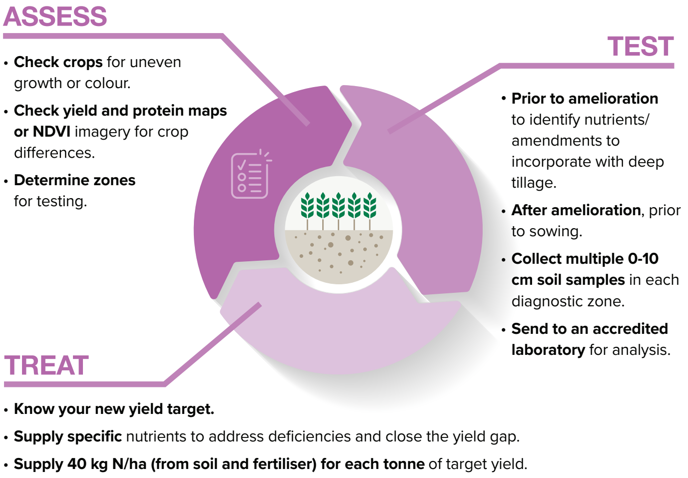
TEST

- **When the soil is wet,** typically in winter.
- **Use a cone penetrometer** to measure the penetration resistance (PR).
- **Record the depth:**
  - where the PR = 1.5MPa
  - where the PR = 2.5MPa
- **Record the maximum PR**

TREAT

- **Deep tillage options**
  - Deep ripping to treat high soil strength; use inclusion plates to redistribute soil layers and to incorporate surface applied amendments.
  - Soil inversion (e.g. Plozza plow) to bury water repellent layers.
  - Soil mixing (eg. spading, ploughing) to dilute repellence and incorporate amendments e.g. lime to treat acidity.

Figure 1.9: Management of nutrition.



ASSESS

- **Check crops** for uneven growth or colour.
- **Check yield and protein maps or NDVI** imagery for crop differences.
- **Determine zones** for testing.

TEST

- **Prior to amelioration** to identify nutrients/ amendments to incorporate with deep tillage.
- **After amelioration**, prior to sowing.
- **Collect multiple 0-10 cm soil samples** in each diagnostic zone.
- **Send to an accredited laboratory** for analysis.

TREAT

- **Know your new yield target.**
- **Supply specific** nutrients to address deficiencies and close the yield gap.
- **Supply 40 kg N/ha (from soil and fertiliser) for each tonne** of target yield.

Chapter 2: Mitigation

Mitigation or seeding-based approaches

Mitigation strategies that have been shown to enhance crop establishment in repellent soils include:

- wetting agents (surfactants) or water-retaining agents (humectants) applied at sowing;
- sowing on top of (on-row) or alongside (edge-row) the previous year's crop stubble, as it can increase access to in-furrow moisture;
- furrow openers and/or seeding attachment designs that enhance deeper moisture delving up to the seed zone, grade topsoil into ridges on the inter-row and/or control the furrow backfilling process, keeping the water-repellent surface layer out of the seed zone; and
- stable water-harvesting press-wheel furrows that enhance rainwater capture within the seed row.

If on-row/edge-row sowing is not possible, and the profile is not uniformly wetted (Figure 2.1), there is anecdotal evidence that sowing across the previous year's crop rows on an angle can aid germination by increasing the interception of moist soil in existing stubble rows. Research suggests that combining multiple seeder strategies increases the chances of successful crop establishment.

Figure 2.1: Soil moisture distribution after 50mm of rain in a water-repellent sand in the SA Mallee, showing wet soil below the lupin stubble crop row and pockets of dry soil in the inter-row (cleared) under a thin wet crust. The soil layer below 8 to 9cm was uniformly wet.

Photo: Jack Desbiolles

Figure 2.2: Paddock adoption of row-guided sowing with large-scale machinery needs accurate autosteer guidance and reliable seeder tracking stability.

Photo: Jonathan Dyer

Seeding sandy soils

KEY POINTS

- Crop establishment in water-repellent sands can be improved by accessing soil moisture available after the opening rains, either within the stubble row or in the inter-row subsurface below the dry layer (up to 20cm deep)
- On-row or edge-row sowing and sub-surface (it is the 10-20cm layer) moisture lifting achieved consistent benefits in small plot trials
- Combining these techniques with a seed zone soil wetter maximised the benefits
- Angled-row sowing is a practical compromise when accurate row-guided seeding cannot be implemented
- Seed and fertiliser separation can provide complementary benefits

Managing water repellence at seeding: moisture access strategies

Best practice

Maintaining surface ground cover is critical in sustaining productivity and managing both erosion and weed risks on water-repellent sandy soils. Current seeder strategies to improve crop establishment on water-repellent sands include:

1. maximising access to available soil moisture following opening rains;
2. minimising competition for moisture within the seed zone;
3. maximising furrow water-harvesting capability; and
4. combining all the above with a soil wetting agent.

This section summarises strategies 1) and 2), while 3) and 4) are addressed in the following section: Soil wetters.

Rainfall infiltration

Rain falling over a non-wetting soil surface forms run-off, which flows towards low-lying zones such as remnant press-wheel furrows, machinery wheel ruts or livestock footprints, then infiltrates preferentially via existing root system pathways. In addition, standing stubble helps capture and channel rain to the base of the root system in the furrow, resulting in moisture accumulation below existing stubble rows with inter-row zones remaining dry. As the soil becomes wettable at depth, the moisture gradually equalises across from the stubble row to the inter-row zone (Figure 2.3: Top).

At three water-repellent sites in 2018-19, an equivalent 7 to 9mm of extra moisture was measured in the 0 to 40cm depth zone under stubble rows after opening rains.

Soil moisture access

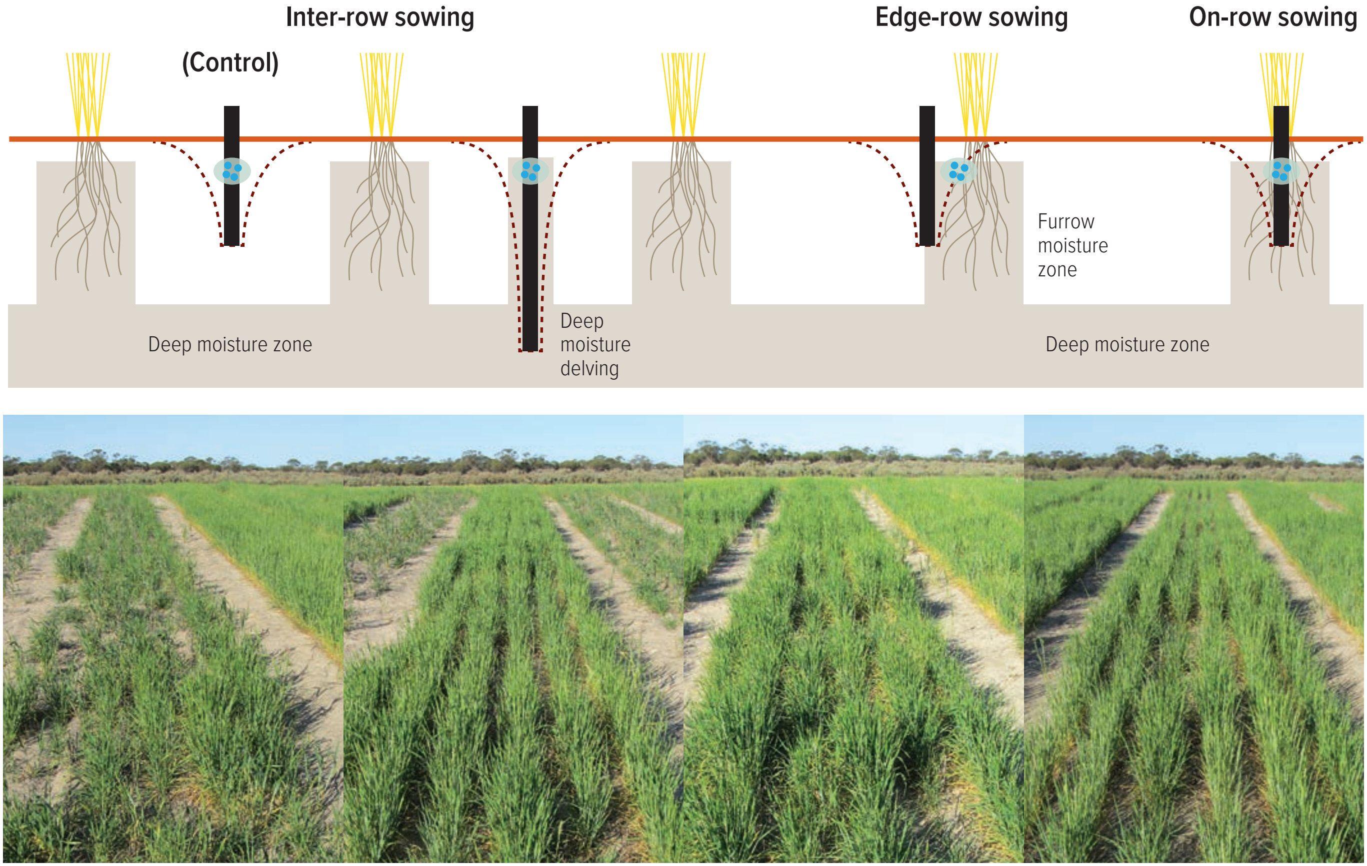
The above wetting process leads to opportunities at seeding time for strategies depicted in Figure 2.3: Top, including the following:

- Placing seeds into available stubble row moisture using edge-row or on-row sowing techniques: In both cases, real-time kinematic (RTK) positioning accuracy via tractor autosteer is required, sometimes complemented with implement steering, together with a stable-tracking seeder bar. Although edge-row sowing maintains stubble row integrity, it is challenging in practice (see page 16). On-row sowing is both easier to achieve and most effective at improving seed germination. However, with tyne seeders, the technique fully uproots stubble rows and leads to residue clumping and potential blockages, while with disc seeders significant crop establishment losses can arise from residue hairpinning. Overall, on-row sowing is less impactful when implemented into pulse stubble. Crops sown into higher-moisture furrows also benefit from improved mineral fertiliser availability, greater N mineralisation and potential root disease suppression from more active microbial activity.
- Lifting deep soil moisture up into the seed zone by using long-reaching openers set at a low rake angle: This moisture-delving option requires independent seeding row units with press-wheel regulated seed delivery where a deeper furrow can be adjusted on-the-go over water-repellent zones to restrict the high draught overall penalty while not significantly affecting seed placement.

Field evidence of benefits

In a replicated small plot trial at Murlong (SA Eyre Peninsula) in 2019, the above techniques (edge-row/on-row sowing and inter-row sowing with deeper moisture lifting) combined with a soil wetter applied in the seed zone were able to significantly increase barley crop establishment by 70 to 75 plants per metre squared (m^2) relative to the baseline inter-row sowing with soil wetter, which established 28 plants/m^2 (see Figure 2.3: Bottom). The benefits were maximised (Figure 2.4) with an additional 92 plants/m^2 under on-row sowing with soil wetter, using a paired-row wing attachment, compared with the baseline treatment (Desbiolles et al., 2020).

Figure 2.3: Top: Conceptual representation of moisture zones under stubble rows merging with deeper wetted layer (shaded), after opening rainfall on a water-repellent soil, and possible seeding techniques that can be used to access this moisture. Bottom: Corresponding barley crop establishment snapshots (inclusive of seed-zone soil wetter) at 14 weeks after sowing (2019 – Murlong field trial).



Photos: Jack Desbiolles

Similar barley crop establishment benefits (increase of 67 to 75 plants/m^2) from on-row sowing with or without deep moisture lifting were validated (without a soil wetter) under a replicated small plot trial at Younghusband (SA Mallee) in 2021, relative to an inter-row sowing baseline, which established 23 plants/m^2.

Edge-row sowing challenges

Edge-row sowing requires greater guidance accuracy than inter-row sowing and is especially reliant on seeder tracking stability. In ‘up/back’ sowing operations, there is a need to manually nudge the AB-line when changing direction to remain accurately on track, which is cumbersome and complicates sowing in subsequent years. To avoid this limitation, two alternative techniques compatible with a constant AB-line annual setting can be used, namely:

1 Edge-row sowing on annual AB-lines using paired row seeding systems. This is the most commonly adopted scenario but allows only one side outlet of paired row seeding to benefit from stubble row moisture. The AB-line is offset annually by an amount to suit the width of the paired row attachment and the position of the stubble row from the moisture-benefiting outlet. For instance, to suit 75mm wide paired row wings on a tyne seeder, edge row sowing in Year 1 requires the AB-line to be offset one way by 60 to 70mm and the following year this offset corrected by 90 to 100mm the other way. This process is repeated on a two-year cycle.

2 Edge-row sowing on constant AB-line using a side-banding system and adjusting the tyne positioning from year to year. This approach is more cumbersome, more practical with small seeders, and requires sufficient tool bar space, but allows all seeds to be delivered into stubble row moisture. For instance, to suit 35mm offset side banding wings symmetrically fitted, facing inwards on a tyne seeder, edge-row sowing in Year 1 requires all tynes to be shifted outwards by 35mm, then in Year 2 the tynes are shifted inwards by twice this amount (70mm), while left-hand and right-hand wings are swapped over across the seeder. In Year 3, the tynes and wings are returned to the original positions and directions. This process is repeated on a three-year cycle.

With the above, it is always recommended that annual sowing maintains the same seeder path in each paddock. Seeder bars with limited tracking stability may sometimes pull back into the old furrows but active implement steer can help mitigate this issue.

Angled-row sowing

In situations where seeder tracking is poor due to design limitations, soil variability, paddock topography or shape, sowing at an angle to existing stubble rows allows for placement of seeds into some moisture when crossing stubble rows. This simplified strategy is not compatible with controlled-traffic farming and typically produces wavy crop establishment patterns (Figure 2.5) but ensures some early ground cover is achieved and soil erosion risks are mitigated. Research is yet to explore the impact of furrow opener designs and angle of approach relative to the stubble rows on optimising crop establishment performance.

Figure 2.4: Best-established barley crop snapshot at 14 weeks after sowing in a severely water-repellent sand at Murlong, 2019, from on-row sowing using a paired-row opener with soil wetter delivery to each outlet (right). After 174mm of growing season rainfall, this treatment yielded 2.4t/ha relative to a 1.0t/ha grain yield under the control (inter-row sowing with wetter, Figure 2.3 – left).

Photos: Jack Desbiolles

Figure 2.5: Angled-row sowing: banded pattern of crop establishment from sowing at a 10° angle to the stubble row direction reflects the crossing of previous year rows.

Photo: McGlasson Rural Systems

Fertiliser toxicity

When soil moisture is marginal or uneven in a water-repellent sand, the risks of fertiliser toxicity to the seed are increased. Fertiliser toxicity (IPNI, 2013) consists of:

- the osmotic or ‘salt effect’ inducing competition for soil moisture, causing potential seedling dehydration and death. Concentrated fertilisers (high ‘salt-index’) placed close to the seed maximises risk, while lower application rate and higher seedbed utilisation dilute exposure; and
- ammonia toxicity from urea (and potentially from ammonium-containing fertilisers in high pH soils) occurs as a ‘gas plume’, which is toxic to both seeds and roots.

These effects are more likely on sandy soils compared with loams or clays and therefore can variably affect different parts of a paddock, such as in swale–dune systems. Under these conditions, split-banding fertiliser away from the seed zone consistently improves seed germination rate. The risk of toxicity is mitigated if sowing is followed by significant rains; however, a 50mm vertical separation between seeds and fertiliser eliminates issues in most situations, while a lateral separation is also required where ammonia toxicity is possible. Particularly sensitive crops such as canola, lupins and lentils benefit from minimal or no fertiliser placed in the seed zone under a marginal soil moisture situation. Seed and fertiliser separation implies greater furrow disturbance, which combines well with deep moisture lifting technique.

Soil wetters

KEY POINTS

- Modern soil wetting agents comprise surfactant blends that combine penetrant (promoting water infiltration) and humectant (promoting water retention) properties
- Significant crop establishment benefits have been achieved in recent trials in SA from soil wetting agents applied in the seed zone or split-applied between the seed zone and furrow surface
- Crop establishment and grain yield benefits seem to be greatest when combined with stable furrows that remain effective for water harvesting over the growing season
- It is difficult to predict which soil wetter chemistry is best suited to different local water repellence contexts, but all soil wetting agents have some potential to provide benefits under best practice

Managing water repellence at seeding: soil wetting agents

Soil water repellence causing patchy and poor crop establishment depends upon seasonal conditions, but wetting agents can mitigate the risks.

Properties of soil wetting agents

Soil wetter chemistries are varied and complex; little is known of their individual suitability to local water repellence. Modern soil wetter chemistries consist of surfactant (surface-active agents) blends, classified mostly as 'non-ionic' type (that is, have no charge and do not react with ions in water). These multi-action surfactant blends have 'penetrant' and 'humectant' properties.

- Surfactants with penetrant properties lower the surface tension of a liquid, allowing it to infiltrate more readily and spread into a water-repellent soil.
- Surfactants with humectant properties contain 'block copolymers' that effectively promote the retention of the liquid within a target zone, such as the furrow seed zone. Humectant properties are important to counter the risk of leaching.

Soil wetting agents may have residual effects in the year following the initial application, but this is normally limited (McDonald and Davies, 2018).

Best practice application

In exposed sandy paddocks, furrows experiencing infill or collapse after seeding are common. The risk is significantly lower when inter-row sowing into standing stubble and using large, 'open V' press-wheel tyres with side shoulders to help stabilise furrows (Figure 2.7).

As dry sowing into water-repellent sands without standing residue protection is very risky, recent research has focused on the use of soil wetting agents when sowing after the opening rainfall into partially wetted profiles. Here are recommendations to help secure best outcomes.

- Liquid delivery achieves a continuous stream of application along the seed row. This is easier to achieve at higher application volumes (for example, 80 to 100 litres per hectare).
- With some new chemistries now applied in the seed zone, it is critical that liquid systems are checked for delivery accuracy (a coloured dye can be used for calibrating delivery). This is particularly important for deep furrow tilling systems designed to backfill the lower furrow and for paired row seeding systems ensuring that liquid delivery reaches both seed outlets.
- For products applied behind the press-wheel, it is also important to ensure the liquid stream reaches the base of the press-wheel furrow with minimal fluctuation from wind or vibrations. Label requirements often state the need to apply the wetter onto a settled furrow surface and not to mix into loose backfill. Narrow spray pattern nozzles able to achieve a 2 to 3 centimetre wide

Figure 2.6: Soil wetter (wetting agent) chemistries vary and can affect the extent of early crop establishment benefits at any given site.

