Managing multiple soil constraints – long-term benefits from strategic tillage and soil amendments

Stephen Davies, David Hall, Tom Edwards, David Dodge, Chris Matthews, Chad Reynolds, Jo Walker, Department of Agriculture and Food

Key messages

- On compacted and acidic deep sand near Mingenew the combination of soil inversion and liming has shown greater and more sustained yield benefits over 10 seasons than either liming or inversion on their own.
- On repellent and compacted deep sandy duplex near Esperance, soil inversion, rotary spading and clay-spreading have resulted in consistent and significant crop yield benefits over 5-seasons whereas mitigation approaches have shown minimal benefit.
- Soil amelioration benefits are larger and last-longer when multiple soil and agronomic constraints are addressed.

Aims

To assess the long term impact and benefits of practices to manage sandplain soil constraints on crop productivity, profitability and soil properties.

Method

Mingenew

A replicated plot trial was established on deep yellow sand in 2007 on a farm near Mingenew. Constraints at the site included subsoil acidity and compaction, mild topsoil water repellence and weeds, particularly wild radish and ryegrass. Treatments were applied once-only in 2007 and comprised soil inversion with a 3-furrow Kverneland mouldboard plough and surface application of limesand in a range of combinations. Treatments applied were:

1. Untreated control
2. 2 t/ha lime (surface applied)
3. Mouldboard plough (soil inversion)
4. 2 t/ha lime applied then mouldboard ploughed
5. Mouldboard ploughed then 2 t/ha lime applied
6. 1 t/ha lime pre + mouldboard plough + 1 t/ha lime post

In 2007 the site was sown late with a barley cover crop. In 2008 canola was sown across the site using a cone seeder. From 2009 onwards the site has been sown across with the grower's machinery and managed along with the rest of the paddock. In 2013 the entire site was deep ripped by the grower to a depth of 40cm. For the 2010-2012 seasons not all treatment plots were harvested for grain yield, only bulk replicated yield comparisons between mouldboard ploughed and unploughed treatments were measured. From 2013 onwards yields of all treatments have been measured. Soil profile sampling was undertaken in 2007 and 2014.

Gibson

A replicated plot trial was established on the Esperance Downs Research Station in 2012. Soil is pale deep sandy duplex with more than 60cm of sand over clay. Topsoil water repellence was very severe. Treatments included a range of mitigation approaches for repellent soils involving alternative seeding systems in comparison with amelioration approaches including strategic deep tillage or spreading clay-rich (66% clay) subsoil at a rate of 170 t/ha with two incorporation depths. In addition to these treatments the site was split for either 0 or 2 t/ha surface applied lime, spread prior to the tillage treatments being applied.

Seeding and tillage treatments applied once-only in 2012 were:

1. Control – knife point seeding
2. Zero-till disc seeding
3. Winged points
4. Paired-row seeding boots
5. Soil inversion (Square plough)

6. Rotary spading
7. Claying – shallow incorporation to 15cm with rotary spader
8. Claying – deep incorporation to 35cm with rotary spader

The soil amelioration treatments (deep tillage and claying) were all sown with the standard knife points. Annual measurements have included crop emergence, crop nutrient uptake, peak biomass, grain yield and quality, soil water, water repellence and soil strength. Soil water repellence is assessed using the molarity of ethanol droplet (MED) test, soil water using a neutron tube and soil strength using a cone penetrometer.

Results

Mingenew

Soil pH ($CaCl_2$) measured in 2014 showed that where lime had not been applied (control and mouldboard only), the subsoil pH from 10-40cm averaged between 4.3-4.4 (Fig. 1). For any of the treatments where lime was applied the subsurface soil pH in the 10-20cm layer was much improved ranging from 4.9-5.1, but there has been little improvement in the deeper layers (Fig. 1), probably indicating that insufficient lime has been applied to get further movement.

