# Re-engineering the subsoil of pale, deep sand

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## Key messages

* Pale, deep, water-repellent sands are often prone to further constraints in the subsoil, such as compaction and low cation-exchange capacity.
* Significant yield improvement resulted when plots that had been clayed and spaded were deep ripped to reduce the subsoil strength and so increase the depth of root growth.
* Further yield improvement and deeper roots were recorded when fertiliser was incorporated with the use of top-soil inclusion plates behind the ripper.

## Aims

* Determine if deep tillage improves root growth and yield of crops on pale, deep sand that has been previously ameliorated with the incorporation of clay-rich subsoil to a depth of 300mm.
* Assess the effect of tillage and nutritional treatments implemented separately and in combination on root growth.
* Evaluate methodologies and technology designed to incorporate amendments deep into the subsoil (>400mm).

## Introduction

Crop production on sandy soil (defined as less than 5% clay content) in the Western Australian wheatbelt is commonly constrained by a combination of soil water-repellence, subsoil compaction, acidity and low water and nutrient holding capacity (van Gool 2016). Several field trials have demonstrated that spreading clay and mixing it through the top 300mm with a rotary spader can simultaneously ameliorate these constraints and dramatically increase crop production (Hall et al 2010, Roper et al 2015). However, Davies et al (2019) identified that only half of the reported spaded sites on pale, deep sand continued to show a yield increase after two years and that the benefit was modest compared with sites with more clay in the subsoil or a shallower texture change.

To investigate further, we studied subsoil root growth at several sites that had been previously ameliorated. This analysis indicated that although the amelioration often demonstrated an increase in root growth in the top 300mm there was little root growth detected below this depth (Scanlan et al 2013). In addition, we measured soil water at these depths that was unused after the crop had senesced. The capture of subsoil water by deeper root systems can make a valuable contribution to yield particularly on deep sandy soil (Lilley and Kirkegaard 2016). Therefore, we formed the hypothesis that to increase the long-term economic benefit of ameliorating the topsoil we also needed to identify and remove the constraints to deeper subsoil root growth.

Root penetration in the subsoil could be restricted due to increased soil strength following incorporation of clay with a spader (Moore 2001). Reducing subsoil strength through deeper ripping has been shown to increase the depth of root penetration and improve water extraction from deep in the profile (Tennant and Hall 2001).

Additionally, a low cation-exchange capacity in the subsoil provides limited substrate to capture and release soil fertility. Incorporating organic amendments into the subsoil could provide a foundation to promote nutrient sequestration and cycling. Equally, high rates of nutrition could be incorporated that could then stimulate the proliferation of root growth.

We do not know in what combination these factors constrain subsoil root growth. Therefore, we implemented treatment combinations separately and in combination to measure their effect on subsoil strength and fertility. The aim was to isolate the factors restricting root growth while also determining the most effective methods for removing the subsoil constraints.

## Methods

In 2017, an experimental site south-east of Salmon Gums was spread with 500t/ha of subsoil containing 27% clay and then spaded to a depth of 300mm. Following amelioration, the soil at the site was sampled at four locations for physical and chemical analysis (Table 1). Molarity of ethanol tests were conducted on the top 0-100mm samples and water was quickly able to infiltrate in all samples. In March 2018, 15 treatment combinations were imposed: these were incomplete combinations of five amendments with four tillage treatments (Table 2). Each treatment combination was replicated six times. Ripping with and without inclusion plates was done to a depth of 500mm and a auger trencher (Trenchmaster 150) used to incorporate the amendments in a slot to a depth of 700mm. Both ripping and trenching were undertaken parallel to sowing.