Photo: Jack Desbiolles

Figure 2.7: Water-harvesting stable furrows (left) shaped by wide V-shouldered press-wheel tyres (right) help soil wetter effectiveness, while maintaining standing stubble is often best practice for minimising furrow infill over time.

Photos: Jack Desbiolles

spray footprint (Figure 2.8) can help maximise infiltration over the width of lateral seed spread beneath, using penetrant-type surfactants.

- Dual-zone placement, with a penetrant-type surfactant on the furrow surface and a humectant-type surfactant in the seed zone, has the potential to improve the reliability of soil wetter benefits. However, this higher-cost choice also doubles the volume of application and requires a dual delivery system.

Do soil wetters perform?

While many growers have tried soil wetters, few have experienced reliable benefits. Field-based research in WA has had mixed results (Davies et al., 2019). International research also points to some complexity of interactions, whereby specific soil wetter chemistry can modify the extent of water repellence over repeated applications.

Table 2.2 summarises the latest outcomes of soil wetter evaluation on wheat or barley crops involving nine site-years (a mix of small plot replicated trials and large plot demonstrations in SA) conducted between 2018 and 2021. Approximately 48 per cent of the soil wetter treatments evaluated achieved significant yield benefits. Among these treatments, plant density increases of up to 55 to 80 plants per m^2 at five weeks after sowing were obtained at four of the nine site-years, leading to grain yield gains of 50 to 100 per cent.

Results to date support the general hypothesis that the full potential of soil wetters (including in-season benefits) is best able to be expressed where effective water-harvesting furrows can be maintained over the season. This potential may be highest under low-decile growing season rainfalls, which is in accordance with Western Australian experience.

Figure 2.8: Application of soil wetter behind water-harvesting 'open V' press-wheels via a narrow (15 degree) flat fan nozzle achieving a stable 3cm wide spray footprint at the base of a firm furrow.

Photo: Jack Desbiolles

Table 2.2: Improvements in crop response due to soil wetter treatments (T = number of wetter treatments tested at each site) relative to controls over nine site-years in recent SA-based research (2018–21).

Site, T, year (context)	Control crop, plant density (plants/m^2) and yield (t/ha)	Plant density increase (plant/m^2)	Grain yield increase (%)	GSR (Apr–Oct) (mm)	Furrow condition
Murlong I, 13, 2018 (grazed wheat stubble, cross-sowing)	**Wheat** 48 & 1.02	0–58 Av. 27	0–21 Av. 7.2	**Decile 2** 193	Early furrow infill
Murlong I, 13, 2019 (standing wheat stubble, inter-row sowing)	**Barley** 27 & 1.10	0–56 Av. 17	23–97 Av. 44	**Decile 1** 174	Stable wide V-furrows between standing stubble
Murlong II, 3, 2019 (standing wheat stubble) – Inter-row sowing – Edge-row sowing – On-row sowing	**Barley** 6 & 0.58 61 & 1.45 100 & 2.0	+22 +39 0	+63 +15 0	**Decile 1** 174	Wide furrows between standing stubble
Younghusband I, 2, 2020 (lentil stubble, cross-sowing)	**Wheat** 144 & 2.78	0 (ns)	0–6	**Decile 8** 251	Wide furrow
Younghusband I, 2, 2021 (standing wheat stubble, inter-row sowing)	**Barley** 24 & 0.93	71–82	47–50	**Decile 2** 169	Wide V-furrows between standing stubble
Younghusband II, 1, 2021 (standing wheat stubble, cross-sowing)	**Barley** 81 & 0.68	25	56	**Decile 2** 169	Wide V-furrows
Coombe (flat), 3, 2020 (lucerne pasture)	**Barley** 120 & 4.38	14–17	0–5	**Decile 5** 308	Early furrow infill
Coombe (rise), 3, 2020 (lucerne pasture)	**Barley** 90 & 2.37	0–15	0–10	**Decile 5** 308	Early furrow infill
Wharminda (rise), 2, 2021 (grazed fallow, inter-row sowing)	**Wheat** 89 & 1.70	0–43	0 (ns)	**Decile 6** 228	Narrow furrows and ridging

GSR = growing season rainfall.

Maximising water-harvesting furrows

The water-harvesting potential of furrows is maximised when:

- large V-profile press-wheel tyres with side shoulders are used (for example, 150mm wide tyre with 110mm wide V at 105° included angle – see Figure 2.7);
- sufficient downforce pressure is applied (2.5 to 3kg/cm width) to effectively consolidate the furrow surface; and
- excessive furrow disturbance is avoided (via controlled speed and reduced furrow depth) to minimise furrow-ridging and press-wheel 'rooster tail'.

A uniform water-harvesting furrow system is easier to achieve with wide row spacings.

Care should be taken to position water-harvesting furrows across slopes to control surface run-off and erosion risks. Achieving stable water-harvesting furrows is challenging in exposed non-wetting sands due to the high risk of furrow infill under dry conditions. Field evidence suggests that furrow infill risks can be mitigated by inter-row sowing or accurately edge-row sowing into standing stubble to help protect from high winds.

Cost of applying soil wetters

The chemical cost per hectare is driven by the choice of chemistry, number of application zones and the rate applied. The optimal combination of these factors is a function of the severity of water repellence.

In a small well-controlled replicated plot trial over 2018-19, 13 different products and combinations were evaluated where the product costs ranged between $12 and $41 per hectare.

The financial cost can be mitigated by treating only paddock zones where water repellence is strongest by turning on/off a dedicated liquid supply line. Over the two-year period integrating one poor and one excellent response season, the value of crop yield gains per treated hectare reached 2.5 to 9.7 times the product cost recovery threshold.

Figure 2.9: Crop establishment snapshot at five weeks after sowing: some soil wetter chemistries showed consistent benefits (e.g. bottom) relative to a no-wetter control (top) over two seasons at Murlong, SA.

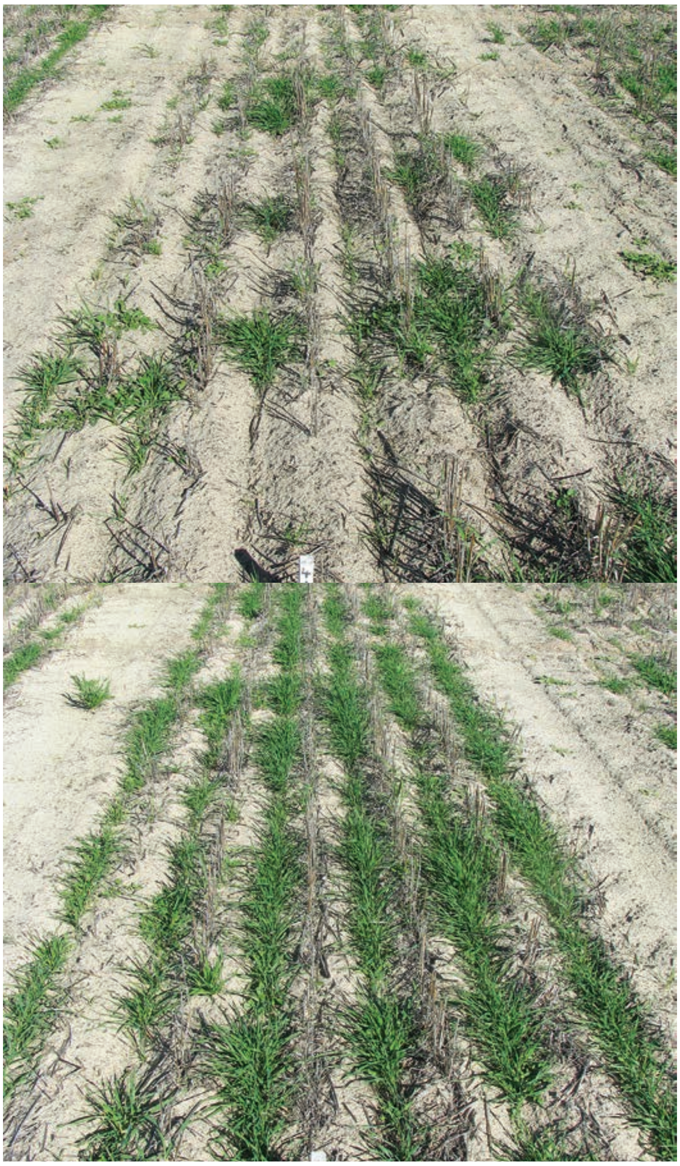


Photo: Jack Desbiolles

Chapter 3: Amelioration

Figure 3.1: Example of straight shank tynes (Agrowplow AP51 Ripper) with inclusion plates fitted.

Figure 3.2: Grizzly Deep Digger with parabolic tynes.

Figure 3.3: Williamson-Agri CT ripper with low disturbance Michel tyne (curved sideways).

Figure 3.4: Triangular-shaped spades on curved tynes are fixed to a central shaft that rotates at ~90revs/min[10].

Figure 3.5: Press-wheels on the back of the spader help to firm the surface and reduce wind erosion risk.

Figure 3.6: Topsoil incorporation can be seen here in a pocket, which is common when spading at higher speed.

Assessing alternative implement options

Sandy soils do not have the capacity to shrink and swell, so they have limited ability for natural repair once compacted (resulting in high soil strength) and therefore often benefit from being physically disturbed via deep tillage. Strategic deep tillage can be used to alleviate multiple soil constraints.

Deep ripping, rotary spading and one-way disc ploughs are rising in popularity to treat multiple constraints. Some detail on these implements is provided below in Table 3.1.

Deep ripping shatters hard or compacted subsurface soil layers to allow greater rooting depth, improving crop access to deeper profile nutrients and moisture, resulting in higher yields. It is important to target ripping to those sands where hard or compacted layers are the primary constraint. Where acidity, water repellence or subsoil toxicities exist, alternative amelioration practices may be required instead of, or in addition to, ripping. Where clay-rich subsoils are prone to water logging and dispersion, the addition of gypsum or organic materials may help to encourage aggregation.

Key considerations when selecting a deep ripper:

- ripping depth required;
- tractor power available;
- tyne type and tyne spacing adjustment (Figures 3.1–3.3); and
- can the ripper be fitted with inclusion plates if necessary?
- should an amendment be pre-applied to the surface?

Table 3.1: Examples of strategic deep tillage approaches, working depth and incorporation characteristics.

	Strategic deep tillage method	Implement working depth (m)	Implement impact on incorporation of soil amendment and/or topsoil	% topsoil buried below 0.1m
Ripping	Ripping only	0.3–0.7	Minimal incorporation, depending on ripper type. Backfill to 0.15m.	5–10
	With topsoil slotting (inclusion plate)	0.3–0.7	Topsoil slots from surface typically to depths of 0.35–0.40m, but ripping depths can extend to 0.70m. Can partially incorporate surface-spread amendments (e.g. lime, nutrients, organic matter).	10–15
Mixing	Large offset discs	0.2–0.3	Offsets throw soil one way then back again, mixing of topsoil and surface-spread amendments (e.g. lime, subsoil clay, organic matter) typically occurs between 0.15–0.25m depth.	Not measured
	One-pass tillage – tyne	0.3–0.35	Mixing of topsoil and surface-spread amendments to 0.15m and some deeper inclusion to 0.30m possible depending on tyne design.	Not measured
	Rotary spader	0.3–0.4	Mixes to maximum working depth of 0.35–0.4m. Can incorporate a range of surface-spread amendments (e.g. lime, gypsum, organic matter, subsoil clay, nutrients etc). Mixing uniformity varies with speed.	50–60
Inversion	Modified one-way disc plough	0.25–0.4	Partially buries topsoil or surface-applied amendments, such as lime or organic matter, in an arc from surface down to a depth of 0.25–0.35m. Burial quality varies with speed.	60

Table adapted from Davies S, Armstrong R, Macdonald L, Condon J and Petersen E (2019). 'Soil Constraints: A Role for Strategic Deep Tillage'. Chapter 8 In (Eds J Pratley and J Kirkegaard) *Australian Agriculture in 2020: From Conservation to Automation* pp 117-135 (Agronomy Australia and Charles Sturt University: Wagga Wagga).

Figure 3.7: John Shearer one-way 5GP plough, modified to fit Plozza discs.

Figure 3.8: A typical soil profile following inversion using Plozza Plow discs.

Inclusion plates can be fitted to ripping tynes (Figure 3.4) with the intent of funnelling surface soil layers into the rip line, in a process commonly referred to as 'topsoil inclusion' or 'topsoil slotting'. Fitting inclusion plates can cause a significant increase in draught/power needed to pull a ripper, so their addition should only be considered where there is a need and likely benefit from incorporating a surface layer or applied amendment deeper in the soil profile, such as for treating subsoil acidity with lime. The design of inclusion plates has a significant impact on inclusion quality.

Rotary spading is an approach used when soil mixing is required, such as to dilute water-repellent surface layers, or to incorporate clay, lime or organic amendments. Rotary spaders are also very efficient at treating compaction throughout their working depth (between 200 and 400mm).

Spaders typically mix topsoil in the 0 to 30cm depth, while also bringing some subsoil to the surface, therefore incorporation is not 100 per cent, with material tending to be buried in pockets (Figure 3.6).

Rotary spaders can work between 3 and 7 kilometres per hour (km/h), but if better mixing is required then slower speeds should be used. Consider the product that is being mixed into the soil profile; products such as clay and lime should be mixed well. Research shows reverse-direction dual-pass spading at a low speed can achieve very uniform mixing.

Inversion ploughs such as modified one-way disc ploughs (Plozza Plow) are used for the treatment of water repellence or acidity, and the deeper burial of weed seeds. Modifications to a traditional one-way plough involve fitting larger and more concave discs, the removal of every second disc to suit greater spacing (Figure 3.7), increased breakout pressure on the jump arms, and often involve adding more weight to the plough, depending on the model used. These modifications allow deeper working depths, more space for soil to turn over and a greater degree of inversion. They are a popular option compared to rippers or spaders due to their low modification and operation costs, and increased suitability for use in rocky soils. However, soil inversion quality varies, and is the most extreme form of soil physical disturbance that leaves a fully bare, very soft surface at high risk of wind erosion, particularly in very deep sands, so its cost savings must be carefully weighed against this increased risk. One pass 'plough and sow' combinations are anecdotally used on farm.

Ripping technology

KEY POINTS

- Deep ripping tyne technologies vary in their ability to loosen, mix, delve and rearrange clods within the profile
- Key strategies to minimise costs include:
  - rip no deeper than necessary
  - operate above the tyne critical depth
  - optimise timing (soil moisture)
  - use winged tynes at an optimised spacing when operating deep
- Opportunities exist for optimising multi-depth tyne layouts and spacings for maximum loosening efficiency and reduction of total draught

Technology considerations for cost-effective subsoil loosening

The extent and longevity of soil and crop responses to deep ripping are often site-specific and sometimes timing-specific. These aspects are increasingly well documented, whereas there is less information available on optimising the performance of the deep ripping operation itself. This section reviews key principles of efficient deep ripper technologies.

Deep ripper performance

When assessing the physical performance of deep ripping (or subsoiling) machinery, key considerations of soil–machine interactions are:

1 **How much draught is required?** Soil strength, depth and speed of the ripping operations significantly influence the implement draught and tractor power requirements. The ripper tyne design and layout on the bar can also affect draught.

2 **How complete is the soil disturbance?** After deep ripping, the loosened soil profile typically narrows down at depth, leaving unripped soil zones between tynes. Tyne design, spacing and layout can affect this outcome, quantified by the proportion of the soil profile loosened.

3 **How energy efficient is the operation?** Efficient loosening is expressed as the amount of pull required (for example, draught force, kilonewton; kN) per unit of furrow loosened area (for example, metre squared; m^2). Optimising this specific resistance ratio (kN/m^2) is critical to maximising efficiency.

4 **What is the quality of soil disturbance?** The quality of the soil disturbance is assessed against other objectives complementary to soil loosening, such as seeder-ready finish (for example, clod size distribution, surface finish roughness), profile re-consolidation risks (soil clod rearrangement, which influences ease of recompaction), and impact on other soil constraints (for example, quantity of clay delved to the surface, efficacy of sublayer mixing or efficacy of surface amendment inclusion).

The above performance parameters are important for reducing costs and improving the efficiency of deep ripping; however, their agronomic impacts on both the extent and longevity of crop (biomass) response are not well documented.

Figure 3.9: High-disturbance ripper using narrow-spaced delving tynes to bring up soil from deeper layers, combined with levelling spike rollers to provide a levelled finish.

Photo: Jack Desbiolles

Tyne technology

The soil-engaging components of a deep ripping tyne consist of a shank (or leg) associated with a primary loosening point (or foot), with or without wings, generating the bulk of draught requirements. The foot component is designed to loosen the soil profile from depth, while specific point design and leg attachments can also delve the subsoil (that is, lift soil from deeper layers up along the front of the tyne) or include topsoil at depth (that is, falling in behind the tyne) resulting in some mixing within the profile. Deep ripper tyne designs may be categorised as follows (Figure 3.10):

A and B: Conventional narrow shank (A, straight; B, parabolic). The leg portion splits the loosened soil upheaved by the point and has a small draught component mitigated by its rake angle being lowest for parabolic designs.

C: Curved or bentleg slanted narrow shank with offset point. This design can achieve uniform surface disturbance where the slanted shank bypasses the bulk of loosened soil upheave, minimising its draught component. Such asymmetrical tynes can be arranged in various layouts across the bar, both side-to-side and front-to-back (Figure 3.15).

D: Wide continuous face shank. These are used for combined profile loosening with delving/mixing of sublayers. The face plate is typically set near a 45° rake angle, extends up to the soil surface (Figure 3.9) and is a significant component contributing to draught. Its action causes soil from deeper layers to flow upwards in a delving process, released both within the profile and onto the surface.

E: Winged narrow shank. In this design, wings are added to straight/parabolic shanks or integrated into their primary loosening points (Figure 3.14). While the primary point facilitates penetration into hard soils, at full depth the wing portion adds to the downward pull and broadens the bottom of the loosened profile to greatly increase total loosening.

