FINAL REPORT

UMU00041

Assessing the nutritional benefits of clay amendment and cultivation of sands

PROJECT DETAILS

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Summary

Addition of clay to sands covers approx. 160,000 hectares. From a survey of 30 growers, 87% reported that claying increased crop yields, however, poor subsoil incorporation in the topsoil could result in adverse effects on yields. From a survey of 97 clay pits, a wide range of variation in chemical properties and clay content were identified, with significant implications for grower practice. Varied potassium (K) status of subsoils and of the sands amended are the main nutrient management findings of this study. The key recommendation is that clay pits need to be analysed before use in order to ensure that profitable crop management decisions can be made for the clay-amended sands.

Conclusions

Variation in the texture and chemical properties of subsoil clays can be considerable among clay sources within a single pit, among paddocks within a farm and among farms.

The subsoil clays tested on average had higher nutrient retention (cation exchange capacity (CEC)), K, sulphur (S) and boron (B) than topsoils, however, in many cases subsoils contained the same or even less K, phosphorus (P) and/or S than the topsoil to which they were added.

Subsoils with properties that could harm plants were comparatively rare. High levels of salt and B were found in a minority of samples. In cases where there is adequate mixing during incorporation, the dilution of the subsoil would result in no harmful effects to plants.

High phosphorus retention index (PRI) and phosphorus buffering index (PBI) values were found in two subsoil samples which could result in decreased plant available P due to greater P sorption on the clay-amended sands. If the initial soil P level is marginal, addition of subsoils with high PRI could induce P deficiency.

Crop yields increased as a result of clay amendment at three of the four sites on the South Coast of Western Australia (WA). The average annual yield increase attributed to the clay amendment exceeded 35%. In the case of the Dalyup experiment, the increase in crop yields was approx. 50% and this was 14-15 years after initial application. The experiments that did not show any yield benefit from claying had more than 6% clay and K levels below thresholds that would induce K deficiency and also had low levels of water repellence.

The Bolgart clay treatments had contrasting effects to those at Dalyup in relation to K supply. While subsoils increased K supply and availability at Dalyup, at Bolgart there was no evidence of increased K availability to crops with subsoil addition. Indeed the results suggest that the subsoil clay limited K availability, but the mechanism was not clear. At the two sites at Badgingarra, while the subsoil clay was low in extractable K, addition on a low K sand increased crop yields, but addition to K-adequate sand had no significant effect on crop yields. In a pot experiment, clay containing 100mg Colwell K/kg acted as a source of additional plant available K. Further analysis of K forms in amended sands suggests that K was not fixed by the subsoil clay added to the clayed treatments. While some of the clays collected in the clay pit survey on the South Coast contain illite that may supply K for crops, there was no evidence gathered to suggest subsoils sorb K and limit K availability.

Higher levels of soil K, P and B were reported in the majority of the clay-amended treatments when compared to the controls. Reductions in zinc (Zn) were found at two sites as a result of clay amendment, but were not likely to have induced Zn deficiency in crops.

In the Dalyup experiment of 2013 where clay addition increased wheat yields, it depressed plant nitrogen (N) concentrations. This suggested that greater N fertiliser may be required to ensure sufficient N when crop yield is increased by clay amendment. However, in the following year, N treatments were applied to test this hypothesis, but the results were ambiguous due to a long dry spell in the spring and low yield of canola.

From the results, it was concluded that the main effect of clay addition on crop nutrition is on K due to the wide variation in K levels of both the subsoils added and the topsoil amended.

Recommendations

The important advice to growers from this study is that key subsoil clay properties should be tested prior to applying subsoil. At present, three out of four growers reported they did not use a soil test to select subsoil clay. Since subsoil texture and chemical properties vary, there are opportunities through soil testing to identify the sources of subsoil which will be most beneficial to crop production and avoid those that will produce limited profit. Across a farm, paddocks of deep sand or deep sandy duplex can be prioritised according to the properties of the subsoil. Targeting the paddocks where greatest benefit can be obtained will generate profit that can be used to fund the treatment of other paddocks over time. Soil tests should include clay %, Colwell P, Colwell K, extractable S, pH, electrical conductivity (EC), and PRI and PBI, and could also include extractable B in those regions where high subsoil B is common.

