Sandy soil constraints in south east South Australia: a guide to their diagnosis and treatment

Mel Fraser, PIRSA
May 2020

Funded by: The South Australian Murray-Darling Basin Natural Resources Management Board and the South East Natural Resource Management Board through funding from the Australian Government's National Landcare Program.

Key messages:

- Most sandy soils have multiple constraints that vary with individual sand types and their location in the landscape.
- It is vital to look below the surface to diagnose the presence, extent and severity of different constraints.
- Treatment strategies should address the range of constraints present to get the best results.

Background

There are more than 2.2 M ha of sandy soils in the Murray Mallee and South East regions of South Australia that are prone to develop poor fertility. Despite improvements in crop management and agronomy, there is often a large gap between the potential grain yield that could be achieved, based on rainfall, and the actual yields of crops grown on sandy soils[1].

Underlying soil constraints that contribute to this 'yield gap' include physical and chemical impediments that are inherent (naturally derived) and may be outside a farmer's control for treatment, and others that are more dynamic, meaning they can change over time with different management practices[2].

The most common chemical and physical constraints encountered in sands throughout the Southern Mallee and Upper South East regions are:

- Water repellence
- Stratified and subsurface acidity
- Poor nutrient fertility and water holding capacity
- Compaction and hard setting

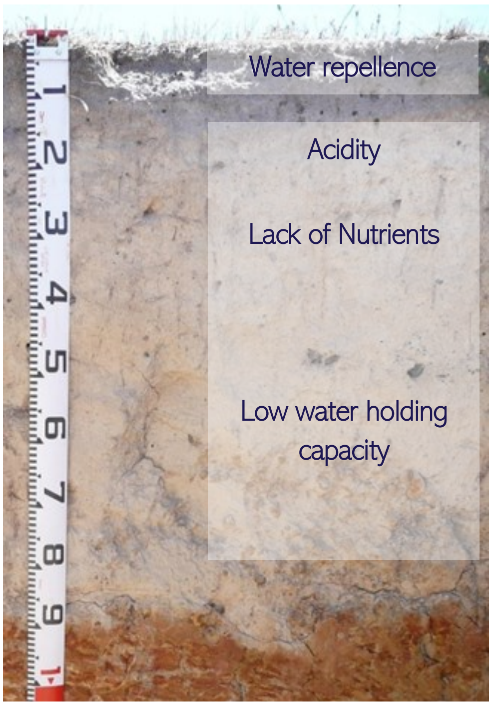

Figure 1. A sandy soil profile affected by four constraints that contribute to poor crop water use.

These constraints rarely occur in isolation (Figure 1) and together result in poor root growth and crop water-use, severely impacting grain yields. However, there are a range of emerging treatment strategies that can be

[1] Macdonald et al (2019). Underperforming sandy soils – targeting constraints for cost effective amelioration. GRDC Adelaide Update paper. Accessed here
[2] Fact sheet: Making sense of physical indicators. Accessed here

employed to combat these constraints, including low cost solutions that are applied annually, and higher intervention, higher cost strategies that result in longer lasting, or permanent, results.

Methods to diagnose these key constraints on-farm are presented here, along with assessment of the yield gap, and options for their treatment.

1. Diagnosing Sandy Soil Constraints

As the presence and extent of constraints varies across sandy dune swale landscapes, the aim of diagnosis is to identify:

- Where the different constraints exist in the paddock topography
    - How do the constraints differ between the dunes, mid-slope and flats?
- The depth of layers affected by different constraints
    - At what depths do different constraints start and stop?
- The severity of the constraint/s present
    - Is the constraint mild, moderate or severe?

To reliably achieve this aim, paddocks should first be separated into strategic diagnostic zones for soil assessments, otherwise important issues can be missed or diluted.

Tips to identify diagnostic zones for sampling:

- Aerial imagery (such as Google Earth) can provide an indication of soil type and topographical zones, providing a good base layer map to separate out dunes and swales (Figure 2a).
- Soil proximal sensors, such as electromagnetic induction (EMI), identify changes in soil properties (Figure 2b) and often show a strong correlation to crop and pasture production. At a cost of $15 to $20/ha, EMI maps are a worthy investment. They require thorough ground-truthing after collection to confirm the cause of variation (soil type, moisture content, salts).
- Plant production measures such as above ground green biomass as shown by normalised difference vegetation index (NDVI; Figure 2c) and grain yield maps can both identify the boundaries of different production zones. Maps derived in a legume phase (beans, lentils or chickpeas) are useful for detecting acidity issues, as these crops are particularly sensitive to low pH.

The number of diagnostic zones generated (usually 3 to 5) will depend on the variation within the paddock and its size; zones will typically separate the dunes, mid-slope and heavier flats. Once these maps have been created, field-based diagnosis of the soils' physical and chemical fertility can begin.