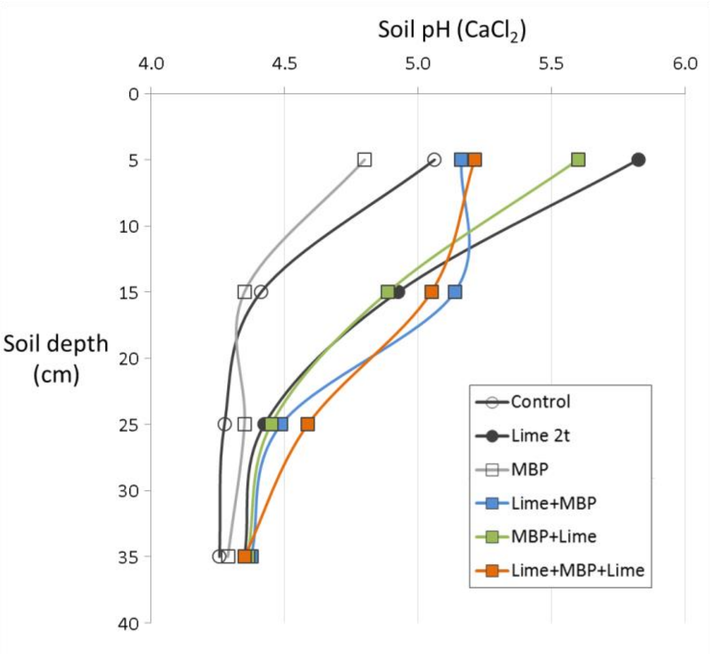

Figure 1. Soil pH ($CaCl_2$) profile for a yellow deep sand near Mingenew, WA, December 2014, in response to surface application of 2 t/ha limesand (Lime 2t), soil inversion with a mouldboard plough (MBP) or combinations mouldboard ploughing and lime applied either pre (Lime+MBP), post (MBP+Lime) or split as two 1t/ha lime (Lime+MBP+Lime) applications, all applied in 2007.

The wheat crop grown in the 2016 season was the 10th crop since the experiment commenced in 2007. Over those 10 years significant yield increases have been measured in each of the cereal years (Fig. 2). For the first 3 cereal crops in 2007, 2009 and 2011, the impact of mouldboard ploughing alone could account for the increases in grain yield (Fig. 2). In the subsequent cereal crops, in 2013, 2014 and 2016, there have been benefits from the interaction between mouldboard ploughing and liming (Fig. 2). Interestingly the order in which lime was applied in relation to the mouldboard, either all before, all after or split half-and-half, has not resulted in significant differences in crop yields. The results demonstrate the importance of incorporating lime with surface liming alone only providing a yield increase in the 2014 season when barley, a more acid sensitive species, was grown (Fig. 2). It is likely that had more lime been applied surface liming may have shown a greater benefit. Break crop benefits were only measured in lupin in 2015, again showing a significant yield increase from the combination of mouldboard ploughing and lime but not from each individually (Fig. 2). The canola yield decline in 2008 was not statistically significant and issues were largely a result of seeding too deep in the mouldboard plots. Surface crusting in loamy sands and pre-emergent herbicide damage can also be issues which affect canola in deep ploughed soils although these did not appear to be issues at this site.