On average, subsoils contained much higher K concentrations than topsoils, and they represent a medium to long term pool of K for supply to crops. On low K soils, this supply can correct a deficiency. Alleviation of K deficiency explains increased crop yields in a number of cases of clay amendment that were reported. Conversely, growers adding low K subsoils need to be aware that K deficiency may limit crop yields on clay-amended fields, and limit the financial return on the investment. In these cases, with the benefit of soil test information for both the subsoil and the treated sand, increased K fertiliser will help to achieve the full benefits of increased yield potential on clay-amended fields.

When yield is increased by 35% or more, as reported in this study, increased nutrient demand to achieve the higher yield potential is inevitable. An increase in N supply is predicted, but since the results were inconclusive, further research is needed to clarify how to modify N fertiliser practice to achieve yield potential while minimising the risks of haying off.

Incorporation of clay and its effect on observed haying off require further investigation. The addition of subsoil clay, its distribution through the soil profile and its effect on the soil water balance is not fully understood. If haying off on clayed areas can be alleviated, there may be potential for further yield increases.

Outcomes

Economic Outcomes

Averaged over 15 years, the Dalyup field experiment showed a crop yield increase of 50%. At the Esperance Downs Research Station (EDRS) experiment over four years, relative crop yield increase from clay addition was 42%. However, at other experiments there was no change in yield on clay-amended sands. The Colwell K level of the subsoil and of the sand amended explained most of the responses obtained. Low K subsoil (less than 50mg K/kg) did not increase crop yields, while subsoil with 100mg K/kg or more increased crop yield if the sand also had low Colwell K.

The cost of clay addition is $700-$900 /ha, and the payback period is three to seven years. For such a large investment, some certainty of returns is crucial. The survey of clay pits indicates that some subsoils contain as little as 10% clay, whereas others contain up to 75% (mean value was 39% clay). Levels of K varied from 19mg to 1,090mg Colwell K/kg (mean 331mg K/kg). Without soil testing of the clay before use, some growers will be adding subsoil with insufficient clay to make a difference to final soil clay percentage (target is 3-6%). Others will be adding subsoils that have no benefit for crop K nutrition or have high P fixation capacity that may induce P deficiency in crops.

To maximise the returns on investment, soil testing of the subsoil is highly advisable. It can lead to more profitable decisions on which subsoils to select, and on the fields to treat or not to treat. In addition, better fertiliser decisions can be made for clay-amended sands, in particular for K nutrition.

Environmental Outcomes
Water repellent sands on the South Coast region of WA often only reach 30% of water-limited yield potential. The large inefficiency of water use leads to inefficient use of other inputs, such as fertiliser. Hence raising yield to 70% of water-limited potential after claying leads to more efficient input uses. Other environmental outcomes from clay addition include reduced

wind erosion and small but significant increases in nutrient retention, soil pH and organic carbon (C).

Social Outcomes
No specific social benefits were identified. However, at a personal level, claying to increase crop productivity can improve the self esteem of some growers among their peers.

Achievements/Benefits

Clay addition can increase nutrient levels by two mechanisms: By directly adding to the nutrient pool and by retaining more of the nutrients applied. Conversely, clay addition can reduce plant available nutrient levels through adsorption and fixation and also through higher removal due to increased yields. Moreover, by stimulating increased growth, clay additions may dilute nutrients in the plant and induce deficiency if the values in untreated soils were already marginal.

Bolgart
Two field experiments were completed at Bolgart, 130km north east (NE) of Perth: clay incorporation methods, and delving and spading.
Clay addition in the Bolgart experiment increased yields in 2010 and 2011, but not in any of the following four years. Indeed in 2014, there was a negative effect of clay addition on lupin yields. At the Bolgart site, the low molarity of ethanol droplets (MED) value in 2013 suggests that water repellence was not a constraint in the latter years of the experiment even though clay content in the 0-30cm layer was only 1.5-2.5%.

At the Bolgart clay experiment, there was no obvious benefit of clay amendment for K concentrations in sands or in crops. Indeed in 2014, clay treatment appeared to decrease the concentrations of K in lupin leaves. The subsoil added at Bolgart contained 32-63mg Colwell K/kg and apparently contributed negligible plant available K. Even after five years, with annual K fertiliser applications of 13kg K/ha, there was no indication that clayed soils either contained more plant available K or supplied more to crops probably because the annual K additions were only sufficient to replace what would be removed by 2-3t of wheat grain/ha.
Clay addition without incorporation decreased crop yields in the first two years, and even in year 5 continued to do so. This reinforces the learning from clay application elsewhere that thorough incorporation of subsoil clay is necessary to maximise benefits.

