Composted chicken manure incorporated by trenching increased crop performance on sodic grey clay soil

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Abstract
Grey sodic duplex clays in WA are very difficult to manage and often under perform. These soils are very dense and hostile to root growth. An experiment was established (Ongerup) on this soil type in 2015. The site has been bulk sown and managed in a continuous cropping rotation. Treatments were three manure rates (0, 10, 20 t/ha), two gypsum rates (0, 3.5 t/ha) and with/without incorporation by trenching (0.9m spacing). The average crop yield response when manure was incorporated by trenching was 30-40% higher than the control treatment compared to 0-15% higher without trenching. Gypsum responses were limited to the faba beans in 2020 when manure was not applied. A boom-bust phenomenon occurred in several years where enhanced mid season crop performance (boom) associated with trenching and manure did not result in greater yields (bust). Yield increases were the result of improved biomass or stem/tiller numbers primarily driven by improved root exploration and water utilisation.

Key Words
Amendments, subsoil constraints, soil management

Introduction
The agronomic management of sodic non-cracking grey clay soils is a problem across the South West of Western Australia. They are prone to hard setting and surface crusting when the soil is dry and surface water ponding when conditions are wet. This experiment was designed to evaluate the potential for deep incorporation of organic manure and gypsum amendments to improve productivity on these difficult soils.

Methods
The experiment was established at Ongerup (S33.971, E118.663) in April 2015. The soil was a gritty grey non-cracking sodic clay duplex, also known as "Moort soil". The experiment design was a complete factorial in randomised blocks with trenching treatments applied to whole rows in four replicates. The gypsum (0, 3.5 t/ha) was sourced from local suppliers (80 – 90% purity) and a composted chicken manure was applied as the organic matter treatment (0, 10, 20 t/ha). Amendments were either surface spread or were "trenched" in April 2015. Where trenched, the amendments were laid out on the surface along the length of the plots at 900 mm intervals resulting in four trenches per plot. A 'Ditch Witch®' trencher was used to incorporate the amendments into trenches 400mm deep by 100mm wide and manually backfilled once trenching was complete. The gypsum application rate of 3.5 t/ha was selected based on previous experience. Manure application rates were selected based on research in Victoria and adopted from (Gill et al., 2008).

Table 1. Crop type and cultivar, rainfall, fertilizer inputs, seeding and harvest dates and yields over the six experimental seasons.

	2015	2016	2017	2018	2019	2020
Crop	Wheat; cv Mace⚐	Barley; cv LaTrobe⚐	Canola; cv Bonito⚐	Wheat; cv Scepter⚐	Barley; cv Flinders⚐	Faba bean; Samira⚐
Annual Rainfall (mm)	329	505	509	285	298	361
May-Oct Rainfall (mm)	230	281	275	197	251	237
Fertilizer N:P:K:S kg/ha	48:12:11:7	44:12:12:5	85:24:12:5	70:12:12:5	72:12:12:5	6:11:0:1
Seeding Date	24 May	10 May	12 April	01 June	21 May	01 May
Seed Rate (kg/ha)	80	80	4	80	80	140
Potential Yield (t/ha)	5.03	7.04	4.58	3.91	5.34	3.31
Yield Range (t/ha)	2.65 - 3.19	2.38 - 4.59	0.51 - 0.97	3.63 - 4.15	5.37 - 8.03	3.05 - 4.02

Each season's crop was bulk sown with knife points into retained stubble perpendicular to the trenching and plot orientation at 300mm spacing for all seasons except 2020 which was sown on 600mm row spacing. The experiment was managed as part of the whole paddock with the host grower providing all in-season crop management (Table 1). Plant measurements were collected throughout the seasons and grain was harvested using a plot header except for 2019 season where only a hand sample was collected. Potential yields were calculated using the following method: Yield potential (kg/ha/mm) = 22 x ([(Nov to Mar rain x 0.3) + Apr to Oct rain] – 60) x 1.12, where 22 = efficiency parameter for cereals (14 = canola, 15 = faba beans), 0.3 = out of season rainfall discount factor, 60 = evaporation estimate and 1.12 = conversion allowing for dry weight (Hunt & Kirkegaard, 2012). Statistical analyses were conducted using Genstat® software (18th Edition; VSN International: Hemel Hempstead, UK).