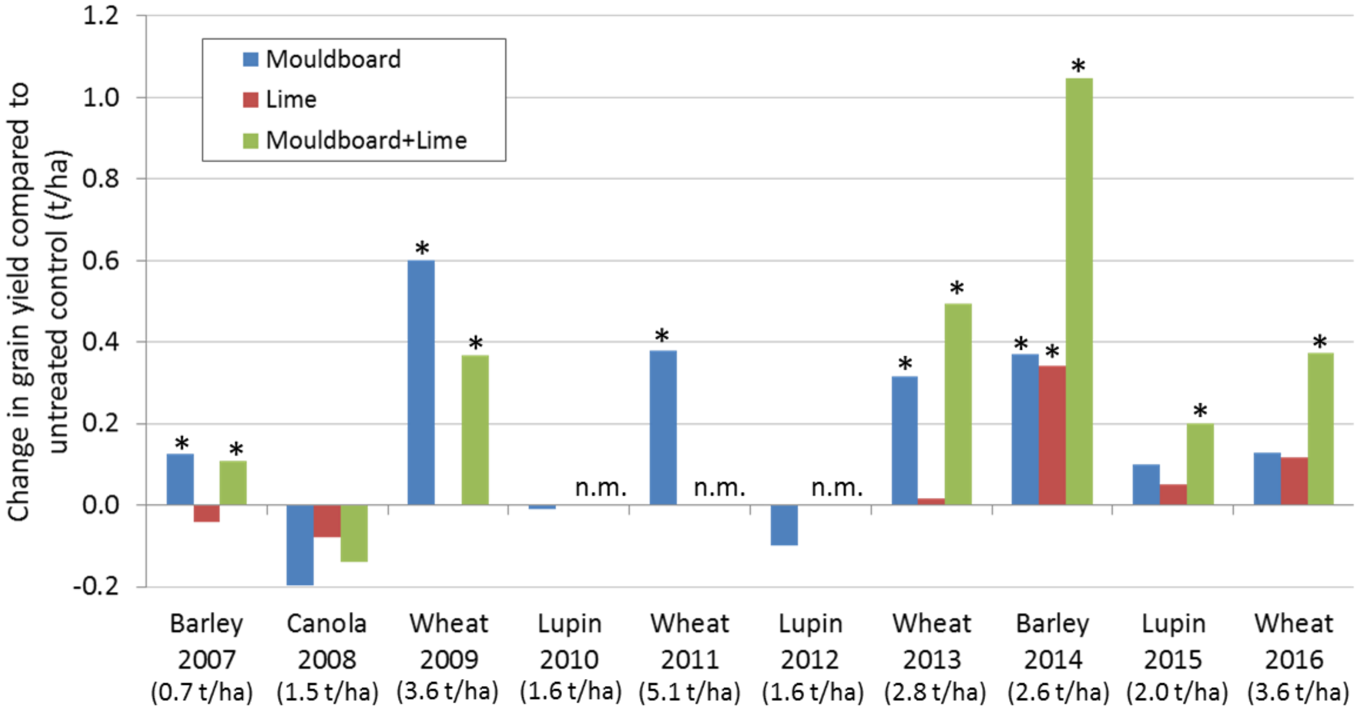

Figure 2. Change in grain yield relative to an untreated control for one-off mouldboard plough and liming treatments on their own or in combination applied once only in 2007 on deep yellow sandplain at Casuarinas, WA. Bars marked with an * indicate yield changes that are significantly different from the untreated control at P=0.05; n.m. = not measured; whole site deep ripped in 2013; 'mouldboard+lime' is average of all three treatments which included a combination of lime application and mouldboard ploughing; grain yields for control treatment shown in brackets under each cropping year .

The increasing benefit of incorporated lime over time is reflected by the cumulative financial returns from the soil amelioration treatments (Fig. 3). Returns to mouldboard ploughing started accruing after the third season and have continued since. In other mouldboard trial sites more immediate yield responses are often measured but this did not occur at this site due to a very late sown cover crop in the first season and the poorly sown canola crop in the second season. From the seventh season (2013) onwards, additional yield benefits from liming and in particular incorporated lime have also been measured with lime making a substantial contribution to the returns (Fig. 3). The combination of mouldboard ploughing and incorporated lime has resulted in the greatest returns, now totalling an additional gross benefit of $770/ha over the 10 years of the experiment.