In 2010, the spader tillage appeared to increase crop yields more than the offset disc tillage, especially with clay addition. The increase in yield with spader tillage persisted for the first three years. But in the fourth year (2013), disc and spader tillage gave equal crop yields while in the fifth year, yield appeared to be higher with the initial offset disc tillage.

The delving plus spading treatment consistently produced the highest yield in each of the three years, especially in 2013 which had the highest yield potential due to above average growing season rainfall. This was despite lower plant populations with canola in 2014 and wheat in 2015, and the more severe S and K deficiency symptoms and lower overall leaf S concentrations in canola in 2014. Since the MED values were low, alleviation of water repellence is not a likely explanation. Delving plus spading had a minor effect on clay content in the 20-30cm layer. However, it decreased soil strength to 60cm.

Spading alone also increased yield of wheat in 2013 and 2015, but not with canola in 2014. Spading had similar effects to delving plus spading on plant populations in each year. The increase in plant population of wheat in 2013 and the decrease in canola plant population were consistent with the yield responses, but in 2015 yield increased while plant population was depressed by spading.

The dominant constraints at this experiment appeared to be subsoil compaction that was most effectively alleviated to 60cm depth by the delving treatment. The depletion of soil water to 60cm depth within the delve line compared to the no-till plots suggests that greater soil water uptake occurred and that this could explain the higher yield in each of the three years with delving and spading of soil.

Even though delving and spading increased yields, there were negative effects in years two and three on crop establishment which may mean that the yield benefits of the treatment were under-estimated. Moreover, in year 2 (2014), delving and spading appeared to induce S and K deficiency, and in general the levels of Colwell P and several other nutrients in 0-10cm depth were decreased due to mixing topsoil in 0-30cm depth.

The soil was extremely low in Colwell K. Deep tillage treatments had no significant effect on Colwell K in the 0-30cm layer.

Hence the apparent improvement in K uptake by wheat with delving and spading may be due to improved root depth. Despite the extremely low Colwell K concentrations and appearance of leaf symptoms of K deficiency, plant concentrations in 2014 appeared adequate. In 2014, the low rainfall after July may have meant that inadequate soil water was the primary limitation rather than K for canola yield.

Spading was most effective in achieving a uniform mixing and pH increase in 0-30cm depth. Delving preceding the spading was less effective, possibly because it incorporated more acid subsoil clay into the profile or that the clay incorporated in 0-30cm depth had a greater pH buffering capacity.

The present experiment revealed numerous effects of delving and spading on crop growth. The varied expression of these constraints may alter responses to delving and spading from site to site and year to year. In the present study with high subsoil compaction, delving effects on root activity below 20cm and access to soil water were probably dominant. Secondary effects due to dilution of nutrients by mixing in the 0-30cm layer, and possibly increased leaching of mobile nutrients may be important in some years due to the marginal soil status of N, P, K, S and possibly B. In other deep sands, but not the present site, subsoil acidity may also determine crop responses to delving and the efficacy of incorporating lime with delving and/or spading. Finally, the present site had limited clay to above 70cm depth and hence was probably not an ideal site for boosting profile clay content through delving. At sites where clay is within 30-50cm depth, greater clay incorporating by delving and to a lesser extent spading may produce different responses. At sites with high levels of water repellence, additional responses to spading and delving would be expected due to improved crop establishment and weed control.

Badgingarra

Two field experiments were studied at Badgingarra, 220km N of Perth.

In five crops harvested since the Badgingarra clay rates experiment started in 2009, clay addition had no significant effect on crop yields. The site had low levels of water repellence when assessed in 2013. The subsoil used at Badgingarra was low in K (26-36mg Colwell K/kg). However, the sand to which clay was added in the clay rates experiment had more than adequate extractable K. Hence, in that experiment there was little influence of clay addition on crop K nutrition. Flag leaf analysis confirmed that wheat K status was adequate. While the sand on this site had Colwell P levels in the marginal range of grey sands, there was no consistent effect of clay addition or rate on Colwell P values in the 0-10cm layer.

At the lime, clay and incorporation experiment, clay had positive effects on yields in 2013 and 2014. Even though the same subsoil material was used as the clay rates experiment, the soil test values at the experiment were lower in Colwell P and K than the clay rates experiment. With addition of clay, Colwell K was increased from 39mg/kg, which is considered deficient for cereal crops, to 52mg/kg which is adequate. Hence the alleviation of K deficiency may explain the increase in crop yields with clay addition, but soil P levels remained deficient. The increase in yield with clay addition was consistent with an increase in flag leaf K from 1.3% K which is deficient to 1.5% K which is close to adequate.