**Table 1. Initial soil sampling of the trial site after spreading of subsoil (27% clay) on soil surface and spading but before the experimental treatments were imposed. Values represent an average of four sampling points on each corner of the trial (±se). Soil properties of the subsoil clay are included.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Depth (mm) | Clay (%) | pH (CaCl2) | Organic carbon % | Phosphorus Colwell mg/kg | Potassium Colwell mg/kg | Cation exchange capacity cmol+/kg |
| 0-100 | 5.6 (0.7) | 7.6 (0.2) | 0.69 (0.1) | 17.6 (1.6) | 70.5 (7.0) | 5.0 (0.4) |
| 100-200 | 5.9 (0.7) | 7.7 (0.2) | 0.7 (0.1) | 15.5 (1.4) | 66.0 (10.4) | 5.2 (0.6) |
| 200-300 | 3.6 (0.3) | 7.3 (0.0) | 0.4 (0.1) | 13.3 (2.3) | 37.5 (16.5) | 2.5 (0.3) |
| 300-400 | 3.1 (0.3) | 7.4 (0.1) | 0.3 (0.0) | 7.5 (0.6) | 21.0 (2.6) | 1.4 (0.2) |
| 400-500 | 2.9 (0.0) | 7.0 (0.2) | 0.2 (0.0) | 5.8 (0.6) | 19.0 (1.30 | 1.0 (0.1) |
| 500-600 | 5.6 (2.7) | 7.0 (0.2) | 0.2 (0.0) | 4.3 (0.6) | 56.0 (33.3) | 1.7 (1.0) |
| 600-700 | 9.0 (5.5) | 7.0 (0.2) | 0.2 (0.0) | 3.0 (0.4) | 95.0 (62.5) | 2.7 (2.0) |
| 700-800 | 8.3 (2.9) | 6.9 (0.1) | 0.2 (0.0) | 3.0 (0.5) | 30.5 (5.3) | 0.9 (0.2) |
| Subsoil | 27 | 8.8(water) | 0.2 | <2 | 300 | >10 |

|  |  |  |  |
| --- | --- | --- | --- |
| Deep tillage (strips) | Amendment | Rate (kg/ha) of 2018 amendment | Description each treatment tested |
| None | Basal 2017 clay only | None | Control |
| Trench | Basal 2017 clay only | Trench Control |
| Ripping | Basal 2017 clay only | Ripping control |
| Ripping +inclusion | Basal 2017 clay only | Ripping + Inclusion control |
| None | Manure pellets | 5000 | High nutrition, soil fertility substrate |
| Trench | Manure pellets | High nutrition, soil fertility substrate, deep placement |
| Ripping | Manure pellets | High nutrition, soil fertility substrate, reduce soil strength |
| Ripping +inclusion | Manure pellets | High nutrition, soil fertility substrate, reduce soil strength, some deep placement |
| None | Matched rate complete fertiliser | 1264 | High nutrition |
| Trench | Matched rate complete fertiliser | High nutrition, deep placement |
| Ripping | Matched rate complete fertiliser | High nutrition, reduce soil strength |
| Ripping +inclusion | Matched rate complete fertiliser | High nutrition, soil fertility substrate, reduce soil strength, some deep placement |
| Trench | Pea straw | 10000 | Soil fertility substrate, deep placement |
| Ripping | Red Loam | 10000 | Soil fertility substrate, soil strength reduced |
| Ripping +inclusion | Red Loam | Soil fertility substrate, soil strength reduced, some deep placement |

The fertiliser included was designed to match the nutrition of the chicken manure (Table 3). The inclusion of pea straw (29 Carbon: 1Nitrogen) was included to determine whether the incorporation of organic matter with lower nutritional benefit was sufficient to stimulate root growth and yield. It was not possible to leave the pea straw on the surface or combine with the ripping treatments as the amount of material interfered with the tines of the ripper and the seeder. For this reason, an additional amendment of red loam was included in combination with the ripping treatments (only). This material was sourced on-farm and had a clay content of 15%.

