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EPARF
EYRE PENINSULA
Agricultural Research Foundation

WELCOME

I would like to welcome everyone to another EPARF Member day. Firstly, thank you to all the people who helped to put the day together and for the speakers who agreed to come along to pass on their knowledge to our members.

Once again thanks to our sponsors who make the day more of an “event” for everyone to enjoy. Our sponsors I would like to thank are:

Nufarm	AGT	Free Eyre Grain
Curtis’s	Letcher Moroney	CBH Grain
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Special thanks to Rabobank for supplying refreshments during the day and BankSA for providing the evening meal.

There are also some new staff at MAC that I would like to introduce; Mariano Cossani (Regional Research Agronomist, Senior Research Officer) and Jake Hull (Farm Manager).

Please introduce yourself and make them feel welcome.

Today’s topic is looking at sandy soils and how to increase the productive capacity of some of these soil types. Unfortunately the EP has some tricky soils and over the years they have proven to limit the yields of crops. The idea to host a day looking at soils has been floated around for a while now and with Rural Solutions New Horizons project up and running with some positive outcomes it was felt the time was right to put things together.

Some of us may remember a few years ago Sam Doudle had some experiments called the grave site plots where the idea was to bury nutrients deep in the soil profile to promote root growth deeper into the subsoil. These plots showed good yield benefits but how to extrapolate these small plots to a paddock scale was the problem.

But let’s see what some of the current practices being looked at now are and how they are performing.

Cheers

Simon Guerin

PROGRAM

Start	Time + Q's	Topic	Speaker
1.00	10	**Welcome and Introduction**	Simon Guerin - EPARF Chairperson
1.10	20	**Sandy Soils - Defining the Issue**	Brett Masters - PIRSA
1.30	30	**Amelioration of constrained sandplain soils in WA**	Dr Stephen Davies - Dept Ag WA
2.00	30	**Seven lessons learnt from seven years of research on Mallee sands**	Dr Rick Llewellyn - CSIRO
2.30	**20**	***AFTERNOON TEA***	
2.50	10	**EPARF AGM**	Simon Guerin - EPARF Chairperson
3.00	20	**New Horizons trial results - what do we do now?**	David Davenport - PIRSA
3.20	30	**Huge yield benefits from Spading Trials in the SA Mallee**	Chris McDonough - Insight Extension for Ag
3.50	10	**Farmer Experience - Inversion Ploughing**	Ben Pope - Farmer, Warramboo
4.00	10	**Farmer Experience - Spading**	Hayden Whitwell - Karawatha Park, Kimba
4.10	20	**Improving furrow sowing and developing management strategies for water repellent sands**	Dr Stephen Davies - Dept Ag WA
4.30	40	**Panel Session**	All speakers Andy Bates - Facilitator
5.10	5	**Evaluation**	Naomi Scholz
5.15	5	**Close**	Simon Guerin - EPARF Chairperson
5.20		**Drinks and BBQ tea**	

SANDY SOILS – DEFINING THE ISSUE

Brett Masters

Soil and Land Management Consultant – PIRSA, Port Lincoln

Almost 3 million hectares of land on the Eyre Peninsula have been cleared for agricultural production. Work undertaken in the Government of South Australia's soil mapping program has classified the soils of South Australia into 15 groups and 61 subgroups (DEWNR Land Information Unit 2007). Sandy soils on Eyre Peninsula make up around 51% of the area cleared for agriculture and can be broadly classified into 4 main groups (Table 1).

Table 1: General description and area of sandy soils on Eyre Peninsula

General soil description	PIRSA Land Information Subgroup	% of the area on EP cleared for agriculture
Calcareous sand to sandy loam soils	H1, A1 and B1	29%
Shallow sandy soils	B1, B3, B7 and B8	4%
Deep siliceous sands	H2 and H3	9%
Sand over clays soils	G1, G2, G3, G4, G5	9%

There are also another 64, 746 ha (2% of the area cleared for agriculture) of non-calcareous soils that have surface soil textures in the range loamy sand to sandy loam (Subgroups D5, D6 and F2).

Sandy soils are inherently prone to wind erosion as a number of soil characteristics can restrict crop germination and growth; and consequently surface cover for protection against wind erosion. These characteristics include;

1. Low inherent fertility
2. Poor moisture holding capacity
3. Water repellence.

Low inherent fertility, (cation exchange capacity) and low soil organic carbon is found in around 83% of the surface soils of the agriculture land of Eyre Peninsula. Of this there is around 453, 000 ha (16% of the area) considered to have very low inherent fertility.

Sandy soils have very low cation exchange capacity (a measure of the soils ability to adsorb and store positively charged nutrients; cations) compared to soils with higher proportions of clay. Generally organic carbon values are also low in sandy soils, often below 0.5% in the topsoil and even lower in bleached A2 horizons. Calcareous soils with similar texture often have higher organic carbon levels. This may be due to greater protection of organic carbon from microbial attack, lower levels of microbial activity, or some other factor.

Whilst sandy soils have good drainage and are not prone to waterlogging they have poor inherent capacity to absorb and retain moisture. Sand grains are larger particles compared to clay with much less lower surface area. There is less capacity to absorb water and retain it in the soil matrix.

The breakdown of plant residues by fungal hyphae can result in hydrophobic (water-repelling) waxy residues coating sand particles. This can result in uneven wetting of the surface soil as water runs off patches of water repellent soil into depressions and moves into the soil profile via preferential flow pathways. When this water hits an impervious layer the soil profile begins to back fill from the bottom of the profile back into to the A horizon. This results in patchy germination of crops and pastures. A number of rainfall events of more than 12 mm and late autumn/early winter rainfall totals of more than 25 mm per month are required to ensure even wetting of the soil surface.

The much lower surface area of sands compared to clay soils makes them more prone to water repellency and is rarely observed in soils with a clay content above 5%. It is estimated that around 16% of the area cleared for agriculture on Eyre Peninsula has a moderate inherent risk of water repellency (water repellence expressed in around 1 of every 3 years), with around 0.3% of the area having a severe risk of water repellence (water repellence expressed in most years). An increased expression of water repellence may be observed where there is an;

- Increase in years with drier autumns
- Increase in soil organic matter from long term stubble retention and minimum tillage
- Increase in the frequency of dry and early seeding, as the soil doesn't have time to wet up prior to seeding
- Use of narrow knife points for seeding as the flow of dry, water repellent soil around the sowing point result in a concentration of this soil in the furrow.

The single grain structure of sandy soils results in poorer aggregation of soil particles leading to greater potential for soil compaction. Research from Western Australia (Hagan *et al*) suggests that 10 t of axle weight results in compaction to 300 mm depth with heavier machinery causing compaction even deeper in the profile. This research suggests that many cropping soils with sandy textures to a depth of 500 mm would require deep ripping to 550 mm or more to address hardpans.

In addition to these issues calcareous variants of these soils have low nutrient availability due to "tie up" (particularly phosphorus, manganese and zinc), potential toxicities (boron and salt) as well as an increased root disease risk that can all considerably impact crop and pasture production. How these issues can be best addressed is still a major question.

References:

DEWNR Land Information Unit (2007) "Soils of South Australia's agricultural lands", Department of Environment, Water and Natural Resources.

DEWNR Land Information Unit (2007) "Land and Soil Spatial Data", Department of Environment, Water and Natural Resources.

Isbister, B, Hagan, J and Blackwell, P "The changing options for soil compaction management in the WA wheatbelt", DAFWA (2015).

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PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

NOTES:

AMELIORATION OF CONSTRAINED SANDPLAIN SOILS IN WA – AN OVERVIEW OF CURRENT PRACTICES AND RECENT DEVELOPMENTS

Dr Stephen Davies

Research Officer – Soil Productivity – WA Department of Agriculture and Food

Article prepared by: Stephen Davies, Paul Blackwell, Wayne Parker, Chad Reynolds, Giacomo Betti, Craig Scanlan, Bindi Isbister, David Hall, Chris Gazey – WA Department of Agriculture and Food

Introduction

The south-west agricultural region of Western Australia has a diverse range of sandplain soil types (Table 1) that are situated across a wide range of climatic zones. They are important soils in WA because they are the dominant soil in many parts of the wheatbelt and can potentially perform well in drier seasons. Many of these soils naturally have topsoil water repellence and relatively poor water and nutrient holding capacity. The soil pH is typically neutral to acidic, although some duplex soils can have strongly alkaline B horizons. Agriculture has often intensified and induced further constraints in these soils with increasing subsoil acidification and compaction. Soil water repellence also appears to have increased in severity although this can also be partially explained by reductions in rainfall and/or changes in rainfall distribution, in addition to the impacts of agronomic practices, including the increased prevalence of dry sowing. Soil constraints can often occur in combination on these soils (Table 1) and this can be an important driver for soil amelioration which can sometimes overcome multiple constraints and in so doing result in large increases in productivity.

Table 1: Summary of some of the main sandplain soil types in the WA south-west agricultural region, their area and typical constraints.

Soil Type	Typical Soil Classification	Area in Agric. Zone (M ha)	Typical Constraints
Pale deep sand	Tenosol	1.24	Topsoil: Water repellence, Acidity Subsurface: Compaction, Acidity, Water & Nutrient Holding Subsoil: Compaction, Acidity, Water and Nutrient Holding
Yellow deep sand	Tenosol	1.36	Topsoil: Water repellence, Acidity Subsurface: Compaction, Acidity, Water & Nutrient Holding Subsoil: Compaction, Acidity, Water & Nutrient Holding
Sandy earths	Kandosol	1.55	Topsoil: Acidity Subsurface: Compaction, Acidity Subsoil: Compaction, Acidity
Deep sandy and duplex sandy gravel	Ferric Tenosol Ferric Kandosol	1.14	Topsoil: Water repellence, Acidity Subsurface: Acidity, Water & Nutrient Holding Subsoil: Acidity, Water & Nutrient Holding
Shallow sandy duplex	Sodosol Chromosol	2.27	Topsoil: Water repellence Subsurface: Alkalinity, Sodicity, Waterlogging Subsoil: Alkalinity, Sodicity, Waterlogging, Structure
Deep sandy duplex	Chromosol Sodosol	2.42	Topsoil: Water repellence, Acidity Subsurface: Acidity, Water & Nutrient Holding Subsoil: Alkalinity, Sodicity, Structure

Amelioration of WA Sandplain Soils

For grain growers in Western Australia strategic amelioration or renovation of sandplain soils in WA is typically undertaken to remove or reduce the impact of soil and biological constraints thereby enhancing crop productivity and profitability. Agronomic benefits such as improved control of herbicide resistant weeds and root diseases and promoting improved root exploration in the subsoil so that crops perform better during drought and heat stress and use water and nutrients more efficiently are also important drivers. Soil amelioration approaches typically involve either the strategic application of a soil amendment, such as lime, dolomite, gypsum, organic matter or clay-rich subsoil, or the use of deep tillage or, typically, a combination of the two. For the purposes of this overview we will look predominantly at deep tillage and clay spreading approaches but will also discuss how these tillage approaches impact on the incorporation of soil amendments.

Deep Ripping with Topsoil Slotting

Research conducted in the 1970's and 80's demonstrated that on deep sands and sandy earths in WA wheat roots could extract water from depths ranging from 1.4 to 2.5 metres (Hamblin *et al* 1982; Hamblin *et al* 1988; Tennant 1976). The capacity for roots to extract water from such depths is critical on these soil types, which typically have relatively low water holding capacity, and the use of deeper subsoil moisture is critical for grain filling and overall water use (Delroy and Bowden 1986). The increasing problems of subsoil acidification and subsoil compaction, often in combination, can dramatically reduce the final rooting depth that crops can achieve and the effective density of roots in the subsoil.

Subsoil compaction is one of the least recognised and under-diagnosed constraints on deep sandplain soils. As machinery sizes and axle loads have increased and there has been relatively low adoption of controlled traffic farming systems in WA the severity of the compaction problem has continued to worsen. Hardpans as a result of machinery compaction have become harder and significantly deeper. Historically peak soil strength typically occurred at depths of 10-25 cm and typically reached strengths of 2.5 to 3.0 MPa (Hamblin *et al* 1992; Schmidt *et al* 1994). Recent soil strength measurements on deep sands and sandy earths throughout WA indicates that peak soil strength now occurs at depths of 20-50 cm, with strengths ranging from 3.0 to 5.1 MPa (Figure 1).

Deep ripping has been a relatively common practice for some of the deeper sandplain soils of WA and reviews of the yield responses demonstrate the significant yield gains achieved (Table 2).

Table 2: Summary of reviews of grain yield responses to deep ripping in WA sandplain soils.

Source	Time period	Soil type(s)	No. Trials	Avg. Yield Response	
				t/ha	%
Davies (2006)	1990-2005	Various	62	0.48	25
Jarvis (2000)	1981-1989	Loamy sands	46	0.65	37
Crabtree (1989)	1982-1986	Sandy duplex (<30 cm sand)	13	0.06	4
Crabtree (1989)	1982-1986	Sandy duplex (>30 cm sand)	22	0.33	22

Traditionally deep ripping in WA was done to depths of 30-40 cm, and historically this depth was adequate to remove the hardpan (Figure 1). However now because of the deeper and more severe soil compaction there may be a need for even deeper ripping to more fully remove the hardpan and realise larger yield benefits.

