Economics of ameliorating soil constraints – on farm research

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Take home messages

- On farm research trials are an important supplement to intensive experimental (small plot) research with conclusions from both types of research informing our understanding of how to close the yield gap in constrained soils
- Yield responses in on farm trials were generally lower than those observed in small plot studies with somewhat similar interventions
- Lower responses were likely related to inadequate underlying nutrition, as evidenced by the large responses to organic nutrient additions and deep P placements in more northern sites
- The benefits of ripping, nutrition or organic matter are likely to be shorter-lived compared with calcium additions
- Identifying the appropriate rate and placement/depth to intervene remains an outstanding, yet critical, knowledge gap.

Background

Extensive areas of the Northern Grains Region (NGR) are believed to have sodic soil, which contributes to significant yield gaps between the water-limited potential and actual grain production (Hochman and Horan 2018; Orton *et al*., 2018). This gap is due to a combination of physical, chemical, and biological limitations that reduce the soil's ability to capture, retain, and supply soil resources like water and nutrients to the plant. Sodic soils are generally dispersive and are defined as having a high exchangeable sodium percentage (ESP). However non-sodic soils can also be dispersive (due to high pH) and sometimes sodic soils (particularly those with high electrical conductivity (EC)) can behave as though they are not. Constrained soils commonly exhibit dispersive characteristics at multiple depths, which can lead to structural issues and limit root exploration. Additional factors such as soil acidity, salinity (both its presence and absence), limited nutrition, and compaction can further constrain crop yields. Often these factors interact and require a holistic approach when diagnosing and ameliorating soil constraints.

Ameliorating soil constraints is both technically complex and financially costly and is often best achieved when fields are dry and have low amounts of retained stubble. However, successful amelioration can improve water storage, enhance root access to water and nutrients, and ultimately increase crop yields. In wetter seasons, improvements may lead to better access to deep nutrients, while in drier conditions, when soil moisture is critical for filling grain, the benefits may result from access to additional stored water.

This project, established in 2019, featured a dual approach of establishing 6 'core' replicated research (small plot) trial sites and 16 unreplicated commercial scale sites (on farm research, OFR). The role of the small plot sites was to explore the mechanisms behind amelioration of constrained soils while the large-scale OFR sites sought to validate findings using commercially feasible rates and equipment. These OFR sites and results will be the focus of this report. Results from the core sites can be found in the links under further reading.

On farm research sites

Several constrained sites were identified with collaborating growers and commercial scale research strips were installed between 2019 and 2023 which have been monitored for yield since. They are distributed across the NGR between Forbes, NSW and Tara, QLD (Figure 1). A broad range of soil types are represented ranging from highly weathered, stable red soils through to younger grey and black cracking clays. Correspondingly, soil cation exchange capacity (CEC) ranges between 2 and 38 $cmol^+$/kg soil in the surface (0–10 cm) and increases to between 7 and 57 $cmol^+$/kg soil at depth (40–60 cm). Exchangeable sodium percentage ranges between 0–15% in the surface (0-10cm?) and is more commonly sodic at depth with an average ESP of 14% (observed range 0–23%). The soils are typically alkaline (although some sites are acid in the surface) and are exclusively alkaline at depth with typical values above pH 8.

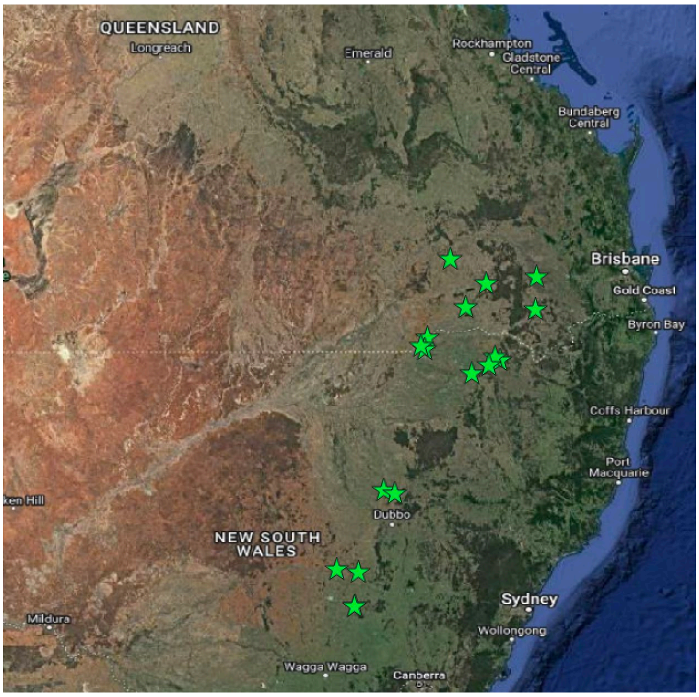

Figure 1. Locations of on farm research sites distributed across the Northern Grains Region

