Targeted amelioration of constraints in deep sands to maximise crop water use

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Abstract
Amelioration of sands has gained momentum in overcoming physical constraints, water repellence, and inherently low fertility in the Southern cropping regions of Australia. This paper collates findings across 13 experiments with physical constraints and 10 experiments with water repellency combined with physical constraints. The research highlights opportunities for soil amelioration to close yield gaps and provide significant ongoing yield benefits, but reveals risks associated with yield losses in very low rainfall scenarios. Across experiments which targeted physical constraints, all sites without significant repellence or subsoil toxicities demonstrated positive first-year yield responses to deep ripping ranging from 0.2 t/ha to 1.2 t/ha. On average the yield gains were 0.6 t/ha and represented a significant closing of the yield gaps in many environments. While most experiments demonstrated multiple years benefit from ripping, yield penalties were evident following consecutive drought years (2018, 2019), with poor season penalty risks in deeper ripped soils (60 cm vs 40 cm). Across experiments with water repellence and where subsoil toxicities are not present, spading treatments had an average annual yield response of +0.8 t/ha. Although spading is often more effective in highly repellent sands, inclusion-ripping has shown benefits that persist over multiple years. Understanding the key constraint and the soil and seasonal risks associated with amelioration techniques are critical to success with these techniques.

Keywords
Ripping, spading, ploughing, soil compaction, water repellence, yield gap

Introduction
Water-use and yields on sandy soils are commonly limited by a range of soil constraints that reduce root growth. Constraints can include a non-wetting topsoil-layer causing poor crop establishment, soil pH (both acidity and alkalinity), poor nutrient supply or compaction. Uptake of amelioration practices to improve productivity in sandy soils has gained strong momentum in recent years (Hall et al. 2020, Unkovich et al. 2020, Davies et al. 2019, Macdonald et al. 2019). These practices include deep ripping which aims to shatter hard/compacted layers, and deep ploughing and spading which aims to mix and dilute repellent or hostile layers, and/or incorporate topsoil into bleached layers. Measurements of key soil properties and resulting crop responses to amelioration are presented to demonstrate how soil modification can increase access to water. This research aims to (i) improve the diagnosis and management of primary soil constraints across deep sandy soils in the Southern low-medium rainfall environment and (ii) to define which sandy environments and amelioration treatments are more likely to provide reliable increase in crop water use, resulting in yield benefits.

Methods

A range of research experiments have been established across the low to medium rainfall sandy soil environments of South Australia, Victoria and southern New South Wales (Table 1). Sites (Table 1) are categorised according to the primary soil constraints identified and the amelioration techniques tested. Research experiments were established between 2014 and 2019 at two levels of intensity. In Table 1, there are the intensely managed sites where full characterisation is available (characterised according to methodology outlined in Rayment and Lyons (2011)), while yield data was collected at the 11 low intensity sites. Rainfall was measured on site or obtained from the nearest BOM station. Treatments included a range of deep ripping and/or ploughing, with/without additional amendments (fertiliser, N-rich hay, chicken manure, clay). This paper discusses findings relating to deep tillage practices (ripping, spading) alone, without including responses to incorporation of amendments. All treatments were replicated four times in a randomised complete block design. All plots were managed with inputs considered at the top level of local practice so control plots represent current best management practice.

Table 1. Summary of sites targeting a range of different constraints including the long-term average annual and growing season rainfall (mm), an indication of the target soil constraints.

Research Site_Yr Established	Avg. Ann Rain mm	GS Rain mm	Topsoil Repellence MED	Severe (>2.5MPa) soil strength cm	Surface* OC %	Surface Colwell P mg/kg	Surface pH H_2O	Surface EC cmol+/kg
Physical constraints and low inherent nutrition (deep ripping at 30-60cm)								
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
Water repellency, physical constraints and low inherent nutrition (spading, ripping and inclusion ripping)								
Bute_15	394	298	1.9	20-70	0.5	48	5.9	2.8
Murlong_2018	335	251	2.3	**	0.7	17	7.1	4.3
Karoonda_2014	339	235	2.2	10-40	0.4	21	6.8	2.4
Brimpton Lake_2014	398	377	2.3	**	0.6	24	6.0	2.1

*Surface is 0-10cm depth #Not analysed

Results and Discussion

Ripping deep sands with physical constraints - shattering to maximise root exploration and crop water use