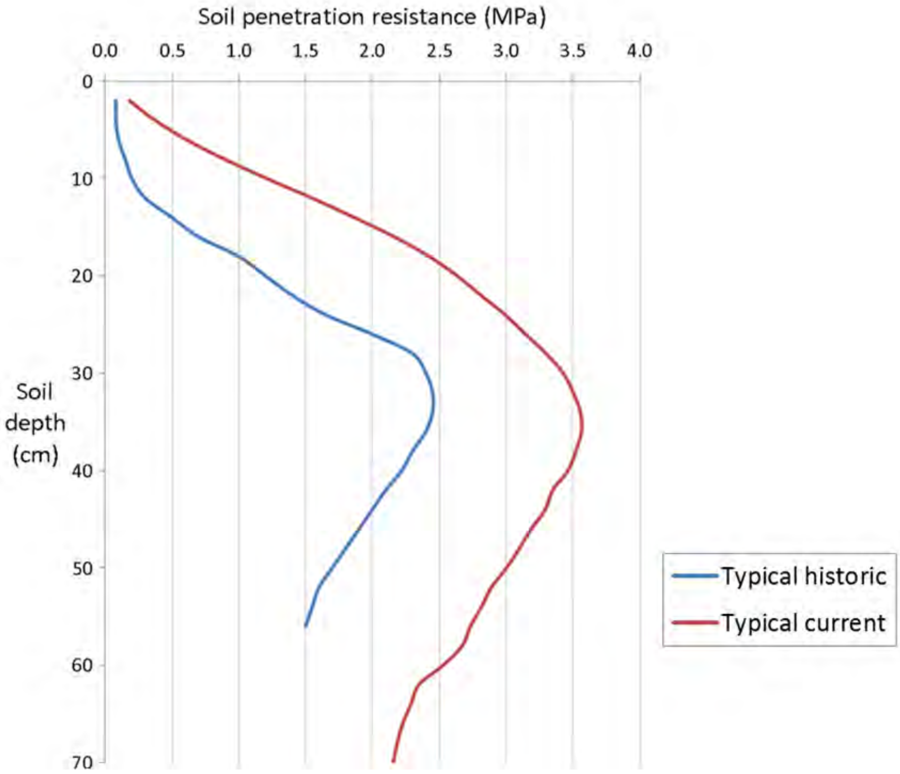

Figure 1: Plot showing typical soil penetration resistance measures for deep WA sandplain soils. Graphs are mean values for historic (1980's) and 'current' (2005-present) cone penetrometer measurements.

Recent research is demonstrating the value of even deeper ripping on further improving crop yields (Table 3). On average deep ripping to 30 cm increased wheat grain yields in these trials by 0.15 t/ha (7%) but very deep ripping to 50 cm or more increased yields by 0.52 t/ha (35%) on average (Table 3).

Table 3: Summary of deep ripping trials conducted during 2014-15 showing the crop responses to deep ripping at different depths and the impact of topsoil slotting (inclusion) on crop grain yields.

Crop	Location	Soil Type	GSR (mm)	Control Yield	Ripped 30 cm		Ripped 50-70 cm		Ripped 50-70 cm + topsoil slotting	
					Yield	%	Yield	%	Yiel d	%
Wheat	Wubin	Deep sand	228	2.1	2.7	29	3.0	43	-	-
Wheat	Binnu	Deep sand	219	0.8	0.8	0	1.4	75	1.8	125
Wheat	Binnu	Loamy sand	219	2.1	2.1	0	2.8	33	3.6	71
Canola	Moora	Loamy sand	177	1.9	2.2	16	2.8	47	2.9	53
Wheat	Beacon	Sandy duplex	240	3.8	3.9	3	3.5	-11	4.5	15
Wheat	Broomehill	Sandy duplex	227	1.8	2.0	11	3.0	67	-	-
Wheat	Munglinup	Sandy duplex	280	3.6	3.6	0	3.6	0	4.2	17
Lupin	Walkaway	Deep sand	219	1.2	-	-	2.3	92	-	-

An additional development in deep ripping practices is to put an opener on the back of the deep ripping tyne which while ripping runs below the soil surface allowing loose sandy topsoil to fall into the ripping furrow (Images 1 and 2). This results in the formation of vertical seams, or columns, of topsoil being created in the subsurface soil (Image 2). The aim of this development is to provide a nutrient and OM-rich pathway for root growth into the subsoil, to overcome subsurface acidity constraints and to improve the longevity of the ripping benefit. Addition of topsoil slotting to the very deep ripping further improved grain yields with an average wheat grain yield response of 0.95 t/ha (57%) compared to the 0.52 t/ha (35%) yield response from ripping only without topsoil slotting (Table 3).

Image 1: Soil openers on the back of deep ripping tynes. The openers run below the soil surface allowing loose sandy topsoil to be slotted deeper into the profile.

Image 2: Soil profile in severely repellent pale deep sand showing seams of topsoil incorporated into the subsurface soil from use of soil openers attached to the back of deep ripping tynes.

Ongoing research will be used to assess the longevity of the very deep ripping benefits and whether topsoil slotting helps maintain the benefits for longer. The other critical aspect for maximising the longevity and benefit from deep ripping is to implement a fully-matched controlled traffic farming system. For many deep sandplain soils it is possible to demonstrate that deep ripped areas remains soft after at least 4-5 years in controlled traffic situations. For those soils that undergo some natural re-compaction through settling and cementation processes the inclusion of organic matter is likely to help prevent this and maintain the rip lines is a soft condition in a controlled traffic scenario. Controlled traffic will ultimately result in a much improved return on investment through improved longevity of the deep ripping benefit and a reduced need to repeat the deep ripping with its associated cost.

Strategic Deep Ploughing – Soil Inversion and Deep Soil Mixing

Adoption of minimum and no-tillage grain cropping systems began in the mid- to late 80's in Western Australia after which adoption was some of the most rapid and extensive in Australia (D'Emden and Llewellyn 2006; Llewellyn and Emden 2010). The adoption of no-till was important for improving the efficiency of seeding, reducing soil moisture loss and for soil conservation (Llewellyn and Emden 2010) and the reduction in wind erosion on sandplain soil was particularly critical. Several decades after no-till adoption, however, another consequence has been that cropping soils have become highly stratified with organic matter and nutrients concentrated at the soil surface which is subjected to rapid and frequent drying exacerbated by reductions in winter rainfall. Over the same period there have been significant increases in subsoil acidification and compaction and increasing problems with herbicide resistant weeds. While liming rates have been increasing in WA movement of surface applied lime into acid subsoils has been slow partly due to reduced rainfall and minimal soil mixing which means the problem has continued to worsen. As a result growers are adopting one-off strategic deep ploughing to help address these combined issues followed by an immediate resumption of minimum or no-till cropping practices. Strategic deep ploughing tends to take one of two forms: either deep soil mixing, typically with rotary spaders or large offset disc plough, or soil inversion using mouldboard, square or modified one-way disc ploughs. Potential problems and issues include an acute short-term wind erosion risk until a cover-crop is re-established on the site, destruction of the continuity of existing biopores and root channels, re-compaction and deep wheel ruts, surface crusting, seeding too deep and increased risk of pre-emergent herbicide damage.

Deep Soil Mixing

The process of one-off deep soil mixing blends topsoil and subsurface soil together although the thoroughness of the mixing process depends on the type of plough used and soil conditions at the time. These options are particularly suited to incorporating soil amendments, particularly lime and clay-rich subsoil. The process also re-distributes nutrients through the profile, loosens the soil to the working depth of the implement and can reduce soil water repellence.

Rotary spaders are effective at burying some topsoil and lifting seams of subsoil to the surface. In repellent soils these seams act as preferred pathways for water entry (Image 3) and this improves the overall wetting of the soil profile and can significantly improve crop establishment (Image 4). Overall rotary spaders tend to bury about two-thirds of the topsoil in the 10-25 cm layer. Wheat grain yield increases in response to rotary spading are on average 600 kg/ha in the first year and around 300 kg/ha in subsequent years (Table 4) although the responses on severely repellent soils can be much greater. Current trials indicate that the benefit from rotary spading can last at least 4-5 years. At some sites the yield benefits are still large and it appears that responses will continue for many more years while at other sites it appears as though the response is starting to decline. In WA soils are typically deep ripped prior to spading as this increases the working depth of the spader, reduces wear and tear and removes rocks and stumps from the profile reducing the risk of damage. Spaders are costly to use, in part due to a relatively slow work rate and are relatively expensive to maintain so care needs to be taken with their use.

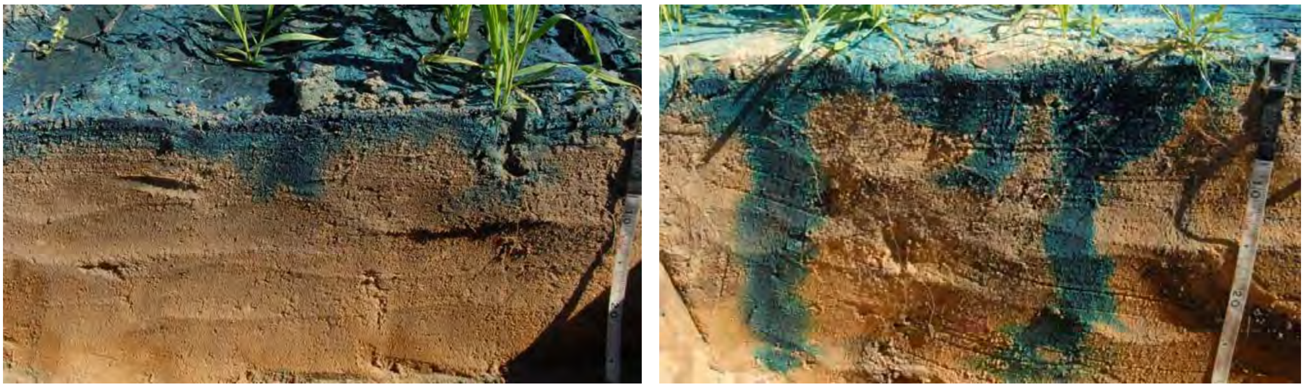

Image 3: Infiltration of water containing blue dye into a repellent sand that is either untreated (left) or has been rotary spaded (right), demonstrating how the seams of subsoil lifted to the surface by the spader has created more pathways for water entry.

Image 4: Improved wheat establishment as a result of rotary spading (left) on severely water repellent sand compared to the sparse and patchy establishment in the untreated soil (right).

Soil Inversion

Complete soil inversion is the most extreme form of deep soil tillage as it buries the topsoil in a distinct layer below a layer of subsoil (Image 5). This buried layer of relatively concentrated organic matter and nutrients greatly promotes root growth and proliferation at 15-35 cm and unlike the topsoil is not subject to such rapid and frequent drying cycles throughout the growing season. The subsoil brought to the surface is typically low in organic matter, lower in fertility and in WA is typically more acidic than the original topsoil. Depending on the soil type the subsoil brought to the surface can have higher clay content. This can be an advantage in preventing a recurrence of water repellence but can also create problems due to increasing evaporative losses from increased water holding at soil surface and surface crusting. In repellent soils the inverted subsoil brought to the surface is wettable (Figure 2) and so water tends to infiltrate evenly from at the soil surface (Image 6) which can significantly improve crop establishment.

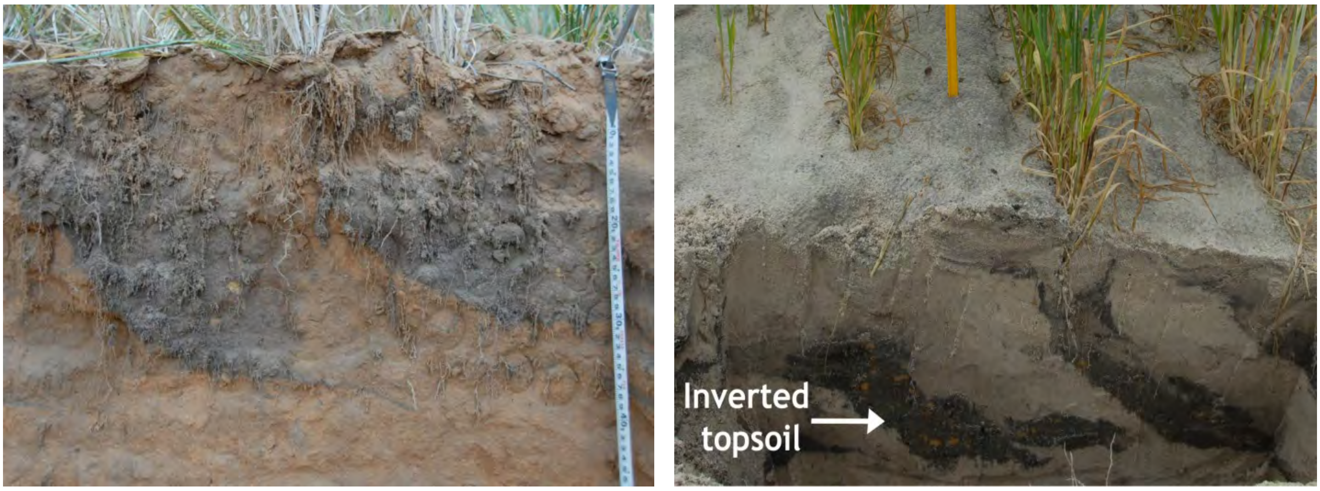

Image 5: Buried topsoil as a result of mouldboard ploughing. Note prolific root growth in buried topsoil (left image).