When all the treatments were imposed, the entire experiment was sown to wheat (*Triticum aestivum* cv ScepterPBR symbol) at 50kg/ha with 50kg/ha of DAP ZnCu and 70L/ha of UAN. Poor seasonal conditions in 2018 lead to poor establishment and significant head loss, so only limited measurements were recorded. In May 2019, the experiment was sown to barley (*Hordeum vulgare* cv La trobePBR symbol) at 50kg/ha with 60kg/ha of MAP and 70L/ha of UAN.

**Table 3. Rate of application of pelletised chicken manure and blended composite fertiliser and nutritional breakdown of each at the rates applied.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fertiliser amendment | Rate (kg/ha) | N (kg) | P (kg) | K (kg) | S (kg) | Ca (%) | Cu (%) | Zn (%) | Mo (%) | Mn (%) | Fe (%) | Mg (%) |
| Chicken manure | 5000 | 245 | 45 | 85 | 26 | 95 | 1 | 1 | 0 | 2 | 9 | 14 |
| Fertiliser blend | 1264 | 245 | 45 | 85 | 26 | 97 | 1 | 1 | 0 | 2 | 9 | 14 |

Three 0.5m2 cuts per plot were taken at maturity to determine crop biomass. From these samples a sub-sample of tillers was counted to determine the number of tillers per m2. This sample was then further threshed to give a seed yield (not reported) and this was used to calculate the harvest index. The reported measurement of yield was achieved with a Wintersteiger® trial header with 1.78m front that travelled in the same direction across each plot. A sample of seed was captured by the header for each plot and analysed for protein by an infratech™.

Soil strength was evaluated in August using a Rimik® CP40-II penetrometer to record soil penetration resistance at 20mm intervals to a depth of 600mm. Three replicates were taken for each plot each with a further three insertion replicates. Sixteen soil pits were excavated at the end of July, one for each treatment. Root abundance and depth were then assessed on the face of each pit, as detailed in McDonald et al (1998). Volumetric water content (VWC) was measured using a Hydrosense II two-pronged time domain reflectometry meter along the excavated face of the soil pits. Soil samples were taken from the exposed face of each soil pit for chemical analysis (not reported in this paper) and to calculate gravimetric water content (not reported in this paper).

Analysis of variance was carried out on the yield components using replicates of tillage treatment strips as the blocking structure. For each component the least significant difference at 5% was calculated for the full interaction of tillage by amendment. A linear regression model was fitted to several independent variables to determine how well they explained the variation for the dependent variable of yield.

## Results

Seasonal conditions were poor in 2019 with 154mm of growing season (April–October) rainfall resulting in low yields across all treatments (Table 4). Eight treatment combinations recorded a significant increase in yield compared to the ‘no-tillage clay-only’ (hereafter called the control) (p <0.05). The low harvest index and high protein levels in the grain suggested that the crop was suffering water stress during grain fill. Biomass and harvest index accounted for a large amount of the yield variation (Table 5). The volumetric water content measured at 500mm in the soil profile was inversely related to the yield for each treatment and showed a strong, negative relationship.

When pooled for all amendments, ripping and ripping with inclusion yielded significantly more than the control tillage while the trench treatment did not differ from the control. In 2019, ripping to reduce subsoil strength significantly increased yield by up to 200%. Reduced soil strength (Figure 1) and increased root growth beyond a depth of 300mm were also recorded for all treatment combinations that included ripping (Figures 2a–d). Ripping and ripping with inclusion plates reduced soil strength to below the critical level of 2500KPa to a depth of about 550mm. No extra yield benefit above ripping the clayed plots was observed when 5t/ha of chicken manure or fertiliser with the same nutritional input as the manure was spread on the surface before ripping.

Trenching did not significantly reduce soil strength (Figure 1). However, the value reported is an average across the whole plot and there was a substantial difference in soil strength depending on whether the measurement was taken in line with the trenching implement or in between the trenching implement. Trenching effectively incorporated these amendments down to 600mm and this improved the root abundance that was measured when averaged on and off the slots (Figure 2a–d).

