Diagnosing constraints is key to cost effective amelioration: Do responses in NSW sands differ from the broader Southern sandy context?

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Key words

soil constraints, compaction, ripping, chicken litter, crop water use

GRDC code

CSP00203

Take home message

- Amelioration of sandy soils has gained momentum across the Southern regions, but it can be difficult to know which sandy environments will respond and which represent higher risk for return on investment.
- While many ripping trials shown multiple years benefit (ranging 0.2 t/ha to 1.2t/ha), nil responses and yield penalties are evident in some environments, including the south western NSW region.
- In contrast to other trials within the Sandy Soils program, the Yenda site has not responded to physical amelioration but has consistently responded to higher nutrition treatments including urea and chicken litter.
- Before committing to a deep amelioration plan it is useful to consider:
  a) what yield gains may be possible through improved nutrition or optimised agronomy.
  b) which soil constraints are (or are not) present and where they are in the profile.
  c) what machinery and or amendments are most suitable for improving the soil condition.

Background

Soil amelioration practices have been gaining momentum across Australian cropping landscapes in recent years. These practices typically involve a range of strategic deep tillage with/without the use of soil amendments. They aim to overcome soil constraints such as compaction, acidity, nutrient stratification, subsoil sodicity/toxicity, and in some soils water repellence.

Soil amelioration offers opportunity to improve yields where the condition of the soil limits root exploration and consequently water and nutrient use. Up-front costs of amelioration range from around $60/ ha for simple ripping (~30 cm), to several hundred dollars per ha for more intensive mixing practices or amendment incorporation. Machinery choice, soil type/condition, depth of operation, and work rate all have an impact on altering soil condition and on the implementation costs. In the low-medium rainfall environment return on investment (ROI) is not always guaranteed.

The GRDC Sandy Soils Initiative (CSP00203) aims to improve our understanding where and when amelioration of deep sandy soils is likely to achieve cost effective gains in the low-medium rainfall Southern region. The core underlying framework within the research program is to:

i) understand the yield gap across the southern sandy environment. The yield gap is useful in guiding expectations around potential yield gains.

ii) identify and prioritise the primary soil constraints in sandy soils across the Southern region that commonly limit early vigour and deep rooting capacity.

iii) target and optimise amelioration approaches by understanding the impact and effect longevity that machinery and/or amendment types have on the underlying soil condition and associated improvements in crop water use.

This paper summarises research findings relevant to this framework, highlighting the responses to physical amelioration in sandy soils across the Southern region. Additional details are provided on the NSW case study based at Yenda and established in 2017. This site, with physical, nutritional, and subsurface acidity constraints has four years of monitoring crop responses to physical amelioration (sweep tine, ripping) with/without amendments (chicken litter, higher urea, or lime).

It is important to note that responses to amelioration vary depending on the yield potential, on soil type, and the combination of constraints that are limiting crop water use. There are several GRDC investments targeting amelioration of other soil types relevant to the south western NSW region. These include ameliorating dense clay subsoils (GRDC DAV000149) and managing subsoil acidity (GRDC DAN00206). Focusing on findings from within the Sandy Soils initiative, these broader soil types are outside the scope of this paper.

Trial site overview

Research (10) and validation (18) sites were established between 2014 and 2020 on sandy soils across the low-medium rainfall zone of the Southern cropping region. Sites collated for this paper (Table 1) include those with physical, nutritional and chemical constraints, but do not include sites with water repellence (see Macdonald *et al.* 2021). An overview presented in this paper focuses on crop response to deep tillage practices (ripping, spading) alone.

Further to this amelioration treatments across trial sites have included a range of deep ripping and/or ploughing approaches, with/without additional amendments (fertiliser, N-rich hay, chicken manure, clay). The Yenda site is fully described in Haskins *et al.* (2018) and is characterised by a physically hostile sub-surface layer (high soil strength at ~15 cm) that co-occurs with acidity (pH 4.7). These treatments include: best practice (BP), single application urea (291 kg/ha), or chicken litter (3t/ha, IBS) in unmodified soil; and, sweep cultivated (30cm) practices including best practice, BP+lime, and single application chicken litter (3, 6, 9 t/ha); and an annual 3t/ha chicken litter, where the first year had sweep cultivation. Single application treatments, and deep cultivation events were applied in the year of establishment only (2017). The amount of N applied in the urea treatments and the 3t/ha chicken litter treatments was approximately equal (134 kg N/ha).