Critical depth

Efficient soil loosening with a narrow shank ripper tyne requires a point set at a low angle of approach and of sufficient width and lift height to achieve loosening of the whole profile from full ripping depth. There is a critical depth beyond which this loosening capacity is lost, whereby the loosened area is drastically reduced, combined with a high draught arising from soil compaction and smearing developing at depth. Deeper critical depths can be achieved by greater lift height and wider points (Figure 3.11).

Figure 3.10: Types of ripper tynes: A) conventional with straight and B) parabolic narrow shank, C) curved slanted narrow shank, D) wide continuous face delving shank, and E) winged narrow shank.

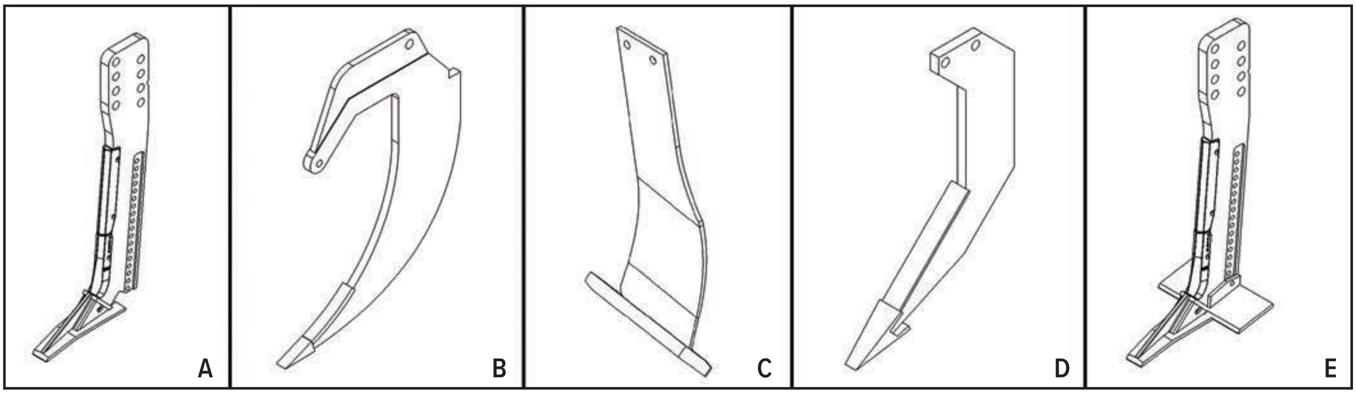


Figure 3.11: Impact of tyne design on soil disturbance patterns and critical depth. Loosened soil boundary is represented by the brown line and lateral compaction stresses by arrows.

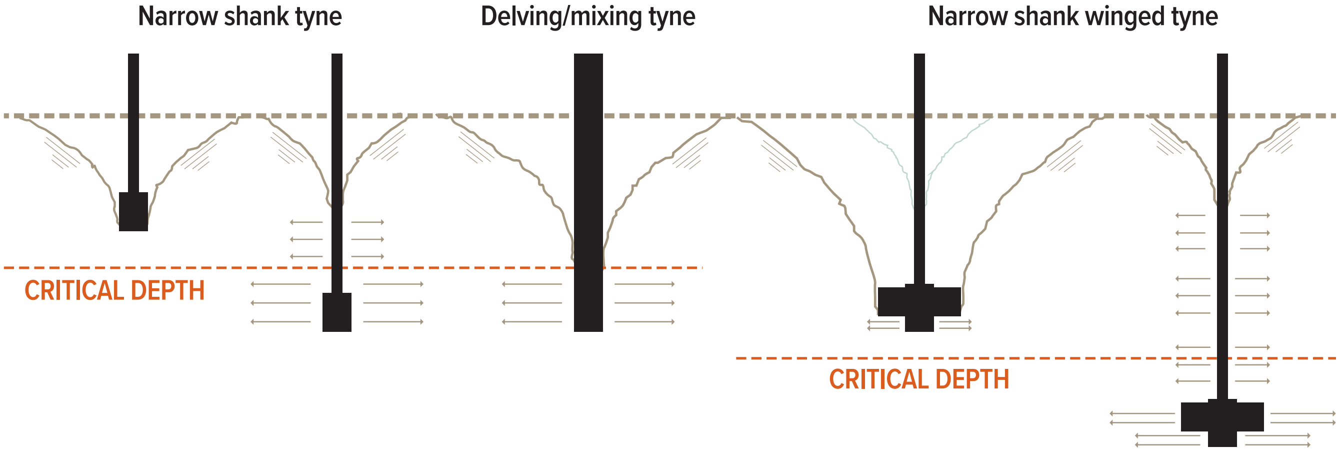


Table 3.2: Example impacts of operational settings on the performance of a narrow shank ripper tyne (type A in Figure 3.10) in a deep red sand at Caliph, SA Mallee, 2019 (dry bulk density ranging 1.47–1.53 grams per cubed centimetre [g/cm³] in the 200–600mm depth range).

Factors relative to baselines	Single tyne draught, kN (relative)	Loosened area, m^2 (relative)	Specific resistance, kN/m^2 (relative)	Drawbar power, kW	Notes
Baseline 1: Single tyne 400mm depth, 4.0km/h	**3.4 (ref=1.0)**	**0.099 (ref=1.0)**	**34.5 (ref=1.0)**	**3.8**	**No wings**
Impact of adding wings	4.8 (x1.4)	0.147 (x1.5)	32.7 (x1.0)	5.3	300mm wide, 43mm lift height, 145mm above tip
Impact of deeper depth (600mm)	9.2 (x2.7)	0.167 (x1.7)	55.1 (x1.6)	10.2	No wings
Combined impact of deeper depth + adding wings	11.4 (x3.0)	0.255 (x2.6)	44.7 (x1.3)	12.7	300mm wide, 43mm lift height, 145mm above tip
Baseline 2: Single tyne 600mm depth, 4.0km/h	**9.2 (ref=1.0)**	**0.167 (ref=1.0)**	**55.1 (ref=1.0)**	**10.2**	**No wings**
Impact of adding wings	11.4 (x1.2)	0.255 (x1.5)	44.7 (x0.8)	12.7	300mm wide, 43mm lift height, 145mm above tip
Impact of faster speed (7km/h)	12.1 (x1.3)	No data	--	23.5	No wings

Notes: Drawbar power (kW) = draught (kN) x speed (m/s); 1kN ≈ 100kgf (kilogram-force); 1m/s = 3.6km/h. The effects of multi-tyne interaction were not quantified.

For cost-effective loosening, it is therefore pivotal that rippers be operated above their critical depth, by selecting suitable tyne designs and layouts for the targeted depth and soil context, and by avoiding soft and wet soil conditions at depth. Winged tynes have significantly deeper critical depth thresholds than tynes without wings (Figure 3.11).

In heavy textured soils, moisture should be on the dry side of the lower 'plastic limit' (the soil moisture beyond which the soil changes from a semi-solid and friable consistency to a plastic one) for maximum effectiveness. While the impact of high soil moisture is less critical in deep sandy profiles, ripping during overly dry conditions significantly increases clod size and surface roughness, power requirement and machinery wear, which translate into higher costs of operation, including a greater need for follow-up tillage operations.

Operating depth

Research shows the draught force in a compact soil is typically proportional to the square of operating depth, so operating 50 per cent deeper is expected to more than double (= x 2.25) the draught requirement. This effect can be seen in Table 3.2 when operating 50 per cent deeper (for example, from 400 to 600mm) increased the loosened area by 69 per cent but at the cost of a 2.7-fold increase in draught, therefore augmenting the specific resistance by 60 per cent, which indicates a much less efficient loosening process.

Adding wings

Adding wings is one of the best ways of increasing the energy efficiency of subsoiling, especially when operating at greater depth. Key design features of wings include width, sweep and rake angles of approach, total lift height and front-edge distances above and behind the ripper point tip. The data in Table 3.2 show that 300mm wide and 43mm lift wings fitted at 145mm above tip increased tyne draught by 41 per cent and 24 per cent at 400mm and 600mm ripping depth, respectively, while augmenting the loosened cross-sectional area by 49 and 53 per cent, respectively. This leads to a more efficient loosening process as shown by a corresponding decrease in the specific resistance by up to 19 per cent. Benefits reported in literature (Spoor and Godwin, 1978) range between a 30 and 60 per cent reduction in specific resistance from adding wings, being greatest in cases where the wingless tyne was operated below critical depth. Optimum design and positioning of wings on the shank also affects the benefits. The optimum wing lift height is the minimum necessary to remain above critical depth, while greater lift height accentuates the extent of clod rearrangement. Wing width can be increased within practicality to maximise the loosening at depth.

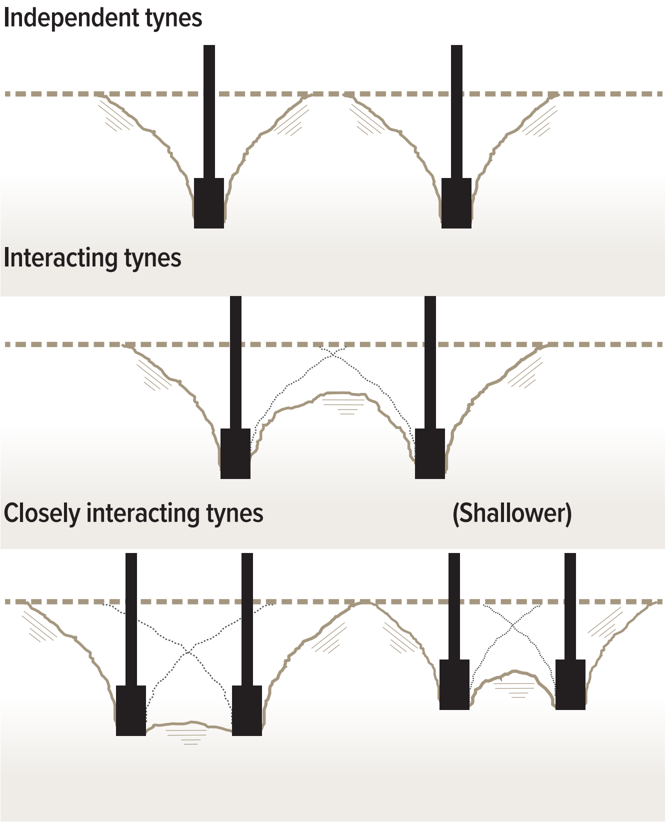
Operating speed

Faster operating speed increases the ripper tyne draught force to a smaller extent, which is a function of the volume of soil moved and its rate of displacement during loosening. As the drawbar power varies in proportion to both the speed increase and any associated draught increase, tractor power is therefore consumed rapidly by a higher speed of operation. For instance, in Table 3.2, increasing speed from 4 to 7km/h at 600mm depth raised the drawbar power 2.3-fold (from 10.2 to 23.5 kilowatt [kW] per tyne).

Tyne interactions

When two ripping tynes within a leading/trailing tool bar layout are spaced close enough to interact, some extra soil volume between them is loosened at depth (Figure 3.12). This lowers the draught of the trailing tyne and reduces the overall specific resistance. As the spacing narrows further, the area loosened eventually peaks, then reduces quickly, which leads to a rise in specific resistance. Beyond the optimum, the total draught per unit width of ripper increases through an 'overcrowded' tyne layout. Optimising tyne spacing is therefore key to minimising total draught requirement and maximising loosening efficiency. Requirements for greater clod rearrangement, layer mixing/delving and topsoil inclusion may, however, justify the use of less energy efficient, narrower spacings.

Figure 3.12: Impact of tyne spacing on soil disturbance pattern. Note: the undisturbed dome or ridge between rip lines represents a loosening gap relative to the targeted area of *spacing x depth* while the optimum tyne spacing is also affected by ripping depth.



Shallow leading tyne (SLT) layouts allow for a two-stage soil loosening process, reducing the draught load of the deeper tyne and increasing its critical depth threshold. SLT layouts therefore favour a longer window of ripping into wetter conditions and can significantly reduce clod size. The shallow tynes can be set to operate directly in-line or in between the main rip lines.

In-line SLT layouts are commercially available in Australia following local research (Hamza et al., 2013), while older literature (Spoor and Godwin, 1978, Godwin et al., 1984) suggests that offset SLT layouts may have the greatest potential to improve soil loosening efficiency, which would allow increased tyne spacing, minimising ripper total draught. Ongoing research is underway to shed light on the above.

Figure 3.13: Expected impact of offset shallow leading tynes on increasing the loosened soil area of a winged tyne. Shallow tyne spacing and depth can be optimised for maximum effect, allowing the spacing between deeper winged tynes on the ripper to also be increased.

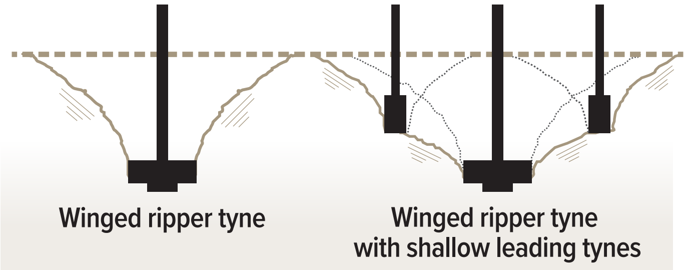
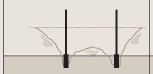
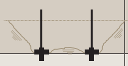
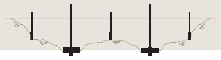


Figure 3.14: Parabolic narrow shank ripper fitted with winged high lift points for maximum soil loosening depth capacity.

Photo: Hatzenbichler Agro-Technik GmbH

Table 3.3: Optimum tyne spacing guidelines[+] for maximum loosened soil area and minimum specific resistance.

Deep ripper tyne type	Shallow leading tynes (SLT)*	Deep ripper tyne optimised spacing[t]	Notes
Conventional narrow shank	No 	1.0-**1.5** x depth	Tynes must operate above critical depth
Winged narrow shank		1.5-**2.0** x depth	For example, wings extending to 300–420mm overall width - Specific resistance is reduced
Offset SLT layout ahead of winged narrow shank 	Yes – depth = 40–60% of full ripping depth Spacing = 125–250% of full ripping depth	2.0-**2.5** x depth	- Reduced deeper tyne draught with minimal/no change in total draught - Large potential increase in loosened area - Specific resistance very significantly reduced - Maximum effects at wider SLT spacing and deeper SLT depth

*SLT located at a minimum 1.5 x depth of ripping distance ahead of deep ripper tynes

[t] Expected range to guide in situ validation by soil condition

[+]Source: clay soil data after Spoor and Godwin 1978; Godwin et al., 1984

Figure 3.15: Curved slanted narrow shank ripper for low-disturbance loosening.

Photo: Jack Desbiolles

Tyne layouts in a 'V' formation provide a more continuous lift across the machine and leave a more level surface finish, while some manufacturers claim reduced draught benefits.

A continuous wave of soil upheave can be obtained when tynes operate in unison, side-by-side on a single rank. A commercial application optimised with narrow shank tynes fitted with large, low-lift wings and offset points (for example, AGRISEM TCS blade) reports significant draught savings per metre width. Research is underway to shed light on the above under Australian sandy soil contexts.

Paddock guide

Cone penetration data

The ripper draught requirement is a direct function of 'soil strength', critically affected by soil moisture and exacerbated by physical soil compaction (packing density) and hardsetting behaviour. The cone penetration resistance – measured at field capacity – quantifies the severity of 'excessive' soil strength (cone index >2.5MPa, see Figure 3.16) significantly impacting root growth and plant vigour, and identifies the depth of loosening required for remediation purposes.

Tractor considerations

The tractor's ability to deliver drawbar power is controlled by its weight and tractive efficiency, the latter being a function of the traction device (tyre/track) and the soil surface conditions. In high-draught tillage operations, the tractor can be either traction or power limited.

Traction-limited situations occur when there is not enough grip at the soil surface to deliver the required pull at the drawbar. This is very common when ripping deep and in soft surface sand conditions. Increasing traction capacity requires extra weight onto the driving axles (for example, ballast or via weight transfer) and improved traction device efficiency (for example, lower tyre pressures, use of high-flex tyres, duals/triples, tracks). A balance between slippage and rolling resistance losses is required for optimising tractor power use efficiency.

Power-limited situations occur when good traction under heavy weight loading is available relative to the implement draught requirement (for example, narrower ripper or shallower ripping in firm soil conditions). This situation allows for higher ripping speeds up to the limit of the available tractor power.

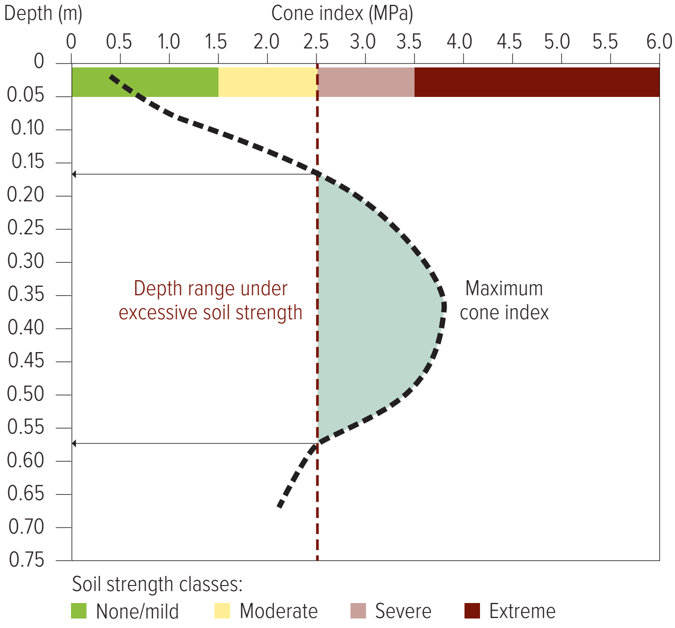
Tractor–implement matching is always important to avoid power-limited conditions at low ripping speeds, where the tractor transmission can be overloaded under excessive torque, leading to damage over time. In this instance, reducing the implement draught load (for example, narrower width) is the safest approach that also allows higher speeds to match the initial work rates.