Treatments were tailored for each site according to soil tests, and feedback from collaborating growers was used to determine practical and relevant treatment plans. As a result, there is a wide range of treatments applied at these sites and there is little consistency between treatments across the suite of trials. Generally, growers applied gypsum (or sometimes lime for acid surface soils) at site specific rates (relative to soil tests). Typical application rates were in the range of 2–6 t/ha but some treatments were up to 14 t/ha. These treatments were applied as a source of available calcium to compete with sodium on the soil exchange and reduce ESP. Sometimes gypsum and lime were applied together in the same strip and other times were applied spatially separately (lime on surface and gypsum at depth). Deep phosphorus was included in most trials, building on previous research demonstrating widespread P deficiency and high P-responsiveness in NGR subsoils. Other amendments included elemental S (as an alternative to gypsum) and organic matter (as composted manure or biosolids). Some treatments were applied to the surface, some were applied to the surface and incorporated with deep-ripping, and some were applied at depth. Sub-surface applications were carried out using a specialized deep ripper, which placed the gypsum in bands at depths ranging from 20 to 50 cm, depending on the location of the soil constraint.

Treatments were implemented as single strips, each at least one header width wide to allow harvesting with commercial headers. These large-scale, paddock-length (500 to 3000 m long) treatment strips allow for multiple sampling points across spatially diverse soil, enabling assessment of how different amelioration strategies perform across varying soil types within each paddock. Because commercial headers collect yield data at approximately two-metre intervals, this approach generates a high-resolution dataset. This allows for precise evaluation of treatment performance within the paddock and helps determine whether a given treatment effectively improves yield. To support this analysis, each paddock was zoned based on soil variability using a range of geospatial classification methods – generally summarised in this dataset as regions of relatively lighter (less clay) soil or relatively heavier (more clay) soil. Zoning of fields included viewing historical yield data, electromagnetic induction (EMI) surveys, bare-earth satellite imagery, and historical NDVI (Normalized Difference Vegetation Index) data. Treatments were deliberately placed through the most variable areas of each paddock to capture responses across different zones. By combining paddock zoning with high-resolution yield data, this approach provides robust insights into treatment effectiveness across soil types, allowing for evaluation of whether a specific treatment produces a measurable yield response in each zone.

Results and discussion

While strip data is at scale, it is not replicated so drawing statistical conclusions is challenging. However, by integrating data across all sites we can draw conclusions about what is generally occurring with treatments across the NGR. Since no two sites have the same suite of treatments, we have grouped treatments into those where calcium was added to address sodicity constraints (gypsum and lime treatments), where deep P was added, where deep cultivation (deep ripping) occurred and where organic amendments were added (including composted manures and biosolids). We also zoned fields into regions of relatively lighter (less clay) and relatively heavier (more clay) soil types. The data presented here covers the 2021–2024 seasons and includes crops such as wheat, barley, canola, chickpea, lupins and sorghum.

Surprisingly, 90% of the OFR sites indicated a positive average response to amendments with a global mean of about 10% benefit above that of the control soil at that site. This obviously varies across sites and not all treatments have worked well at each site, but on average, intervening resulted in about 10% better yields than the untreated control treatments (Figure 2).

Generally, the addition of calcium sources (gypsum in high pH soils and lime in more acid soils) increased yields by about 10% with a trend (not significant) towards better responses in lighter textured soils (Figure 2). Generally, application rates for calcium ranged between 2–14 t/ha equivalent of gypsum. Based on calculations presented in the GRDC dispersive soil manual, the gypsum requirement of these soils can be calculated based on soil tests and these application rates of gypsum (or lime) are on average about 50% of what is required to reduce ESP to 3% in the top 60 cm. Generally, these have been applied on the surface and in a few cases have been either 'ripped in' or applied at depth with specialised equipment. With the limited statistical power from these trials there is not yet strong evidence to compare these treatments.

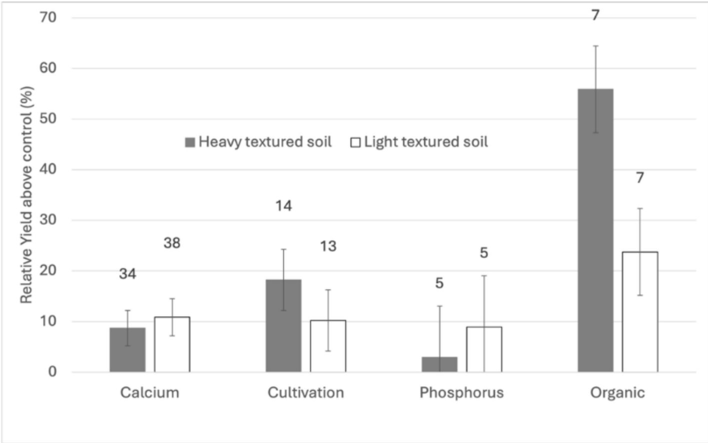

Figure 2. Relative yield of generalised constraint amendment strategies compared with untreated control; calcium (gypsum or lime), cultivation (deep ripping), deep phosphorus, and organic (composted chicken or feedlot manure or biosolids). Unreplicated field results have been pooled according to the type of treatment across 16 sites in the northern grains region with wheat, barley, canola, chickpea, lupin and sorghum crops. Bars represent the mean relative yield for relatively lighter and heavier zones within the field; error bars denote standard error while the number above the bars indicate the number of crops that contributed to this value.