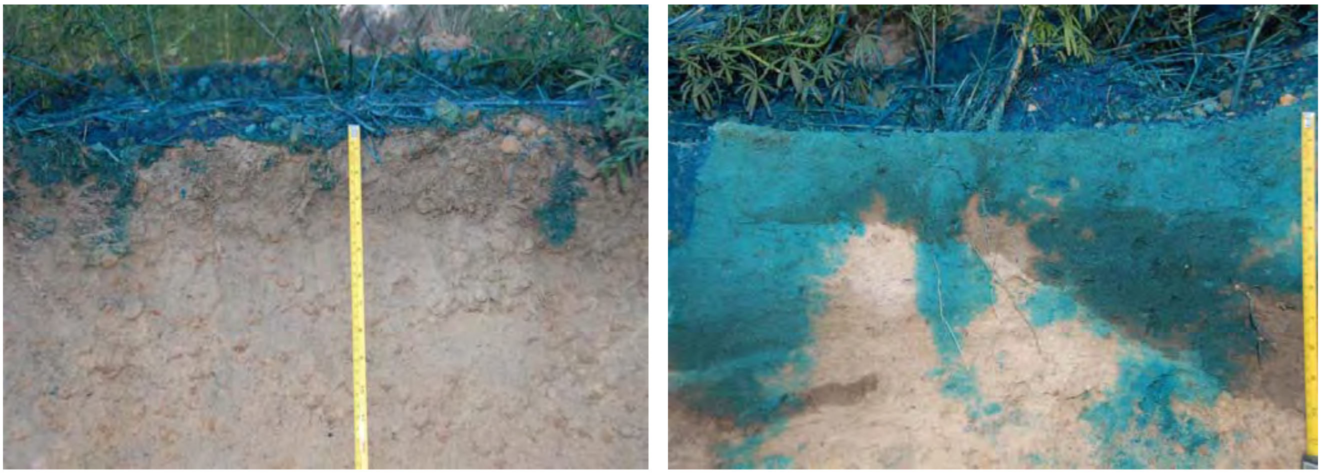

Image 6: Infiltration of water containing blue dye into water repellent sandy gravel that is either untreated (left) or has been inverted using a mouldboard plough (right).

Image 7: Improved establishment from soil inversion using a mouldboard plough (right) compared to very poor establishment on the untreated severely repellent pale deep sand (left).

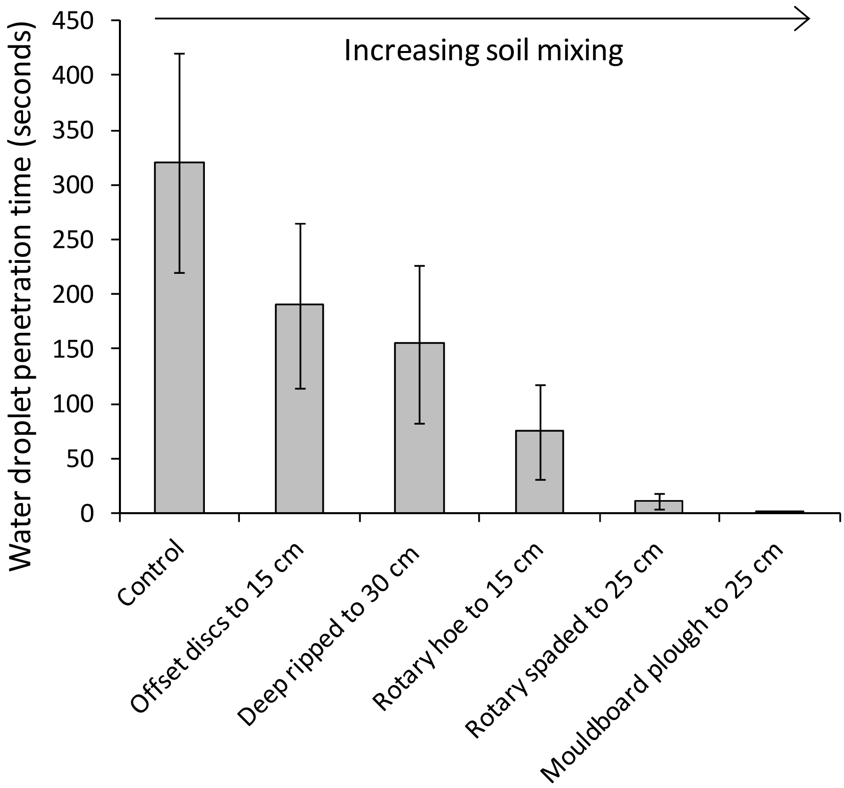

Figure 2: Impact of a range of one-off cultivation treatments the water repellence of pale deep sand at Badgingarra measured using water droplet penetration time in the laboratory. Bars are standard error of the mean (n = 4). Adapted from Roper *et al* 2015; data Davies *et al* 2012.

On severely repellent soil the yield responses to soil inversion can be large and sustained over many years (Figure 3). On severely repellent pale deep sand at Badgingarra one-off mouldboard ploughing in 2010 has increased the yield of each crop by 1.0 t/ha or more for the 6 seasons the site has been measured (Figure 4). This site is severely repellent and the yield of the control crops is always low, even in wetter seasons. It is likely that the improved yield benefits in the lupin years would help maintain the yield benefits in the cereal years due to higher fertility coming from the legume break-crop. While the crop yield increases at this site are impressive they are not necessarily typical with yield responses in other soil amelioration experiments more commonly resulting in yield increases of 400-700 kg/ha. On average the wheat yield response to soil inversion is about 500 kg/ha in the first year, with 400 kg/ha in subsequent years (Table 4). In many of the trials and on-farm demonstrations the benefits from the inversion seem to be quite long lasting, with measured benefits for 5 or more years.

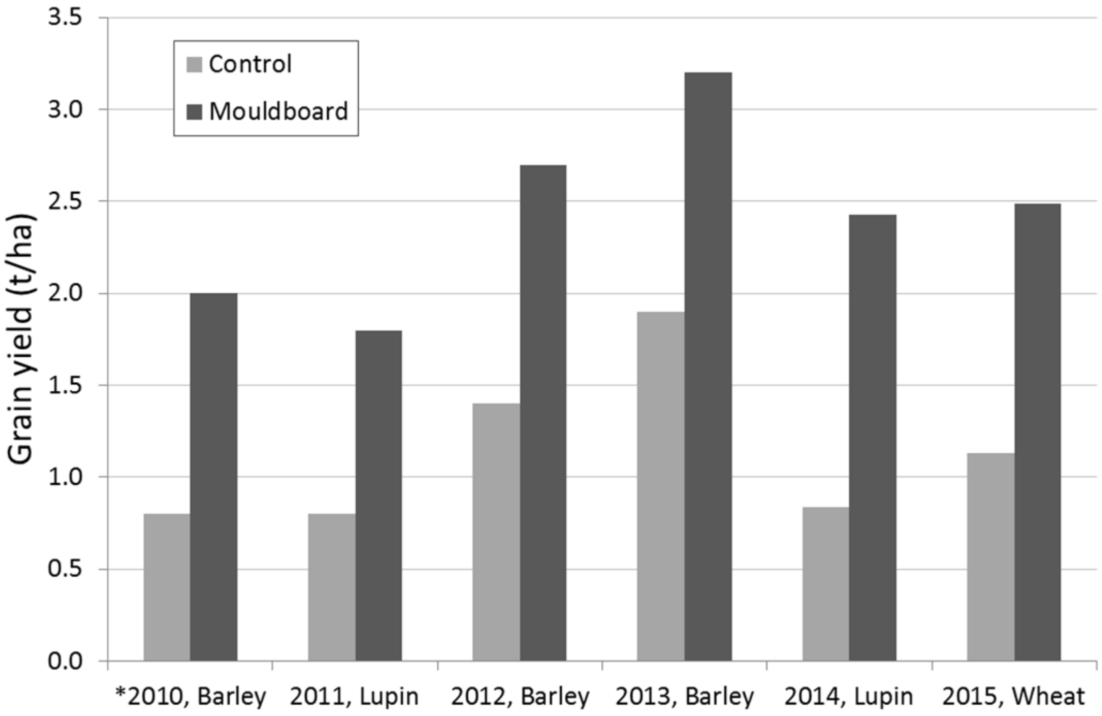

Figure 3: Grain yield (t/ha) in untreated and mouldboard ploughed treatments over 6 seasons for severely repellent pale deep sand at Badgingarra (Kenny site). *2010 was the year the mouldboard ploughing (soil inversion) was done and sown to a barley cover crop.

Burial of topsoil can have similar effects as burying compost or manure encouraging more dense crop root proliferation at depth. Root density analysis on trials (Figure 4) has demonstrated significant changes in root distribution with topsoil burial. In the control soil 70% of the roots were found in the top 10 cm while with soil inversion this shifted such that 70% of the roots could be found in the 10-30 cm part of the profile. Buried topsoil is less subject to frequent wetting and drying cycles compared to topsoil at the surface and the associated organic matter can have an important role in holding water and nutrients in the root zone.

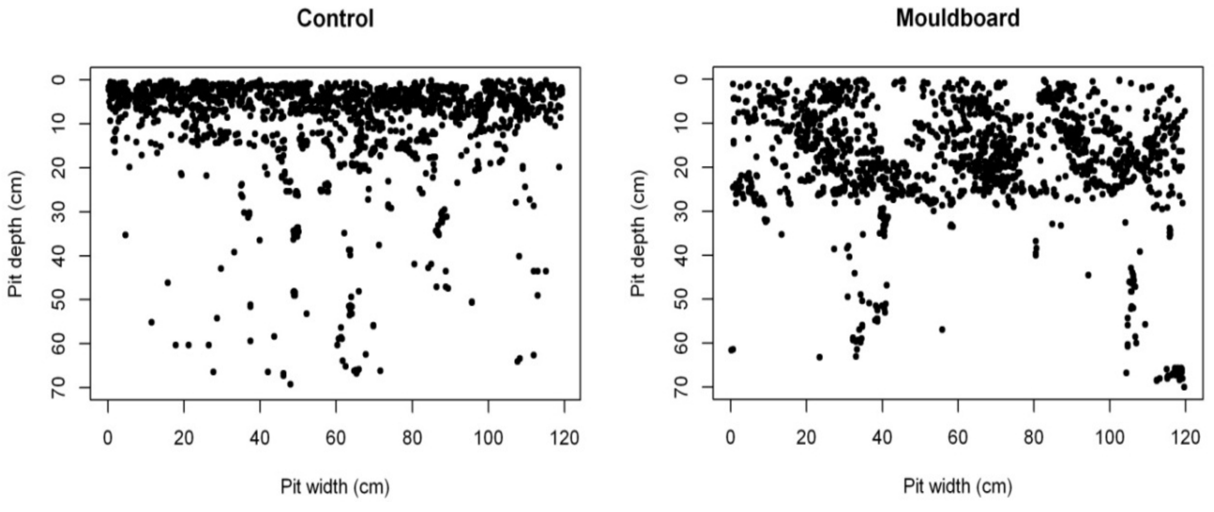

Figure 4: Wheat root interception diagrams on a soil pit face in deep yellow sand at Badgingarra in untreated (control), rotary spaded or mouldboard ploughed soil. Each dot represents a wheat root at the soil pit face.

Table 4. Summary of deep tillage methods, suitable soil types and typical wheat yield responses based on WA research.

Deep tillage implement	Working depth (cm)	Estimated cost ($/ha)	Mechanism	Suitable soil types	Typical wheat yield response (t/ha) Year 1	Typical wheat yield response (t/ha) 2+ Years	Longevity of benefit (years)	Main constraints addressed
Standard ripping	30-40	$50-60	Deep working tynes break out hard pans, minimal soil mixing.	Deep sands, loamy sands & deep sandy duplex	0.2-0.5	0.1-0.3	3+ (> with CTF)	Compaction
Very deep ripping	50-70	$80-90			0.6*	?	3?	Compaction
Very deep ripping with topsoil slotting	30-70	$90-100	Openers behind ripper tynes allow topsoil to fall into the profile.		1.0*	?	5+	Compaction, subsoil acidity, deep nutrition
Rotary spader	30-35	$150-200	Rotating spades bury about 70% of the topsoil and lift seams of subsoil to the surface.	Deep sands, loamy sands & deep sandy duplex	0.6	0.3	5-7	Subsoil acidity, water repellence, deep nutrition, compaction, resistant weeds
Offset disc plough (deep working)	35-45	$50-60	Large scalloped offset discs mix soil to working depth. Deep ripping prior to offsets can increase working depth and mixing efficacy.	Deep sands, loamy sands, deep sandy duplex, sandy gravels	0.5*	?	?	
Mouldboard plough	35-40	$100-150/ha	Skimmers and plough boards invert soil into furrows – very effective burial of topsoil.	Deep sands, loamy sands, deep sandy duplex, sandy gravels, loamy gravels	0.5	0.4	5-10+	Water repellence, resistant weeds, deep nutrition, compaction, subsoil acidity
Square plough	30-40	$80-100/ha	Plough boards invert soil into furrows.					
Modified one-way disc plough	35-40	$60-80/ha	Every second disc removed and large (28in+) discs fitted. Inverts the soil, typically on an angle from the surface.		0.9	?	5-10+?	