Tools to include in an on-farm diagnosis kit:

- Shovel, post hole digger or front end loader
- 3 x buckets
- Push probe or penetrometer
- pH indicator dye (e.g. Manutec)
- Camera and stop watch (telephone)
- Hand trowel
- Rain water
- Medicine/eye dropper (from the chemist)
- Zip-lock plastic bags and marker pen
- Tape measure or ruler

Figure 2a. Aerial photograph of a paddock with typical dune swale topography in south east South Australia[3].

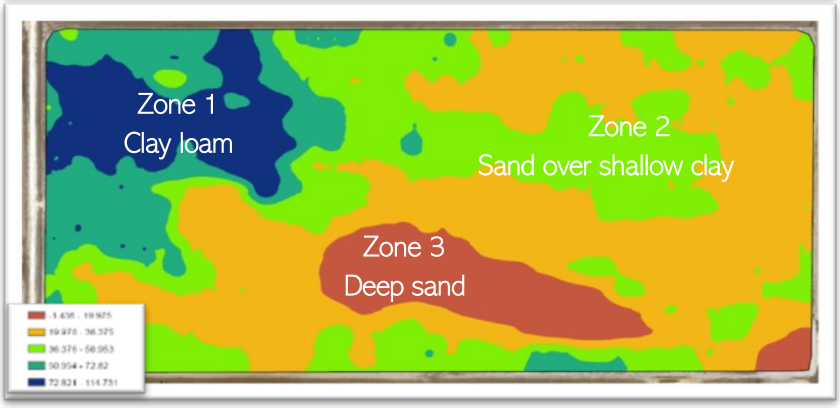

Figure 2b. Map showing differences in soil electrical conductivity, collected using an electromagnetic induction sensor (EM38); ground truthing showed three distinct soil types in the paddock, reflected by the conductivity zones.

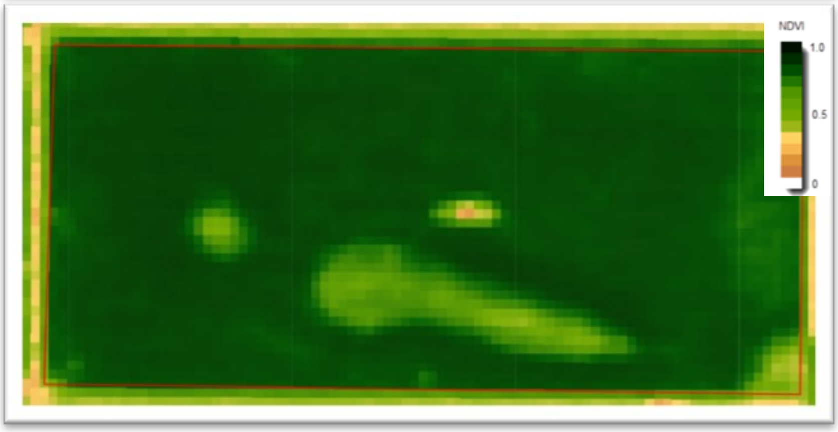

Figure 2c. Normalised difference vegetation index[4] (NDVI) of a winter cereal crop, showing lower above ground green biomass in October in Zone 3.

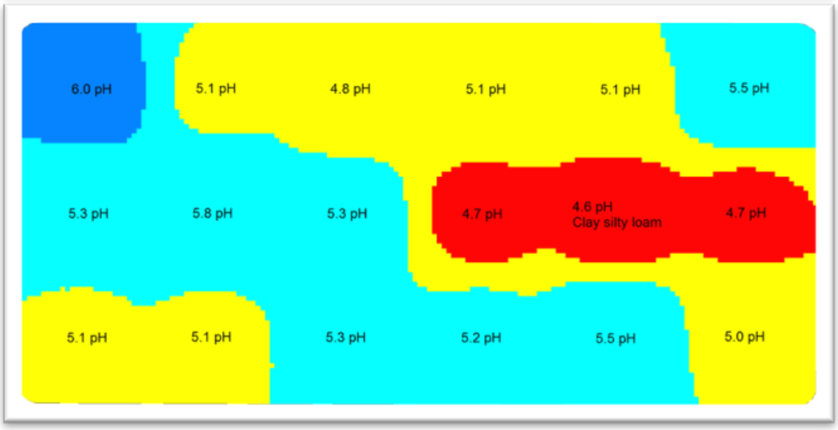

Figure 2d. Soil pH_{Ca} map, generated using a grid-sampling technique, whereby 8 samples are collected within each 2 ha grid, analysed and reported. Soil pH shows a correaltion with the soil types as identified by EM38 (2b).

[3]Accessed: https://www.ceresimaging.net/
[4]Accessed: https://irrisat-cloud.appspot.com/#

1.1 Water repellence

Water repellence is a common problem on sandy soils, with waxes from decayed organic material coating grains to make them hydrophobic, impeding water infiltration and affecting seedling germination early in the season. The presence and severity of water repellence can be determined annually by conducting a water droplet penetration test, which assesses the time it takes for (de-mineralised) water to infiltrate the soil (Figure 3). This test is best conducted in summer and autumn and must be conducted on dry soil. Sample from zones into which you intend to sow this year, either on-row, edge-row or mid-row.