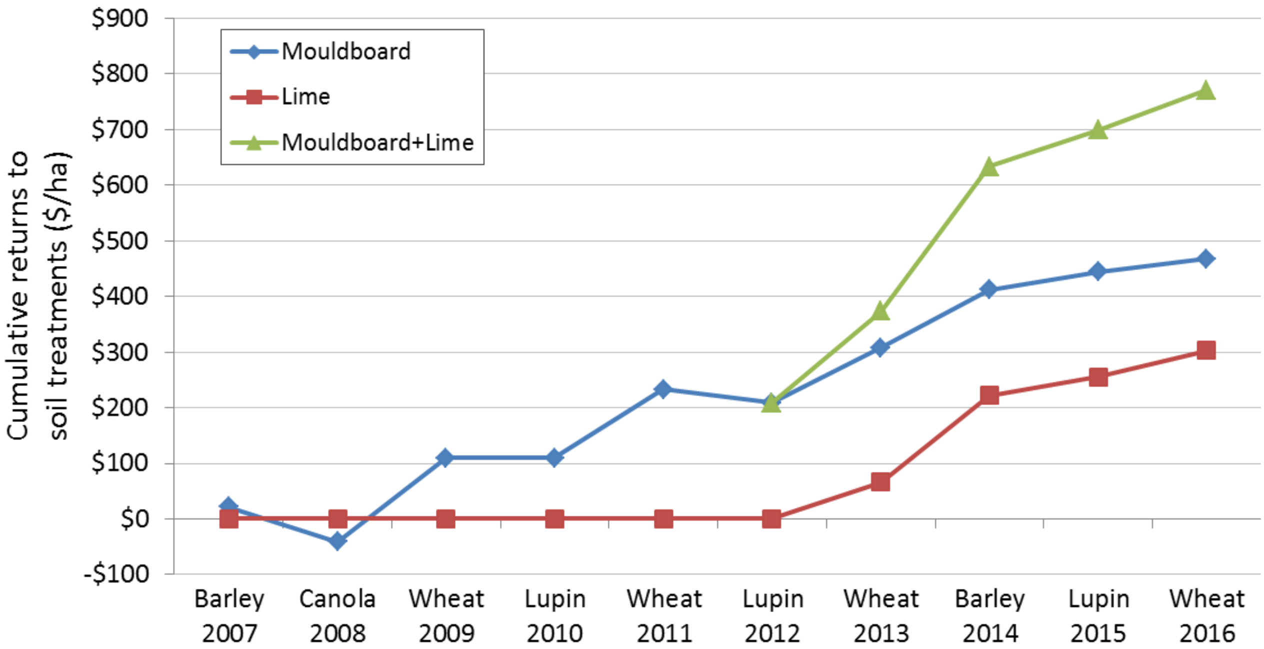

Figure 3. Change in cumulative $/ha returns for one-off mouldboard plough and liming treatments applied in 2007 on their own or combined on deep yellow sandplain near Mingenew, WA.

As well as crop productivity and profitability benefits the soil amelioration treatments have shown ongoing benefits in ryegrass control. Ryegrass biomass was measured in 2016 with the combination of mouldboard and liming having, on average, 25% lower ryegrass biomass than the control (data not shown). Mouldboard or liming on its own did not impact on ryegrass biomass in 2016. Ryegrass biomass was also measured in 2014. In that year ryegrass biomass was much higher than in 2016 and the combination of mouldboard ploughing with lime reduced average ryegrass biomass by 75%, with significant declines due to liming and mouldboard ploughing on their own also (Davies *et. al.* 2015).

Gibson

The soil at the Gibson site has a distinct hardpan with severe compaction from 20-40cm and moderate compaction from 10-20cm (data not shown). Soil inversion removed this hardpan to depth of 35cm and spading to depth of 40cm in 2013 with soil strength slowly increasing over subsequent seasons but still less than the control (data not shown). Soil water repellence, measured in 2016, was very severe (MED =3.2) for the control, severe (MED=2.5) for spading, moderate (MED=1.4) for soil inversion and low (MED=0.5-1.0) for the claying treatments (data not shown).

The 2016 season is the fifth cropping season since the experiment commenced. In 2012, the first year of the trial, wheat grain yield did respond to lime but in subsequent seasons there have been no further yield impacts from liming (data not shown). The soil pH at the site ranges from 5.2 at the surface to 4.8 in the subsoil, so while soil acidity is starting to develop it is not yet low enough to be responsive to lime. For the other soil management treatments the mitigation seeding treatments have generally shown no or even negative grain yield responses over a range of seasons and crop types (Fig. 4A). In particular yield responses to disc seeding have been disappointing with significant yield declines in barley in 2014, canola in 2015 and wheat in 2016 (Fig. 4A). In 2015 the canola was also affected by sulphur deficiency early in the season which may have exacerbated the reduced yield. The reason for the poor performance of the disc seeding is unclear and contrasts with other research (Kerr *et. al.* 2017), it requires further investigation. Establishment with the discs has been poor and this may be related to having to use them at relatively low speeds in the trial which can affect seeding depth and throw of repellent soil. Poor establishment has resulted in reduced crop competition and poorer weed control. The site is highly responsive to deep (30+cm) tillage and the discs result in the least soil disturbance.