Results

The boom and bust of crop growth

The soil disturbance from the trenching in 2015 brought sodic subsoil to the surface that negatively affected crop growth and development for much of that season. In addition, the higher nutrient supply provided by the surface applied manure pellets over stimulated vegetative growth for which there was insufficient soil water available during grain fill to support the crop through to maturity as indicated by high screenings and small grain size. When both of these factors were combined in this first season, larger yield reductions were observed (Figure 1). This reduction in treatment yields corresponds to 53 – 63% of the potential yield which indicates the gap in yield that may be overcome if soil constraints are addressed. This is a clear example of the "boom-bust" of crop growth often seen in Western Australian cropping systems where favourable growing conditions or high nutrition over stimulates vegetative growth ("boom"), which more rapidly depletes finite stored soil water reserves and often leads to a reduction in grain yield from the subsequent lower soil water supply during grain filling ("bust"). The "bust" is most commonly brought about by a sudden decline in spring rainfall and/or high temperatures that exacerbates the soil water depletion by the high biomass crop which fails to meet the demands of grain filling. Sale et al. (2020) also noted that improvements in crop yields from trenching and organic addition were most likely to occur in higher rainfall years.

The 2018 season was characterised by dry conditions causing later sowing and little stored soil water from pre-season rainfall events. While the 2018 growing season rainfall was low (Decile 1), the lower plant establishment, favourable growing conditions and regular rainfall promoted tiller production and accumulation of biomass. Plant establishment across the experiment was approximately 40% of that expected but both the anthesis tiller number and anthesis biomass responded positively in trenched treatments compared to respective controls and increased as treatments were compounded. Roots were found to be more prolific and extended to greater depth within the trenches when measured in September 2018. However, there was no evidence that the roots had extended (laterally or vertically) beyond the trenched zone either in the trenched alone or where the trenches had been organically enriched. The soil surface (0 – 10 cm) was often dry during the season, which limited the nutrient availability and hence less crop growth in the untrenched manure treatments compared to the manure+trenched treatments. Nutrient concentrations in plant tissue tests at anthesis showed higher concentrations of nitrogen and potassium in trenched treatments compared to untrenched. All treatments were able to achieve between 93% and 106% of the calculated yield potential of 3.91 t/ha in 2018 with no significant difference in grain yields. Almost all of the trenching treatments had lower grain size compared to the un-trenched treatments in the 2018 season. Since this was not reflected in yield responses or any other trait measured, it is most likely a result of the limited seasonal resources and indicative of a "boom-bust" season. When there is limited soil water there is a relationship between seed number per square metre and seed size. For example, in the trenched treatments when manure was added the more favourable rooting environment promoted increases in tiller production at anthesis ($p<0.10$) which increased the potential grain number per square metre ("boom"). However, with low soil moisture conditions during the season, especially during grain fill, there was insufficient soil water available to either develop the extra heads and/or fill the extra grains produced ("bust"). Additional rainfall leading up to and after flowering would most likely have enabled the ameliorated treatments that had more vegetative tillers to develop additional heads and better fill grain which would further increase grain yield compared to treatments with lower tiller numbers. Hence these results show that the ameliorated treatments had the potential to produce higher yields if environmental conditions were more favourable.