Ripping deep sands with physical constraints - shattering to maximise root exploration

Yield responses to ripping across seven research trials (2017-2020) and two validation trials with physical constraints are summarised in Figure 1. Except for one non-responsive site, all sites demonstrated a positive response to ripping in the first year (Figure 1b). Yield gains ranged from 0.2t/ha to 1.2t/ha, with an average gain of 0.6t/ha. The non-responsive example, Yenda NSW, has had unfavourable seasonal conditions including severe frost (2017), and consecutive drought years (2018, 2019), and is the only site that has subsoil acidity.

Trial site responses in years after the ripping treatments demonstrate an average yield gain of 0.3t/ha, but also include a higher incidence of yield penalties of up to -0.6t/ha (Figure 1). All observed yield penalties relate to the 2019 season and represent a consecutive year of dry seasonal conditions. Positive responses in the more favourable 2020 season show benefits ranging between 0.3t/ha and 0.9t/ha, including sites that suffered penalties in 2019.

Table 1. Summary of research sites targeting physical and nutritional constraints, including the long-term average annual and growing season rainfall (mm), an indication of the target soil constraints. Amelioration treatments reported within include deep ripping (30 - 60 cm), *sweep cultivation (30 cm) aiming to overcome physical constraints through shattering.

Research Site_Yr Established	Avg. Ann Rain	GS Rain	Topsoil Repellence	Severe (>2.5MPa) soil strength	Surface^ OC	Surface^ Colwell P	Surface^ pH	Surface^ ECEC
	mm	mm	MED	cm	%	mg/kg	H_2O	cmol+/kg
Bute_B_18	394	298	0	25-35	0.5	26	8.8	2.9
Lowaldie_19 (2)	339	235	0	30-70	0.4	17	7.5	2.4
Ouyen_17 (2)	333	213	0	15-65	0.4	12	6.6	2.4
Carwarp_18	286	174	0	15-45	0.3	13	6.3	2.1
Waikerie_18	245	157	0	15-55	0.5	11	8.1	5.0
Yenda_17 *	295	252	0	15-48	0.2	39	5.8	2.6
Bute_15	394	298	1.9 (mild)	20-70	0.5	48	5.9	2.8

^Surface is 0-10cm depth; Validation sites: Similar amelioration treatments have been implemented targeting physical and nutritional constraints in sites (six sites) that do not suffer water repellence. This includes Monia Gap in NSW.

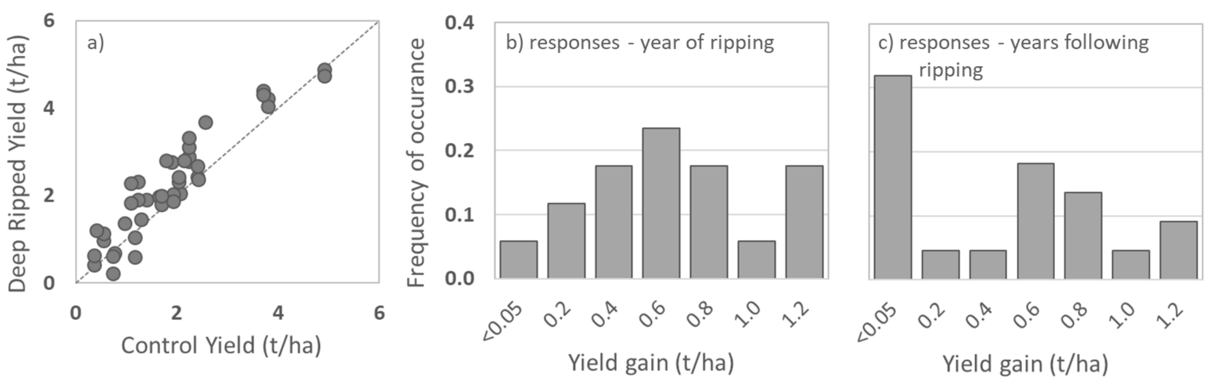

Figure 1. Annual crop yield (t/ha) responses to deep ripping in sands where physical issues are considered dominant including a biplot of unmodified control yields Vs deep ripped yields (a); frequency distributions of yield gains (ripped yield – control yield) in the year of ripping (b) and distribution of yield gains in subsequent years following ripping (c). Data represent treatment averages across seven CSP00203 research trials (multiple years, n=4) and two validation trials (single year, n=3) with a total of 40 response years.