Diagnosis

In paddock observations:

- Within each diagnostic zone, expose a level surface for testing by carefully scraping off the surface organic matter and 2-3 mm topsoil layer in an area free of standing stubble, weeds and plant roots. Using an eye dropper, carefully place 3 consistently large droplets of rain water on the surface (dropped from the same height; Figure 3), recording the time it takes to infiltrate; determine the degree of repellency (see Table 1). Consider repeating this at 20, 40, 60, 80 and 100 mm depths to gauge repellency through the sowing layer. Repeat in at least 2 other locations within each diagnostic zone to confirm.

Collecting samples:

- Scrape off the surface organic matter and 2-3 mm topsoil layer. Collect a sample from the top 50 mm and place in bucket #1. Collect a second sample from the 50-100 mm layer and place in bucket #2. Ensure samples are representative of the whole depth layer.
- Repeat in 3 to 5 sample locations within each zone, combining samples from each depth in the relevant bucket; mix well. Collect combined soil in labelled sample bags.
- Repeat for each diagnostic zone within the paddock.
- Spread and level a layer of each soil on a labelled plastic tray (takeaway or similar); place in a warm/sunny spot until fully dry. Assess the degree of repellency, following the water droplet penetration procedure as described above.

Table 1. Severity of water repellence as indicated by the water droplet penetration test[5].

Non-repellent	Water infiltrates dry soil in 5 seconds or less.
Mild	Water takes longer than 5 seconds, but less than 60 seconds to infiltrate.
Moderate	Water takes 60 to 240 seconds to infiltrate.
Severe	Water takes more than 4 minutes to infiltrate.

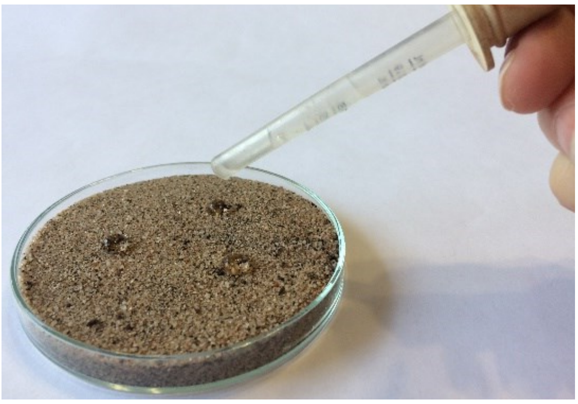

Figure 3. Soil is severely repellent if a droplet of water remains on the surface for longer than 4 minutes.

At the Lab: The Molarity of Ethanol Droplet (MED) test is used to objectively assess the severity of repellence. Follow the 'collecting samples' procedure described above and send to an accredited laboratory for MED analysis. An agronomist can assist with sample submission forms.

[5]Davies et al (2018). Soil water repellence – diagnosing the problem. Accessed here

1.2 Acidity

Acidity is a severe soil degradation problem that can greatly reduce the productive potential of crops and pastures by stunting root growth, limiting nutrient availability and releasing toxic amounts of aluminium into the soil solution. Under no-till cropping, stratified acid bands in the surface and subsurface layers are becoming increasingly common in soils that were previously thought to not be prone to the development of acidity.

Acidity is diagnosed with a pH test, which measures the amount of hydrogen ions in a 1:5 solution of soil to water (pH_W), or soil to calcium chloride (pH_{Ca}). As pH can be affected by soil moisture status and seasonal conditions, it is recommended to measure pH_{Ca}. This test is offered by all commercial laboratories and enables test results from different seasons to be more reliably compared. The pH_{Ca} is often 0.5 to 1 unit lower than pH_W. To achieve optimum plant growth, the soil pH_{Ca} should be maintained above 5.5 in the top 10 cm, and above 4.8 in the subsurface (below 10 cm).

As with water repellence and compaction, surface and subsurface acidity often isn't uniform across whole paddocks, but rather appears in certain soil types or positions in the landscape (see Figures 2a to 2d). Its presence is often masked by traditional 0 to 10 cm soil sampling, with an often alkaline 0 to 5 cm layer diluting acidic bands below, resulting in an overall pH value that doesn't cause alarm. Where stratification and/or subsurface acidity is present, strategic soil sampling methods are required to accurately detect pH variability and its severity in the profile.

pH indicator dye can be used to quickly and cheaply determine whether acidity is contributing to poor plant growth, but as the indicator solution can deteriorate over time and the observations are visual (subjective), care should be taken with interpreting results.