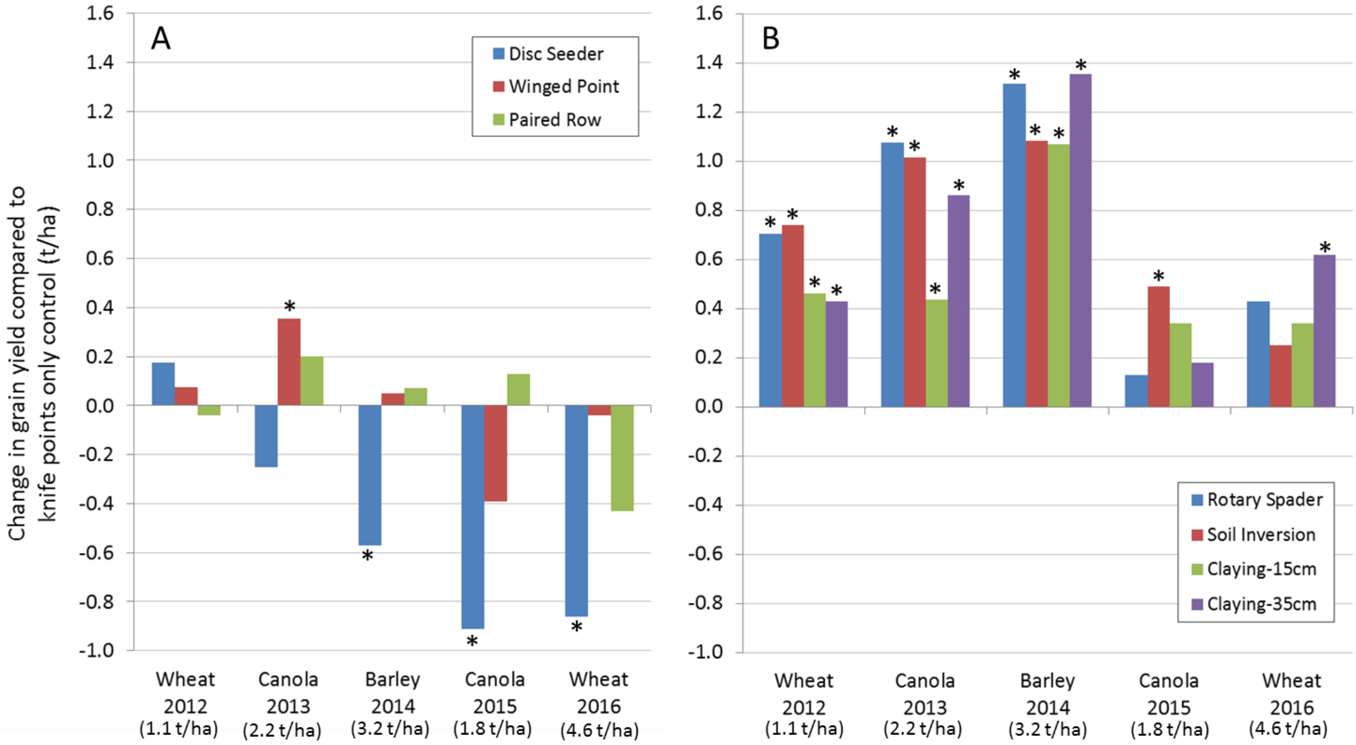

Figure 4. Change in grain yields over 5-seasons relative to narrow knife-point sown control for a range of annually applied seeding (mitigation) treatments (A) and soil amelioration treatments (B) applied once-only in 2012, for deep sandy duplex soil at Gibson, WA. Bars marked with an * indicate yield changes that are significantly different from the untreated control at P=0.05; grain yields for the knife point sown control treatment shown in brackets under each cropping year.

In contrast, both the strategic deep tillage and clay spreading, soil amelioration treatments have resulted in large grain yield increases (Fig. 4B). For the deep tillage treatments there has been no significant difference in grain yield responses between the spading or soil inversion (Fig. 4B). Deep tillage has increased average grain yields by 72% (725kg) in first year wheat, 58% (1045kg) in year 2 canola and 45% (1200kg) in year 3 barley. In 2015, year 4, sulphur deficiency affected early canola growth and yield differences were lower, more variable and not significant for any of the treatments except for soil inversion (Fig. 4). The deep tillage treatments, rotary spading and soil inversion, have yielded as well as or better than the claying for each season for the first 4-years of the experiment but in 2016 claying combined with deep incorporation was the best performing treatment. Clay incorporation depth has made a difference in yields in 2013 and 2016. In 2013, second year canola, deep clay incorporation performed better with a 48% (860kg) yield increase than shallow incorporated with a 24% (435kg) yield increase (Fig. 4B). In 2016, deep clay incorporation increased yield by 14% (620 kg). Otherwise both clay treatments have performed similarly, with a 44% (445kg) wheat yield increase in year 1 and a 46% (1215kg) barley yield increase in year 3 (Fig. 4B). Other research has demonstrated the additional benefits of deep ripping clayed soils (Hall *et. al.* 2010) and using this to remove more of the hardpan, particularly in the shallow incorporated clay treatment, could well result in larger yield gains. Soil and tissue testing also indicates that claying has improved potassium and boron nutrition of the crops (data not shown). Research indicates that subsoil clays used for spreading can sometimes contain significant quantities of nutrients, in particular potassium, sulphur and boron (Bell *et. al.* 2017).