Clay pit survey

A high degree of variation in clay content was found among the clay samples collected. Approximately one-tenth of subsoil samples had clay contents less than 25% which would be of doubtful value for clay amendment.

The PRI levels in the subsoil clays were comparatively higher than topsoil samples. This suggests that some degree of P retention would occur in clayed soils. Experimental results from Mokhtari (2014) and Hall et al. (2015) have confirmed this with significantly higher adsorption and P levels, respectively, in clay-amended soils. The experimental data support anecdotal reports that growers increase nutrient levels (N, P) in clay amended soils (N. Blumann, personal communication). Initially, the rationale was that the additional nutrients were required to meet higher demand associated with greater productivity. However, higher levels of P supply may be required initially to offset higher levels of P sorption in clay amended soils. In the longer term if the clay added retains more P and prevents P leaching, lower P rates may be possible while maintaining crop productivity.

Esperance field experiments

Three of the four experimental sites resulted in significant yield increases as a result of clay addition. When averaged across all years, the addition of clay resulted in yield increases of 50% (Dalyup), 42% (EDRS-E1), 36% (Gibson) and 0% (EDRS-W7) when compared to the control treatments. The improvements in yields can be attributed in many cases to improvements in crop germination resulting from clay ameliorating water repellence. However, in many seasons emergence was not affected by clay addition yet grain yield increases still occurred and may be attributed to increased nutrient levels and nutrient retention (CEC), as well as improved water retention found in clay amended soils (Hall et al. 2010). The site that did not show any grain yield increase to the addition of clay had 3.6% clay without amendment, was not highly water repellent (MED 1.6) and had soil K levels exceeding 130mg/kg.

Clay amended soils had increased N levels in the soil at the long term Dalyup trial site and in plant tissue analysis at EDRS (E1) trial in 2014. Nitrogen levels at the other sites were unaffected by clay addition. However, even with increased N availability and increased N uptake in clay amended sands, the dilution of plant N may reduce concentrations in shoots below levels required for optimum growth and yield. In 2013, for example, leaf N concentrations declined in clay amended sands. Based on the hypothesis that clay amendment was tipping crop growth into N deficiency, a supplementary N treatment was applied in 2014 to canola. The supplementary N increased canola shoot N above the critical concentration and resulted in shoot growth being positively correlated with leaf N. However, there was no effect of the supplementary N on seed yield of canola, possibly because of the prolonged dry spell during August-September 2014, and the low seed yield obtained (0.4t-0.7t/ha).

Soil P levels were increased as a result of clay addition at both long term trial sites at Dalyup and EDRS (W7). The P levels in canola tissue samples from the clay+spader treatment were also increased at EDRS (E1) in the third year of the experiment when compared to the control. The higher PRI and PBI values found associated with subsoil clays also indicate that P is more likely to be adsorbed and may even be fixed as a result of clay amendment. The consequence of this for crop nutrition will depend on whether soil P levels are above, near or below the critical Colwell P values.

The K levels in both soil and plant tissue samples were significantly increased at all sites as a result of clay amendment. At the Dalyup site, the addition of subsoil at rates of 200t/ha and 300t/ha resulted in soil K levels exceeding the minimum threshold (40mg/kg). The K levels in the clays used at the Dalyup and EDRS (E1) ranged from 350mg to 1,000 mg/kg. The K concentrations in subsoil of the Dalyup and EDRS (E1) experiments were above average relative to the 85 subsoils analysed from the clay pit survey. Illite is a minor mineral in some clay pit samples, while in others it was present in trace amounts. There was no clear evidence of K availability being limited by K addition in the Esperance experiments.

Although S has been found to be generally high in subsoil clay samples along the South Coast, the effect of clay amendment on S nutrition was not conclusive. It is likely that low inherent levels, leaching and sorption by added clay determine plant access to S.

In terms of micro nutrients, copper (Cu), iron (Fe), and manganese (Mn) were relatively unchanged in both soil and plant samples across all treatments and experiments. Zn was reduced in soil and plant tissue samples by clay addition in the Dalyup and EDRS (E1) trials. Boron was increased as a result of clay addition at the Dalyup site and EDRS (E1) sites when compared to the control.