Cumulative yield responses across seven multi-year research trials are summarised in Figure 2. Three sites (Bute'15, Lowaldie, and Ouyen) demonstrated cumulative gains (2+ t/ha) over multiple seasons, and three sites had seasonally variable responses leading to little cumulative benefit after 3 years (Bute'18, Carwarp, Waikerie). Early economic estimates reflect the variability in site and seasonal responses demonstrated across the region. Large net present value (NPV) of between $221-$746 can be achieved at sites with multiple season responses (Bute'15, Lowaldie, Ouyen). Seasonal response variability can limit economic return in marginal environments, where small positive first year (decile

1, 2018) responses are negated by second year (decile 1, 2019) penalties (e.g. Waikerie and Carwarp). These seasonally driven risk penalties were larger in deeper ripped treatments, suggesting that profile re-charge may have been inadequate in this drought period. These sites will require positive responses in the 4th year (2021) to achieve an overall positive return on investment. Variability in the response highlights the importance of understanding where responses might be influenced by seasonal risks and where soil constraints have not been adequately ameliorated for long-term effect.

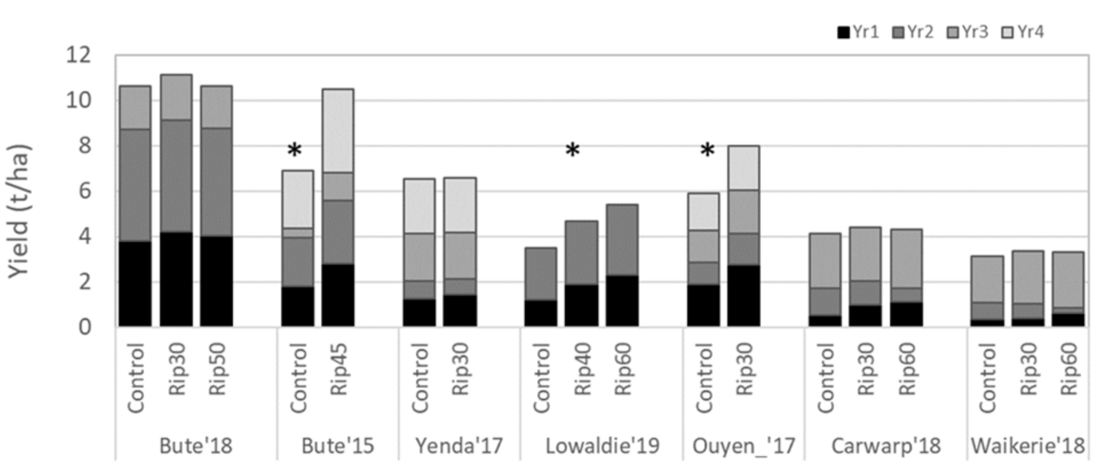

Figure 2. Cumulative yield responses (t/ha) across seven research sites (site & year of establishment) in unmodified (control) and ripped treatments (rip depth cm). Data are averages of four field replicates, with * indicating which sites had significant (P<0.05) cumulative differences. All sites have inherently low fertility and physical constraints.

Responses to high nutrient amendment or lime amendment at Yenda NSW:

The Yenda trial site is characterised by a physically hostile sub-surface layer (~15 cm) that co-occurs with acidity. Yenda remained unresponsive to physical amelioration alone (ripping, sweep cultivation) across four seasons (Figure 2). Although there was a lack of yield response to the physical treatments alone (sweep-tine, deep ripping), there is evidence of lasting impact on soil strength (Figure 3). Soil strength was evaluated on a moist profile after rain in March 2020, three years after implementation of amelioration treatments. The unmodified control soils show root limiting values of soil strength (>2kPa) within 10 cm of the surface, and severe root restriction (> 3.5 kPa) extending between 17and 35 cm depth. Profile loosening was still evident to about 20 cm for the sweep tine treatments, and to about 30 cm for the deep ripped treatments. These data suggest that although physical constraints are severe in these soils, other soil or environmental constraints continue to limit productivity.