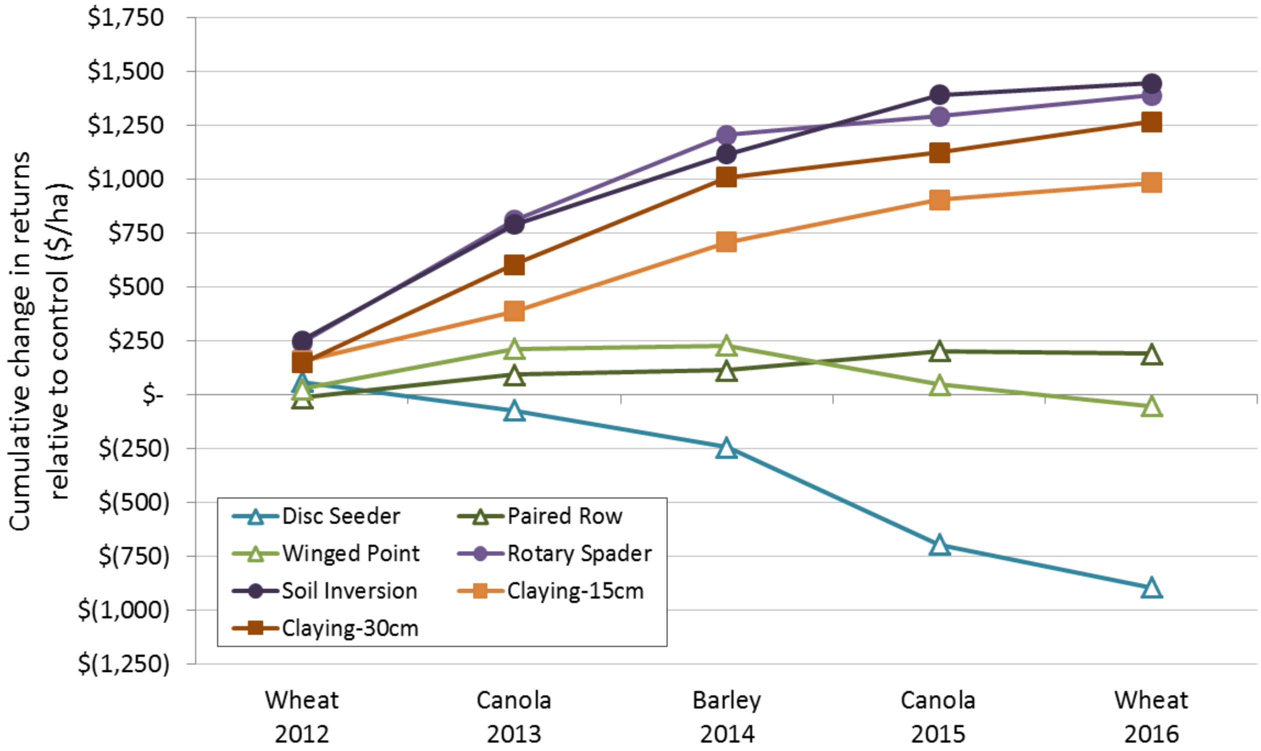

Figure 5. Cumulative change in $/ha returns over 5-seasons relative to a narrow knife-point sown control for a range of seeding (mitigation) treatments applied annually or deep tillage and clay spreading soil amelioration treatments applied once-only in 2012 on deep sandy duplex soil, Gibson, WA.