**Table 4. Barley (*Hordeum vulgare* cv La trobePBR symbol) performance in 2019 averaged across six replicates for each of the 16 treatment combinations. Indications of significance at the p<0.05 (\*\*) level ‘no-tillage clay-only’ (control) treatment.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tillage** | **Amendment** | **Average t/ha** | **Average tillers/m2** | **Average biomass t/ha** | **Harvest index average** | **Average protein** |
| No tillage | Basal 2017 Clay only | 0.27 | 269.84 | 1.97 | 0.11 | 20.53 |
| Manure pellets | 0.30 | 319.98 | 2.85\* | 0.10 | 20.73 |
| Matched rate fertiliser | 0.38 | 308.44 | 2.48 | 0.10 | 20.87 |
| Ripping +inclusion | Basal 2017 Clay only | 0.62\* | 279.55 | 2.72 | 0.22\* | 19.23 |
| Manure pellets | 0.78\* | 344.61\* | 3.63\* | 0.23\* | 19.68 |
| Matched rate fertiliser | 1.03\* | 405.42\* | 4.48\* | 0.23\* | 19.27 |
| Red Loam | 0.74 | 290.19 | 2.87\* | 0.25\* | 18.90 |
| Ripping | Basal 2017 Clay only | 0.79\* | 300.90 | 3.10\* | 0.26\* | 17.95 |
| Manure pellets | 0.62\* | 331.55 | 3.45\* | 0.19\* | 20.12 |
| Matched rate fertiliser | 0.82\* | 285.57 | 2.95\* | 0.20\* | 19.87 |
| Red Loam | 0.65\* | 315.26 | 3.03\* | 0.23\* | 19.12 |
| Trench | Basal 2017 Clay only | 0.44 | 261.68 | 2.45 | 0.19\* | 18.65 |
| Manure pellets | 0.48 | 308.49 | 2.70 | 0.14 | 19.68 |
| Matched rate fertiliser | 0.54\* | 297.25 | 2.77 | 0.19\* | 20.30 |
| Pea straw | 0.44 | 318.62 | 2.81\* | 0.17 | 19.52 |
|  | LSD 0.05 \*\* | 0.25 | 62.32 | 0.82 | 0.08 | 1.32 |
|  |

**Figure 1. Average cone penetrometer readings for each of the tillage treatments. Measurements taken at 20mm intervals to 600mm. Least significant difference at a 5% level displayed for 100mm increments.**

**Figure 2a–d. Root abundance of the tillage treatments amended with a) basal clay in 2017 b) matched rate complete fertiliser c) manure pellets and d) pea straw or red loam. Root abundance was scored 1–5 according to the method described in Land and Soil Classification (McDonald et al 1998). Ratings were given for each 50mm x 100mm grid to a depth of 500mm (±s.e).**

Ripping with inclusion plates was as effective at reducing subsoil strength as the ripping treatments (Figure 1). This method also had the potential to incorporate some of the amendments deeper in the profile. The incorporation of the matched-rate fertiliser increased root abundance at depth above the levels recorded for just ripping and inclusion of the basal clay only (Figure 2a–d). The yield for the inclusion of the match-rate fertiliser was the highest recorded and was significantly higher than ripping and fertiliser alone (Table 4).

Incorporation of the chicken manure increased yield and improved root abundance compared to the deeper inclusion of surface-spread clay. However, these benefits were not significantly different to the treatments where the amendment was applied in combination with ripping, likely since inclusion would have been minimal. The incorporation of pea straw with the trencher did not significantly improve yield over the control. The ‘red loam with ripping’ and ‘ripping with inclusion’ treatments significantly increased yield over the control but this benefit should be apportioned to the tillage component as there was no additional benefit to the inclusion over the ripping alone.