Yield responses are summarised in Figure 1 with all sites having a positive response to ripping in the first year (Figure 1b). Yield gains ranged from 0.2 t/ha to 1.2 t/ha, with an average gain of 0.6 t/ha. Subsequent year responses to ripping had an average yield gain of 0.3 t/ha but also include a higher incidence of yield effects of up to -0.6 t/ha. Yield penalties were only observed in 2019, following a very dry 2018 (<100 mm growing season rainfall) and penalties were larger in deeper ripped treatments (60 cm compared to 30 cm) despite physical constraints extending beyond 30 cm depth. Ripping responses in the higher GSR of 2020 had benefits of 0.3-0.9 t/ha at responsive sites. The figure (1c) showing residual responses to ripping will adjust as the experiments progress given most experiments presented will generate a further 2-3 years of data.

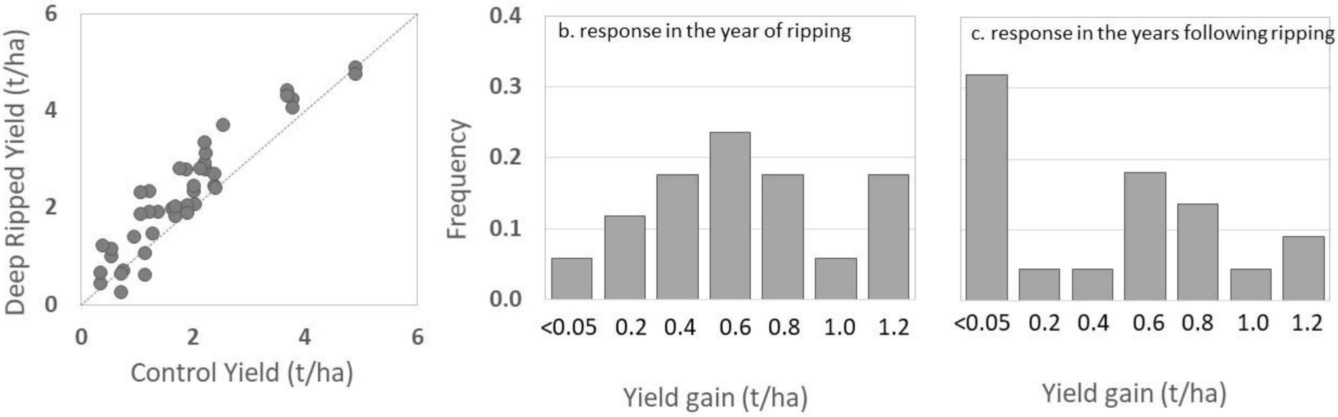

Figure 1. Annual crop yield (t/ha) responses to deep ripping in sands where physical issues are dominant as a) biplot demonstrating unmodified control yields against deep ripped yields with the dotted line representing 1:1, b) frequency distributions of yield gains (ripped yield – control yield) in the year of ripping and c) subsequent years following ripping across sites.

Despite being geographically close, cumulative yield gains from ripping at Bute_B_18 have been limited compared to responses at the Bute_15 experiments (Trengove et al. 2018). Comparison of these two experiments under a similar rainfall environment emphasises the effect of the nature and severity of constraints on the response. Soil profile characterisation indicates that the sites differ in their physical constraints, water holding, chemistry (Table 1) and subsoil properties (kaolinite clay, calcite, silica, and iron) (data not shown). Physical constraints in sandy soils can result from physical processes alone (tight packing of particle to give a high bulk density) or chemical processes which bind or cement particles together as the profile dries. Further research is underway to identify the causes and behaviour of subsoil cementing in these sandy environments and its potential role in limiting long-term effects of amelioration.

Water repellent sands – mixing to maximise water infiltration and root exploration

