Mind the Gap: targeting profile amelioration in Southern region sandy soils.

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Abstract
Soil profile amelioration practices are gaining momentum to improve productivity on sandy soils in the Southern region. Diagnosing the underlying soil constraints and understanding the yield gap are important factors in supporting cost-effective management decisions. Drawing on findings from nine multi-year trials, we present the impact of different deep tillage practice (ripping, topsoil slotting, spading) with/without amendments on crop production in a range of sandy soils with different soil constraints. In sands with physical and nutritional constraints, yield responses to ripping alone ranged from nil responses in very dry seasons (decile 1) to 1.1 t/ha (average ~0.5 t/ha). Further yield gains, of 0.5 t/ha or more over-and-above the ripped treatment were commonly achieved through the addition of chicken manure, and sometimes with fertilisers. In water repellent sands, spading led to annual gains of between nil and 1.4 t/ha. However nil responses are also observed on acidic sands and/or under dry seasonal conditions. In water repellent sands, additional gains achieved from incorporation of N-rich hays lead to further gains, largely in the first 2-3 years, with 5-year cumulative gains of around 2.3 t/ha. Further trials will be undertaken to optimise the timing of nutrient release through managing the form of nutrition and the depth of placement, and to improve the understanding of the timing of nutrient availability, mineralisation/immobilisation dynamics and the contribution of micronutrients.

Key Words
Soil constraints, compaction, deep ripping, spading, amelioration

Introduction
There is considerable interest in strategic deep tillage and profile amelioration approaches to overcome a range of soil constraints that limit rooting depth and crop water use on sandy soils in the Southern region. Deep tillage approaches include deep ripping with/without inclusion plates, and deep cultivation such as spading or inversion ploughing. These mechanical approaches can be combined with fertilisers, ameliorants (lime, gypsum, clay), or organic amendments for the long-term amelioration of specific soil constraints. The intensity of profile modification has implications for the cost of implementation, traffic-ability, erosion risks, and on the lasting impact of the soil changes on grain yields. It is therefore important to understand the potential gains from specific treatment combinations on sandy soils in the low-medium rainfall environment. Common soil constraints include a natural tendency to compact and/or hard set, a poor ability to supply and retain nutrients, water repellence, and nutrient issues associated with acidity or alkalinity. Some sands also suffer sub-surface toxicities. This paper provides an overview of key research results within the GRDC Sandy Soils Program (CSP00203), focusing on the amelioration trial component. Project work focusing on seeder-based mitigation strategies are presented by Desbiolles et al. (2019).

Methods
Trial sites and experimental design
Experimental sites span the Southern region, ranging from 157 mm to 298 mm growing season rainfall, with estimated yield gaps of between 1.9-3.0 t/ha (Table 1). All sites have physical and nutritional constraints, while two suffer acidity, and four are affected by water repellence (Table 1). The combination of constraints, amendment availability, and estimated yield gaps were used to direct experimental plans for trials implemented during 2017/2018. The treatments included combinations of ripping with/without inclusion plates, and with/without deep placement of nutrient rich amendments (fertiliser, chicken litter, and/or N-rich hay). Spading practices were included at two sites. There is one longer-term trial capturing four years of response data (see Trengove and Sherriff 2016). The amendments included fertiliser packages (including micro-nutrients based

on soil testing) and a range of organic amendments including chicken manure (2.5-7.5 t/ha), N-rich hay (vetch or lucerne), C-rich hay (oaten) and/or compost. Due to acidity being a common issue in NSW sandy soils and the presence of a hostile soil layer approximately 15 cm deep (Haskins et al., 2018), the NSW experiment also included lime treatments with deep ‘sweep’ cultivation (30 cm).

Four sites suffer from water repellence issues, including three long-term trials (est. 2014, Fraser et al. 2016), and one Eyre Peninsula trial established in 2018. At the long-term sites, treatments include spading approaches to dilute/bury the repellent layer and to incorporate amendments including clay, N-rich hay (10 t/ha lucerne) and a fertiliser nutrient package (Fert) as detailed in Fraser et al. (2019). A new experiment on the Eyre Peninsula has included spading in comparison to deep ripping with inclusion plates (Rip+IP), with/without a fertiliser nutrient package or N-rich hay (6 t/ha lucerne).

Table 1. Summary of experimental sites including the long-term growing season rainfall (mm), an estimated yield gap (t/ha, based on water limited potential minus current attainable yields), an indication of the target soil constraints, and an overview of the deep tillage practices and amendment treatments.