Despite a nil response to sweep cultivation or ripping, the broader Yenda trial demonstrates growth responses to high nutrient treatments (Figure 4a). The four-year cumulative yield gain across the three best performing treatments (6t/ha, 9t/ha, or 3x 3t/ha) was 2.3 t/ha (±0.17) above the unmodified control (6.5 t/ha total). Except for 2018 (lupins), these treatments provided relatively consistent gains (0.68-0.85 t/ha) across the three seasons (wheat), despite frost (2017) and limited seasonal rainfall. Profile soil analysis indicates that the mineral N profile in these treatments remains elevated and further work aims to estimate the associated N budget and input use efficiencies. The observed responses to high nutrient inputs are generally consistent with wider trial results, where response to chicken litter appears to be more consistent than fertilisers (Figure 4b).

In contrast to the wider Sandy Soils project trial set, subsurface acidity (pH 4.7) was identified as a target constraint, with experimental treatments including surface application of lime prior to sweep tine incorporation. A surface lime treatment was not included, as it is known that surface application of lime if often ineffective in correcting subsoil acidity in low rainfall environments due to slow downward migration of alkalinity. The four-year cumulative gain from lime incorporation was small (0.5 t/ha) and suffered higher variability compared to other treatments. Although the sweep cultivation operated to 30 cm, there was little evidence that the lime was incorporated to this depth, and soil pH changes were limited to the top 10 cm. This is further supported by computer simulation modelling, where findings indicate a limited mixing capacity of the sweep tine compared to other deep plough methods such as spading (Figure 5). Further research has been conducted at site near Bute (Yorke Peninsula) to evaluate the impact of mixing performance on crop responses to lime application in an acidic sand (Ucgul *et al.* 2020).

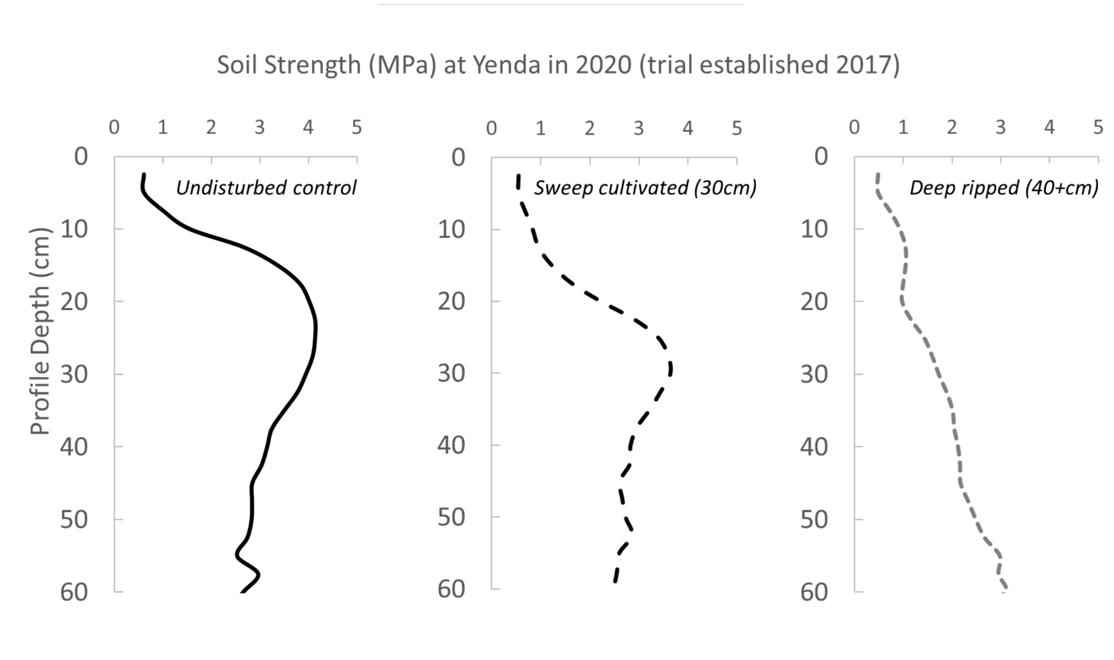

Figure 3. Soil strength (MPa, penetrometer) at the Yenda trial site in the undisturbed control, sweep cultivated, and deep ripped treatments. Soil strength > 2.5 MPa is considered limiting to root growth and occurring from 12 cm depth of the control profile at this site.