In-paddock checks

When assessing ripper performance in the paddock, consider the following:

- Adjust deep ripping depth from the unripped surface, probing to the lowest point in the profile. Adjust the ripper front to back and across to achieve uniformity.
- The surface upheave is a key indicator of reduction in soil bulk density from the extent of loosening and clod rearrangement within the profile. Operating below critical depth will show minimal upheave, while low-disturbance, even-lift subsoilers may also leave a flat finish with limited signs of loosening, except a reduction in soil strength.
- Using a simple 12mm diameter push rod (feeler probe with handle), assess the loosened profile by gauging every 50mm across rip lines for the shape and depth of the unripped boundary. Where possible adjust the ripper depth to ensure the full depth of soil strength constraint is loosened between rip lines.
- An open pit is useful to visualise the extent of clod rearrangement, clod size and soil layer mixing within the profile.

Figure 3.16: Example cone penetration resistance highlighting excessive soil strength (shaded portion >2.5MPa) and the required depth of loosening – about 0.6m*. Note: The severity of excessive soil strength arises from the maximum cone index value and the associated depth range. The energy required to loosen the soil profile increases with the total area under the cone index curve, particularly in the deeper part.



*The required ripper depth will vary according to its ability to extend soil loosening into the zone between tynes. High efficiency tyne design and layouts minimise the extra depth setting below the identified depth of constraint.

Soil mixing by spading

KEY POINTS

- Rotary spading is a cyclical process controlled by the extent of soil engagement between successive blades, the so-called ‘bite length’
- Shorter bite length associated with slower ground speed significantly improves the uniformity of soil-amendment mixing, which can be further enhanced by a second spading pass, at best, in the opposite direction
- Topsoil layer mixing concentration typically peaks in the layer immediately below the surface and quickly reduces with depth
- A slow ground speed is required to more effectively mix topsoil into deep layers
- During spading, the redistribution of a deep soil layer up into the profile is less effective than the redistribution of an upper layer down into the profile. In both cases, the mixing uniformity is improved by a slower ground speed
- Spading after deep ripping or spading on a second pass requires 20 to 25 per cent less tractor engine power, whereby the saving in power take off (PTO) is partially mitigated by reduced self-propelling, increasing draught
- To achieve a high uniformity of mixing significantly increases spading costs per hectare (ha) while the returns via improved crop yields are not well documented and likely to vary depending on soil constraints and amendment contexts

Understanding the process of soil profile mixing with rotary spaders

This section reports on recent research aiming to understand the factors affecting the uniformity of soil profile mixing by rotary spading and the implications for paddock operations.

Rotary spaders were introduced from Europe to Australian grain growers in 2009 and have since transformed the ability to ameliorate sandy soil profiles down to a depth of 350 to 400mm by mixing surface-applied amendments, loosening compacted layers and incorporating water-repellent and/or low pH topsoil. With its superior mixing ability compared with tyne or disc-based implements, rotary spading has been shown to produce significant and sustained grain yield improvements in many sandy soil contexts (Fraser et al., 2016). As an intensive tillage operation, spading leaves little to no crop residue on the surface, exposing the soil to erosion.

Specific design adaptations have gradually been made to reduce the risk of soil erosion and boost the adoptability of spading for ameliorating sandy soils (Desbiolles et al., 2019). These include large rear press-wheels leaving a consolidated profile with treaded furrows and one-pass ‘spade and sow’ techniques (Figure 3.18), which allow rapid crop establishment in soft post-amelioration seedbeds, therefore minimising the window for erosion.

Features of rotary spading

The spader is characterised by a cyclical loosening process centred around the ‘bite length’, this being the distance of forward travel between two successive blade actions, dictating the extent of soil engagement by each blade (Figure 3.19). The bite length is a function of the rotational speed (revolutions per minute; rpm), ground speed (km/h) and the number of blades distributed on the periphery (typically 3 to 6). With a three-blade spader configuration, the bite length is 350 to 400mm for an operating speed of 5.5 to 6km/h, but can be reduced or increased in direct proportion to ground speed.

Photo: Jack Desbiolles

Figure 3.17: Research in the southern region over the past seven years has highlighted consistent crop benefits from ‘mixing by spading’ in a variety of deep sand and surface amendment contexts.

Figure 3.18: a) One-pass 'spade and sow' operation timed into a moist soil profile is a safer sandy soil amelioration technique able to quickly re-establish ground cover while facing no soft soil-related trafficability issues; b) Example of barley crop establishment in Victorian Mallee context following a successful 'spade and sow' operation.

Photo: Farmax Spader – Groocock Soil Improvement

Photo: Jack Desbiolles

Soil mixing process

The soil mixing uniformity is primarily controlled by the bite length, while operating depth and blade design also have some impact. Computer simulations based on discrete element method (DEM) modelling and confirmed by paddock observations have revealed how a longer bite length leads to amendments being increasingly dispersed into hotspots rather than uniformly distributed along, across and down the spaded profile.

During the downward stroke of spading, the vertical wings of the blade slice through an undisturbed soil segment with little soil entrainment (that is, the blade makes a clean cut without dragging in much soil down the profile).

At the lowest point of the profile, the wings are almost in a horizontal position and are able to carry a scoop of soil towards the surface during the blade upward stroke. In this cyclical process, topsoil concentration occurs within the profile as shown by the bands of blue sand depicted in Figure 3.20. Decreasing the occurrence of concentrated hotspots or pockets underpins the process of improving the uniformity of mixing by spading.

Some of the soil (including topsoil) is carried out of the mixed profile by the blades and thrown onto the spader shield with a portion recirculating to the front (Figure 3.20a). These outward soil projections inside the spader shield and at the front of the spader can clearly be seen in paddock operations.

The full process of soil profile mixing can be analysed in computer simulations by tracking the movement of top, middle or bottom soil layers during spading. With this, we can assess the extent of amendment incorporation (for example, surface-applied lime or manure), soil constraint dilution (for example, water-repellent top layer or acidic sublayer) or beneficial layer distribution (for example, loamy or clay layer in sandy duplex soil).

Depth distribution

A primary objective of spading is to mix the surface layer, often with surface-applied amendments, into a deficient profile. This top-down mixing process often carries an expectation to 'bury at depth', for example resistant weed seeds or surface water repellence. Figure 3.21 depicts a typical distribution of top layer particles with depth, showing a peak (or bulge) of greater concentration within the soil profile just below the surface layer. The data consistently show that some surface particles remain within the top layer post-spading, which highlights the dilution by mixing – rather than by full burial – features of the spading process.

This top-down mixing process occurs simultaneously with the relocation and mixing of other layers within the profile, including a bottom-up mixing process (see further down).

In water-repellent sands, the spading process dilutes the high-repellence surface layers by taking water-repellent soil down into the profile and bringing up wettable deeper layers.

Impact of speed

Figure 3.21 also illustrates the simulated redistribution of the topsoil (0 to 50mm) after spading various layers down to 300mm depth. Perfectly uniform mixing should result in about 17 per cent of the topsoil in each of the six layers, as indicated by the dotted line. Spading at 3km/h comes close to this ideal, with greater percentages (6 per cent extra) of topsoil in the 50 to 100mm layer and smaller amounts (3 to 8 per cent less) at depth. The bulge layer feature in the 50 to 100mm depth is greatest at 9km/h, indicating the need to maintain a slow forward speed (that is, a short bite length) to achieve a more even average distribution with depth. In some cases, slower spading can displace the bulge layer to lower depths (Figure 3.23), increasing the average depth of incorporation.

Spading depth

Depth of spading helps incorporate the topsoil into deeper layers, but this is most effective when operating at a slower speed (see Figure 3.22). The spaded deeper layers contain the least topsoil, with particles isolated into more discrete spots.

This reduction with depth is most pronounced at higher speed. Spading deeper rather than shallower concentrates a greater quantity of surface particles in the bulge layer relative to the expected average (for example, twice as much at 9km/h, see Figure 3.22), while the depth of the bulge layer within the profile remains unchanged, that is, just below the surface layer.

Bottom-up mixing

Another objective of spading may be to simultaneously achieve a bottom-up mixing outcome, for example the mixing of higher clay content sublayers into a water-repellent sandy surface soil.

In this context, Figure 3.23 shows the average redistribution of the 200 to 250mm deep layer up into the profile following spading to 300mm depth. The graph shows that the bottom-up mixing process is less effective than the top-down mixing of the surface layer in Figure 3.21. In this simulation, 37 to 68 per cent of particles (maximum at 9km/h) were left in the initial layer with some displaced to the layer below. This is due to the impact of a very localised interaction by the blade within deeper soil layers.

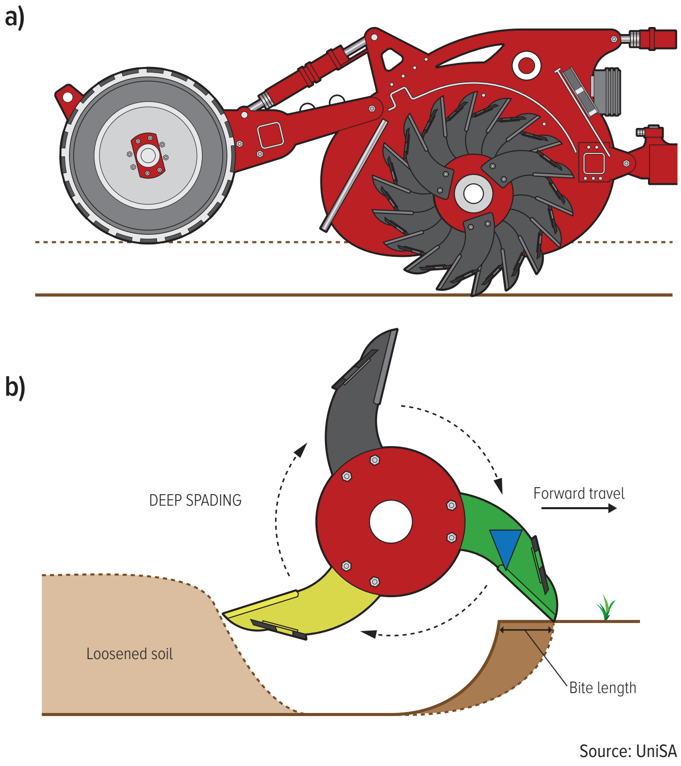
The spading simulation at 300mm depth shows some ability to bring up some soil (13 to 20 per cent, minimum at the high speed) from the 200 to 250mm layer to the top 100mm layer where it may be further mixed by secondary tillage, including during crop seeding.

The ability to lift soil from the 250 to 300mm layer would be significantly less. This suggests the need to spade to a depth beyond the layer of interest to be able to bring enough of it up into the topsoil.

Spader design

Figure 3.24 shows the difference in simulated topsoil distribution with depth between two contrasting spader designs. While both designs display a similar top-layer distribution pattern with depth, the Design 2 spader (with sets of six small left and right-hand blades spread around the rotor) was slightly better than Design 1 (with sets of three full blades spread around the rotor) at incorporating top-layer particles deeper into the profile at slower speeds, and also displacing the bulge layer of concentration deeper into the profile (from 50 to 100mm at 9km/h to 150 to 200mm at 3km/h).

Figure 3.19: Rotary spader staggered blade distribution across the rotor width a) and fundamental bite length feature b).



Source: UniSA

These differences between designs were negligible at the higher speed. Further simulation work will aim to look at the impact of the different blade configurations on relative power requirements.

Soil profile moisture

Spading wet soil with some level of soil particle cohesion increases entrainment (or dragging down) by the blade relative to spading dry soil, which tends to increase the burial of the surface layer to depth (data not presented). It seems that increased clustering of particles occurs when spading moist soil compared with dry soil, which may reduce the mixing uniformity within the profile. It may be more important to spade slowly in wet conditions to achieve similar mixing uniformity. More work is required to quantify this effect.

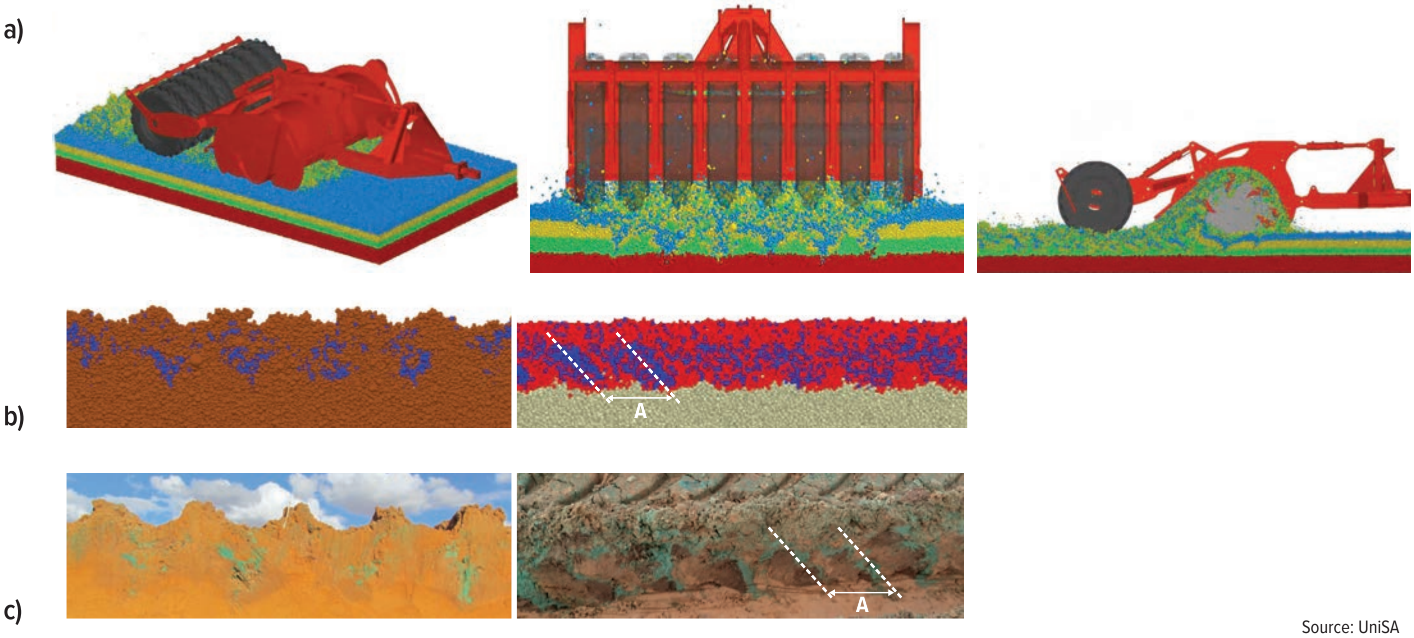
Uniformity of mixing within layers

While Figures 3.21 to 3.24 show only the average concentrations by layer, Figure 3.26 displays the variability within each layer of a spaded profile, in a 2D top view pixelated format.

The figure contrasts the redistribution within the spaded profile of the surface layer (0 to 50mm) and of a 200 to 250mm deep layer at 3 and 9km/h speeds. Also shown is the spading direction, which reveals the cyclical footprint of the spader blades at their respective bite length and spacing across the width.

The pixelated layer-by-layer display provides a clear appreciation of the 3D pattern of particle mixing, in particular:

Figure 3.20: a) Isometric, rear and side views from a computer simulation of a rotary spader operating at 300mm depth and 9km/h through a multi-layer sandy soil profile. b) Simulated mixing of the top layer (blue particles) into the profile, across the spaded width (left) and along the travel direction (right). The mixing outcome shows pockets of concentrated blue particles in a cyclical pattern repeated at an amplitude length (A) equal to the bite length. c) Similarly spaded profiles observed in the paddock using a blue top layer of sand as a tracer of mixing.



Source: UniSA

1. The visualisation of the bulge layer of surface particles peaking in the layer immediately below (as shown in Figure 3.21), and the localised release pattern in the layers below into distinct hotspots, decreasing in size with depth.

2. The visualisation of the bulge concentration of deep layer particles remaining in their original layer after spading (as shown in Figure 3.23), showing portions of the 200 to 250mm deep soil particles scooped by each blade and released across layers in a localised fashion under high spading speed, while much better distribution at low speed is shown, despite some banding contrasts remaining in the original layer, and fading above it.

3. In both cases, a similar banded contrast displayed at depth under low-speed spading, either from uncaptured sections of the original deeper layer or from hotspot features following the entrainment of surface layer particles down the profile.

4. The visual differences in surface soil particles left in the 0 to 50mm layer after spading, which is an indicator of unincorporated surface amendment, unburied surface weed seeds, or remaining surface water repellence, depending on the context of spading.

Multi-pass operation

Multi-pass spading is an effective way of increasing the mixing uniformity, but the overall work rate is halved and the cost of spading per ha (10,000m^2) nearly doubles.

For the best impact on mixing uniformity, the second pass spading should be conducted in the opposite direction and, where possible, offset by half the blade spacing.

Although crop responses to high uniformity spading are not well documented, recent research in SA suggests significant extra benefits may arise under high uniformity spading of lime into an acidic sandy soil (Ucgul et al., 2022), while crop responses may differ in other contexts such as spading chicken litter into a nutrient-deficient sand. More work is required to understand where the crop is most likely to benefit from high quality (and more costly) soil/amendment mixing when ameliorating sandy soil profiles.

Power requirements

Research conducted in SA has shown that the spader power take off (PTO) torque requirement is approximately proportional to forward speed or bite length. Conversely, the spader draught decreases with greater bite length, as the spader more effectively pushes itself along at faster forward speed. A zero net draught was found at 6km/h when spading at 350mm depth, with the spader effectively pushing the tractor at faster speeds.

This self-propelling effect is more effective at shallower depths whereby the spader more actively pushes the tractor. The above features help explain how the overall tractor engine power requirement may be affected in operation.

Field measurements conducted in a sandy soil context in Upper South East SA (Ucgul et al., 2022) showed that the engine power increased – after a threefold rise in speed (from 3 to 9km/h) – by 99 per cent and 71 per cent at 250mm and 350mm spading depth, respectively.

This makes fast spading more economical per ha, particularly when spading deeper, but as shown in the sections above achieves a much lower mixing uniformity. In contrast, when spading 40 per cent deeper from 250 to 350mm, a similar engine power increase of 95 per cent and 68 per cent was measured at 3 and 9km/h, respectively, showing how the cost of deeper spading

Figure 3.21: Simulated pattern of topsoil (0–50mm layer) particle distribution after spading to 300mm depth showing a peak in the layer immediately below surface (% indicate the redistributed proportions of the original 100 per cent surface layer). The contrast over three speeds shows the peak is much less pronounced at slow speed, indicating a more uniform distribution with depth. Red circling marks the tracked original layer of interest.