*Based on very limited data sets

Other tools suitable for soil inversion include square ploughs and modified one-way disc ploughs. Chamberlain and Shearer one-way disc ploughs are being used by a number of growers in WA as a means of inverting the soil much more cheaply given the low capital cost required to purchase and modify a second-hand one-way plough. The one-way ploughs are modified by removing every second disc, which is important because it allows sufficient space between the discs for the soil to fully turn over. With every disc in place the soil will just be thrown up onto the jump-arm and back of the neighbouring disc and fall down in a mix. The growers also fit bigger, scalloped, discs, typically 28-30 inches or more, to engage the subsoil and bury repellent topsoil. Shearer ploughs are heavy but on the Chamberlain ploughs growers often add extra weight to improve the soil penetration which is further aided by having fewer and larger discs. The ploughs tend to be used partly closed up rather than fully open to achieve a degree of bulldozing which allows the soil to roll through the disc and be turned over. Another advantage of one-way ploughs is they can be used on gravel soils provided there is not too much cemented gravel rock.

Image 8: A modified one-way disc plough being used to invert water repellent sandy gravel (left image) and the soil inversion achieved using a modified one-way plough on repellent pale yellow deep sand (right image) near Badgingarra WA, 2015.

Clay Spreading

In WA clay spreading has traditionally been carried out using carry graders which apply the clay-rich subsoil in relatively thick ‘windrows’ which need subsequent smudging, cross-working and incorporation. This approach has often proved successful in cooler and wetter climates along the south-coast but has given mixed results in central and northern parts of the wheatbelt. High clay rates and inadequate incorporation coupled with dry seasons, poor finishes or mid-season dry spells has often resulted in claying increasing haying off and reducing grain yields. An alternative approach to spreading clay is to spread lower rates using a heavy duty multi-spreader (Image 9). This can result in more even spreading and negate the need for additional smudging to spread heavy ‘windrows’ of clay. At these more moderate rates incorporation with offsets and cultivators is often sufficient, reducing the need for more costly deep incorporation required when heavy rates are applied.

Image 9: Spreading of clay-rich subsoil onto water repellent sand using heavy duty multi-spreaders near Moora 2016 (left image) and Binnu 2009 (right image).

Trial results indicate that clay spreading using multi-spreaders at more moderate rates can still consistently improve crop yields over many seasons. In more responsive repellent soil types there has been a 400 kg/ha average cereal grain yield increase, an increase of 37-42% (Table 5). On less responsive more productive soil the average yield gain was 300 kg/ha. Establishment has been very even and consistent on these treated soils and there is sufficient clay to stabilise the soil surface and reduce the risk of wind erosion, even in the event of stubble loss from fire or grazing. The subsoils used in the trials typically had clay contents ranging from 30-40% and were quite friable (when not too wet) but levels of K and S were lower than in some clays tested on duplex soils along the south coast.

Table 5: Grain yield responses to clay spreading at low rates onto water repellent sandplain soils in the West Midlands, WA.

Year	Site 1 – Pale Deep Sand (120t subsoil/ha)				Site 2 – Pale Sand over Gravel (100t subsoil/ha)				Site 3 – Pale Deep Sand (150t subsoil/ha)		
	Crop	t/ha	%		Crop	t/ha	%		Crop	t/ha	%
2009					Wheat	0.42	16		Wheat	0.1	5
2010					Canola	-0.01	0		Canola	*	*
2011	Wheat	0.37	26		Wheat	0.54	16		Wheat	0.4	24
2012	Lupin	*	*		Canola	*	*		Canola	*	*
2013	Wheat	0.4	18		Wheat	0.34	11		Wheat	0.6	26
2014	Lupin	0.43	46		Barley	0.15	5				
2015	Wheat	0.50	38		Wheat	0.14	19				
Average Cereal Yield Increase		*0.42*	*27*			*0.32*	*13*			*0.37*	*18*

* Yields unavailable due to hail damage or missed harvest.

Long-term Impacts of Amelioration

Soil amelioration is slow and costly and it is necessary to have long-term benefits to achieve a good return on the investment. One of the longest continuous running replicated plot trial we have was established in 2007 on deep yellow sandy earth, in a cropping paddock near Mingenew. The site had subsoil acidity, mild water repellence and a weed burden consisting mainly of wild radish and ryegrass. One-off soil inversion was achieved using a 3-furrow Kvernerland mouldboard plough (MBP). Limesand sourced from Dongara was applied to selected treatments at a rate of 2 t/ha. Treatments applied in 2007 were as follows:

1. Untreated control
2. 2 t/ha surface applied lime
3. Mouldboard plough (no lime)
4. 1 t/ha lime then Mouldboard plough then another 1 t/ha lime
5. Mouldboard plough then 2 t/ha lime
6. 2 t/ha lime then Mouldboard plough

The site was sown to cover crop of barley in 2007. In 2008 the site was sown to canola using the DAFWA coneseeder. From 2009-2014 the site has been sown across using the growers seeder.

In 2007, the first season, the Stirling barley cover crop was sown late, 28 July, so yields were low with the untreated control yielding 680 kg/ha. Despite the low yields mouldboard ploughing had 20% higher yield at 807 kg/ha. In 2008 canola was sown across the site using a coneseeder but sinkage on the mouldboard plots significantly reduced establishment and yields were slightly reduced. Since then there have been significant yield responses in each of the cereal years with yield increases due to ploughing ranging from 300-600 kg/ha (Table 6). In 2009 there was no response to lime applications either surface applied or incorporated but there was a significant wheat yield response to mouldboard ploughing. In 2015 a significant but small lupin yield response was measured for the first time (Table 6).

Table 6: Crop type, growing season rainfall (GSR), yield changes and additional income benefits for 2007-2015 seasons following soil amelioration with a combination of mouldboard ploughing and lime applied once-only in 2007. (n.m. = not measured)

Year	GSR (mm) April-October	Crop type	Crop price $/t	MBP t/ha over NIL	Lime t/ha over MBP	MBP $/ha Benefit	Lime $/ha Benefit
2007	233	Barley	220	0.1	0	22	0
2008	313	Canola	625	-0.1	0	-63	0
2009	384	Wheat	250	0.6	0	150	0
2010	257	Lupin	200	0	n.m.	0	n.m.
2011	361	Wheat	310	0.4	n.m.	124	n.m.
2012	313	Lupin	250	-0.1	n.m.	-25	n.m.
2013	350	Wheat	330	0.3	0.2	99	66
2014	226	Barley	260	0.4	0.6	104	156
2015	216	Lupin	330	0.1	0.1	33	33
					Total $ returns	**445**	**255**

Detailed measurements were made in 2014. In 2014 the entire site was deep ripped by the grower to depth of 35-40 cm. Hand harvest samples were taken at crop maturity in 2014 and assessed for shoot biomass, yield components and ryegrass biomass. Soil sampling to measure soil pH and other properties was undertaken after plot harvesting from the same locations the hand harvest samples had been taken. In 2014 a more acid soil sensitive Fleet barley crop was grown. Barley yields were increased by around 300 kg/ha for both surface liming and mouldboard ploughing without additional lime (Figure 5). In combination mouldboard ploughing and lime increased barley yield around 1 t/ha in 2014 (Figure 5), the order with which the lime as applied in relation to ploughing was not significant.

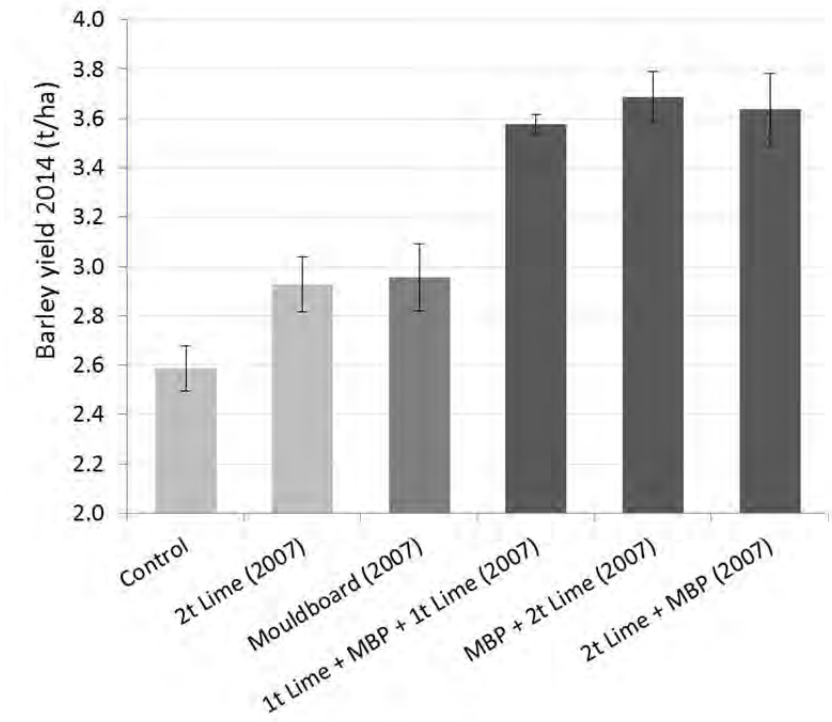

Figure 5: Impact of lime application and mouldboard ploughing in 2007 on barley grain yield in 2014.

In 2014 ryegrass biomass was measured in each treatment as visual differences in ryegrass density across the treatments were evident. Ryegrass shoot biomass was highest in the untreated control at just over 500 kg/ha (Figure 6). Mouldboard ploughing on its own had 36% lower ryegrass biomass but the impact of surface liming was even greater with a 54% reduction in ryegrass biomass (Figure 6). The combination of mouldboard ploughing with lime further reduced ryegrass biomass by up to 75%, with a trend towards lower biomass where some lime had been applied after mouldboard ploughing (Figure 6).

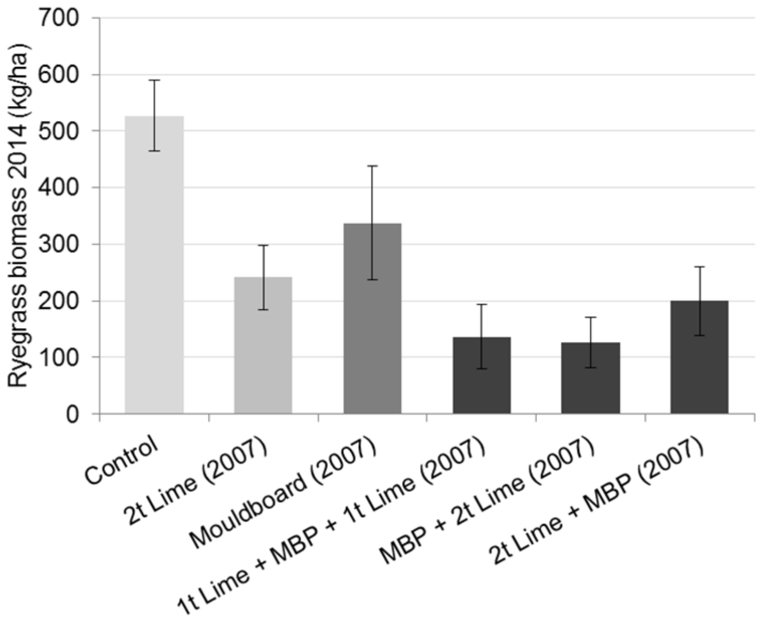

Figure 6: Impact of the lime application and mouldboard ploughing in 2007 on above-ground ryegrass biomass in 2014.

Additional income benefits from the treatments have been determined over the course of the experiment using September grain prices for each growing season (Table 6). This has not taken into account the cost of the amelioration treatments which is estimated at $150/ha for mouldboard ploughing and $50/ha for application of lime at 2 t/ha. Returns over the 9 seasons of the experiment have more than covered these costs with returns from liming providing an additional $255/ha over the past 2 seasons alone (Table 6). Overall the combined additional income generated from the combination of both soil inversion and liming has been over $700/ha over the course of the experiment.

This experiment demonstrates that soil amelioration that addresses multiple constraints can have long term productivity and agronomic benefits, in this case with improved weed control despite being a small plot trial. In many soil amelioration experiments the yield responses over the first two seasons can cover the cost of the amelioration treatments, with any subsequent yield gains being additional profit.