The cumulative change in financial returns reflects the consistent benefits achieved by the amelioration treatments, and, in contrast, the lack of, or sometimes, negative responses of the seeding treatments relative to the knife-point control (Fig. 5). Deep tillage has proven vital with spading, soil inversion and deep incorporated clay treatments resulting in the biggest increases in income with a total of over $1250 of extra grain grown over the 5-years (Fig. 5). The shallow incorporated clay has also performed well but has earned $250 less income over the 5-years then the deep incorporated clay. The cost of clay spreading can vary depending on the method used. For spreading clay subsoil with a multi-spreader then incorporating shallow with offset discs or deep with deep ripping and rotary spading, the estimated cost is $345/ha for shallow and $475/ha for deep incorporation. This is a cost difference of $130, so based on this it is still a benefit to have the deep incorporation. Another option may be to include deep ripping with the shallow incorporated clay as this may give the deep tillage benefit in conjunction with the long-term benefit of ameliorating water repellence with clay. Given the initial cost of spading and soil inversion are of the order of $120-150/ha these are easily the most profitable treatments to date. Performance of the seeding treatments has been poor and this is reflected in the low or reduced income over the 5-years.

Conclusion

This research demonstrates that soil amelioration benefits can last for up to 10 years when multiple constraints are addressed. Over the past 2-years of the Mingenew trial (2015 and 2016) only the combination of mouldboard ploughing with lime application has shown significant yield increases. It is clear from this and other soil acidity research (Gazey *et. al.* 2014) that 2 t/ha lime applied in 10-years is inadequate and it is possible that had additional lime been applied the yield benefit would have been greater. At the Gibson trial the only treatments to show long-term benefits are the amelioration approaches which have reduced both soil water repellence, compaction and in the case of claying, also provided a crop nutrition benefit.

This research demonstrates that amelioration approaches which address multiple soil and agronomic constraints will be the ones which show long-term productivity, agronomic and profitability benefits. At the Mingenew site more lime will be applied in 2017 and ongoing longer-term benefits beyond 10-years will continue to be assessed. At the Gibson site some of the non-performing seeding (mitigation) treatments will be replaced by some more recent developments in soil amelioration approaches (e.g. deep ripping with topsoil slotting) and the site will continue to be assessed.

Key words

Compaction, water repellence, acidity, soil inversion, liming, claying, rotary spading, mouldboard ploughing

References

Bell RW, Hall D, Sochacki S (2017) Crop nutrition and the response to claying of sands. 2017 GRDC Grains Research Updates, 27-28 February, Perth, WA. www.giwa.org.au/2017researchupdates

Davies S, Hagan J, Reynolds C, Smee V, Lefroy W, Andrew J, Newman P (2015) Long-term responses to soil amelioration – benefits will last more than 10 years! 2015 Agribusiness Crop Updates, 24-25 February 2015, Perth Western Australia. www.giwa.org.au/2015-crop-updates

Gazey C, Oliver Y, Fisher J, Andrew J, Carr S (2014) 20 years of soil acidity RD and E in Western Australia—what have we learnt? 2014 Agribusiness Crop Updates, 24-25 February 2014, Perth, Western Australia. www.giwa.org.au/2014-crop-updates

Hall DJM, Jones HR, Crabtree WL, Daniels TL (2010) Claying and deep ripping can increase crop yields and profits on water repellent sands with marginal fertility in southern Western Australia. Australian Journal of Soil Research 48, 178–187.

Kerr R, Ward P, Roper M, Micin S, Davies S (2017) Managing water repellency with minimal soil disturbance. 2017 GRDC Grains Research Updates, 27-28 February, Perth, WA. www.giwa.org.au/2017researchupdates

Acknowledgments

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. Thanks and appreciation to Bob and Murray Preston for hosting and helping manage the Mingenew site for 10-years!! This research has been funded ‘over-the-years’ by GRDC and DAFWA through a number of projects covering weeds, subsoil constraints, soil acidity and soil water repellence. The research is currently funded through DAW00244 soil water repellence and DAW00242 subsoil constraints projects which are part of GRDC’s Soil Constraints West group of projects. Thanks to Trevor Bell and Steve Cosh for in-field technical services support.

GRDC Project Number: DAW00244 (water repellence) and DAW00242 (subsoil constraints)

Reviewed by: Geoff Anderson (DAFWA)