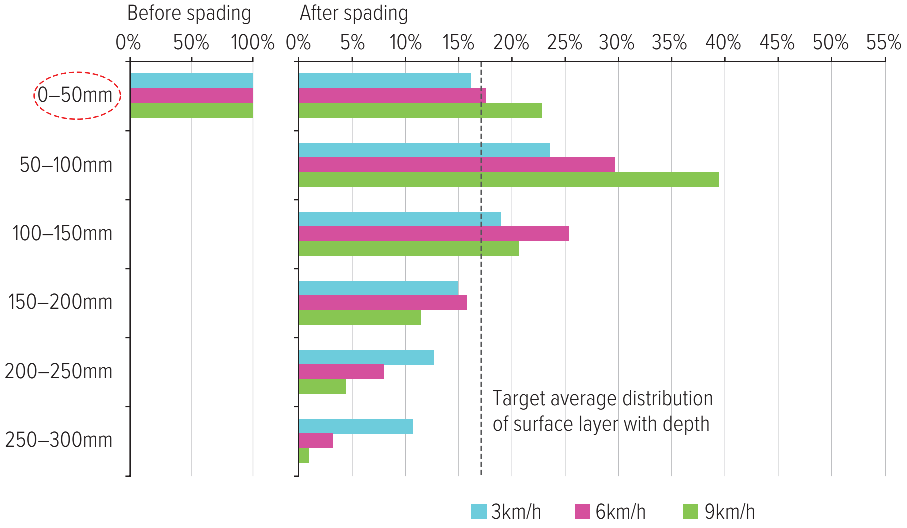
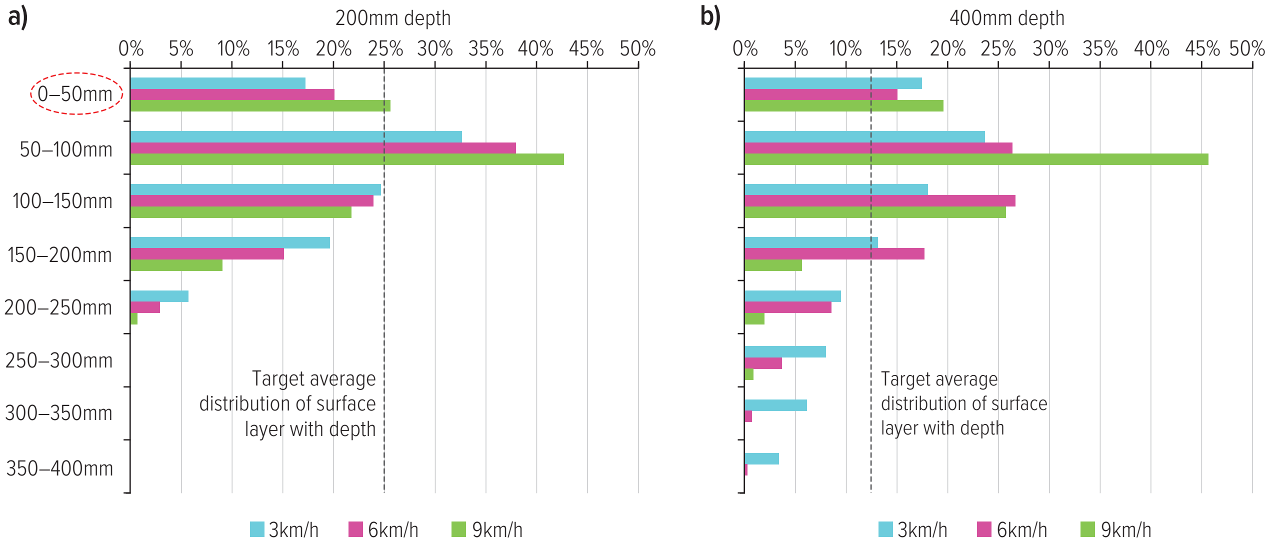


Figure 3.22: Simulated effect of spading depth (a) 200mm and (b) 400mm on topsoil (0–50mm layer) particle distribution down the profile (% indicates the redistributed proportions of the original 100 per cent surface layer). Red circling marks the tracked original layer of interest.



is much more significant but, in relative terms, is minimised at faster speeds.

In similar paddock trials, spading into a deep-ripped profile reduced the tractor engine requirements by 22 per cent on average relative to unripped soil, with maximum power savings obtained under higher spading speed. Similarly, the power requirements of a second pass spading were 23 per cent lower on average than an equivalent first-pass spading, across a range of depths and speeds, with the best reductions occurring at high speeds.

In both cases, the power reduction benefits of spading into a pre-loosened soil integrate the effects of reduced PTO torque, of increased draught from reduced ‘self-propelling’, and of slightly greater operating depth due to sinkage compared with spading into the undisturbed profile.

Overall, these results highlight that a majority of power is expended from purely moving large volumes of soil during spading, whether from a pre-loosened or an undisturbed base.

Commercial spaders are now available with optional pre-ripping tynes (Figure 3.25). Such combination implements offer an innovative basis to address multiple constraints within a deep profile, such as via deep loosening, sub-layer delving and/or topsoil inclusion prior to mixing of the upper profile and surface packing. One-pass ‘rip, spade and sow’ operations into moist profiles provide low-risk soil amelioration solutions.

Figure 3.23: Simulated mixing outcomes of the 200 to 250mm deep layer particles within a 300mm deep spaded profile at three contrasting speeds (% indicates the redistributed proportions of the original 100 per cent of the 200 to 250mm layer). Red circling marks the tracked original layer of interest.

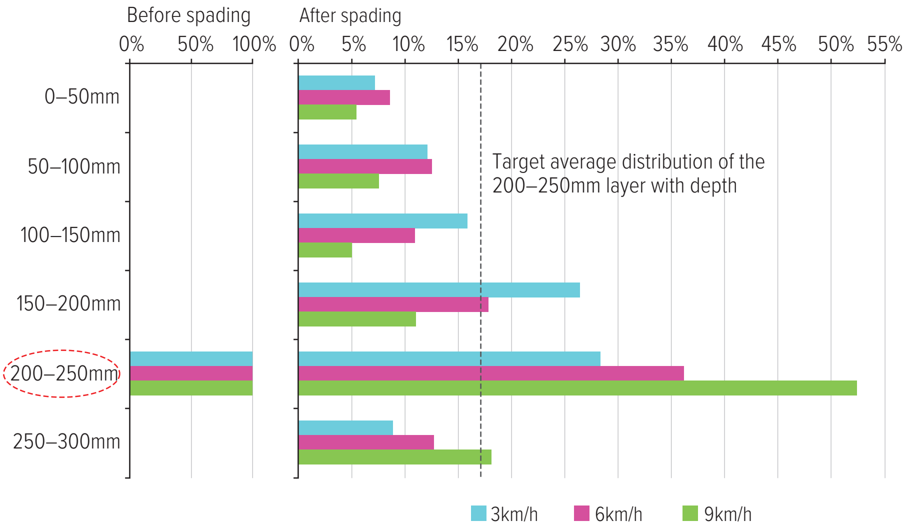


Figure 3.24: Simulated effects of spader design on the top-layer distribution with depth following spading to 300mm depth at three speeds (% scale indicates the redistributed proportions of the original 100 per cent surface 0 to 50mm layer). Note: Design 1 uses sets of three large blades around the rotor and Design 2 uses sets of 3+3 left-hand and right-hand smaller blades around the rotor. Red circling marks the tracked original layer of interest.

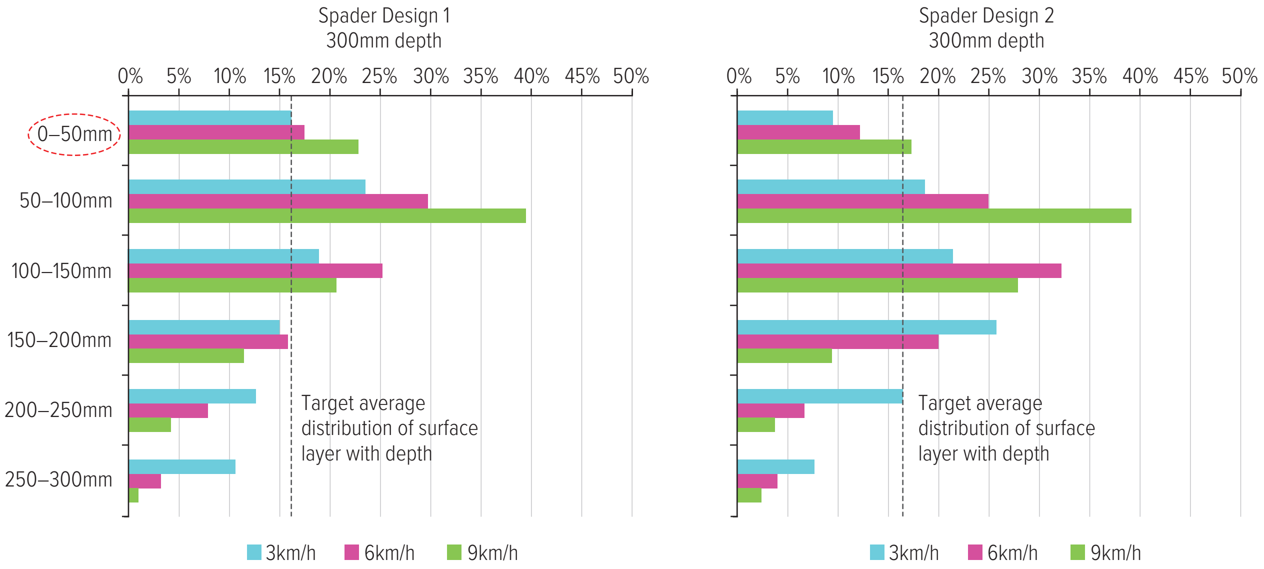


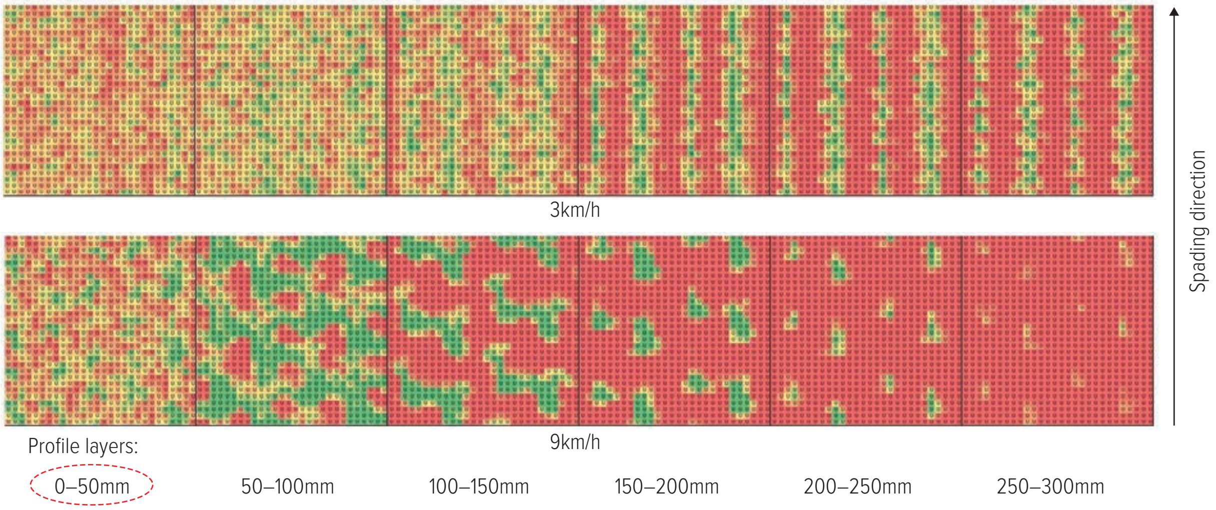
Figure 3.25: Combining deep ripping with spading in one pass is now commercially available and allows complementary remedies to be applied towards multiple constraints within a deeper profile.

Photo: Farmax Spader – Groocock Soil Improvement

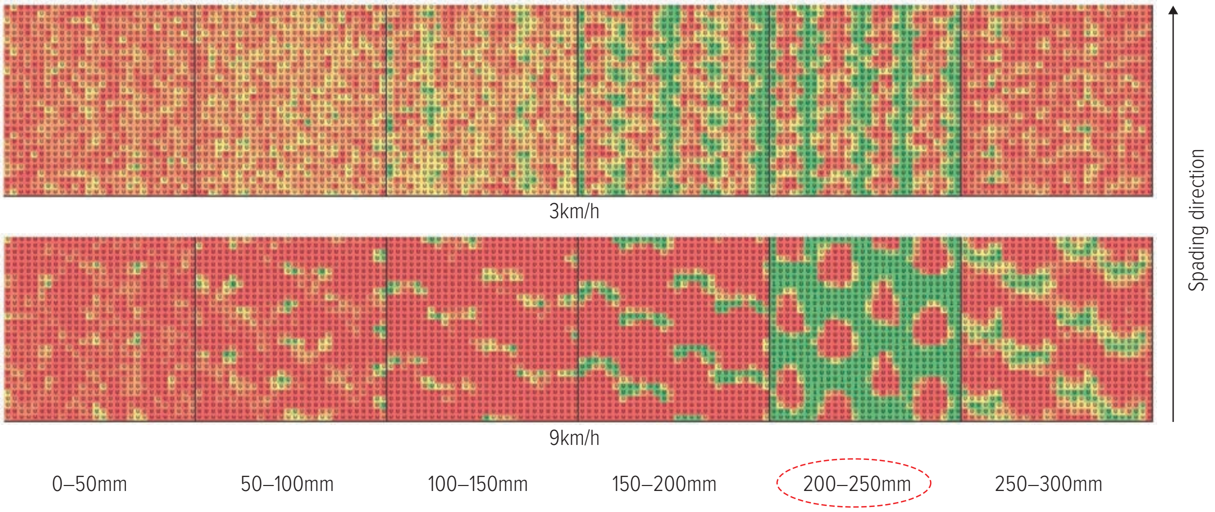
Photo: Imants Spading Western Australia

Figure 3.26: Top view simulation (50x50mm pixel resolution) of the distribution of 0 to 50mm topsoil particles (a) or 200 to 250mm deep layer particles (b), within individual layers of a 300mm deep spaded soil profile, at two speeds. Colour coding: light yellow to dark green indicates increasing concentration of tracked particles from the layer of interest, red colour indicates all other soil particles from layers outside the layers of interest. Each layer in top view represents an area of 1.4m wide x 1.5m travel. Red circling marks the tracked original layer of interest.

a) Top layer distribution down into the profile



b) Lower layer distribution up into the profile



Inclusion ripping technology

KEY POINTS

- Inclusion ripping technology is designed to drop topsoil deep into the rip line during the process of subsoil tillage.
- Adding inclusion plates to a deep ripper significantly increases the draught requirement, but this may be minimised by using improved ripper point and plate combinations.
- The depth of the plate bottom edge has the greatest impact on the draught force.
- The plate design and settings, ripping speed, timing of operation, soil type and moisture are key factors driving the inclusion performance.
- High ripping speed significantly reduces the amount of topsoil inclusion, but this can be mitigated by increasing the length of the plate.
- The operating depth of the top edge of the plate relative to the soil surface determines the thickness of topsoil layer being included, but the impact of soil upheaval while ripping needs to be factored in.
- Computer simulation is a powerful tool to help optimise solutions for passive inclusion and ultimately for more selective active inclusion systems.

Understanding passive inclusion ripping

This section summarises the latest on the mechanics of topsoil inclusion following recent and ongoing research in SA, which built on the pioneering development of topsoil slotting technology in WA in the early-mid 2010s (Parker, 2017). Implications for inclusion plate design and operational settings are explored.

'Inclusion rippers' refer to subsoiling or deep tillage implements fitted with inclusion plates. These plates consist of a braced pair of flat plates bolted behind a deep ripping tyne and spaced to form side-shields (Figure 3.28, left). During deep ripping in loose sandy soils, the cavity forced open by the tyne is expanded by the plates, which allows large quantities of topsoil to fall over their upper edges (Figure 3.28, right) deep within the loosened soil profile. Figure 3.29 outlines the terminology of inclusion plate geometry.

The aim of inclusion plates is to create a column of improved soil down the profile in subsoil that has been previously constrained by any number of limitations to root growth, for example, high strength, poor structure, nutrient deficiencies, acidity or alkalinity. Inclusion ripping often results in additional crop biomass and grain yield when compared with deep ripping alone, and with longer-lasting benefits as suggested in recent research (McBeath et al., 2022).

This is particularly the case in stratified sandy soils when the topsoil is rich in organic matter, mineral nutrients and/or amendments (for example, lime or manure). Inclusion of these topsoils improves depleted sublayers, the growth of deep roots and uptake of moisture and nutrients.

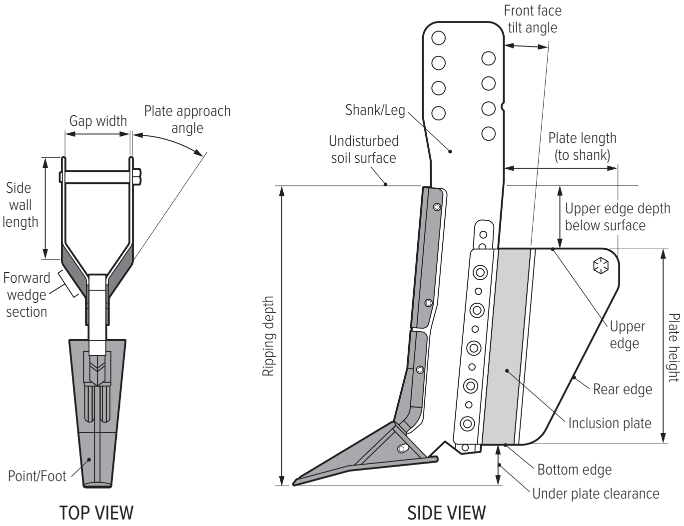
Figure 3.27: Inclusion ripping in deep sandy soils has the potential to boost the crop response beyond deep ripping alone.

Photo: Jack Desbiolles

Figure 3.28: High-capacity inclusion plate (600mm length to shank) fitted to a narrow shank subsoiler tyne (left) and the topsoil backfilling process while inclusion ripping to 600mm depth (right).

Photos: Jack Desbiolles

Figure 3.29: Parameters of ripper tyne and inclusion plate geometry.