Diagnosis

- Within each diagnostic zone, dig 3 to 5 holes to 40 cm, creating a flat vertical soil profile face.
- Apply pH indicator liquid dye down the profile and then apply the powder and let the colour develop (Figure 4). Alternatively, you can use a Dig Stick soil probe (spurr probe) to remove an intact soil core and apply the same procedure to assess the change in pH.
- Once the colour reaction is complete, use the diagnostic colour card to determine the pH down the profile. Any acid layers will be visible as bright green or yellow colours. The pH measured with this dye is equivalent to pH_W, so the ideal pH is between 6 and 8 on the card (Table 2).
- Use a tape measure to identify the positions of any pH changes and take a photo, including the tape measure for future reference.

At the Lab: If acidic areas have been identified using pH indicator dye, additional soil sampling and more accurate laboratory pH measurement and other analyses are recommended:

- Within each diagnostic zone, collect 10 to 15 cores, combining the soil from each relevant layer depth in a clearly labelled bucket.
- Depending on the position of the acid layer in the profile, soil depths for sampling might include: 0-5, 5-10, 10-20 and possibly 20-30 cm. If acidity is more common in the 5-15 cm layer, then depths of 0-5, 5-15 and 15-25 cm are more appropriate.
- Thoroughly mix the samples for each layer depth for each zone and bag a sub-sample; send to an accredited laboratory for pH_{Ca} analysis, organic carbon % and a soil texture assessment (this information is needed to calculate a lime rate). Aluminium (measured in $CaCl_2$) is also warranted.

Table 2. Severity of acidity, as determined using a pH indicator kit, which is equivalent to the pH in water.

Rating	pH
Neutral	7
Mild	6.5
Moderate	6
Strong	5.5
Severe	5 and below

Alternatively, precision soil sampling approaches, such as grid-based (Figure 2d) or on-the-go Veris® pH mapping can provide more detailed data on the variability in surface pH and possible stratification. These maps can be used to generate variable rate lime prescriptions.

Figure 4. Example soil pit face with pH indicator dye applied. An alkaline surface layer can be seen (purple), overlying acidic soil (bright green) below 3 cm.

1.3 Nutrient status and soil texture

Nutrient deficiencies and subsoil toxicities are common in sandy soils and can change rapidly within paddocks. Monitoring soil nutrient fertility in the top 10 cm of soil provides an indication of whether nutrients and organic carbon are being maintained or mined in your system over time. All commercial accredited laboratories measure nitrogen, phosphorous, potassium, sulphur, exchangeable cations and organic carbon in their basic soil test suites. Soil texture determinations, such as particle size (% sand, silt and clay), provide an indication of the soils' ability to retain and supply soil water (water holding capacity).

Interpretation guidelines are usually included with soil test results but to derive the most benefit, recommendations should be tailored to the individual soil types within each diagnostic zone; an agronomist can assist with these interpretations. In-season tissue testing can also provide a useful indicator of nutrient availability to the plant, rather than total nutrient concentration in your soil.

Assessing the chemistry and texture in the subsoil is also warranted, particularly where clayey B horizons are present within the rooting zone, and also when considering deep ripping operations, so as to avoid disturbing areas where subsoil toxicities exist. The common subsoil constraints include extremes in pH (both acidity and alkalinity), salinity and elevated chloride, sodicity and toxic concentrations of boron. Various testing packages are offered at commercial laboratories to assess these constraints.

Diagnosis

- Collect soil samples from each diagnostic zone to assess soil nutrient status and soil texture; for crops and pastures collect samples from the 0 to 10 cm layer.
- Subsoils are commonly sampled in 10 to 30, 30 to 60 and 60 to 90 cm depth increments, however, horizon boundaries should not be crossed, so the increments selected should reflect soil horizon characteristics.
- A 'fit for purpose' guide to soil sampling can be found here, and tips for specifically diagnosing subsoil constraints can be found here.
- Precision approaches to soil fertility assessment can also be conducted using grid sampling methods.

1.4 Compaction and hard setting

Plant roots need to easily penetrate soil in order to rapidly grow. Their ability to do this is impeded when the soil is compacted (high bulk density caused by machinery compression or livestock trampling[6]) and/or when the soil strength is too high. Soil strength is a measure of the soil resistance to failure when a force is applied, and is very dependent on the clay and soil moisture content. Soil strength often increases as the profile dries, including in sands where oxides of iron and manganese are present, as these are prone to forming cemented layers (hard setting).

Diagnosis

Soil pit observations

- Hard and compacted layers can sometimes be visually observed in sands by digging a pit in each diagnostic zone and looking and feeling for changes in soil structure. Compacted layers or hardpans often have a distinct massive or blocky appearance when dry, and may have fractures through them where plant roots are preferentially growing.
- Crop vigour and the depth and pattern of root growth can also be useful indicators of physical issues; excavate the soil carefully under crop rows to explore the rooting pattern, including under wheel ruts.
- In late spring and summer, compacted layers may be wetter than the soil above it, indicating that plant roots have been unable to penetrate this layer to extract deep soil moisture reserves.