During the 2020 season, a legume crop (faba bean) was sown that had a much lower requirement for nitrogen as supplied from the manure treatments. While grain yields for all ameliorated treatments were higher than the calculated potential yield of 3.31 t/ha, the measured plant traits and highest yields from non-manured treatments indicate a nutrient induced "boom-bust". The greatest yield response from any single treatment was for the gypsum or trenching treatments (3.86 t/ha, 3.89 t/ha respectively), and the highest yield obtained was for the combination of these two treatments (4.2 t/ha). Other high yielding treatments of "manure + trenching" were comparable to the trenching only treatments which indicates that the application of the manure had little additive effect on crop yield that was seen in previous seasons. This is in contrast to other seasons where manure responses in non-legume crops were observed. The mature biomass of the crop was higher for all manure treatments than all non-manure treatments indicating a nutrient response, but this increase was largely not significant. Higher biomass treatments were not the highest yielding treatments indicating the 2020 crop failed to capitalise on this higher biomass during a drying grain filling period in October.

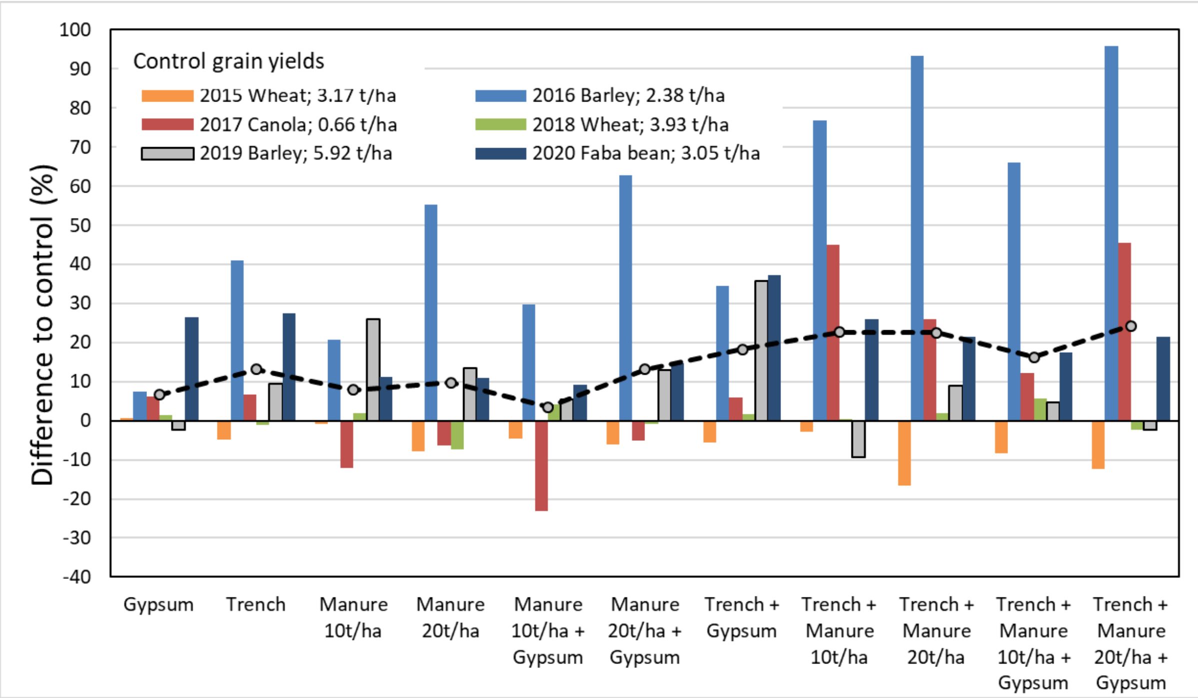

Figure 1. Grain yield response as the percentage change to the control treatment for 2015-2020 seasons. The "Average" line is the average of seasonal results across the six seasons.