Source: UniSA

Mechanics of inclusion

A backfilling process or inclusion happens naturally behind a tillage tyne, whereby the loosened, flowable topsoil falls into the cavity left by the tyne prior to closing. This passive inclusion process can be controlled and maximised by adding inclusion plates fitted behind narrow shank tynes.

The inclusion process starts with the soil directly above the upper edge of an inclusion plate falling over the edge and dragging layers above it into the cavity. The inclusion outcome is affected by plate design, paddock operational factors and soil properties such as flowability. Inclusion is most effective in dry sandy soils. Soil cohesion in loams or clay reduces flowability, and pre-tilling the top layer may be necessary to create soil tilth, reduce moisture and improve flow.

The impacts of plate length, upper-edge depth and under-plate clearance on inclusion performance have been investigated via computer simulations using discrete element method (DEM) modelling (GRDC 2019) and were validated in the SA Mallee during 2019. The DEM simulation can be used to track and visualise soil particle movement and final topsoil inclusion outcomes.

Figure 3.30 illustrates a ripper tyne with a high-capacity inclusion plate during three stages of moving through soil layers represented by different colours. The inclusion outcome in the bottom diagram (Figure 3.30c) shows how the inclusion space is filled with particles from various layers above. The included soil contains layers initially located below the top edge of the plate (for example, green and yellow), due to the upheaval associated with the loosening process (Figure 3.30b).

The gradational mix of coloured particles within the inclusion space suggests that inclusion occurs mainly as a ‘full layer collapse’ over the plate edge and not as a ‘surface-first’ shedding process, which is consistent with paddock observations.

The depth of the top edge of the plate relative to the surface determines the thickness of topsoil layer included. This implies that shallow settings are required to maximise the inclusion of topsoils containing top-dressed amendments near the soil surface, such as lime.

However, shallow settings also minimise the soil volume eligible for natural inclusion, and are therefore better suited to an active inclusion system (see last section).

Quantifying inclusion performance

The proportion of each topsoil layer shown within the inclusion space (Figure 3.30c) can also be quantified by DEM simulations for a more detailed analysis of the impacts of plate design, soil conditions and operational settings. This supports an optimisation process for reliable inclusion outcomes.

Figure 3.31 illustrates in a colour-coded form the relative quantities of the original layers within the inclusion space in 50mm increments down the profile. The three graphs contrast the inclusion outcomes of a control ripper tyne with no inclusion plate operating at 4km/h (Figure 3.31a), a baseline commercial inclusion plate operating at 7km/h (Figure 3.31b) and a high-capacity inclusion plate operating at 4km/h (Figure 3.31c).

Figure 3.31a shows minimal inclusion achieved by the tyne alone in both quantity and depth below origin, while layers have also been pushed upward from soil heaving during loosening. In comparison, the installation of a commercial baseline inclusion plate (Figure 3.31b) was able to include significantly greater proportions of particles in the adjacent layers immediately below the depth of origin, but only small quantities were able to reach down to 200mm below the depth of origin.

The inclusion outcome was significantly improved by using a high-capacity plate combined with a slower ripping speed (Figure 3.31c), which maximised the proportions of 0 to 150mm layer particles included throughout the profile, reaching near-full depth. The inclusion space mainly contained particles originating from the top four layers, rather consistently with depth. Specifically, the high-capacity plate operating at 4km/h resulted in the top 250mm soil layers being successfully included down to 550mm depth and forming 60 to 75 per cent of the soil present within the 350 to 550mm depth zone, unlike the commercial inclusion plate operating at the faster speed, which included negligible quantities in that same depth zone.

These simulations show the critical importance of matching the top-edge length to the ripping speed to achieve the intended inclusion outcome, and the challenge of successfully including a large quantity of surface soil deep into the profile. The drier the topsoil, the greater the flowability and the more effective the inclusion process.

The impact of moist sublayers on optimum plate depth and on the effectiveness of dry surface layer selection for inclusion requires further investigation.

Optimising passive inclusion set-up

Top-edge depth setting

In practice, the plate upper-edge is commonly set in the range of 100 to 150mm below the undisturbed soil surface. However, the effect of the soil upheaval during loosening by the ripper tyne additionally brings deeper layers (commonly 150 to 200mm) above the top edge of the inclusion plate as shown in Figure 3.30b. The amount of upheaval during the ripping process needs to be factored into the optimum plate depth setting, relative to the actual layer targeted for inclusion.

Plate length

The plate length (to shank) combined with the side-wall length (Figure 3.29) has a significant effect on the inclusion capacity at speed, while the forward wedge section has the least contribution. In practice, the whole length of the plate is not fully functional, with the active part concentrated over the rear section depending on ripping speed and topsoil flowability. Slow speeds in dry flowable soils maximise the length of the active portion of any given plate and promote greater inclusion. To date, the plate length used in paddock research has been limited to 600mm, but DEM simulations suggest that longer plates may provide additional benefits. Extra-long plates are likely to require modifications to manage the range of soil forces encountered.

Under-plate clearance

Inclusion plates are commonly added to straight or parabolic narrow shank ripper tynes, but such combinations are yet to be optimised for draught requirements. A deep setting of the plate reduces the under-plate clearance above the ripping point, and typically forces the lower section of the plate to engage with undisturbed soil, expanding the furrow opening at depth. This engagement greatly impacts draught force and is associated with high wear and potentially deep layer compaction and smearing.

Figure 3.32 shows examples of increased draught across a range of inclusion plates on a deep sandy soil. The extent of ripper tyne draught increase (+36 to 75 per cent under the experimental conditions) was directly associated with the reduction of under-plate clearance (from 181 to 31mm).

The same dataset confirms that with a constant bottom-edge setting, a longer plate does not require significantly more draught.

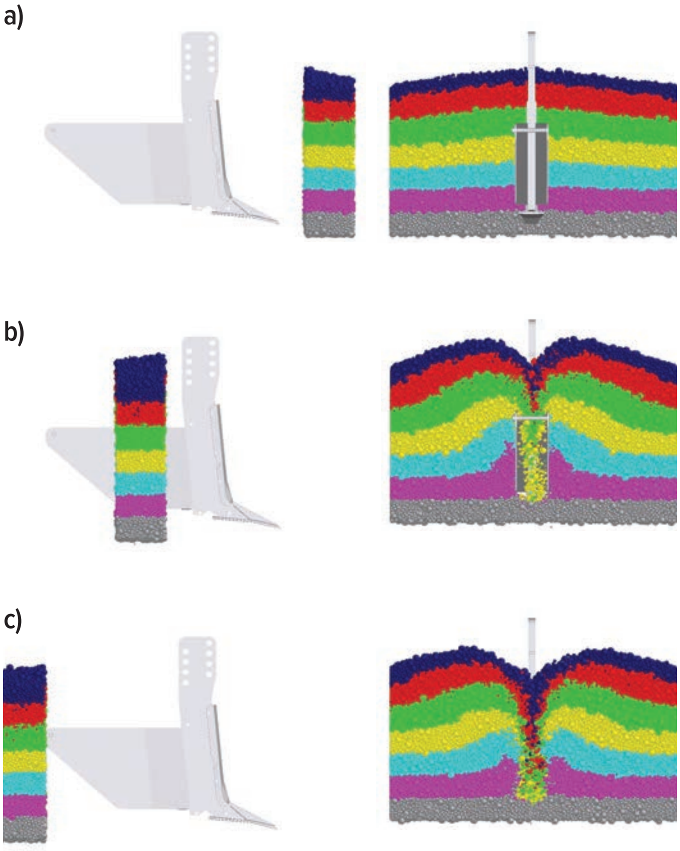
Figure 3.30: Computer simulations of the process of topsoil inclusion with a ripper tyne and inclusion plate, tracking the movement of soil layers over a 600mm deep profile.

a) Soil profile with layers in their original locations in early stages of loosening by the tyne.

b) Fully upheaved soil profile during loosening with additional sublayers lifted above the plate edges in the early stages of inclusion.

c) Inclusion outcome showing a gradational mix of soil layer particles.

NB: The simulation reflects high-capacity inclusion plates (390mm H x 600mm L x 131mm W) operated at 4km/h in a dry sandy soil profile with good flow properties.



Source: UniSA (software: Altair EDEM^{TM})

Inclusion gap width

The gap width of large capacity inclusion plates used in field tests ranged from between 131 and 185mm with a 600mm length to shank. In comparison, the width of commercial plates fluctuates between 80 and 160mm but associated with short lengths in the range of 250 to 300mm.

Under dry, flowable soil conditions, the gap width is usually optimised to mitigate blockage risks from surface residue and weeds. In cloddy soil conditions, inclusion capacity and reliability are both improved with a wide plate gap.

At similar plate height and under-plate clearance settings, a wide inclusion plate increases draught due to greater interaction with the lower furrow and increases soil surface roughness via greater bulldozing of the loosened profile.

Figure 3.31: Simulation-based inclusion performance for three contrasting tynes operating at 600mm depth in a dry flowable soil.

a) Control ripper tyne with no inclusion plate.

b) Typical commercial size plate (290mm H x 250mm L x 131mm W) operated at 7km/h.

c) High-capacity research plate (390mm H x 600mm L x 131mm W) operated at 4km/h.

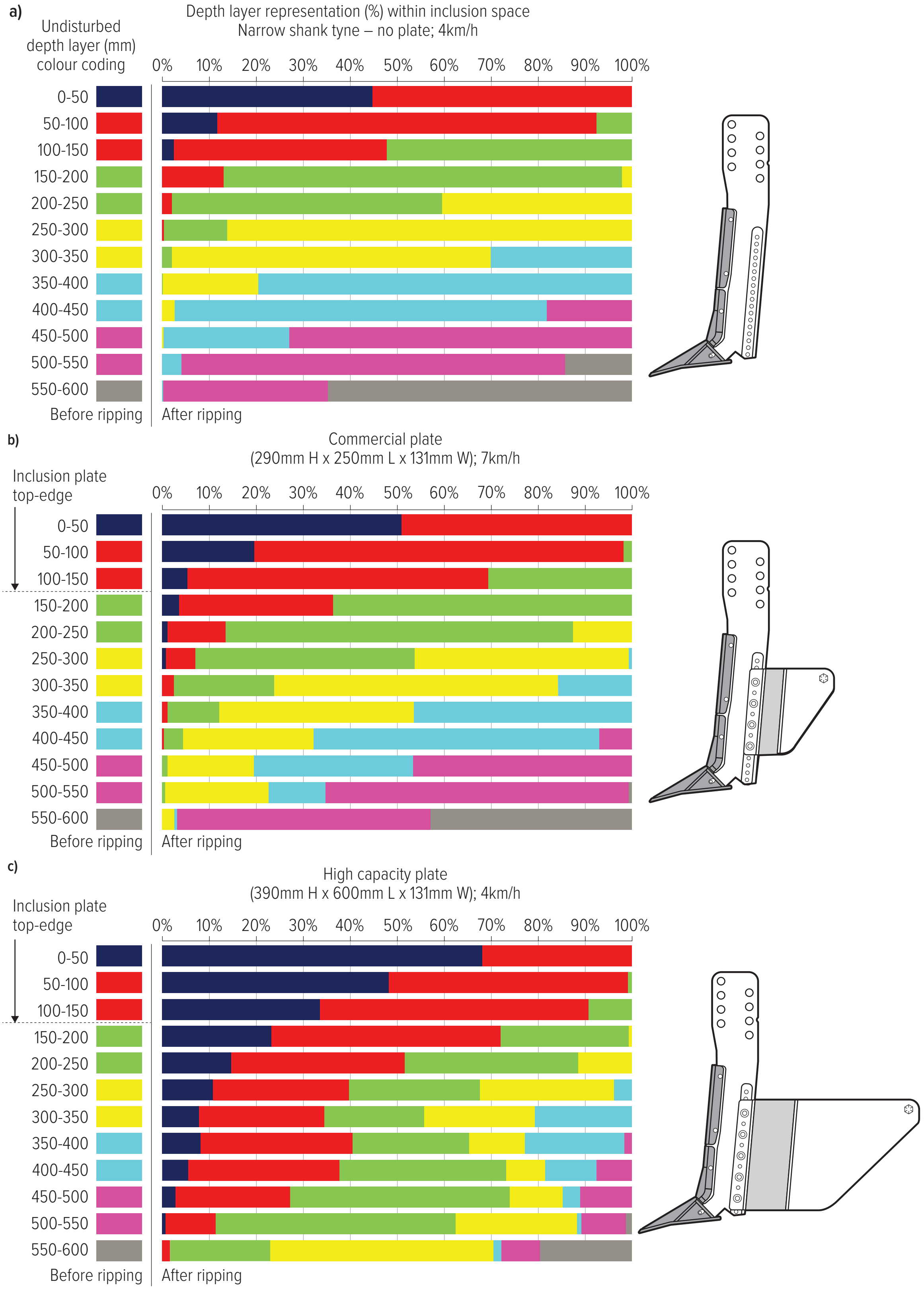
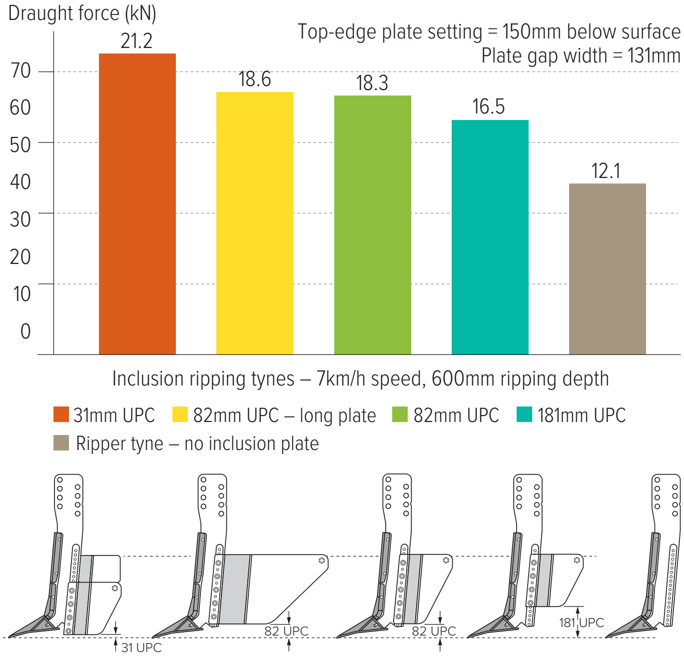


Figure 3.32: Effect of under-plate clearance (UPC) on inclusion ripping tyne draught (Caliph, SA Mallee, 2019, deep red sand, 1.47 to 1.53g/cm^3 dry bulk density at 0.2 to 0.6m depth).



Source: UniSA

Plate strength considerations

Significant soil forces act on the forward wedge section, subjecting the plates to high wear. High-strength steel plates reduce wear rate and the addition of an inner brace helps maintain the gap width during operation. Design solutions should integrate the inner brace within the forward wedge section to keep the active rear portion of the plate as unrestricted as possible. This ensures that the uniformity of the backfilling process is not interfered with and reduces the risks of blockage.

Plate strength and draught issues become less critical when inclusion plates are set with a high underside clearance and where the ripping point incorporates wings to sufficiently broaden the lower parts of the furrow and minimise stress on the plates. Some commercial solutions include wear plates bolted over the forward wedge section, also strengthening the inclusion plates (Figure 3.33).

In wet and heavy textured soils, excessive soil build-up over the plate surface is a potential issue, which is yet to be successfully mitigated. Low adhesion material and slatted designs may minimise draught penalties and maintain inclusion performance.

Figure 3.33: Commercial inclusion plates exist in many shapes and sizes, and evaluation using computer simulation can help guide their selection and settings for best results in the paddock.

Research opportunities

Ongoing research continues to shed light on the mechanics of inclusion. For instance, the impact of a vertical rear-edge (square plate) rather than tapered, and a downward sloping top-edge, as seen on some commercial inclusion plates, are being explored (Figure 3.33). There is also a need to optimise designs to promote soil layer mixing – rather than banding – which may be an important consideration for amendments such as lime and gypsum. More research on the different combinations of ripper points and inclusion plates is required to find the most energy-efficient combinations for high-capacity inclusion. Opportunities also exist to optimise a two-stage inclusion process, whereby similar inclusion outcomes may be achieved with more compact plates.

The limited control over the layer included and depth of inclusion with a passive inclusion process underpins a rising interest in active inclusion systems. For example, the use of skimmer discs can positively direct large quantities of the topsoil down into the inclusion space. Research is planned to further develop active inclusion solutions, following some early proof-of-concept work to date (Figure 3.34).

Figure 3.34: Proof-of-concept active inclusion system (top) is able to maximise inclusion capacity (bottom-left) and achieve a consolidated and levelled seeder-ready finish (bottom-right).

Photos: Jack Desbiolles

Soil inversion by ploughing

KEY POINTS

- Mouldboard, disc or square ploughs can address surface soil constraints by inversion and burial but their performance can be affected by a range of factors
- A key function of ploughing in sandy soils is to invert the 0–400mm topsoil profile and bury surface-applied amendments, stubble residue, non-wetting topsoil and resistant weed seeds
- Ploughs with skimmers (set correctly) will more successfully invert and reliably bury the surface layer to depth
- The speed of work has significant effects on the quality of burial, with each plough performing best at an optimum speed. Generally a speed above 7.5km/h leads to performance decreases
- One-way disc ploughs are not as effective at burial as mouldboard ploughs, especially at higher forward speeds, and work better in deep sands where penetration is easy
- Better results are achieved when ploughing is carried out at the correct soil moisture; waiting until later in the season when moisture increases generally improves performance
- Post-ploughing management is critical to optimise crop establishment and minimise erosion risks

Inversion ploughing principles

Modern ploughs have had incremental changes in their design over time, but the principles remain the same: cutting a soil slice to the working depth required, turning the whole furrow slice over and placing it into the adjacent open furrow. This needs to be done as efficiently as possible with the aim to bury 100 per cent of the old surface soil, leaving sublayer soil on the surface.

This is often not easily achieved in sandy soils, where dry free flowing gutless soil does not invert easily. This can improve as sandy soil moisture increases, much like making a sandcastle. GRDC-funded research has investigated, through field-testing and DEM computer simulation, some of the factors that affect the burial efficacy of surface layers, with a range of mouldboard and disc ploughs.