Soil strength

Simple assessments of soil strength can be made using a *Push Probe*:

- Make a push probe by fixing a handle onto a 600 mm long x 12 mm wide high carbon steel rod; sharpen the tip into a 20-22mm long, smooth cone and etch 100 mm depth increments along the shank of the probe.
- Insert the probe by hand into wet soil. Use the depth increments on the shank to help identify the depth where hard layers start and finish. Such a probe will require 12 kg of down pressure per MPa of soil strength. This means a very dense soil will require up to 40 kg of downward pressure when inserting the probe (equivalent to a soil strength of up to 3.5 MPa; Table 3).

More reliable and objective assessments of soil strength can be achieved using an instrumented *Cone Penetrometer* (Figure 5), which accurately measures the force required to insert a standard sized cone (12.83 mm) into the soil and is reported in either kiloPascals (KPa) or megaPascals (MPa)[6].

- Insert the penetrometer into the soil using steady pressure to achieve a constant speed of 3 cm per second. Note the change in penetration resistance (PR) for different depths in the soil. Repeat multiple times in the surrounding area to gauge the average PR and record the severity for each 10 cm layer (Table 3). Repeat in 3 to 5 locations in each diagnostic zone.

Tips for measurement:

- Push probes and penetrometers should be used when the soil profile is fully and uniformly wet to avoid misleading effects caused by lack of moisture alone; this is best achieved in mid-winter.
  - Download the Soil Water App to assess soil moisture conditions.
  - If the soil is dry, wet up an area in each diagnostic zone using a large bucket or tub with 2mm holes drilled in the bottom. Fix a porous cloth to the base (chux or similar) to assist even wetting across the surface area. Backfill around the outside edge of the bucket using soil to ensure downward infiltration, before filling with water and allowing to drain. The following day, carefully dig down to depth on one edge to confirm the profile wetting is deep enough and collect 3 to 5 penetration measurements on the wet-up area.

[6]Fact sheet: Subsurface Compaction. Accessed here

- Compare paddock readings to un-trafficked areas, such as along fence lines or in native vegetation.
- Avoid wheel tracks, headlands, gate ways and other high traffic areas; alternatively, measure these areas separately to gauge machinery impact on soil compaction.
- Penetrometers are unsuitable for use in soils with more than 10 to 15% gravel[7].

Table 3. Effect of penetration resistance on root growth[6 and 8]

Rating	Penetration Resistance (MPa)	Degree of consolidation	Effect on root growth
Nil	<0.50	Loose	Not affected.
Mild	0.50 – 1.50	Medium	Root growth on some cereal plants may be restricted.
Moderate	1.50 – 2.50	Dense	Compaction developing. Root growth on most plants starts to be restricted.
Strong	2.50 – 3.50	Very dense	Root growth restricted to existing pores and planes of weakness.
Severe	>3.50	Extremely dense	Significant compaction present. Root growth virtually ceases.

Figure 5. An example of an instrumented cone penetrometer, sourced here.

At the lab: Bulk density (BD) refers to the mass of soil in a given volume, commonly expressed in g/cm^3, and primarily affects the soils porosity and strength. BD measurements are useful for confirming compacted layers and are also needed for converting soil nutrient concentrations from mg/kg to kg/ha (e.g. nitrogen).

Bulk density is measured by collecting an intact soil sample using a steel ring of a known volume (Figure 6). The retained soil is dried in the oven at 105°C, weighed, and the BD calculated by dividing the dry soil weight by the total soil volume (a comprehensive method can be found here). Root growth is likely to be severely restricted when the BD >1.6 g/m^3 (Table 4).

Table 4. Bulk density severity rating[8].

Rating	Bulk density g/m3
Very low	<1.0
Low	1.0 – 1.3
Moderate	1.3 – 1.6
High	1.6 – 1.9

Figure 6. Use a steel ring to extract an intact soil core to determine the bulk density.

[7]Pluske W, Boggs G, Leopold M (2017). Soil Quality: 2 Integrated Soil Management. Soils West, Perth, Western Australia
[8]Hazelton and Murphy (2007). Interpreting soil test results: what do all the numbers mean? [2nd Edition]. CSIRO Publishing, Collingwood, Vic.

1.5 The Yield Gap

Once the combination and severity of constraints have been determined, the treatment options for their mitigation or amelioration can be considered. To aid these decisions, it is useful to know the yield gap, i.e. the grain yield you can potentially achieve for different crops in an average season, minus the grain yield currently attained. Estimates of the yield gap across sandy soils in the southern region vary from 1 to 3 t/ha where growing season rainfall is less than 300 mm[1]. It's also helpful to know how much of this gap can be made up by adopting different treatment options, both agronomically and through soil remediation.