Nutrients, crop growth and yield

Across all seasons, except the establishment season in 2015 and un-trenched manure in 2017, all of the treatments had a positive effect on yield (Figure 1). Improved crop yield components resulting from addition of manure and/or trenching shows that yield improvement is possible during most seasons. However, significant yield improvement for each season may not be realised due to adverse climatic conditions. This was most evident in 2016 and 2017 when severe frost restricted yield and during 2018 when dry conditions throughout the season limited crop potential. Yield components measured during the experimental seasons indicated that the crop yield potential for ameliorated treatments were superior compared to the unameliorated controls for all seasons except the establishment season of 2015 and 2020 which was the only legume crop grown. Previous studies (Celestina et al., 2018) have shown that yield responses to added organic amendments such as composts and manures have been driven by the nutrients in such products rather than other organic material properties. A very similar effect has resulted in this experiment evident by the enhanced vegetative growth and improved yield components. However, the environment at the experiment location is such that the crop is not always able to capitalise on the improved nutrient status provided by converting available resources into grain yield. Plant tissue nutrient analysis collected at anthesis in 2018, more than 3 years after amendments were added, show an increased level of nutrient uptake for all macro nutrients for all trenching treatments. The addition of the manure in trenched treatments increased plant uptake substantially compared to the untrenched treatments which is represented by both higher anthesis biomass in 2018 and tissue nutrient concentration. It is believed this effect is a result of trenched manure nutrients being placed in deeper moist soil and more consistently available to the crop compared to the intermittent drying of the soil surface where untrenched manure was applied. In addition, the growth and yield components of trenched plots without manure was consistently greater than the corresponding untrenched plots which indicates the burial of topsoil by trenching alone provides a more favourable environment for crop development. Management options that can more reliably take advantage of the improved nutrient supply and any favourable growing conditions following amelioration by converting finite resources into grain yield are required.

Conclusion

Grain yield responses to amelioration is a complex interaction of the soil characteristics, soil water conditions and plant resource allocation over time. Since grain yield is the result of grain number per area and grain weight, many factors can affect these two parameters during the season from germination to maturity. For example, the lack of rain at the right time can turn a potentially high yield (boom) from high grain number into a low yield with high screenings by reducing grain size (bust). The “boom-bust” scenario of crop growth can be identified from several crop traits such as high anthesis biomass, higher vegetative NDVI, more groundcover and/or high tiller numbers in combination with high screenings, small grain size, and often lower grain yield. Sometimes there is no difference in the grain yield but these other plant traits provide evidence of the “boom-bust”. Such “boom-bust” scenarios are relative to the potential yield of the crop and relatively high grain yield can still be achieved compared to other seasons or locations. The “boom-bust” effect in this experiment has been described for the 2015 season above, but the effect was also observed during the 2018 and 2020 seasons. Balancing profitable crop management and soil conditions to generate more grains per area, at the grain size and grain quality required, is the aim for most growers every season. Any practical methods of management for successful amelioration that enhances yield potential without over stimulating vegetative growth will need to be developed at a commercial scale to make better use of more favourable growing conditions.

Trenching (enhanced root exploration) and composted manure (better long term nutrition) can improve the crop yield components such as tiller and grain number which set the crop up for higher levels of production. However, this increased yield potential will not be realised unless there is sufficient resources available, such as soil water and nutrients, and favourable environmental conditions to allow the crop to capitalise on the improved pre-anthesis growth. The finding that roots were not extending beyond the ameliorated zone is most likely contributing to the high biomass but low grain yield scenario.

Ameliorating these soils, especially by topsoil or amendment burial, has demonstrated significant promise in increasing crop production. This may include modification of in-crop fertiliser applications, crop growth regulators or other management techniques. The 2018 results indicate that regardless of vegetative exploitation of increased resources from ameliorated treatments (eg tillers, anthesis biomass), grain yield will still be constrained by the rainfall amount received. However, the results from 2016, 2019 and 2020 seasons demonstrate that yield improvements are possible during favourable conditions.

These soils are very difficult to ameliorate due to the underlying sodicity and other chemical or physical constraints. As with this experiment, negative effects of exposing sodic subsoil from amelioration of these soils is common in commercial situations. The addition of the high nutrient manure pellets appears to have reduced these negative effects. Whether this same effect can be achieved through strategically placed inorganic fertiliser applications needs further investigation.

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