Issues and Risks

Soil amelioration can give large benefits and help overcome some of the most limiting constraints on crop productivity. Such large changes in soil properties however can result in many other implications and difficulties. Some of the main risks include:

1. Short-term extreme wind erosion risk - complete stubble removal by spading or soil inversion results in an extreme risk of wind erosion. Implementing the practices when the soil is wet and establishing a cereal cover crop as soon as possible is the only way to minimise the risk.
2. Seeding depth control – strategic deep tillage and very deep ripping will leave soils in a very loose and soft condition. This can make seeding the soils very difficult as seeder bars will tend to sink and equipment will leave very deep wheel tracks. Packing and firming the topsoil using rock rollers, rubber tyred rollers and other packers can help but getting the balance right between ‘packing enough but not too much’ can be difficult. For some strategic tillage operations (ripping and possibly spading) the wheel tracks can be left undisturbed giving a firm foundation for traffic. Some growers have built from old seeder frames light and very simple seeder bars for seeding ameliorated soils, which typically do not have deep working points so seed cannot be sown too deep. Some growers have had success broad cast spreading and pressing in seed with packers while others have developed or purchased equipment allowing them to plough and seed in the one pass. Cereals capable of emerging from depth are recommended in the first few years.
3. Herbicide damage – tillage approaches which reduce the concentration of organic matter at the soil surface also impact on the activity of many of the pre-emergent herbicides. Soil inversion is the most sensitive method and considerable crop damage and even seedling death can result from herbicides which now have their full activity. Trifluralin and other pre-emergent herbicides have been shown to damage crops and cereals and canola can be affected. As a result many growers will drastically reduce the rates or pre-emergent herbicides applied or may forego their use for the first few seasons.
4. Soil crusting and hostile subsoil – another risk, again most severe for soil inversion, is the bringing up of subsoil which has chemical constraints, in WA often extreme acidity, or contains enough clay top cause surface crusting and subsequent emergence issues. With soil acidity, surface liming can be used to address the

problem in subsequent years while in the meantime growing more acid tolerant crops. With claying toxicities such as salt and boron can also be a problem, although if more moderate rates are applied and this is then diluted through the sandy topsoil concentrations may not be high enough to be a problem for more tolerant cereal crops. Over time salt and boron will be leached reducing the issue.

5. Re-compaction – soils loosened by very deep tillage or ripping are very prone to re-compaction. Ideally these amelioration practices should be undertaken once a controlled traffic farming system has been implemented to reduce the re-compaction risk. Some growers after deep one-off tillage have used a tracked tractor to re-firm their wheel tracks before subsequent spraying and spreading passes.

CONCLUSION

Soil amelioration using strategic deep tillage or claying is costly and slow to implement which means it can typically only be implemented over relatively small areas in a given year. Given this, it is often important that cheap short-term mitigation options are also implemented over large areas in combination with soil amelioration as this can often give significant whole-farm returns (Blackwell *et al* 2014). In WA soil amelioration has resulted in the biggest benefits when it has been used to strategically to help overcome a suite of soil and agronomic constraints, compounding the benefits associated with the investment. Evidence is building that the benefits of soil amelioration can be long-lasting with deep tillage approaches showing benefits for 5 or more years and be highly profitable. The new approach of incorporating topsoil seams behind deep ripping tynes appears to be a particularly good option for deeper sands, provided they are not severely repellent. Ongoing research will determine the long-term benefits of this approach.

Acknowledgements:

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SEVEN LESSONS LEARNT FROM SEVEN YEARS OF RESEARCH ON MALLEE SANDS

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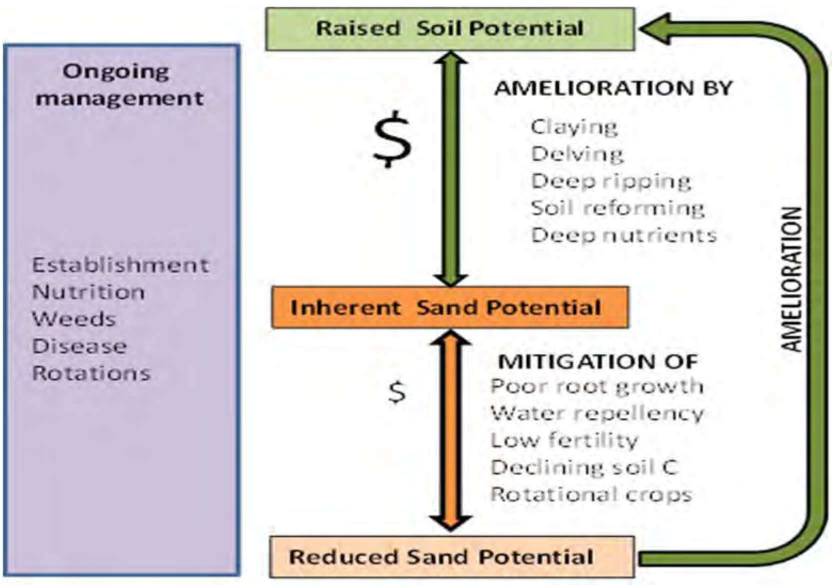
Article prepared by: Rick Llewellyn, Therese McBeath, Vadakattu Gupta, Bill Davoren, CSIRO Agriculture; Michael Moodie, Mallee Sustainable Farming

KEY MESSAGES

1. The case for variable rate soil-specific N for improving production, profit and risk management is undeniable in mallee landscapes.
2. Applying N fertiliser at seeding time has been consistently as good as or better than split applications.
3. N supply through the season will be lower on sands but is still important.
4. Legume breaks can supply enough extra N over subsequent years for an extra tonne of wheat
5. Sowing near last year's crop row can boost crop establishment on non-wetting sands.
6. Sowing near last year's crop row can suppress weed seed set on non-wetting sands.
7. Improved agronomy has allowed productivity from sands to get closer to current potential but there is an opportunity on many sands to raise the soil potential even further through amelioration treatments.

Introduction

In this article we present findings from Mallee based projects conducted in partnership with Mallee Sustainable Farming at Karoonda and Loxton over the last 7 years. The focus here is primarily on agronomic options for ongoing management and mitigation of constraints to production on sands (see diagram below from Unkovich 2014).



Findings

1. Variable rate enables better nutrition management on sands

At Karoonda SA, the wheat crops on the sandy mid-slope, dune crest and deep sands have consistently responded profitably to inputs of N, even with repeated inputs of 40 kg N/ha, while on the swale soil there has been little or no profitable response over the period 2010-2015 (Table 1).

Cumulative gross margins show benefits of +$1014/ha on the mid-slope and +$1150/ha on the dune by shifting from 9 to 40 kg/ha N fertiliser but only +$230/ha on the swale. Even the poorly yielding dune crest soil generated a highly profitable response to increased N fertiliser (+$996). Risk analysis at the paddock and whole-farm level indicates that using variable rate to increase N rates on sands has the potential in many cases to increase average profit without substantially increasing risk.

Table 1: Cumulative gross margin (2010-2015 $/ha) from continuous wheat production comparing 9 and 40 kg N/ha applied at sowing to key Mallee soil types at Karoonda. Gross margin input costs and commodity prices derived from Rural Solutions Gross Margin Guide.

	9 kg N/ha	**40 kg N/ha**
Swale	3090	3321
Mid-slope	2307	3321
Dune-crest	-40	956
Dune	660	1810

2. Applying fertiliser N early has produced good results

Applying all N fertiliser at seeding time has consistently produced good results. Over the 7 year study period at Karoonda splitting the 40 kg/ha N fertiliser rate has never out-yielded applying the full 40 kg N/ha at seeding (9 kg from DAP + 31 kg from Urea) (Table 2). Results from 2015 at Loxton with a range of broadcast timings produced similar results.

Table 2: Cumulative wheat yields (t/ha) 2009-2015 at Karoonda comparing 0, 9 and 40 kg N/ha applied at sowing and 40 kg/ha N split (9 kg at sowing plus 31 kg/ha at GS31, or earlier in later years) on Mallee soil types at Karoonda.

	Nil	**9 N**	**40 N Sowing**	**40 N split**	***LSD***
Swale	18	17	19	18	*3.0*
Mid-slope	13	15	20	19	*2.3*
Dune	8	8	13	13	*3.3*

3. *N supply through the season will be lower on sands but is still important*

Soils with a higher organic matter content and microbial activity generally supply more N through mineralisation. The rate of mineralisation in a growing season is controlled by soil moisture, temperature and the amount and quality of organic matter (e.g. C:N ratio) in the system. Sandy soils have very low organic matter and microbial biomass contents so generally cannot supply high levels of N.

For example, measurements of the N supply potential on swale, mid-slope and dune soils sown to cereal in 2009- 2013 at Karoonda indicate that the topsoil of the swale consistently had the capacity to supply more N to the crop than the sandy mid-slope and dune soils (Table 3). N supply potential measurements made at sowing can provide an indication of likely *in-season* mineralization, dependent on rainfall received within the crop season.

Table 3: Nitrogen Supply Potential (kg/ha/ cropping season in a decile 5 year) of continuous cereal cropping swale, mid-slope and dune soils at Karoonda.

Year and Soil	2009	2010	2011	2012	2013
Swale	37	33	46	58	-
Mid-slope	25	22	29	32	30
Dune	20	22	27	30	25

4. *Legume breaks can supply enough extra N over subsequent years for an extra tonne of wheat*

Break crops have generally led to a total increase in yields over subsequent wheat crops of roughly 1 t/ha and this is mostly due to N supply. In addition to extra mineral N at seeding, break crop experiments at Karoonda have measured benefits in the order of 10-20 kg/ha extra N supply potential for cereal following a legume crop compared with following a cereal.

Including legume crops and pastures has also provided clear soil nitrogen benefits at the MSF crop sequencing site at Mildura (Moodie *et al.* 2015) (Figure 1). Prior to sowing in 2013 (green bars in Figure 1), soil nitrate levels were around 30 kg/ha where a legume crop (or pasture) had been included over the previous two years, while for treatments where no legume break had been included in the rotation, soil nitrate levels were 10-20 kg/ha. Including brown manure vetch led to the highest 2013 soil nitrate levels.

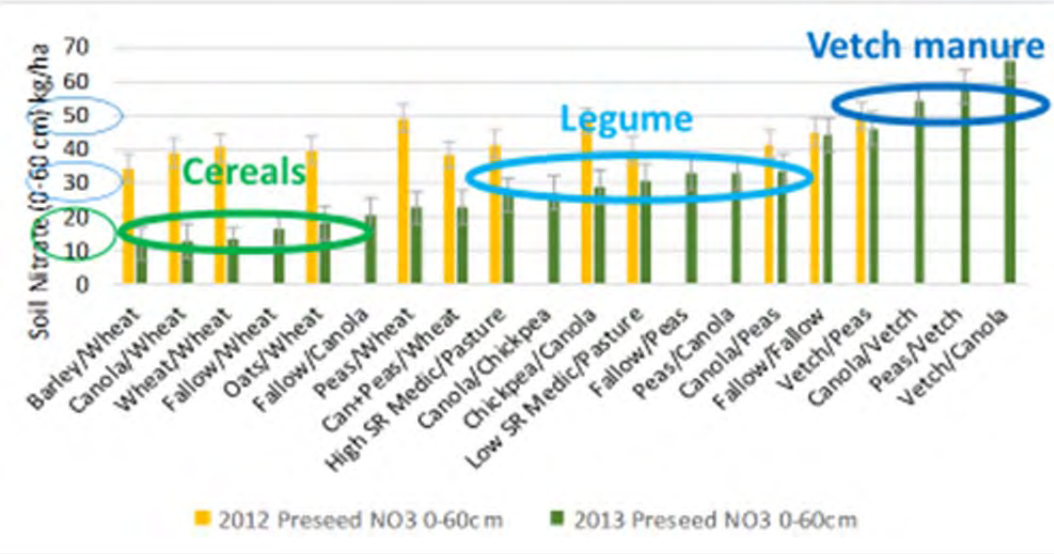


Figure 1: 0-60 cm soil nitrate (kg/ha) measured prior to seeding in 2012 and 2013. Error bars represent the standard error of each treatment. Note: soil nitrate was only measured for each crop type in 2012 and not for each treatment. Moodie, Wilhelm *et al* (2015).

5. *Sowing near last year's crop row can boost crop establishment on non-wetting sands*

In a non-wetting sand at Karoonda, sowing on or near last year's crop furrow allowed seedlings to germinate in a wetter soil (Figure 2), resulting in significant advantages in crop establishment and biomass production. Crop establishment on non-wetting sand was more than doubled with on or near-row seeding in 2015 compared to inter-row seeding. Sowing on-row in sands or loam that did not express non-wetting did not capture the same level of benefits. The potential for higher disease inoculum and a greater likelihood of N tie-up after opening rains needs to be considered, however, in trials so far, less rhizoctonia disease has been measured where crops were sown on-row.