The combination of knowing the *constraints + yield gap + likely yield response to interventions* can assist the selection of economically viable treatments, increasing the likelihood of achieving a sound and reliable return on treatment investment.

Diagnosis

To gain an understanding of the water limited yield potential for different crops in your region and for a range of seasons, visit Yield Gap Australia. For the Coorong district within the SA Mallee region, the reported yield gap for wheat, barley, canola and lupins is 2.9, 3.8, 1.2 and 2.0 t/ha respectively (Figure 7). Some of this gap can be attributed to agronomic inputs, disease, pests and frost, but research results show that substantial yield improvements can be obtained when underlying soil constraints are treated.

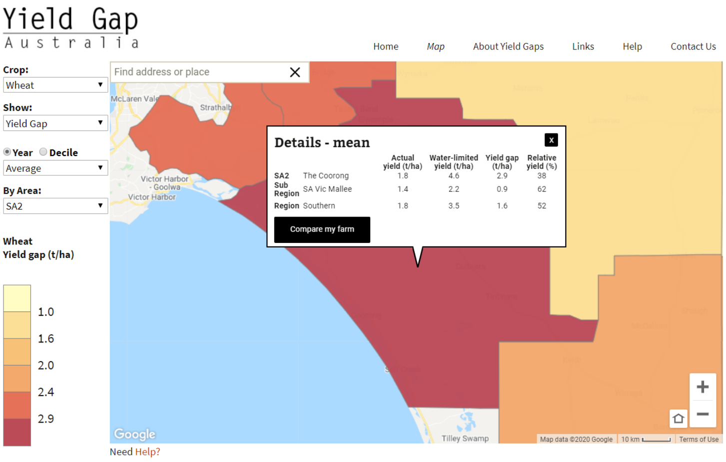

Figure 7. Example of a map from Yield Gap Australia that can help inform economic boundaries for treatment investment.

How much of the yield gap can be closed by overcoming constraints?

In 2016 the GRDC invested in a new research programme to assist grain growers in the southern region to identify and overcome the primary constraints to poor crop water-use on sandy soils in the low to medium rainfall environment. The Sandy Soil project[9] aims to quantify the likely yield gains that can be achieved in sands when their underlying constraints are addressed.

In 2018 a validation programme was also launched which aims to expand and test the results of the research programme at the paddock scale. Results from these trials are reported through relevant farming system groups, GRDC updates and conferences; links to some of these are reported throughout, and listed below.

Read the latest:

- 2019 results from the Victorian Mallee here
- 2019 results from the Upper South East here
- Results from the 5 year New Horizons trial at Brimpton Lake, EP here
- Summary of results across the Sandy Soils research programme here

[9]GRDC Project CSP00203: Increasing production on sandy soils in low and medium areas of the Southern Region. Delivered in collaboration by the CSIRO, University of South Australia, Primary Industries and Regions SA, Mallee Sustainable Farming, AgGrow Agronomy and Trengove Consulting.

2. Treating Sandy Soil Constraints

Opportunities to treat sandy soil constraints to increase crop production can broadly be categorised as:

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 soils inherent ability to hold more water.

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 (drained upper limit) and the amount the crop can extract (crop lower limit), thereby increasing the amount of water available to plants, lifting the yield potential.

Considerations when selecting a treatment option:

- What combination of constraints need to be overcome? Which is the most severe?
- What depths need to be targeted? Where do constraints start and stop?
- Would the soil benefit from mixing/inclusion of topsoil or an amendment?
- Is erosion a risk at the site?
- How much are you willing to invest ($/ha) to treat constraints?

The major constraints encountered on sandy soils in the Southern Mallee and Upper South East, along with a summary of the different treatment options available are presented in Table 5. More detailed explanations of the treatments, and considerations pre and post implementation, are discussed below.

Table 5. 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	×	✓	✓
Acidity	×	×	Lime Alkaline clay	With inclusion plates (IP)	✓	✓
Low nutrient fertility	×	✓	Fertiliser package, Organic amendment, Clay	IP	✓	×
Low water holding capacity	×	×	Clay	×	✓	×
Compaction and hard setting	×	×	Gypsum Organic amendment	✓	✓	✓

2.1 Water repellence

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 (avg. cost = $12 to $20 /ha).
- Sowing on top of (on-row) or alongside (edge-row) the previous year's crop stubble 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 top-soil into ridges on the inter-row and/or control the furrow backfilling process, keeping the water repellent surface layer out of the seed zone.
- Stable water harvesting press wheel furrows that enhance rain water capture within the seed row.

Figure 8. Soil moisture distribution after 50 mm 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 8-9 cm was uniformly wet. Photo: Jack Desbiolles.

If on-row/edge row sowing is not possible, and the profile is not uniformly wetted (Figure 8), 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.