Sites		**GS Rain (mm)**	**Yield Gap (t/ha)**	**Target constraints**				**Est. Year**	**Trial details**	
				pH	**WR**	**Phys**	**Nut**		**Deep Tillage***	**Amendments^**
Bute-I	*Yorke Pen.*	298	3.0			x	x	*2015*	Rip30	ChickM
Waikerie	*SA Mallee*	157	1.9			x	x	*2018*	Rip30, Rip50	Fert, ChickM
Carwarp	*VIC Mallee*	174	2.5			x	x	*2018*	Rip30, Rip60, Spade	N-Hay
Bute-II	*Yorke Pen.*	298	3.0			x	x	*2018*	Rip30, Rip60, Rip+IP	ChickM
Ouyen	*VIC Mallee*	213	3.0			x	x	*2017*	Rip30, Spade	Fert, Hays, ChickM
Yenda	*NSW*	252	3.3	x		x	x	*2017*	Sweep, Rip30	ChickM, Fert
Murlong	*Eyre Pen.*	251	3.7		x	x	x	*2018*	Spade, Rip+IP	Fert, N-Hay
Karoonda	*SA Mallee*	235	3.5		x	x	x	*2014*	Spade	Clay, N-Hay, Fert
Brimpton	*Eyre Pen.*	377	5.3		x	x	x	*2014*	Spade	Clay, N-Hay, Fert
Cadgee	*Upper SE*	410	8.2	x	x	x	x	*2014*	Spade	Clay, N-Hay, Fert

* Deep tillage approaches include: Rip# indicating depth of 30cm, 50cm, or 60 cm; ripping plus inclusion plates (Rip+IP); deep sweep cultivation to 30 cm (Sweep), and spading to 30 cm (Spade). ^ Amendments include: clay, chicken manure (ChickM), fertiliser (Fert) and N-rich hay including lucerne or vetch (N-Hay).

Monitoring impact on soil constraints, plant growth, and crop water use

In all trials, we monitored the impact of profile amelioration on crop growth and yield, and the target soil constraints. Yield responses to deep tillage alone, and to deep tillage with/without amendments, have been assessed for: a) sands without water repellence issues (Bute, Waikerie, Carwarp, Ouyen, and Yenda); b) water-repellent sands (Karoonda, Brimpton Lake, Cadgee, Murlong).

Results

Responses to amelioration within sands with physical and nutritional constraints

Ripping-based approaches, with/without amendments, have been tested across a range of sands where high soil strength (compaction/hard-setting) and poor nutrient supply have been identified as the key constraints. Yield responses to deep tillage practices ranged from a nil response to 1.1 t/ha (Figure 1a), with an average of 0.5 t/ha. The highest gain, 1.1 t/ha above a 1.8 t/ha control crop, was observed in the first year following ripping (30cm) at a trial on the Yorke Peninsula (wheat, 204 mm growing season rainfall). Nil responses were observed to ripping (30cm) at trials with very low growing season rainfall (<90 mm) in NSW and the SA Mallee.

To determine what additional gains can be achieved beyond physical interventions alone, experiments included a range of treatments to improve profile fertility through incorporation or deep placement of fertilisers, chicken litter and/or crop hays (Figure 1b). Yield responses, compared with the corresponding deep tillage control, ranged from a negative response (-0.6 t/ha) to an additional 2 t/ha, with an average gain of 0.4 t/ha. The largest gain was observed at a trial on the Yorke Peninsula (year 2, barley, 441 mm growing season rainfall), where incorporation of fertiliser resulted in a 2 t/ha gain above a 2.8 t/ha deep ripped treatment (2.2 t/ha undisturbed control). A negative yield response was observed following spading of C-rich oaten hay, likely due to immobilisation of nitrogen. To date, yield improvements from the incorporation of chicken litter has proved to be the most reliable amendment, with average gains of 0.6 t/ha above the corresponding deep tillage control, but comparable results can sometimes be achieved with mineral fertilisers. Improved understanding of the timing of nutrient availability, and the macro- and micro- nutrients contributing to improved growth are needed to optimise the fertiliser approach. Nil responses to fertiliser and chicken litter have been observed under dry season conditions (decile 1).