Key factors for plough performance: DEM analysis

When assessing the performance of a plough, the following are key considerations:

- burial – quantity buried versus left on the surface, distribution depth of burial within the ploughed profile; and
- plough design and settings – type of plough, speed of operation and field settings (skimmers, disc rake and sweep angles).

A mouldboard plough and validated computer simulation were used to compare the ability of the plough to bury the surface layer (Figure 3.39a and b). A blue layer of particles was put onto the surface and then used as a method of quantification to assess the inversion performance.

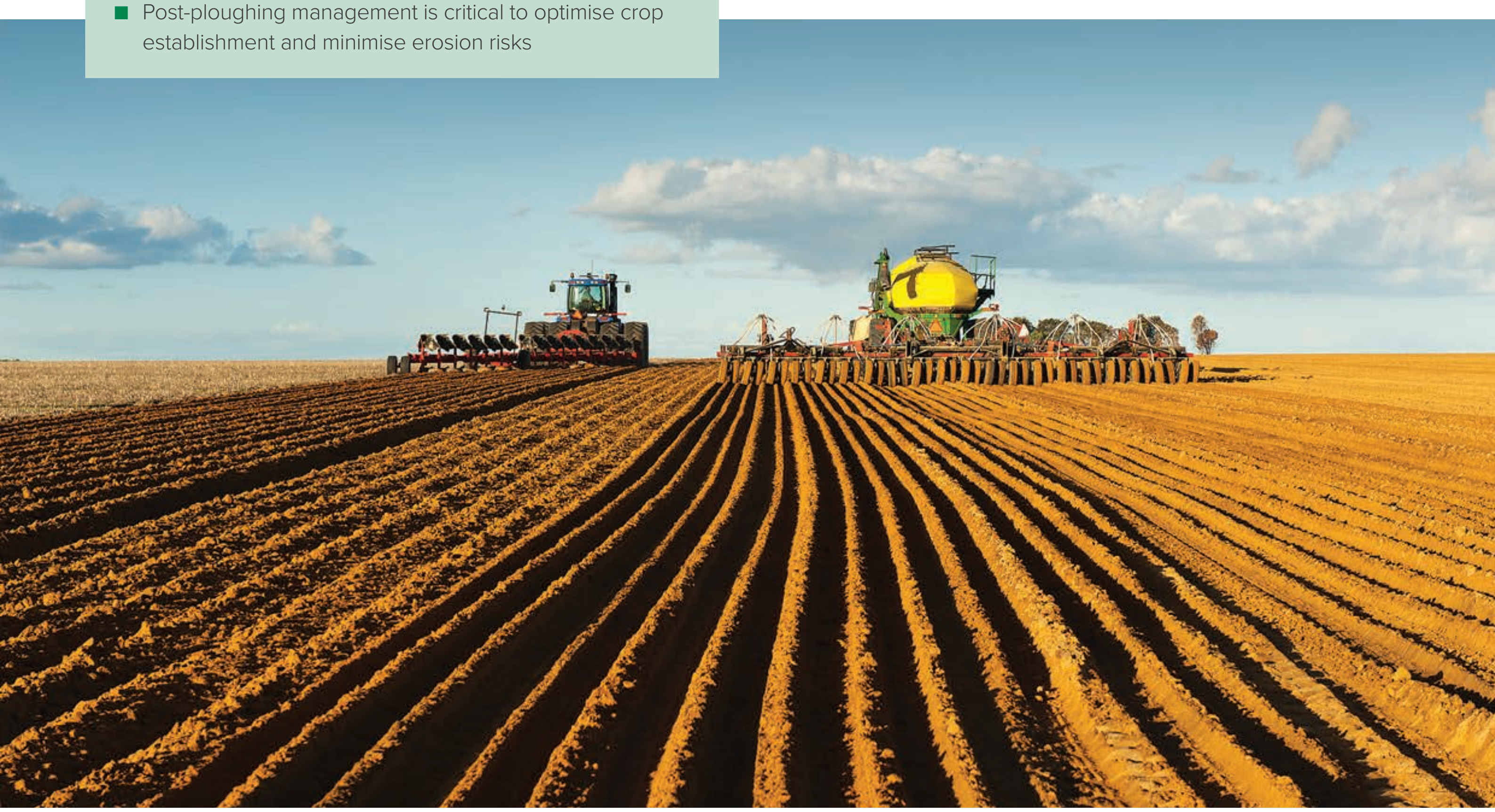


Figure 3.35: Mouldboard ploughing and seeding at Mullewa, WA.

Photo: Evan Collis

Figure 3.36:
a) Kverneland mouldboard and skimmer.

Photo: UniSA

b) Gregoire Besson mouldboard plough.

Photo: UniSA

Figure 3.37:
a) John Shearer prototype two-way high work rate disc plough with skimmers.

Photo: UniSA

b) Plozza modified John Shearer 5GP one-way disc plough.

Photo: UniSA

Figure 3.38:
a) top and 3b) bottom: TATU square plough.

Photo: Serafin Machinery website

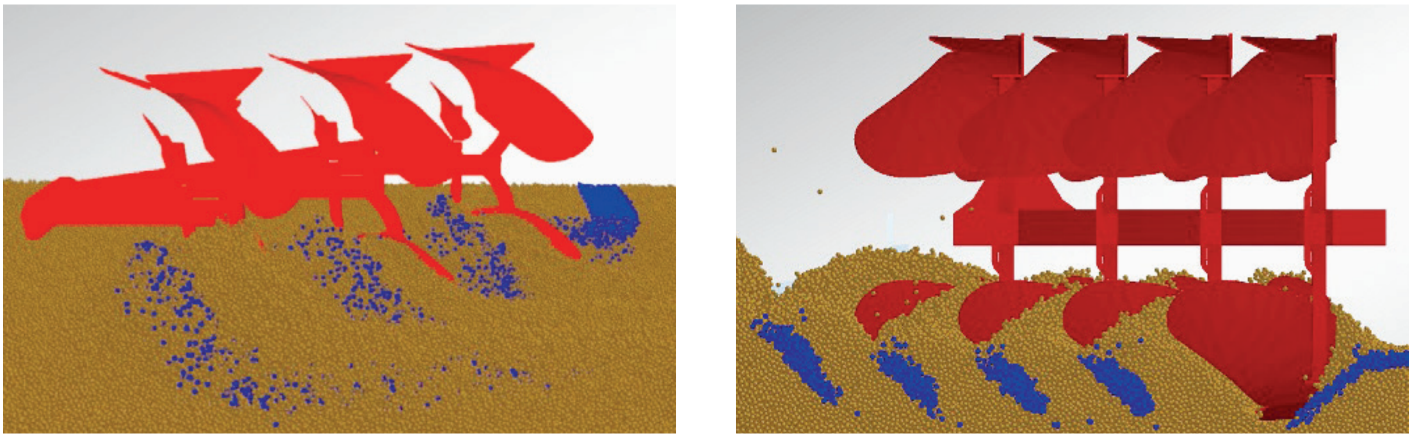


Figure 3.39 a) Side view of computer-simulated plough.

b) Rear view of simulated plough.

Source: UniSA

As can be seen in Figure 3.39a and b, the blue particles originally on the surface are buried as the plough passes over them, leaving minimal blue particles visible on the surface, with the majority found in pockets below the surface along each furrow row.

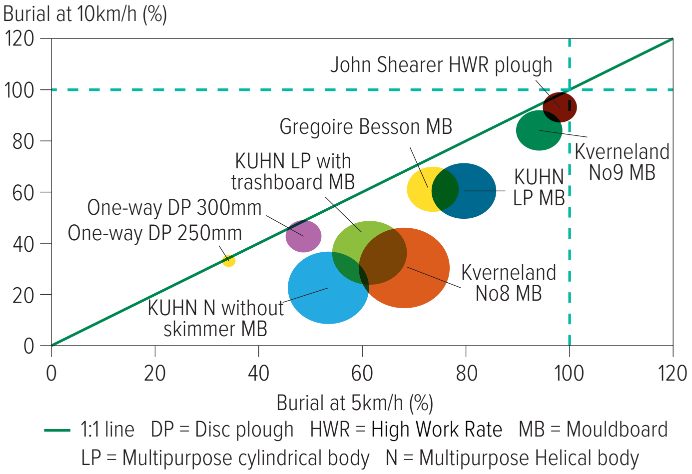
The DEM simulations were then used to investigate the impact of speed on surface burial efficacy of a range of mouldboard and disc ploughs. Figure 3.40 shows the different burial percentages of a range of plough types and mouldboard bodies at two speeds.

For example, the KUHN LP MB buried 80 per cent of the surface layer at 5km/h (horizontal axis) but when the speed is increased to 10km/h (vertical axis), the mouldboard only achieved 60 per cent burial at 10km/h (vertical axis). Overall across the range of ploughs investigated, the lower end of burial efficacy is taken from 45 per cent at 5km/h down to 10 per cent at 10km/h.

DEM computer simulation was used to investigate the benefit of skimmers fitted on mouldboard ploughs. Skimmers improve the amount of topsoil effective burial, especially visible in the 0 to 100mm depth layer (Figure 3.41). Skimmers should be set about 50mm below the soil surface. Deeper skimmer depths do not necessarily increase topsoil burial.

When considering the type of plough to choose, DEM was used to investigate the surface layer burial performance of a mouldboard versus a disc plough. Simulation results indicate that using a mouldboard plough provides better topsoil burial, up to 15% better at removing the top 150mm and up to 25% improvement in placing this into a deeper layer, when analysed using DEM, over a one-way disc plough and this is especially true as speed increases. It can be seen from Figure 3.42 that the mouldboard took the surface soil from the 0 to 100mm layers and significantly increased the percentage in the 200 to 300mm layers when compared to the disc plough.

Figure 3.40: Comparison of surface burial efficacy for a range of plough types and bodies at two speeds.



Larger circles denote a greater range of soil burial outcomes. Circles below the 1:1 line illustrate the reduction of relative burial efficacy at higher speed.

Source: UniSA

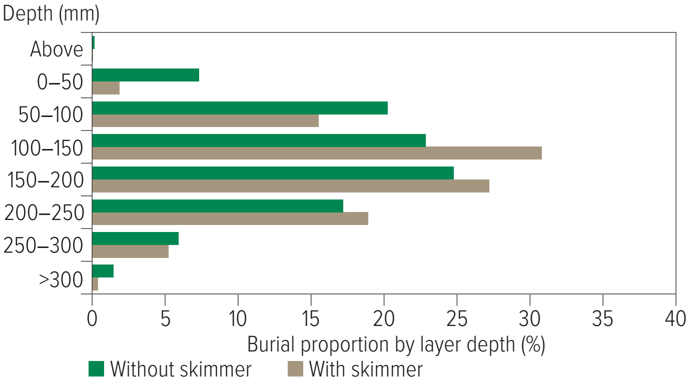
Paddock evidence

When a mouldboard plough is set up correctly, 100 per cent surface burial should be achieved and the surface layer should be buried relatively deep in the profile. Figure 3.43b shows how the crop residue has been inverted to a position at the bottom of the ploughed profile, with the pale subsurface sand covering the darker surface-layer soil. Figure 3.43c shows that if set up and used incorrectly, surface material can be left on the surface, typically in narrow bands on the interface of each furrow. This typically occurs without skimmers or if the skimmers are not set correctly in relation to the main mouldboard body and furrow slice either in its depth or lateral positions.

Similarly, when one-way disc ploughing is done well in deep sandy soil, the surface layers are buried and reasonable depth is achieved. Figures 3.44a and b show cross sections of ploughed profiles with a blue/green surface tracer that was used to evaluate performance. There is generally a wider spread of surface material through the profile with the typical J-curve running from down the profile up to the surface between each ploughed slice. Slower speeds should be used to obtain this good burial whilst waiting until later in the season when soil moisture increases can also improve performance.

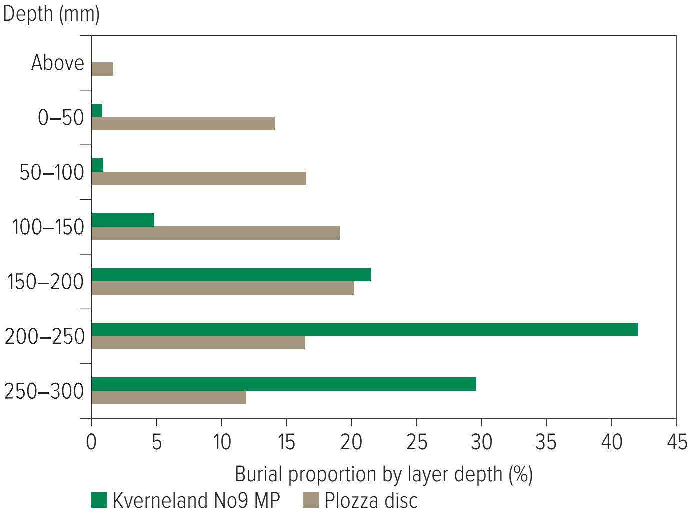
One-way disc ploughs often do not work well in harder soils where the stability of soil penetration can be an issue, or when the operational speed is too high, leading to very poor burial performance. Figure 3.44b shows where the blue/green tracer and crop residue can be seen on the surface and very shallow in the profile. The discs were working too shallow to be filled with sufficient soil to enable inversion.

Figure 3.41: Increased surface sandy topsoil burial from the addition of skimmers.



Source: UniSA

Figure 3.42: A comparison of surface layer burial by a mouldboard plough and a one-way Plozza disc plough at 5km/h.



Source: UniSA

Post-ploughing management

Regardless of which inversion plough type is used, the post-ploughing conditions result in very soft seedbed and a residue-free surface that is very prone to wind erosion. This represents a major challenge for quickly re-establishing ground cover including the follow-up grain crop establishment.

A key first step involves a rolling operation to consolidate the soft soil and facilitate the seeder pass by minimising sinkage, deep rutting legacy and uncontrolled depth of seed placement.

The rolling operation can be problematic if the weight and size of tractor and roller are not matched properly (Figure 3.45).

As part of an improved disc plough development carried out by the University of South Australia (UniSA) and John Shearer under GRDC investment, a one-pass ploughing and seeding solution was developed and tested. This used a proof-of-concept high floatation seeder, which can be towed with the plough or used separately after ploughing. It features seeding coulters designed for clean and tilled seedbed (Figure 3.46) to improve seed placement depth control and large floatation wheels to consolidate the seedbed with minimal sinkage, and leave ridges for wind erosion protection. A towed seeder concept had been tried by WA grower Mick Fels by adapting an old combine seeder towed behind a square plough.

If seeding behind the plough is not practical, increasing the seeding rate, two-pass cross seeding or combining seed broadcasting incorporated with the tyne seeder are strategies used. As seen in the top half of Figure 3.47, combined seeder and seed broadcasting were used to achieve maximum plant numbers and ground cover. This is a recommended approach to effectively stabilise the loose soil and resist the impact of high winds.

Another important consideration is the redistribution and/or dilution of organic carbon (OC) and nutrients following inversion/burial. Research has shown that OC and nutrients are buried deeper in the soil profile (20 to 30cm), so while they are not lost from the system, the amount in surface layers may not meet the nutritional needs of emerging crops, calling for appropriate agronomic management.

Post-ploughing agronomic management

- Supply extra nitrogen and sulfur early in the growing season to boost early biomass production and encourage tillering.
- Conduct a strategic soil sampling program in the second year after amelioration (once the site has settled) to assess nutritional status in the top 100mm.
- Supply customised nutritional package to boost soil fertility and meet the new crop demand.

Figure 3.43:

a) Two-tone soil profile at Midland, WA.

Photo: UniSA

b) Effective burial by mouldboard plough fitted with skimmers, showing concentration of surface residue at the bottom of furrow at Midland, WA.

Source: UniSA

c) Poor mouldboard plough burial at Geraldton, WA.

Source: UniSA

Figure 3.44:

a) Good performance with a one-way Plozza disc ploughing at Malinong, SA.

Source: UniSA

b) Poor performance with a one-way Plozza disc ploughing at Bute, SA.

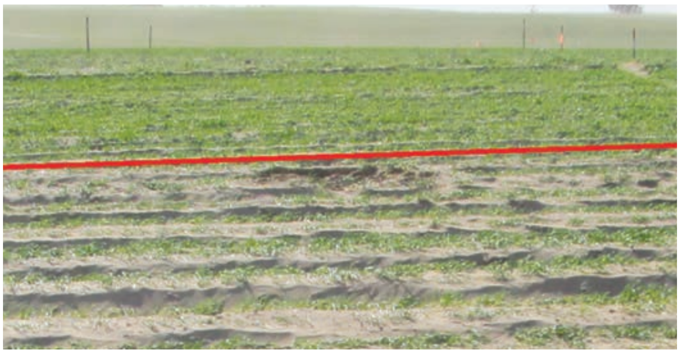
Source: UniSA

Figure 3.45: Post-ploughing rolling operations at Cowangie, Victoria, challenged by soft seedbed tractor sinkage and traction limitations

Photo UniSA

Figure 3.46: John Shearer high-work-rate prototype full inversion disc plough and one-pass seeder.

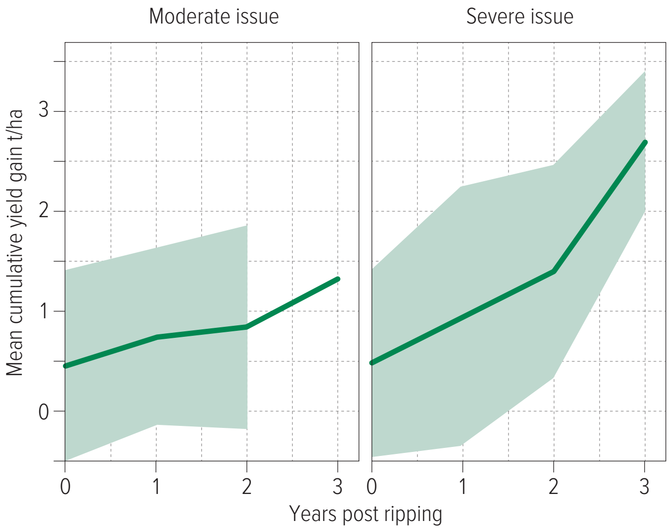
Figure 3.47: A visual comparison of conventional seeding versus zero row spacing (seeder plus additional broadcast) to improve post-ploughing crop establishment and resistance to high wind damage.