Amelioration strategies that reduce or eliminate repellence:

- Strategic deep tillage that mixes or inverts to bury and/or dilute the surface layer of repellent soil: inversion plough, spader or offset discs (see section on compaction and hard setting below).
- Clay spreading can provide a permanent solution by coating coarse sand grains with a fine layer of clay.

Learn more about managing water repellence here and here and read the latest research results here

2.2 Acidity

Acidic soils must be limed– lime it or lose it! Lime treats acidity by neutralising the acid reaction in soils. The carbonate component of lime consumes hydrogen ions in the soil solution and in doing so raises the pH.

- Liming is the only cost-effective way to manage acidity and is best applied to ***prevent*** acidification in the first instance.
- Soil texture, rates of nitrogen fertilisation, rate of product removal, rate of lime applied and desired pH all affect re-liming frequency.
- Lime can come from a variety of sources with different qualities and effectiveness; application rates need to be adjusted to reflect lime quality. If soil magnesium levels are low, consider using dolomitic lime instead.

Mitigation:

- Lime is usually broadcast on the soil surface in summer and autumn. It should be applied at rates to keep the surface pH_{Ca} above 5.5. Calculators can be sourced by contacting brian.hughes@sa.gov.au to calculate lime requirements and costs.
- Clay application and incorporation can help to overcome acidity, providing the clayey material applied is neutral to alkaline (pH_{Ca} >6.5).

Amelioration:

- Lime moves very slowly in soils, about 1 cm a year in most conditions, so incorporation counts when treating subsurface acidity issues. Incorporating lime can speed up the reaction time, and also help to mix and dilute stratified layers. See the section on compaction and hard setting for suitable incorporation methods. Re-application of lime every 3 to 5 years may be required to prevent re-acidification.

Read more about the cause and treatment of surface and subsurface acidity here

Learn more about incorporating lime to address subsurface acidity here

2.3 Nutrient fertility

Mitigation:

- Correct nutrient deficiencies by applying a complete package of specific fertilisers at sowing and in-crop, based on the results from soil tests within each diagnostic zone. An agronomist or consultant can assist with result interpretation and fertiliser formulation to correct deficiencies and meet crop needs.

Amelioration:

- Clay application and deep incorporation can improve plant nutrition, particularly supplying potassium, which is often deficient in sands.
- Incorporating granular or fluid fertilisers via ripping with inclusion plates or rotary spading can help to boost subsoil fertility and provide similar responses to comparable organic amendments.
- Incorporate organic amendments such as legume based hay or pellets, chicken manure, compost or prilled materials to boost organic carbon and supply additional nutrients (primarily nitrogen); expect responses to persist for multiple years.

Read more about long term yield responses on ameliorated sands here

2.4 Water holding capacity

Water holding capacity is the maximum amount of water a soil can hold (known as field capacity). Determined primarily by the soil texture, structure and porosity, sandy soils naturally tend to have a low water holding capacity, typically in the range of 6 to 10 mm for each 10 cm layer[8].

Amelioration:

- Apply and incorporate clay to increase water entry and retention.
- To learn more about clay application methods, rates and incorporation, access this resource:

Spread, delve, spade, invert: a best practice guide to the addition of clay to sandy soils.

MFMG

2.5 Compaction and hard setting

Sandy soils don't have the capacity to shrink and swell, hence, they have limited ability for natural repair once compacted and therefore often benefit from being physically disturbed via deep tillage. Strategic deep tillage can be used to alleviate multiple soil constraints as summarised in Tables 5 and 6; deep ripping, rotary spading and one-way disc ploughs are rising in popularity in SA to treat multiple constraints so some detail on these implements is provided below.

Table 6. Examples of strategic deep tillage approaches, working depth, incorporation characteristics and approximate cost (adapted from Davies et al, 2019[10]; n.m. = not measured).

Strategic deep tillage method		Implement working depth (m)	Implement impact on incorporation of soil amendment and/or topsoil	% topsoil buried below 0.1 m	Approx. cost ($/ha)
Ripping	Ripping only	0.3-0.7	Minimal incorporation, depending on ripper type. Backfill to 0.15 m.	5-10	$50-100
Ripping	With topsoil slotting (inclusion plate)	0.3-0.7	Topsoil slots from surface typically to depths of 0.35-0.40 m, but ripping depths can extend to 0.70 m. Can partially incorporate surface spread amendments (e.g. lime, nutrients, organic matter).	10-15	$55-120
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 0.15-0.25 m depth.	n.m.	$50-70
Mixing	One pass tillage - tine	0.3-0.35	Mixing of topsoil and surface spread amendments to 0.15 m and some deeper inclusion to 0.30 m possible depending on tine design.	n.m.	$70-100
Mixing	Rotary spader	0.30-0.4	Mixes to maximum working depth of 0.35-40 m. 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	$150-180
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 0.25-0.35 m. Burial quality varies with speed.	60	$40-60

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[11]. It's 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.