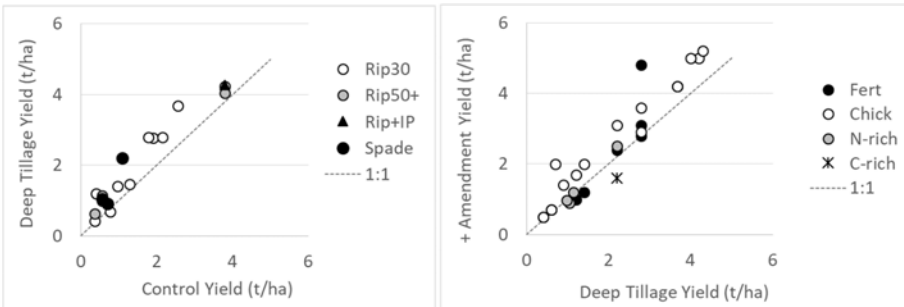

Figure 1. Crop yield responses to deep tillage (a) and to amendment incorporation across six sandy soil sites with physical and nutritional constraints. Data are treatment averages derived from one long-term trials established 2015 (4 seasons of yield data), two trials established in 2017, and 3 trials established 2018. Deep tillage approaches include Rip30, Rip50+ (50-60 cm depth), Rip+IP (inclusion plates), or spading (30cm) and are compared to the unmodified control; incorporated amendments include fertiliser, chicken litter, N-rich or C-rich hay, and are compared to the corresponding deep tillage practice.

Responses to amelioration within water repellent sands with multiple constraints

Spade-based approaches, with/without amendments, have been tested across a range of non-wetting sands. Yield responses to spading non-wetting sands have ranged from small negative responses (-0.6 t/ha) to gains of 1.4 t/ha, with an average of 0.4 t/ha (Figure 2a). The largest response (1.4 t/ha above a 0.5 t/ha control) was observed the year of implementation (2018) at a highly repellent site on the Eyre Peninsula in 2018. Across the three long-term trials (5 years), two sites demonstrated cumulative yield gains to spading alone of 2.2 t/ha and 2.6 t/ha, while a third site was not responsive. This latter site was the only site with yield benefits from clay incorporation (Figure 2b; 0.3-1.1 t/ha/year, cumulative total 2.5 t/ha). Despite evidence that claying has overcome water repellence (MED testing), the yield benefits from spaded clay did not come from improved establishment but were evident in improvements to soil pH, profile moisture and crop biomass returns (~double).

Additional gains from lucerne hay amendment, beyond spading alone, were evident at all sites (Figure 2c). Within the long-term trials (5 years), yield gains ranged from 1.0 t/ha in the first season, to nil to 0.3 t/ha responses by the third season. The cumulative yields from treatment components across these sites (Figure 2d) demonstrates the site-specific responses to treatment components.

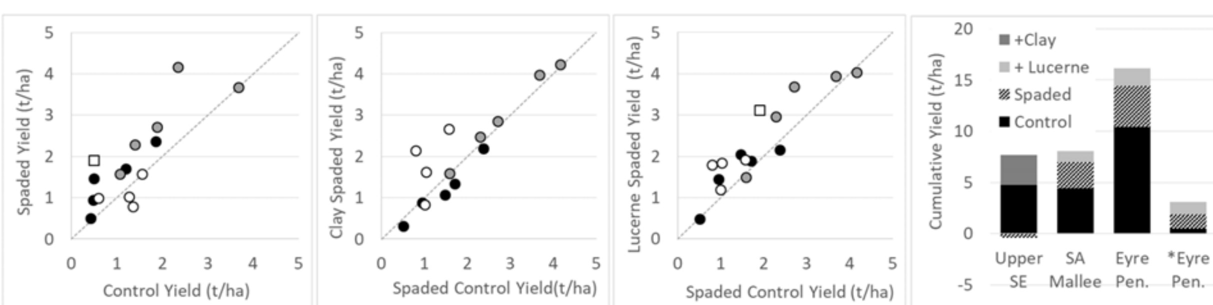

Figure 2. Crop yield responses to spading alone, clay spading and lucerne spading across four water repellent trial sites. Data are treatment averages derived from three long-term trials established in 2014 (5 seasons of yield data; solid/grey/open circles represent different sites) and one new trial established 2018 (square). From left, graphs 2a-c demonstrate treatment yields compared to the unmodified or spaded control, with the one-to-one line included to highlight response direction. Fig. 2d demonstrates cumulative yield gains across the sites for three five-year trials, and a one-year trial (*), stacked according to control, spading, and spaded clay or spaded lucerne treatments.

Conclusion

Across a range of sandy soils trials in the low-medium rainfall zone, deep tillage approaches demonstrated annual yield responses ranging from nil (or negative) to plus 2 t/ha. The trial results indicated the importance of identifying and targeting the primary soil constraints when developing an amelioration plan, and in considering the yield gains expected given the rainfall environment. Nil and negative responses have generally been observed in very dry seasons, and/or where sites have an acidity constraint. Spading water repellent sands demonstrated cumulative gains over 5 years of around 2.3 t/ha where acidity was not present. Responses to incorporation of amendments appear to be more reliable when chicken litter or N-rich biomasses are incorporated compared to fertilisers alone. However, there are instances where gains under fertiliser additions are comparable. Further improvements in understanding the timing of nutrient availability, mineralisation/immobilisation dynamics and the contribution of micronutrients are needed to optimise the fertiliser approaches.

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