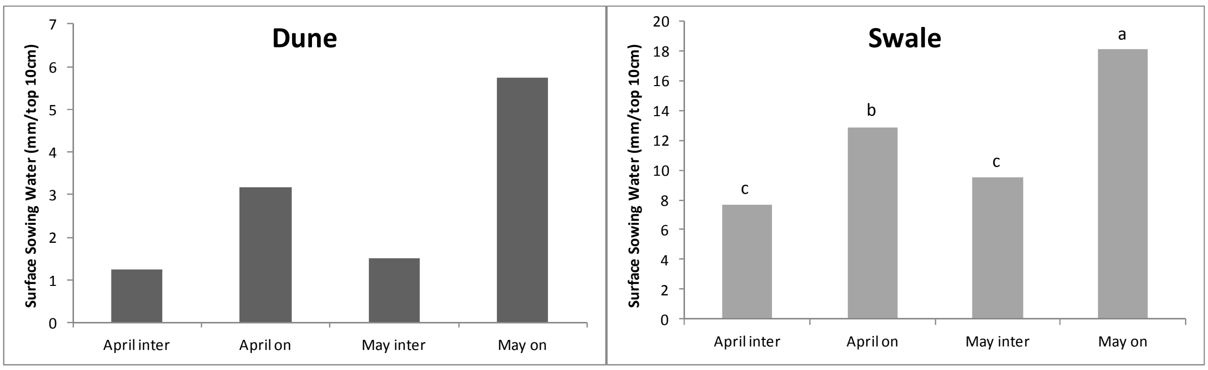


Figure 2: 2015 Karoonda site soil water (mm) measured in the top 10 cm layer at sowing at the April and May sowing dates for plots sown on-row (on) and inter-row (inter).

6. *Sowing near last year's crop row can suppress weed seed set on non-wetting sands*

Seeding near last year's crop row has resulted in brome grass seed production being reduced by over 70% at Karoonda (Table 4). On the non-wetting sand a large proportion of brome grass emerges in the furrow of the previous year's crop row. Seeding near last year's crop row resulted in more crop competition against weeds and better weed suppression compared to having high weed densities growing in the inter-row of the growing crop. The potential practicalities, benefits and risks for near-row seeding is being further investigated.

Table 4: 2015 Karoonda dune brome grass seed production (seeds/m^2)

	Brome seed set (seeds/m^2)
2015 crop sown near the 2014 crop rows	2022
2015 crop sown between the 2014 crop rows	7332

7. *Improved agronomy has allowed productivity from sands to get closer to potential but there is an opportunity on many sands to raise the soil potential even further through amelioration treatments.*

Even within the sandy soil types there is substantial variation in the 'bucket size' or plant available water capacity. This can be determined by the presence of constraints that limit crop water access. For example, the constrained sand dune-crest at the Karoonda trial site has a bucket size of just 31 mm, while the dune and mid-slope sandy soils have 120 and 110 mm. The small bucket size and lower resulting potential yield on the dune-crest means that inputs need to be moderated to account for these constraints, however N application has still been profitable on this soil type (Table 1). The substantial amount of soil water not able to be accessed by the crop also highlights the potential for amelioration treatments to raise the potential of constrained sands.

Further information

More details on this work can be found at http://www.msfp.org.au/publications/research-articles

Unkovich, M. (2014) A review of the potential constraints to crop production on sandy soils in low rainfall southeastern Australia and priorities for research. Mallee Sustainable Farming. http://www.msfp.org.au/wp-content/uploads/A-review-of-the-potential-constraints-to-crop-production-on-sandy-soils-in-low-rainfall-SA.pdf

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NEW HORIZONS TRIAL RESULTS – WHAT DO WE DO NOW?

David Davenport

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Article prepared by:
David Davenport, Amanda Schapel, Nigel Wilhelm, Brett Bartel, Mel Fraser

TAKE HOME MESSAGES

- The aim of this research was to confirm that crop productivity can be substantially improved when soil chemical, physical and biological constraints in sandy soils are treated.
- The impact of these treatments on crop production and soil condition has now been monitored for two years.
- The best soil modification treatments increased crop yields by 70 to 200%, even in challenging seasons.
- Crop productivity on infertile sandy soils can be greatly improved by incorporating organic matter deep into the soil (>30 cm).
- In some cases, crop yields are further boosted with the incorporation of clay and/or fertiliser to depth.
- Treatments that address multiple constraints in these soils provide greater benefit than those addressing individual issues.
- Crop yields are reduced when clay is poorly incorporated into the soil.

Up to 40% (4.1 million hectares) of the broadacre farming area of South Australia has soil constraints that could be overcome through the application of new advances in technology, machinery and soil management. These include non-wetting sands with low fertility and low water holding capacity and heavier soils with poorly structured subsoils. ‘New Horizons’ is a South Australian Government funded program developed to capture an additional $800 million in agricultural production per annum in South Australia from these soils. In 2014, three trial sites were established on sandy soils on the Eyre Peninsula, Murray Mallee and South East; at Brimpton Lake, Karoonda and Cadgee respectively.

The trials consist of 12 treatments including an unmodified control. Soil modifications were all applied prior to seeding in 2014 (Table 1). There are 4 replicates at Brimpton Lake and 5 replicates at Karoonda and Cadgee. Treatments were imposed to address water repellence, compaction, low fertility and water holding capacity and involved the addition and incorporation of clay, fertiliser, organic matter, or combinations of these.

Table 1: New Horizons trial treatments applied at all three research sites in 2014.

Un-clayed Treatments	Clayed** Treatments
Un-modified Control	Shallow Clay incorporated by tillage
Deep nutrition* - “Deep Banded” fertiliser	Shallow Clay with Deep nutrition “Deep Banded” fertiliser
Spading only	Spading + Clay (clay applied prior to spading)
Spading + Nutrition (additional fertiliser applied prior to spading)	Spading + Clay + Nutrition (clay and additional fertiliser applied prior to spading)
Spading + Organic matter*** (high rate of OM applied prior to spading)	Spading + Clay + Organic Matter (clay and OM applied prior to spading)
Spading + Organic matter + Nutrition (additional fertiliser and OM applied prior to spading)	Spading + Clay + Organic matter + Nutrition (clay, OM and additional fertiliser applied prior to spading)

* nutrition treatments involved application of N, P, K, S, trace elements (Cadgee and Karoonda K on deep nutrition applied in 2015)

** clay applied at 450, 500 and 600 tha^{-1} at the Brimpton Lake, Cadgee and Karoonda sites respectively

*** organic matter was applied at 10 tha^{-1} in the form of lucerne hay at Brimpton Lake and Cadgee and lucerne pellets at Karoonda

Wheat was sown on all sites in 2014 and 2015 except for Cadgee in 2015 where barley was sown. Commercial varieties suitable for each situation were used with basal N, P fertilisers applied at seeding to all treatments at rates typical for the district. In-crop nutrition management was matched to the likely potential of each treatment. Treatments with organic matter received less in-crop nitrogen than other treatments.

Measurements taken included:

- **Plant performance**; plant establishment counts, root DNA, biomass (dry matter cuts near flowering), grain yield, grain protein and screenings. Nutrient analysis of youngest emerged leaf blade (2014) and whole tops (2015) for Karoonda and Cadgee only.
- **Soil properties**; taken prior to seeding but following modification, (except for deep nutrition treatments where high fertiliser rates were applied at seeding); exchangeable cations, pH, EC, organic carbon, and bulk density was analysed in 2014 only. Pre-seeding soil mineral nitrogen & gravimetric water have been analysed in both years. Water repellence was assessed in 2015 by MED analysis.
- **Water use**; pre-seeding gravimetric water, post-harvest gravimetric water (no data collected in 2015 due to rain just prior to harvest), continuous soil moisture using capacitance probes at Karoonda and Cadgee in the unmodified control and spading + clay + organic matter +nutrition treatments.

Results

At all sites in both years the highest shoot biomass was recorded on treatments with organic matter incorporated (Table 2).

Table 2: Comparison of biomass (tha^{-1}) for all sites for 2014 and 2015. Figures in bold are significantly different to the control at 5% level.

	Brimpton Lake			**Karoonda**			**Cadgee**	
Treatment	**2014**	**2015**		**2014**	**2015**		**2014**	**2015**
unmodified (control)	1.03	3.53		0.75	1.65		0.77	3.04
deep nutrition	1.54	3.93		**1.10**	1.73		0.89	2.80
shallow clay	1.50	4.59		0.72	1.28		0.94	**3.90**
shallow clay + deep nutrition	**1.63**	3.48		**1.04**	1.87		0.78	3.52
spading	1.14	3.73		**1.21**	2.14		**1.15**	2.98
spading + nutrition	0.91	4.22		**1.64**	**2.40**		**1.40**	2.54
spading + clay	1.33	4.04		**1.48**	**2.65**		**1.25**	**4.05**
spading + clay + nutrition	1.33	4.02		**1.76**	**3.06**		**1.19**	**3.91**
spading + OM	**2.54**	**5.78**		**2.02**	**2.66**		**1.87**	**3.42**
spading + OM + nutrition	**1.96**	**6.02**		**2.41**	**2.50**		**1.73**	**3.21**
spading + clay + OM	**2.32**	**5.72**		**1.96**	**3.16**		**1.99**	**4.31**
spading + clay + OM + nutrition	**2.63**	**6.30**		**2.08**	**3.69**		**2.23**	**4.85**

Generally grain yields were highest where organic matter had been applied with or without clay and/or nutrients (Table 3). Grain yield did not necessarily reflect biomass levels with some low biomass treatments, such as spading without clay, delivering higher conversion of biomass to yield compared to the high biomass treatments with clay applied. This may reflect the dry finish to both seasons at all sites.

Table 3: Comparison of grain yield (tha^{-1}) for all sites for the 2014 and 2015 seasons. Figures in bold are significantly different to the control at 5% level.

Treatment	Brimpton Lake			Karoonda			Cadgee	
	2014	2015		2014	2015		2014	2015
unmodified (control)	1.40	1.89		0.49	0.48		0.59	1.27
deep nutrition	**1.86**	2.18		**1.57**	**0.95**		**0.90**	0.95
shallow clay	**2.01**	**2.75**		0.38	0.31		0.53	1.44
shallow clay + deep nutrition	1.51	2.05		**1.44**	**1.04**		0.67	1.26
spading	**2.29**	**2.71**		**1.47**	**0.95**		**1.00**	1.03
spading + nutrition	1.56	**2.68**		**1.14**	0.63		**1.38**	**0.87**
spading + clay	**2.48**	**2.85**		**1.07**	**0.88**		**0.84**	1.63
spading + clay + nutrition	1.69	**2.48**		**1.05**	0.69		0.75	1.60
spading + OM	**2.96**	**3.69**		**2.05**	**1.45**		**1.19**	**1.84**
spading + OM + nutrition	**2.85**	**3.82**		**2.00**	**1.44**		**1.23**	1.65
spading + clay + OM	**2.62**	**3.42**		**1.57**	**1.55**		**1.00**	**2.12**
spading + clay + OM + nutrition	**2.81**	**3.38**		**1.42**	**1.49**		**1.06**	**2.20**

Discussion

Constraints identified included:

- Water repellence – soil analysis identified that all sites exhibited water repellence with Brimpton Lake having the lowest MED values in the topsoil and with Cadgee having the highest (the higher the MED the greater the repellence). The addition of clay reduced repellence to levels where crop emergence was not affected at all sites. Spading alone was thought to address water repellence by mixing wettable sand from below 0-10 cm into the repellent topsoil but this treatment delivered mixed results with limited benefit at Cadgee. Whilst MED levels suggest all sites are water repellent plant numbers were generally significantly lower only on the control plots in Karoonda in 2015 and the control, spaded and nutrition only treatments at Cadgee in 2015. The impacts on yield are problematic. At Cadgee, despite the lower plant numbers the control delivered greater yield than in 2014 when compared to other treatments.
- Soil bulk density in the 10-20 and 20-30 cm depths of the controls at Karoonda and Brimpton Lake exceeded 1.6 gms/cm^3 – a level that is generally considered to restrict root penetration. Cadgee had not been cropped previously and soil compaction did not appear to be an issue. Spading reduced bulk density but also appeared to provide other benefits as yield increases on spaded only treatments obtained in 2014 were similar across all sites.

- Inherent fertility - all sites had low cation exchange capacity (CEC), particularly in the bleached A2 horizon, with Cadgee being the lowest and Karoonda the highest. Claying increased CEC to the depth of incorporation. Whilst deep clay incorporation treatments generally delivered higher biomass than the comparative non-clayed treatments yield benefits were not demonstrated.
- Nutrition – the addition of organic matter (OM) provided high levels of nutrients with pre-seeding mineralised N on OM treatments at all sites being higher than non-OM treatments. However, non-OM treatments had more in-crop N applied and the total amount of N applied exceeded N requirement for the yields obtained. Comparing soil fertility data to yield results adds further complications. Karoonda appears the most inherently fertile of the sites but delivered the greatest response to the deep nutrition treatments. Cadgee is the most inherently infertile site but delivered the lowest response to the deep nutrition treatments. Tissue analysis at Cadgee and Karoonda did not provide any clear indications of deficiency except for molybdenum that in 2015 was at very low levels in plants from non-OM treatments. This is being further explored in 2016.
- Soil water – there appears to be some increase in soil water on the clayed treatments but results need further analysis.

Economic analysis

Economic analysis has been undertaken but results are problematic as the cost of treatments applied in a research trial are not comparable to farmer practice. Also, the length of benefit will have a large impact on return on treatments and yield data has only been obtained over 2 years. Initial results supported by farmer demonstrations suggest that in medium rainfall districts the addition of leguminous organic matter may be economically viable over 5 years if it can be undertaken for less than $500/ha. Further on-going analysis needs to be undertaken.

CONCLUSION

Treatments that addressed multiple constraints delivered the largest and most persistent production increases with organic matter treatments delivering the largest yield increases combined over the two years. Further research is required, particularly in understanding the role of organic matter and the amount and what form of OM should be applied.