[10]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). Accessed here
[11]GRDC Paddock Practices (2019). Key considerations before deep ripping sandy soils. Accessed here

Key considerations when selecting a deep ripper:

- Ripping depth required
- Tractor power available
- Tine type and tine spacing adjustment (Figure 9 a-c)
- Can the ripper be fitted with inclusion plates if necessary?
    - Should an amendment be pre-applied to the surface?

Inclusion plates can be fitted to ripping tines (Figure 9a) 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 draft/power needed to pull a ripper[11], 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 plate has a significant impact on inclusion quality[12].

Figure 9a. Example of straight shank tines (AgrowPlow AP51 Ripper) with inclusion plates fitted.

Figure 9b. Grizzly Deep Digger with parabolic tines.

Figure 9c. Williamson-Agri CT ripper with low disturbance *Michel* tine (curved sideways).

Read more about the key things to consider before deep ripping sands, ripper selection and set up here

Learn more about the UniSA Agricultural Engineering group, options for managing constraints and inclusion plate design here and here

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. They are also very efficient at treating compaction throughout their working depth (between 200 and 400 mm).

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

Figure 10b. Press wheels on the back of the spader help to firm the surface and reduce wind erosion risk.

Figure 10c. Topsoil incorporation can be seen here in a pocket, which is common when spading at higher speed.

[12]Ucgul M, Desbiolles J and Saunders C (2019). Science of deep ripping. Ingrain Magazine, accessed here

Spaders typically mix topsoil in the 0 to 30 cm depth, while also bringing some subsoil to the surface, therefore incorporation is not 100%, with material tending to be buried in pockets[10] (Figure 10c). Rotary spaders can work between 3 and 7 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 11a) increased break-out pressure on the jump arms and often involve adding more weight to the plough, depending on the model used[10]. These modifications allow deeper working depth, 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.

Figure 11a. John Shearer one-way 5GP plough, modified to fit Plozza discs.

Figure 11b. A typical soil profile following inversion using Plozza Plow discs.

2.6 Management and agronomy post-amelioration

There are several soil and crop management factors that need to be taken into consideration after ameliorating sandy soils, particularly where strategic deep tillage has been used. These should be worked through before embarking on an extensive amelioration programme.

Increased erosion risk: Strategic deep tillage will loosen and soften the soil profile. Much of any standing stubble is likely to be flattened, become unanchored or be incorporated. The reduction in soil cover, coupled with the loosened surface, will leave tilled areas more vulnerable to wind erosion. Flat drum or crumble rollers fitted/towed behind implements can help to consolidate the soil surface in preparation for sowing, but the surface may still be vulnerable to drift if dry conditions persist[11].

Decreased traffic-ability: Loosening of soil to depth, and roughening of the soil surface may decrease traffic-ability after amelioration, particularly where deep ripping has been employed. One way of avoiding this issue is with controlled traffic; the permanent wheel tracks are not ripped, allowing heavy vehicles to travel across ripped areas without any impediment[11]. Alternatively, orienting rip-lines at an angle to sprayer tracks and seeding directions can also improve traffic-ability. Regardless of the tillage type, adopting controlled traffic is recommended post-amelioration to reduce the likelihood of re-compacting the soil, extending the longevity of the treatment response.

Seedbed finish: is important for workability and good crop establishment. When ripping, excessive clod size can be managed either by delaying operations until the soil moisture improves, using a gradual ripping approach over two passes or by pre-rip cultivation, or by considering dual depth ripper designs and/or optional clod-breaker attachments[11].

For soils that have been mixed or inverted, very soft seedbed conditions often prevail, so careful consideration should be given to travel speed, seeder working depth and press wheel pressure settings to ensure optimum seed placement and to minimise soil throw and furrow infill at sowing.

Learn more about crop establishment following amelioration here

Higher crop potential: A successful amelioration operation should increase the yield potential of crops and pastures for several years. It is important to adjust crop nutrient inputs to meet the new yield potential to ensure optimum grain yields and quality are achieved[11], without soil nutrient reserves being mined to deficiency.

The following people are thanked for their contribution and review of this document:

Dr Jack Desbiolles, University of South Australia, Mawson Lakes.
Dr Nigel Wilhelm, South Australian Research and Development Institute, PIRSA, Urrbrae.
Brian Hughes, Rural Solutions SA, PIRSA, Nuriootpa.
Meg Bell, MacKillop Farm Management Group
E: ceo@mackillopgroup.com.au

Contact:

Dr Melissa Fraser

Rural Solutions SA, PIRSA
74 Struan House Road
Via Naracoorte, SA

E: Melissa.fraser@sa.gov.au

M: 0427 084 569

Australian Government | National Landcare Program | MFMG
Government of South Australia | Natural Resources SA Murray-Darling Basin | Natural Resources South East

This project is supported by the South Australian Murray-Darling Basin Natural Resources Management Board and the South East Natural Resources Management Board through funding from the Australian Government's National Landcare Program and NRM levies.