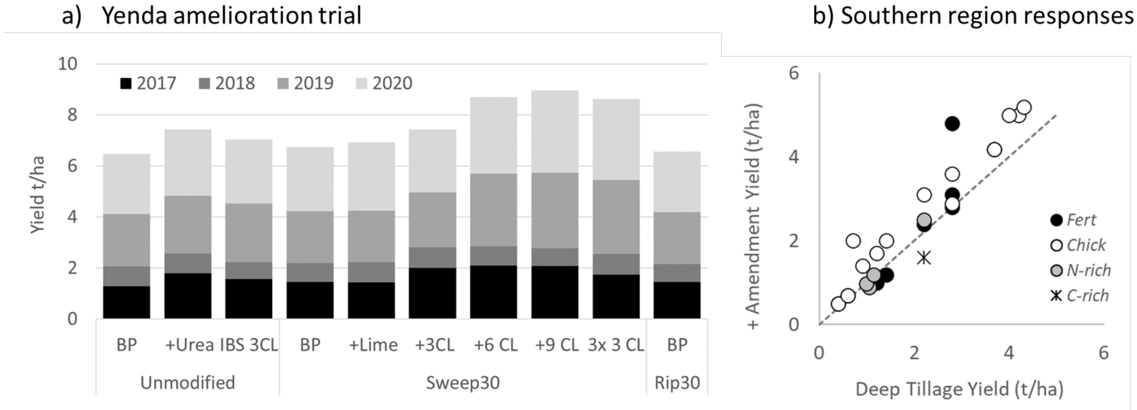

Figure 4. a) cumulative year yield response to amelioration treatments at Yenda, where treatments include: unmodified best practice (BP), +urea, and 3 t/ha surface applied chicken litter (IBS 3 CL); sweep cultivated (30 cm) best practice (BP), +lime (3t/ha), plus 3, 6, or 9 t/ha chicken litter in year of establishment (2017), plus 3 t/ha chicken litter annually; and deep ripped (40cm). Data are averages of 4 replicates, with the cumulative standard error included. The rotation was wheat-lupin-wheat-wheat; b) single season yield comparisons between deep tillage yields (X-axis) and deep tillage + amendments (y-axis) across CSP00203 research trials; amendments include high rate fertiliser, chicken litter, legume hay (N-rich) or oaten-hay (C-rich); data are averages of 4 replicates.

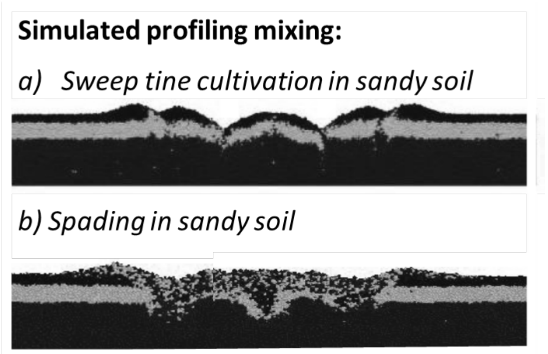

Figure 5. Shows the difference in surface mixing between sweep tine and spading in sandy soils.

Conclusion

Amelioration of sandy soils has gained momentum across the Southern regions, but it can be difficult to know which sandy environments will respond and which represent higher risk for return on investment. While many ripping trials have shown multiple years benefit ranging from 0.2 t/ha to 1.2t/ha, nil responses and yield penalties are evident in some environments, including the south western NSW region. In contrast to other trials within the Sandy Soils program, the Yenda site has not responded to physical amelioration but has consistently responded to higher nutrition treatments including urea and chicken litter. Before committing to a deep amelioration plan it is useful to consider: a) what yield gains may be possible through improved nutrition or optimised agronomy; b) which soil constraints are (or are not) present and where they are in the profile; c) what machinery and or amendments are most suitable in improving the soil condition.

Acknowledgements

This GRDC funded research (CSP00203) represents a collaboration between the CSIRO, the University of South Australia, the SA Government Department of Primary Industries and Regions SA, Mallee Sustainable Farming Inc., Frontier Farming Systems, Trengove Consulting, AgGrow Agronomy, AIREP, and MacKillop Farm Management Group. The research has been significantly enriched by valuable discussions with growers and consultants across the region.

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