Seeding has been undertaken on all sites in 2016 with visual differences in growth between treatments already apparent. PIRSA will continue to support the trials in partnership with the new GRDC Sandy Soils project: ‘Increasing production on sandy soils in low and medium rainfall areas of the Southern Region’.

Acknowledgements:

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NOTES

HUGE YIELD BENEFITS FROM SPADING TRIALS IN THE SA MALLEE

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SUMMARY

- Spading chicken manure results in double the yields in non-wetting sands.
- Yield benefits are a combination of improved nutrition, moisture holding and breaking soil compaction.
- Spading header rows buries 15-30 t/ha straw, reduces ryegrass numbers by around 80%, and significantly reduces spading erosion risks.

2015 Spading Chicken Manure Trial Results

Spading Chicken Manure has doubled yields in the first season at two farmer scale mallee sand trial sites. This includes a non-wetting sand site surrounding a saline seep at Karoonda (Figure 1 and Table 1), as well as a large replicated farmer scale trial at Waikerie covering three sand hills, mid-slopes and loamy flats (Table 2). This included treatments such as clay spreading, chicken manure, and high fertiliser, both left on top and spaded into 40 cm.

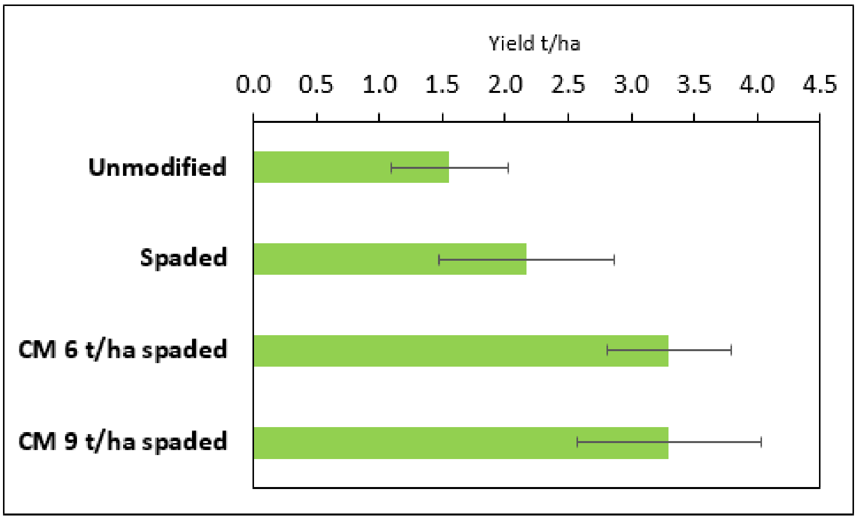

Figure 1: Plot yield comparisons, Karoonda Seeps Spading Trial 2015.

CM= Chicken manure

Table 1: Economic analysis of Karoonda Seeps Spading Trial, 2015

Modification:	Unmodified	Spaded	CM 6t/ha Spaded	CM 9 t/ha Spaded
Average grain yield (t/ha)	1.55	2.17	3.29	3.30
Income @ $220/t	$ 342	$ 478	$ 725	$ 726
Additional income	**$ -**	**$ 136**	**$ 383**	**$ 384**
Cost of modification	$ -	$ 100*	$ 310*	$ 415*
Increase $ in first year	**$ -**	**$ 36**	**$ 73**	**-$ 31**

*Spading contract cost with larger machine that ridges and better firms the soil is approx. $160/ha, not $100/ha

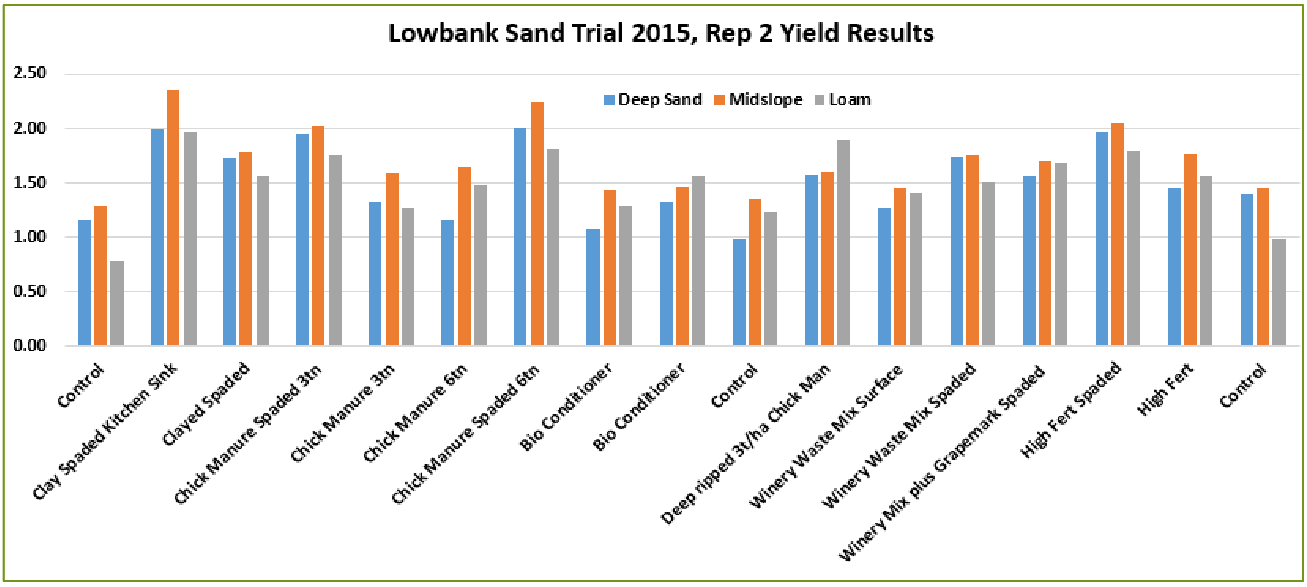

Figure 2: Yield results from the Lowbank Ag Bureau spading trial near Waikerie

Both sites had below average rainfall year with a fast finishing spring. Karoonda had a growing season rainfall (GSR) of just 169 mm (average 235 mm), and 314 for the year (340 mm average). Waikerie had close to their GSR average of 153 mm, and 206 mm for 2015 (average 267 mm).

The success of spading is a combination of breaking compaction, dramatically increasing soil fertility and improving soil moisture dynamics leading to increased rooting vigour and depth. At Karoonda spading alone increased yields by 0.62 t/ha over the control, while spading 6 t/ha of chicken manure increase yields by 1.75 t/ha. At the Waikerie trial each fertiliser treatment placed on the surface gained less than half of the yield increase of spading the treatment in.

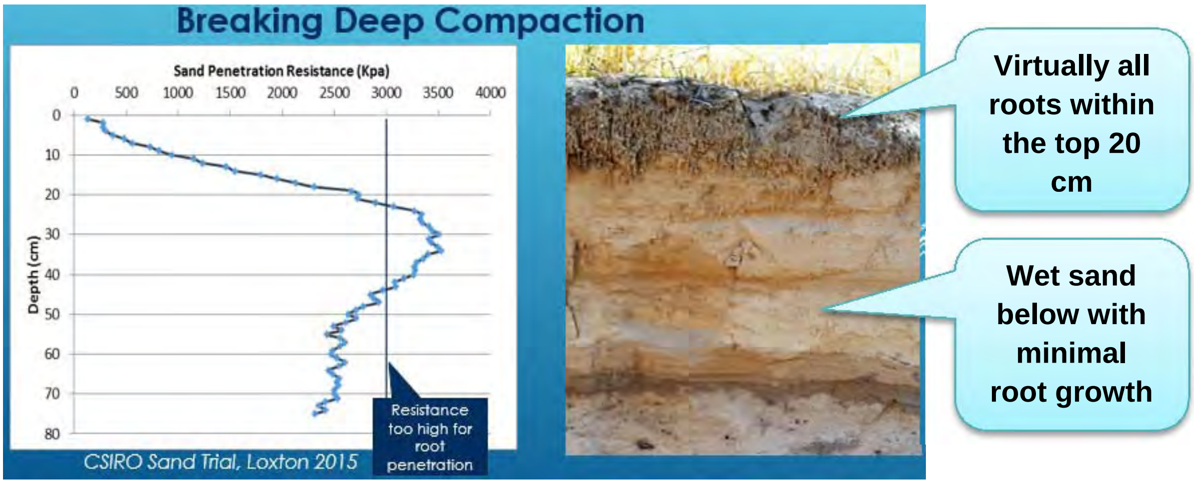

Figure 3: Example of mallee sand soil compaction.

Figure 3 gives an example of deep compaction present in many mallee sands, resulting in few roots penetrating to below 30 cm, where the soil is often still found to be wet after the crop has finished. Spaded areas in the soil pits showed strong roots growth down into the clay at 120 cm at Karoonda, and to 150 cm at the Waikerie site.

Soil moisture probe readings at both sites clearly show that rainfall events were quickly penetrating to 30 cm on the spaded areas, with much improved moisture retention, crops roots quickly accessing this moisture, as well as deeper moisture in profile. At Waikerie there was very little evidence of moisture change below 30 cm either by rainfall events or by crop moisture use on the control areas.

Figure 4: Spaded Chicken Manure site, Karoonda, 3.5 t/ha crop and strong roots beyond 1 m.

Initial economic analysis suggests treatments are affordable with costs recoverable in the short term, with the seemingly optimal rates of spading about 5-6 t/ha manure paying for itself in the first year at Karoonda and an expected two year cost recovery at Waikerie (Table 1 and 2). Other treatments may have produced a better first year gross margin but are not expecting lasting benefits.

Table 2: Gross margin comparisons of treatments at Waikerie trial site 2015.

	Ave Yld Sand & Midslope t/ha	Yield increase t/ha	$/ha Value @ $250/t	Est Cost $/ha	$ GM 1st Yr	Years to pay off
Clay Spaded Kitchen Sink	2.17	0.90	226	650	-424	2.9
Clayed Spaded	1.76	0.49	123	400	-277	3.3
Chick Manure Spaded 3tn	1.98	0.71	178	200	-22	1.1
Chick Manure 3tn	1.47	0.20	49	100	-51	2.1
Chick Manure 6tn	1.41	0.14	34	190	-156	5.6
Chick Manure Spaded 6tn	2.13	0.86	215	290	-75	1.4
Control	1.27		0		0	
Deep ripped 3t/ha Chick Man	1.59	0.32	80	110	-30	1.4
Winery Waste Mix Surface	1.36	0.09	24	30	-6	1.3
Winery Waste Mix Spaded	1.75	0.48	121	130	-9	1.1
Winery Mix/Grapemark Spaded	1.63	0.36	90	150	-60	1.7
High Fert Spaded	2.01	0.74	184	190	-6	1.0
High Fert	1.61	0.34	85	90	-5	1.1

Note that larger spading machine that better firms soil cost about $160/ha, not $100/ha as in this trial.

It is intended that these sites will be monitored over coming years to assess the long term effects of various treatments. While 5-6 t/ha chicken manure may be supplying up to an extra 150 kg/ha nitrogen into the soil (and 40 kg/ha P as well as trace elements), in many cases up to 70 kg/ha N was already removed through the high yielding grain with high protein. So while the benefits of spading chicken manure are expected to be due to more than just N supply, it may still be a significant driver of the high yield in the next few years, and will diminish over time. These are all factors that must be monitored and managed in the coming years. It may well be the case that these sandy soils are now in a better position to respond economically to higher nitrogen application with less risk, due to the improvement in soil health in the top 40 cm.

Limited deep soil tests on the sandhill at the Waikerie site this year have shown about 55 kg/ha higher N in top 60 cm than the control areas. Most of the other treatments were only slightly above or below the control level, including the high fertiliser spaded plot, the 3 t/ha chicken manure on the surface, spaded or deep ripped, suggesting that their benefit effects may not be as long lasting. The 6 t/ha chicken manure spaded also shows over twice the surface levels of Phosphorus, Sulphur and Potassium, but similar levels of organic carbon and CEC at surface and to 40 cm depth. It would be good to see more soil fertility measurements on these trials in the future.

There is a strong concern of mallee farmers over the wind erosion hazard created by spading light sandy soils. This can be minimised by spading close to seeding time and using a machine with large presswheels that leave the ground ridged (Figure 5). Even so, strong winds at seeding time this year saw paddocks sweep after spading. Some farmers are more comfortable with deep ripping their spread manure, which has been shown to be less effective, but still much safer, cheaper and more readily available than spading.

Figure 5: Spading machine purchased by mallee farmer, 4.5 m wide with ground firming presswheels.

Can similar results be achieved without access to manure sources?

The “Mallee Challenge 2016” project is working with a southern mallee farming family who have recently purchased their own spading machine. They are looking to improve their sand country, as well as use it to tackle their ryegrass issues. They are doing this partly by spading pig manure into sand hills, but also spading their header rows instead of burning them, as is common in the district.