Pot experiments

Addition and homogeneous mixing of powdered clays increased K uptake on both the K-deficient Bassendean sand and the K-adequate Esperance sand. After the addition of K fertiliser, the influence of clay on leaf K, shoot growth and K uptake in shoots largely disappeared. In the case of Bassendean sand that contained deficient levels of extractable K, the additional K increased shoot dry weight of wheat. The low K clay in the present study contained 102mg Colwell K/kg. The critical Colwell K level for wheat and canola yield is about 40-50mg/kg. The low K clay was not as low in extractable K as some of the subsoils used in this study, for example the Bolgart subsoil that contained 30-63mg/kg. There was little evidence of increased K uptake due to clay addition at Bolgart, whereas in the present pot experiment, the low K was an effective source of K. It was not as effective as the high K clay which contained 872mg Colwell K/kg which resulted in a 2-fold to 5-fold increase in K uptake into wheat shoots. From the clay pit survey completed on the South Coast region, Colwell K in subsoils used for clay amendment of sands ranged from 19mg to 1,090 mg/kg.

Other research

The delving and claying technologies have been in practice for more than 30 years, and impressive gains in productivity have been reported. However, little in-depth science underpins this technology. The implications for water and nutrient availability, for root distribution and leaching of making soil more heterogeneous by deep tillage, delving and claying are not well understood. As the present project shows, increases in yield are not assured from clay application. There may be more optimal ways to re-engineer these sands when delving or adding clays to enhance crop performance by understanding their influence on soil water storage, nutrient availability and root distribution. Provided the implications of re-engineering are well understood, changes such as delving or claying represent a once off addition with no ongoing maintenance.

In South Australia (SA) and WA, deep sands, sandy gravel and deep sandy duplex soils are widely used as agricultural soils despite their inherently low productivity. Clay addition to topsoils is already used in agriculture to overcome non-wetting of sands, but the current area treated is only 160,000ha. Various studies suggest that addition of clay will increase crop production and soil organic C, reduce leaching of nutrients and decrease erosion. This is a technology that can move sandy soils to a new, high performance state. Present estimates suggest that clay addition is feasible on 3.4 to 10 million ha in Australia. However, not all sites in the present study showed yield increases and hence there is a need to better understand what combination of practices lead to yield increases and what practices should be avoided. Specific research components proposed are:

- Determine the impact of clay and soil type on performance of soils, plant available water, C sequestration and nutrient leaching.
- Various types of coarse topsoils (varying in C, Fe and aluminium oxyhydroxide, clay concentration, pH) and clay-rich subsoils (varying in similar properties) or clay-rich materials (e.g. bentonite, minerals refining residues) should be evaluated to understand their relative benefits.

Increased heterogeneity of profiles
A consequence of claying and delving is to increase soil heterogeneity. Clay exists as clods of varying size in a sandy matrix within re-engineered soils. The heterogeneity of profiles introduces a range of unknown properties to the profile in terms of wetting up after rainfall, soil water and nutrient storage, leaching of nutrients, drying patterns, and root distribution. More detailed research is needed to understand these novel patterns of heterogeneity, their implications for soil performance, including soil biology, and whether more optimal patterns of clay mixing and incorporation can be designed:

1. Determine the rate of accumulation and permanence of C and clay in the soil as a result of clay addition and different land management practices.
Various long-term claying field trials and paddocks with a known history of clay addition in WA, SA and Victoria VIC) can be used. Soil cores would be examined to characterise the nature, form, amount and distribution of the C, nutrients and plant available water in the soils.

2. A series of research trials should be established across WA and SA in different agro-ecological regions and under different land-use systems. Investigations will cover spreading, delving and spading methodologies for clay enhancement of topsoils.

Additional information

Attachments

1. Crop Updates 2015 paper. Long term effects of claying on non-wetting and plant nutrition.
2. GRDC article. Clay testing vital to hone nutrient management.
3. Countryman article. Trials add weight to improved conditions.
4. Countryman article. Clay fix for non-wetting soils.
5. DAFWA article. Claying to ameliorate soil water repellence.
6. GRDC Media Release Western Region. Clay testing vital to hone nutrient management.
7. WANTFA article. Sub-soiling clay might restrict potassium availability for crops.
8. GRDC article. Nutrient benefits of clay the next step.
9. Survey of farmers claying practices.
10. Report - Pot experiments.
11. Report - Effect of claying on crop production and soil nutrition.
12. Bolgart liming/delving trial.
13. Bolgart claying trial.
14. Badgingarra Research Station clay trials.
15. Farm Weekly article. Sub soiling clay restricts potassium?
16. GRDC Ground Cover Supplement July-August 2016. Tests urged before claying water-repellent soils.