**Table 5. R-squared values for measured variables correlated to measured values for yield (t/ha).**

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Amount of variation in yield (t/ha) accounted for | Formula | F probability that slope ≠0 |
| Volumetric Water Content 400-500mm | 58.5 | y=-0.21x+0.785 | <0.001 |
| Harvest index | 67.2 | y=3.29x-0.014 | <0.001 |
| Biomass t/ha | 64.1 | y=0.2973x-0.276 | <0.001 |
| Tillers/ sq m | 25.4 | Y=0.003x-0.435 | 0.352 |

## Conclusion

Ripping with and without topsoil inclusion effectively reduced the strength of the subsoil below 300mm and improved root growth. High subsoil strength in the control plots is indicative of traffic pans and is commonly encountered on deep sand (Henderson 1988). Even under conditions of low traffic intensity, high soil strength and restricted root growth has been observed following strategic tillage operations such as spading (Hall et al 2018). Topsoil inclusion aims to create a slot behind the ripping tine that can incorporate topsoil and surface-spread amendments into the profile. Parker et al (2019) demonstrated that this can provide a positive yield response over ripping alone, particularly on deep sand. However, they found a high degree of variability in yield, depending on the seasonal conditions and soil moisture at the time of ripping.

Although the auger trencher penetrated below the compaction depth, it failed to create break-out beyond its zone of operation to increase the volume of soil that was influenced. The auger trencher effectively incorporated the amendments, which appeared to improve root growth particularly down localised slots. However, there was no significant increase in yield, which indicates that the improvement in root growth was confined to the slots and was insufficient to increase grain yield substantively.

The inverse relationship between volumetric water content at 500mm and yield supports the hypothesis that to improve the longevity of the yield benefit after amelioration, the abundance of roots at depth need to increase. Variation in yield accounted for by volumetric water content at 500mm was comparable to that for biomass and yield index. This confirms that this measurement could potentially be used to diagnose subsoil constraints and evaluate the relative success of amelioration efforts in future research trials (Tennant and Hall 2001).

Gill et al (2009) demonstrated that incorporating organic amendments such as chicken manure into the subsoil provided a large increase in crop yield in the high rainfall zone of south eastern Australia on a sodic clay subsoil. However, Celestina et al (2018) demonstrated that these benefits were difficult to replicate across a range of geographically spread experimental sites with 14 out of 15 trial sites showing no additional benefit over the surface placement of chicken manure. The lack of an effect of organic amendments in our experiment adds further to the suggestion that this method of amelioration could only be relevant in high rainfall environments with severe physiochemical constraints that induce structural decline. Celestina et al (2018) found crop production benefits from the increased nutrient supply of chicken manure and the deep placement of matched fertiliser. Therefore, although deep, sandy soil is not constrained by subsoil sodicity, an inherently low cation exchange capacity means that it is likely responsive to increased subsoil fertility.

Previous research has shown that root systems have a high degree of plasticity and can forage and proliferate when they encounter nutrient-rich patches particularly phosphate, nitrate and ammonium (Drew 1975). This foraging response could be elicited through the deep-placement of nutrients to increase root growth into the subsoil. This is partially demonstrated in this experiment where the combination of ripping and incorporation of fertiliser increased yield and improved root abundance compared to the deeper inclusion of surface-spread clay alone. The deep-placed chicken manure did not provide as consistent a yield response as the fertiliser in the second year of our trial but, as the release of nutrition is likely to be slower, (Stockdale & Rees 1995) results from future years of the trial are required to determine which amendment will deliver longer-term production increases (Celestina et al 2018).

The measured yield improvement in this trial was primarily attributed to reduction in subsoil strength through deep tillage. Beyond their nutritional benefit, there was no indication of further benefits from the deep placement of organic amendments. Incorporating high rates of inorganic fertiliser appeared to improve the proliferation of roots at depth and subsequently yield. Further experimental sites across a range of rainfall environments and years would be required to determine if this result could be reliably reproduced and sustained. We can however be confident that the poor water and nutrient holding capacity in the subsoil of pale, deep sand should be considered a constraint to production and the predominant message we have learned through soil amelioration research is that the production benefits are larger and last longer when the greatest combination of soil and agronomic constraints are addressed.

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