Ten experiments have been established to improve our understanding of amelioration responses in repellent sands, including comparing spading and alternative deep tillage practices (Figure 2). Where subsoil toxicities are not present, these experiments report an average annual yield response of +0.8 t/ha, including examples of substantial gains (+1.8 t/ha) as well as negligible responses in some seasons (Figure 2). While spading is the most effective approach to mix and dilute highly repellent layers, alternative deep tillage practices can offer some benefit by disrupting water repellent layers, or by overcoming co-occuring physical constraints to root growth. Comparison of spading to inclusion ripping at a severely repellent sand (Murlong), demonstrated intermediate benefits from inclusion ripping with a cumulative three-year benefit of 2.9 t/ha from spading compared with 2.2 t/ha from inclusion ripping at 40 cm. Reliable topsoil inclusion poses challenges for this option. Experiments in WA and SA Mallee sands have shown higher draft requirements (+24% to +40%), reduced workrate (-24%), and extra fuel use (+3.7 L/ha) with baseline inclusion ripping compared to ripping alone (Parker at al. 2019). The research to date led by agricultural engineers indicates opportunities to optimise the design of inclusion plates which may improve reliability. In 2020, 2 experiments (Younghusband and Wynarka) on repellent sands have demonstrated yield benefits from using simulation modelling to identify optimised inclusion-ripping set-up that were greater than or comparable to spading. Reliable and effective inclusion of topsoil is strongly influenced by operating conditions (e.g. moisture, operating depth and speed), but design modification alongside optimising operation set-up could provide opportunities to improve inclusion-ripping outcomes.

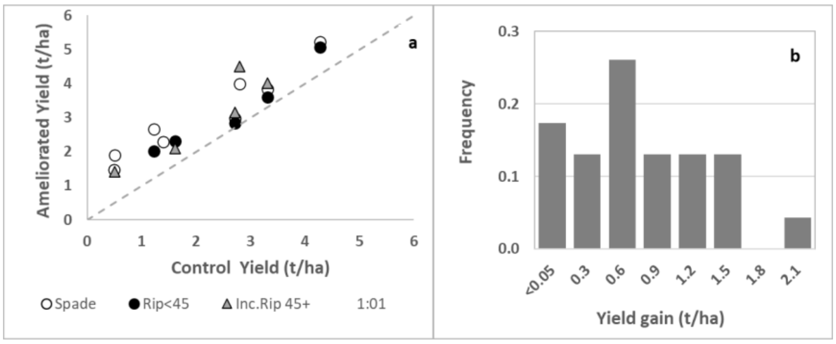

Figure 2. Annual crop yield (t/ha) responses to spading, ripping (<45cm) and inclusion ripping (>45cm) in sands where repellency and physical issues combine as a) biplot of unmodified control yields against deep ripped yields (t/ha) with the dotted line representing 1:1, and b) frequency distributions of yield gains (ameliorated yield – control yield).

Conclusion

Grouping our sites according to primary constraints and reviewing the ability of amelioration strategies to close the yield gap has revealed that physical disturbance techniques closed the yield gap at half of the sites analysed. All sites which targeted physical constraints (without significant repellence or subsoil toxicities) have demonstrated positive first-year responses to deep ripping ranging from 0.2 t/ha to 1.2 t/ha. While most trials demonstrate multiple years benefit from ripping, yield penalties have been evident following consecutive drought years (2018, 2019), with poor season penalty risks more likely in deeper ripped soils (60 cm vs 30 cm). Experiments with spading treatments on water repellent sands showed an average annual yield response of +0.8 t/ha. Although spading remains the more effective amelioration approach in highly repellent sands, optimisation of inclusion-ripping is currently being examined considering significant responses on moderately repellent sands.

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References

Davies et al. (2019) Comparing strategic deep tillage options on soil constraint removal and crop performance across two soil types in Western Australia. Cells to Satellites. J Pratley Ed. Proceedings of the 19th Australian Society of Agronomy Conference,25-29 August 2019, Wagga Wagga, NSW, Australia.

Hall et al. (2020) Soil Management Systems to Overcome Multiple Constraints for Dryland Crops on Deep Sands in a Water Limited Environment on the South Coast of Western Australia. Agronomy 10: 1881.

Macdonald et al. (2019) Mind the Gap: Targeting profile amelioration in Southern region sandy soils. Cells to Satellites. J Pratley Ed. Proceedings of the 19th Australian Society of Agronomy Conference,25-29 August 2019, Wagga Wagga, NSW, Australia.

Parker et al. (2019) Advice to match design of inclusion plates to soil type for optimum effect. GRDC GroundCover Supplement: Soil Constraints Part 1, Nov-Dec 2019.

Rayment and Lyons (2011) Soil chemical methods: Australasia. CSIRO Publishing, Collingwood, VIC.

Trengove and Sherriff (2018). Amelioration of sandy soils - Opportunities for long term improvement, GRDC Grains Research Update, Adelaide 2018.

Unkovich et al. (2020) Challenges and opportunities for grain farming on sandy soils of semi-arid south and south-eastern Australia. Soil Research 58: 323-334.