There also appears to be a trend towards greater responses of heavier (more clay) textured soils to cultivation treatments with average yield benefits in the range of 15% (Figure 2). While we are cautious about recommending deep ripping alone many of these treatments have gone in with deep P and so additional root activity in the more accessible soil profile is likely to stabilise these effects for longer than deep ripping alone. In contrast, lighter soil type regions of the fields appear to be responding more strongly to deep applied P bands which might indicate differences in the background nutritional status of these parts of the paddock. Yield benefits are in the order of 5–10% (Figure 2) but some of the treatments that were assigned to cultivation also included P so these categories are not entirely independent.

There were large responses to organic matter treatments, particularly in the heavier soil regions of these fields. The organic treatments were highly variable with some including 8 up to 100 t/ha of material (composted manures or biosolids). Responses are drawn from a limited number of sites so should be treated with considerable caution as they are site and rate specific. The large responses indicate a significant potential underlying nutritional constraint, and it is thought that the largest benefit of these treatments comes as a result of large amounts of slow-release nutrition that can support additional yields in regions of the field with greater water availability (higher clay content).

Table 1. Summarised average economic performance of generalised constraint amendment strategies; calcium (gypsum or lime), cultivation (deep ripping) and organic (composted chicken or feedlot manure, or biosolids). Unreplicated field results have been pooled according to the type of treatment across 16 sites in the northern grains region with wheat, barley, canola, chickpea, lupin and sorghum crops. Values presented are the means with (standard error). Return on investment reported on an annual basis as an average of the first 4 years of yield benefits.

Treatment	Mean net return ($/ha/yr)	Treatment cost ($/ha)	Annual return on investment
Calcium application (gypsum/lime)	93 (21)	631 (43)	0.15
Cultivation	88 (37)	200 (23)	0.44
Organic amendments	386 (50)	845 (156)	0.46

Treatments were applied between 2 and 7 years ago. Based on the average yearly return from amendments (averaged across all sites and years) calcium applications increase the return by $93/ha/yr with an initial average outlay of $631/ha, breaking even after 7 years. Cultivation treatments were cheaper on average (bearing in mind often included deep P) and paid back after 3 years; while the greater productivity observed over a limited number of sites and seasons to organic amendments had both greater costs and returns, and appeared to pay back after an average of 3 years (but should be treated with caution).

Despite the large variety in interventions, crops, rainfall and soil types across 4 years some general impressions can be drawn.

- On farm research trials are an important supplement to detailed experimental research with conclusions from both types of research informing our understanding of how to close the yield gap in constrained soils
- Yield responses were generally smaller than those observed in small plot studies with somewhat similar interventions
- Smaller responses were likely related to inadequate underlying nutrition, as evidenced by the large responses to organic additions and deep P placements in more northern sites
- The benefits of ripping, nutrition or organic matter are likely to be shorter-lived compared with calcium additions
- Identifying the appropriate rate and placement/depth to intervene remains an outstanding, yet critical, knowledge gap.

Further reading

GRDC dispersive soil manual - https://grdc.com.au/resources-and-publications/all-publications/publications/2023/dispersive-soil-manual

Reflections on 5 years of subsoil constraint economics, GRDC Grains Research Update paper, 2025 - https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2025/03/reflections-on-5-years-of-subsoil-constraint-economics

Soil constraints project - an update on the economic response of long term soil amelioration strategies. GRDC Grains Research Update paper 2024 - https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2024/02/soil-constraints-project-an-update-on-the-economic-response-of-long-term-soil-amelioration-strategies

Ameliorating sodicity; what did we learn about ameliorating sodicity constraints with a range of treatments? Yield responses to ripping, gypsum and OM placement in constrained soils. GRDC Grains Research Update paper 2022. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/03/ameliorating-sodicity-what-did-we-learn-about-ameliorating-sodicity-constraints-with-a-range-of-treatments-yield-responses-to-ripping,-gypsum-and-om-placement-in-constrained-soils

GRDC Grains Research Update, online – Ameliorating sodicity – Central & Northern NSW & Qld (webinar recording) https://grdc.com.au/events/past-events/2022/march/grdc-grains-research-update,-online-ameliorating-sodicity-central-and-northern-nsw-and-qld

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