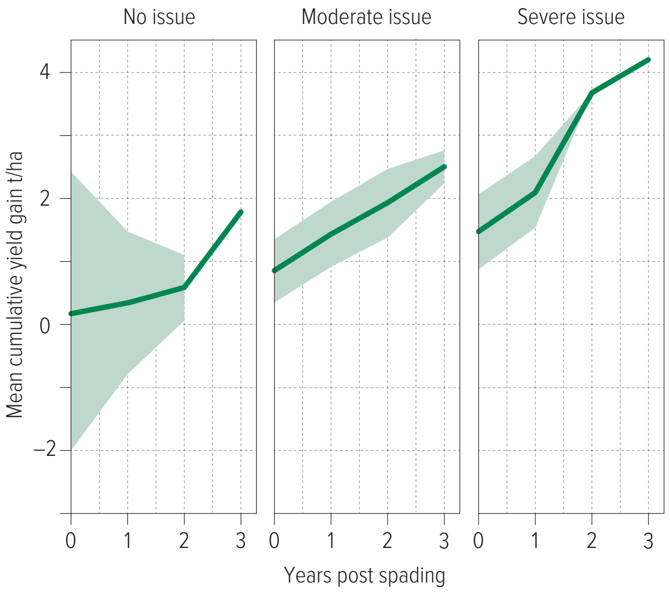
Chapter 4: Evaluation of treatments

Figure 4.1: Southern Sandy Soils project cumulative yield responses (as mean in bold line and cv in green shadow) over time to ripping and spading (amelioration occurred in year 0). The responses have been separated according to the category of constraint and we present the examples of ripping responses according to categories of soil physical constraint (measured by soil strength) and spading responses according to repellence (measured by water droplet penetration test).

a) Ripping
Constraint = Physical



b) Spading
Constraint = Repellence



The crop response to sandy soil amelioration varies according to primary constraint. As an example, Figure 4.1 shows the level of ripping responsiveness over time for soils with moderate and severe physical constraints. While the initial response to ripping is similar for both categories, the cumulative response is greater for sands with a severe physical constraint. Figure 4.2 shows the level of spading responsiveness over time for soils with nil through to severe repellence. The amelioration of repellence relies on the mixing or dilution of surface soil with repellence. The results show that more repellent sands generate a greater cumulative yield response to spading. The shading (coefficient of variation) in the figure demonstrates that there is still quite a range of possible outcomes within each category of constraints, which arises due to seasonal constraints, variation in the soil constraint and post-amelioration management (for example, nutrient input, crop establishment, erosion and so on).

This variation in response does lead to some uncertainty in the level of response that any grower might expect on-farm. For this reason, we have developed an app that provides access to our analysed database of responses to amelioration treatments across 26 experimental sites covering most of the key sandy soil environments of the southern cropping region. The Sandbox app shiny.csiro.au/soil-sandbox allows the user to select sites on the basis of location and relevant constraints and then review both the crop yield responses to treatment by season and cumulatively.

With information about the potential responses to treatments and combined with the grower's own observations, it is then possible to estimate the cost–benefit of undertaking a program of soil amelioration.

Figure 4.2: An example of the view of crop responses to amelioration treatments at a site in the Sandbox app.

Economics of deep ripping

KEY POINTS

- The magnitude and longevity of extra grain yield benefits drive deep ripping returns
- The capital cost and the proportion of responsive paddocks shape whole-farm gains from ripping
- Changes in operational (for example, fuel) or additional fertiliser costs have minimal impact on the economic viability of ripping in comparison to the effect of capital costs
- Where soil constraints can be improved, there are significant economic returns available from deep ripping
- Deep ripping is profitable when the present value of the benefits over an expected period exceed cost at a required discount rate

High soil strength, resulting from factors such as compaction and hard setting, can significantly impede root penetration, therefore limiting access to moisture and nutrients at greater depths. Deep ripping involves the loosening of soil at depths beyond what traditional cultivation methods achieve. This approach holds the potential to enhance yields, particularly in compacted sandy soil conditions. It is important to note that deep ripping demands substantial investment, and its effectiveness can vary considerably based on factors such as site-specific conditions and seasonal variations (Schneider et al., 2017; Unkovich et al., 2020).

This section's main purpose is to offer growers and their advisers guidance on evaluating the economic viability of deep ripping, using farm-specific data. By following the method demonstrated in the example below, growers and advisers can effectively assess the financial gains linked to deep ripping. This approach allows them to customise their decision-making process to align with the specific and relevant conditions of their local context.

Cost–benefit analysis of deep ripping for your farm

Example: deep ripping at 50cm depth at Bute, SA

The cost–benefit analysis presented in Table 4.1 evaluates the influence of soil ripping activities on a siliceous sand at Bute, SA over a seven-year planning horizon. The site has a high level of soil strength with penetrometer resistance exceeding 4000kPa at 30cm depth. In the analysis, soil ripping is performed in the initial year (Year zero), and the crop sequence on-site was followed to evaluate economic return. In this example, a remarkable 283 per cent return over seven years is attained.

Figure 4.3: The cost of deep ripping operations can be minimised by distributing ownership cost over a greater area and maximising power-use efficiency in the paddock.

Photo: Jack Desbiolles

Table 4.1: Cost–benefit analysis example: deep ripping at 50cm depth at Bute, SA.

	Annual replacement fertiliser cost (RFC) ($/t)								50
	Discount rate (DR)								9%
YEAR	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
CROP ROTATION		**Wheat**	**Barley**	**Lentil**	**Wheat**	**Barley**	**Lentil**	**Wheat**	
COSTS									
Ripping to 50cm ($/ha)	140								
Amendments ($/ha)	0								
Replacement fertiliser cost ($/t)	0	0	48	31	40	56	42	29	
Total annual investment costs ($/ha)	140	0	48	31	40	56	42	29	386
Present value factors (PVF)	1	0.92	0.84	0.77	0.71	0.65	0.60	0.55	
Total discounted annual investment costs ($/ha)	**140**	**0**	**41**	**24**	**29**	**36**	**25**	**16**	**310**
BENEFITS									
Yield of untreated (t/ha)		1.8	2.1	0.4	2.6	1.5	0.6	1.2	10.2
Yield of treated (t/ha)		2.8	2.8	1.2	3.7	2.4	1.2	2.0	15.9
Grain price ($/t) less freight		305	246	615	305	246	615	305	
Annual increase in crop value ($/ha)		294	153	496	342	206	353	236	2081
Total discounted annual benefits ($/ha)		**270**	**129**	**383**	**242**	**134**	**211**	**129**	**1498**
Net present value (NPV) ($/ha)									**1187**
Benefit–cost ratio (BCR)									**4.83**

Note: Replacement fertiliser cost = (yield of treated – yield of untreated) × 50
Present value factor = 1 / (1 + discount rate)^year, for example $1/(1+0.09)^1 = 0.92$
Total discounted annual investment costs ($/ha) = total annual investment cost × PVF
Annual increase in crop value = (yield of treated – yield of untreated) × grain price
Total discounted annual benefits = annual increase in crop value × PVF
NPV = total discounted benefit – total discounted investment cost
BCR = total discounted benefit / total discounted investment cost
On the assumptions therein, to achieve break-even in Year 1, a minimum initial grain yield benefit of 1t/ha is needed. This can be calculated as the total discounted investment cost / (Year 1 grain price less freight × Year 1 PVF). In this example, the 283% cost–benefit return over seven years is calculated as follows: (NPV benefit – total discounted investment cost) / total discounted investment cost × 100

Essential elements of a cost–benefit analysis

Costs

RIPPING COST

The assumed cost of deep ripping was set at $140/ha following the assumptions outlined in Table 4.2. The cost of deep ripping is influenced by several key factors, including the ripping depth (affecting power requirements), ripper width, tractor operating speed and field operational efficiency, which is represented by the time spent on the deep ripping process as a proportion of the total time spent in the field, including unproductive time. These assumptions regarding work rates have a significant impact on metrics such as total hectares ripped per hour (coverage) and the total hours needed to complete a ripping project for a given treated area (for example, 200ha). Depreciation is incorporated as an expense for both the tractor and ripper, calculated based on their purchase and salvage values divided by hours of use. Additionally, other costs, such as labour, fuel, repair and maintenance (R&M), can be adjusted to farm-specific circumstances. Extra seeding costs are also considered, accounting for extra tasks such as rolling for firming the ground before seeding.

REPLACEMENT FERTILISER COST

To account for the increased yields resulting from the ripping treatments without depleting soil fertility, extra fertiliser expenses are included in Table 4.1. These costs are incurred from Year 2 onwards. The calculation of these costs is based on the extra yield benefit and a benchmark of $50/t of wheat yield spent on fertiliser for simplicity. This cost is then multiplied by the yield gain to determine the per-hectare expense.

Present value factor (PVF)

Considering the variability in the timing of costs and benefits associated with investments, and the principle that the present value of a dollar is generally higher than its future value, due to the potential to earn interest or investment returns, a discount rate is required. This discount rate is defined as the rate of return required by growers or the opportunity cost of capital, is applied to each projected cashflow to determine its present value.

For this example, we have assumed a nominal discount rate of 9 per cent, which is equivalent to 6 per cent real opportunity cost of capital. This rate is used to estimate the present value factors for each year following deep ripping, using the formula: 1 / (1 + discount rate)^year. Subsequently, the costs and benefits for each year are multiplied by the corresponding discount factor to yield the discounted costs and benefits specific to that year (Table 4.1).

Table 4.2: Ripping cost calculation.

A	**Ripping depth (cm)**	50	
B	**Operating speed (km/h)**	6	Assumption based on prior literature and expert opinion
C	**Ripper width (m)**	4	
D	**Field operational efficiency**	80%	Per cent of time spent doing the deep ripping operation in the paddock
E	**Coverage (ha/h)**	1.9	((C×B)/10)×D
F	**Ripping area (ha)**	200	Case study assumption
G	**Total hours**	104	F/E
H	**Tractor depreciation ($/h)**	26	*(Value of tractor apportioned to ripping — Proceeds from sale apportioned to ripping)/Depreciable hours
I	**Tractor depreciation ($/ha)**	14	H/E
J	**Tractor R&M ($/h)**	10	
K	**Tractor R&M ($/ha)**	5	J/E
L	**Ripper depreciation ($/h)**	38	(Value of ripper – Value of ripper sale)/Depreciable hours
M	**Ripper depreciation ($/ha)**	20	L/E
N	**Fuel consumption (L/h)**	70	Assumption
O	**Fuel cost ($/L)**	1.8	Fuel cost less rebate
P	**Fuel cost ($/h)**	126	N×O
Q	**Fuel cost ($/ha)**	66	P/E
R	**Labour ($/h)**	40	
S	**Labour ($/ha)**	21	R/E
T	**Seeding ($/ha)**	15	To cover the cost of extra activities (for example, rolling after ripping)
U	**Total cost ($/ha)**	140	(I+K+M+Q+S+T)

Note: *Depreciable hours = starting hours – likely hours when sold.
If 20% of the total tractor operating time is dedicated to the ripping task, then the portion of the tractor's value allocated to ripping equals 20% of the tractor's value.

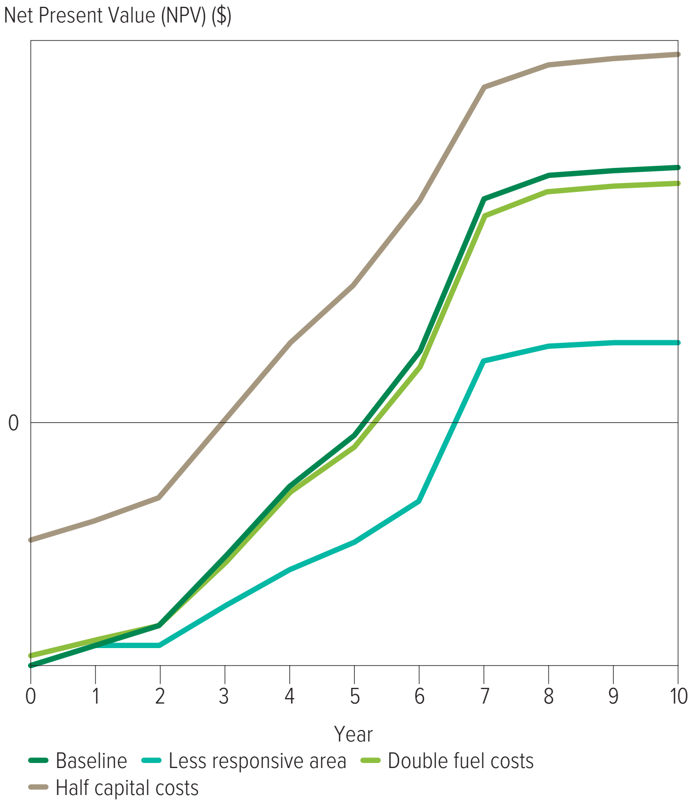
Benefits

The annual increase in crop value is calculated by multiplying the grain prices with the yield uplift resulting from deep ripping for each year. The yield values presented in Table 4.1 are derived from research trial results from an experiment conducted at Bute, SA from 2015 to 2021 (Ouzman et al., 2023). To calculate the discounted benefits, multiply the annual increase in crop value by the respective present value factors.

Rule for positive return project:
Net Present Value (NPV) > 0
Benefit–Cost Ratio (BCR) > 1

A sound investment project needs to consider time lags and apply the necessary discount rate, to account for the investor's cost of capital, opportunity cost and risk tolerance. The cumulative benefits should exceed the total costs by the end of the specified period and at a stipulated discount rate, typically denoted as NPV >0. In this example, a positive NPV of $1187/ha over seven years, calculated by subtracting the total discounted costs from the total discounted benefits, indicates a profitable outcome for the investment in deep ripping. Generally, a higher NPV suggests a more lucrative and financially viable deep ripping project.

Figure 4.4: Potential shape of the NPV curves at a whole-farm scale.



Note: Ripping took place annually in the first six years.

It is important to note that the Bute site example represents a best-case response, showcasing the upper range of gains. Our analysis of the 162 treatment site years, derived from on-farm sandy soil experiments in the southern cropping regions of Australia, indicates that the NPV of deep ripping varies between –$406/ha to $1187/ha. Additionally, there is a 95 per cent chance that a ripping depth of 50cm will yield an NPV above $150/ha within four years.

An alternative financial metric used to assess the economic feasibility of a deep ripping intervention is the Benefit–Cost Ratio (BCR). This ratio represents the present value of the total expected benefits of the ripping operation divided by the present value of its total expected costs. A BCR exceeding 1 implies that the ripping intervention is profitable, as the expected benefits surpass the expected costs. The BCR of 4.83 in this example tells us that for each $1 spent, $4.87 was generated. In general, a higher BCR corresponds to a more profitable ripping project.

There are multiple factors that can influence the NPV that should be considered before embarking on a deep ripping operation. Consider examining the potential implications of a reduced yield benefit compared to expectations due to factors such as unresponsive soils, fluctuations in fuel and capital expenses, and alterations in the total treated area. Figure 4.4 illustrates the possible contours of NPV curves on a whole-farm scale, taking these variables into account.

The shape of the potential NPV curves in Figure 4.4 is based on a whole-farm example with a total farm size of 1470ha and a cropping intensity of 96 per cent. The average growing season rainfall is 207mm. The deep ripping depth was 40cm, with a capital cost of $223,000 for the tractor and $80,000 for the ripper. The fuel cost is set at $50 per hour, and the total area deep-ripped is 125ha. The crops grown on this farm include wheat, barley and lentils. The typical yield on the farm is 3t/ha for wheat, 2.7t/ha for barley and 1.5t/ha for lentils.

Among the 125ha of treated area, 60 per cent is classified as Class A land, which provides the full response to deep ripping, while 30 per cent is Class B land with response at a 70 per cent relative rate. Additionally, there is 10 per cent Class C land, with no response to deep ripping. In this sensitivity analysis, we contrasted a less responsive area with 30 per cent of Class A and B land and 40 per cent of unresponsive Class C land.

For example reducing capital costs had a significant benefit for increasing the NPV, increasing fuel costs had a minimal effect and decreasing the responsive area had a significant negative effect.

Whole-farm factors to consider

- Treat the right area of your paddock at the right depth and right time (soil moisture conditions). Time of sowing and soil amelioration may also coincide.
- Work to minimise upfront capital costs considering outright machinery ownership, syndicated purchase, second-hand purchase or using contractors.
- If establishment risks can be managed, select crop rotations that offer faster returns based on grain prices but also likely to respond to deep ripping.
- Consider time management across the whole farm when undertaking a soil amelioration program so that business-critical tasks are not delayed (for example, ensure sowing time across the rest of the farm is not delayed by the amelioration program).
- Although good returns from ripping sandy soils are likely, crop establishment risks post-amelioration are real. Therefore, attention to improved management and technical solutions is needed to mitigate these risks.

Useful Resources

Soil Quality: 7 Soil Water Repellence ebook https://books.apple.com/au/book/soil-quality-7-soil-water-repellence/id1610874097

GRDC Update Paper (2022) – *Strategies to close the yield gap on three water repellent sandy soils in South Australia* grdc.com. au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/07/strategies-to-close-the-yield-gap-on-three-water-repellent-sandy-soils-in-south-australia

GRDC Update Paper (2022) – *Nutrition management on ameliorated sands* grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/08/nutrition-management-on-ameliorated-sands

Soil Quality: 6 Soil Compaction ebook https://books.apple.com/au/book/soil-quality-6-soil-compaction/id1581017530

Back pocket guide: *Soil and plant testing for profitable fertiliser use* (2022) grdc.com.au/soil-plant-testing

GRDC fact sheet: *Soil testing to determine fertiliser applications* (2021) grdc.com.au/soil-testing-to-determine-fertiliser-applications

GRDC fact sheet: *Soil testing for crop nutrition* (Southern Region) (2014) grdc.com.au/GRDC-FS-SoilTestingS

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GRDC Update Paper (2022) – *Ameliorating sandy soils to overcome soil constraints and improve profit* grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/07/ameliorating-sandy-soils-to-overcome-soil-constraints-and-improve-profit

GRDC Update Paper (2020) – *Deep ripping – where it will work (and where it won't)* grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2020/02/deep-ripping-where-it-will-work-and-where-it-wont

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Agriculture and Food WA: 'Soil inversion to ameliorate soil water repellence' agric.wa.gov.au/water-repellence/soil-inversion-ameliorate-soil-water-repellence

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