Project monitoring of sites on this farm have shown that the header rows from 2-3 t/ha cereal crops last year have approximately 28 t/ha straw in the middle metre, and 14 t/ha a metre either side, giving an averge of close to 20 t/ha straw over the 3 m header row width. One small vetch stubble strip was measuresd at 15 t/ha. While this may not have all the nutition available as manures, it is still a significant level of organic matter. Initial counts have shown the reduction in ryegrass germination was generally 70-80%, which is understood to be an improvement on burning and seed destruction. The farmer intends to move his header rows over so that he covers his whole land after three years of crop. The other advantage is that there is less erosion risk in only spading strips, as was clearly evident this year. There has, however, been about a 30% reduciton in crop germination on areas of heavy sodic clays at the surface.

While this is early days yet, I believe there may be real possibilities in spading in header rows to provide organic matter (and N if vetch residues), and possibly spreading high fertiliser rates in front of the spader, to potetnially emulate the benefits gained by spading in manures.

The results mentioned in this artice are from the following projects:

- “Mallee Seeps Monitoring”
- “Sand improvement through manure profiling in low rainfall Northern Mallee”
- “Mallee Challenge 2015” and “Mallee Challenge 2016”

These projects are funded through the South Australian Murray-Darling Basin Natural Resources Management Board and the Australian Government’s National Landcare Programme.

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NOTES

FARMER EXPERIENCE – INVERSION PLOUGHING

Ben Pope

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Mould board inversion for non-wetting sands

- We farm 5000 ha continuous cropping, mainly minimum till
- Wheat, barley, peas, canola, vetch
- Having a lot of problems with non wetting sand on hills leading to poor germination and staggered germination of grass on hills
- Also chemical damage from pre-emergent herbicides
- Approximately 10% of property has a problem and it's getting worse in our system
- Looked into mouldboard ploughing in Western Australia early 2013 (Thanks to farmers and researchers, Tony Harding, Stuart Smart and Stephen Davies)
- Purchased 2nd hand Kvernleland 8 furrow reversible plough to trial
- 250 ha ploughed, very happy with the results, not without its problems still learning e.g. consolidating the soil after treatment
- Reasons for us to go down the mouldboard path are cost per ha to effectively renovate sandy non wetting hills and added benefits of greatly reducing weed seeds
- Negatives we have found are softness of hills after treatment, rough ends, timing of rainfall to begin treatment (needs to have a wet profile to invert correctly)

Typical poor germination.
Early sown non-wetting hills, sown early May on 15 mm of rain.

Hill 50 metres away mouldboard treated 2 years ago.
Sown 5 days later.

Mouldboard hill in the distance sown with barley.

Strip in the middle Inverted twice with mouldboard plough.
(Back to non-wetting sand on top).

Wheat on mouldboard treated hill.
Note weaker patch to the left of the line (didn't mouldboard down far enough).

Typical non wetting sand seed hasn't germinated after 52 mm of rain over 4 weeks.

A dawn shot – getting it done is a slow process!
This shot also shows it can get through a fair bit of stubble if it is clean and short, 20 cm or less.

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FARMER EXPERIENCE - SPADING

Hayden Whitwell

Karawatha Park – Graham, Barb, Dion and Chelsea Woolford - Farmers, Kimba

Article prepared by: Dion Woolford, Hayden Whitwell

- At Karawatha we run a mixed farming enterprise, growing mainly wheat and barley, and Stud stock Merinos.
- Most of our country is at Buckleboo, we are on the southern boundary of Buckleboo station and hope for 300 mm rainfall on average.
- The rest of the farm 20 km south of Kimba, is either rocky, good or sandy, and is meant to get 350 mm rainfall on average.
- This covers our take on spading. It's definitely non-scientific, and most of our learnings (good and bad) have been trial and error. Practical information and publications on this subject are hard to find, so we've had to heavily rely on other people's experience for extra information.

What is a Spader? What does it do?

It is effectively a large rotary hoe but instead of having narrow tines, it's got spades. We primarily use the spader for incorporating clay (delved or spread) from the surface down through the top 30-40 cm of sandy soil.

Why we spade:

- Purchased block with plenty of white non-wetting sand in 2000
- Started clay spreading straight away, doing a bit every year
- Clay was good at holding the soil together (stopping erosion) but like a lot of early clay spreading, it went on too heavy
- This created a clay-rich topsoil, with white infertile non-wetting sand below
- Additionally, the clay can sometimes be hostile, especially as you move deeper into the pits

Consequently, we'd get a crop up and as soon as the rain stopped, so would the crop.

Spaders are for incorporating/mixing to depth:

- Started getting Zac Halman to do our spading for a couple years, then when he "retired" from spading, we were left with no option other than to purchase his machine, as we had about 120 ha of fresh clay spreading to incorporate.
- Since then we have spaded our old clay-spread country, as well as our new clay-spread country, and more recently done more delving.
- We believe delving is better where clay is within reach, but originally we were spreading the worst tops of the sandhills as a priority, but now that's done, we have moved down the sides of the sandhills, hence the move towards delving.
- Spading is NOT the silver bullet we are all looking for, it is a tool in a system. We feel in most situations, spading should be done in conjunction with delving, spreading, and ripping, not as an alternative to these.
- Our best results have come from spreading the tops of sandhills (where clay is too deep to reach), delving the rest (including the tops) and then spading the whole lot.

Before After

Why Spading has been good:

- It has allowed us to create a living soil. Prior to the clay, there was very little organic matter on top of or in the soil. Once you get stuff growing, it snowballs.
- Better weed control. The grass (mainly brome) is (slightly) more consistent with its germination because the soil gets wet enough, so we could get a kill on it before seeding.
- It can transform paddocks. We currently work on a wheat/barley/vetch and oat rotation for the first three years after spading and it seems to work well. Cover is paramount.

What we've learnt (stuff ups):

- If you're going to spade after spreading clay, keep the clay rates up.
- Maximise the areas (I know it sounds like we are beating our own drum here, but here is the explanation): although the edge of the delved/spaded patch gives us a good indication of the response, it doesn't maximise the returns. There's nothing worse than seeing a beautiful patch of ameliorated country, with thick dark crop on it, surrounded by remaining patches of weak, non-wetting sand that should've been done at the same time. Coming back to get these patches later is not economical. We are still guilty of it this year.
- Avoid "patching out" with the delver. It might save a few hectares of delving, but it's not worth the overall savings. Where the delver turns gets rough and bare, so it drifts anyway and you're better off with "larger, squarer" areas.

Didn't spread far enough

TIPS

- It’s a ruthless process, so do it once, and do it right!!!
- If spread or delved, level/smudge the top first. You can spade straight into it, but the job won’t be as good, no matter what anyone (including yourself) tells you. It’s better to get it flat, and a reasonably even cover, and then rely on the spader to get it down.
- Traction has been an issue at seeding time, make no mistake, spaded soil is soft. There are many different options to combat this, so ask for advice before you get bogged!
- Some like to seed early into warm soil, we prefer to seed into moist soil, as the furrow holds its shape better (less likely to drift). Both options can work.
- Seed it shallow. Some drift is likely; you obviously don’t want it coming from too deep. Keep the seeding rate up, getting it covered is paramount. Feed it too.
- Once it’s been spaded, don’t look at it until seeding time, especially on a windy day. Once it’s been sown, don’t look at it for two months. This is the secret to success.
- If delving, delve along the heading (or very close to it) you are going to sow, spray and harvest it on. If you delve the across this heading, and drive over it in anything other than a tracked machine, you’ll get seasick.
- Once it’s been spaded, don’t drive across the runline. It is soft; it creates ruts, which are rough to cross. The second lap of the sprayer is the worst culprit, but this can’t be avoided. In the chaser bin, avoid turning around on the spaded stuff for the same reason.

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Improving Furrow Sowing and Developing Management Strategies for Water Repellent Sands

Dr Stephen Davies

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Article prepared by: Stephen Davies, Paul Blackwell, Glenn McDonald – WA Department of Agriculture and Food
Margaret Roper and Phil Ward – CSIRO Plant Industry

Introduction

Furrow sowing on water repellent soils can result in water harvesting from the repellent soil ridges into the seed row. Use of narrow knife points for furrow sowing however has meant that much of the dry repellent topsoil flows around the knife point, ahead of the closer plate and press wheel, and is concentrated in the base of the furrow with the seed and fertiliser (Image 1). This results in poor wetting of the seed row (Image 1) resulting in patchy and staggered establishment.

Soil water repellence in cropping systems can be managed by:

1) Mitigation strategies which enhance the wetting up of the seed row by improving the effectiveness of furrow sowing. This improves crop establishment but does not change the nature of the soil water repellence itself.

2) Amelioration strategies which remove or significantly reduce the severity of soil water repellence for an extended period.

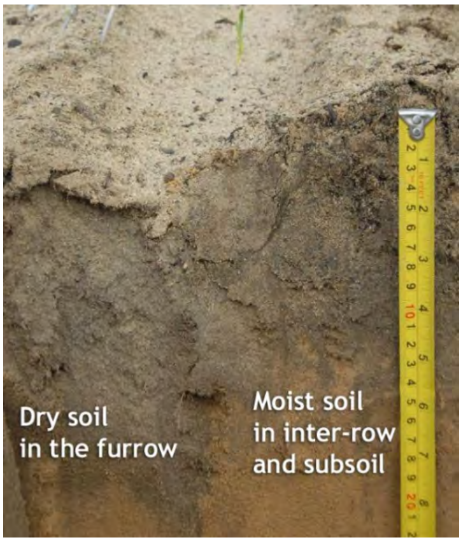

Image 1: Top-down view of a narrow knife point working in repellent soil showing the flow of repellent topsoil around the point and back into the furrow (left) and close-up of cross-section through a furrow (right) showing dry repellent topsoil in the base of the furrow and wet soil in the inter-row and subsurface soil.

Improved furrow sowing for water repellent soils

The main approaches used for improving the effectiveness of furrow sowing on water repellent soils are summarised in Table 1.

Broadly there are three overall strategies for improving the effectiveness of furrow sowing:

1) Improving the grading of repellent soil out of the furrow (winged points, winged boots with paired rows)

2) Improving the wetting up of the furrow using soil wetting agents (banded wetter)

3) Changing the placement of the seed in space (on-row sowing, increased seeding rates) or time (delayed sowing)

Table 1: Summary of improved furrow sowing approaches for better crop establishment on water repellent soils.

Mitigation method	How it works	Approx cost ($/ha)*	Typical change in wheat yield		Other considerations
			(t/ha)	%	
Winged point	Wings help grade repellent soil out of the furrow.	$1-3	0.14	6	Greater soil disturbance. Poorer seed depth control. Increasing sowing speed may further improve soil throw out of the furrow.
Winged boots with paired rows	Wings grade repellent soil, twin rows improve seed distribution and possibly placement.	$3-6	0.4	19	Better weed competition. Greater soil disturbance. Often high wear rates. Wider press wheels needed.
On-row sowing	Seed sown close to previous season's crop row which wets up more easily.	$1-3	?	?	Disease interactions. Stubble handling. Does not always translate to a yield benefit.
Banded wetter	Soil wetters banded on top of the furrow after the presswheels or near the seed improves consistency of soil wetting along the crop row.	$8-15	0.2 (dry) 0 (wet)	16 (dry) 0 (wet)	More effective with dry sowing. Some compatible with UAN and other liquids. Variable benefits across soils and seasons.
Delayed sowing	Soil gets the opportunity to wet up with break-of-season rain. Soil not disturbed dry - dry disturbance can exacerbate repellence impact.	?	Variable	Variable	Knockdown opportunity for weeds. Repellent topsoil is not disturbed dry. Reduced yield potential with later sowing.
Increased seeding rates	Increased sowing density will generally result in higher plant populations even in repellent soil.	Cost of extra seed	Variable	Variable	Increased haying off on soils with low yield potential. Improved weed competition. Poor seeding efficiency, though use of paired rows or ribbon seeding can further improve outcomes.

Winged points and paired rows

One of the cheapest options to help improve the effectiveness of furrow sowing is to use seeding points with small wings. The wings cause the soil to lift as it passes the seeding point causing more of the repellent topsoil to flow away from the furrow and be graded into the ridge. The grading does not completely exclude all of the repellent soil and the yield benefits from this approach tend to be modest, averaging just 140 kg/ha of additional wheat yield (Table 1). It is probably best suited to more mild and moderate repellent soils.

Image 2: Side-by-side comparison of seeding lupins with knife points versus winged boots on a deep yellow water repellent sand at Balla WA, 2011.

Winged seeding boots with paired rows have an even greater effect on crop establishment (Images 2 and 3) and yield in repellent soils with an average cereal yield increase of 400 kg/ha (Table 1).

Image 3: Side-by-side comparison of wheat establishment with knife points (left) compared with winged points and paired seeding rows (right) on a water repellent sandy gravel at Badgingarra WA, 2011.

The establishment benefits of these paired row systems appears to come from: improved grading of the topsoil; distributing the seed through more of the soil (i.e. more rows per ha) reducing intra-row competition; and placing the seed near the shoulders of the furrow may also be an advantage as water often infiltrates through this area around the repellent soil in the centre of the furrow.

Figure 1: Comparison of paired row and knife point seeding systems and their impact on wheat establishment in water repellent sand or sandy gravel (left) and topsoil moisture content in the furrow and ridge on the sand (right), at Badgingarra WA, 2011. Wheat was sown at 70 kg/ha for both seeding systems.

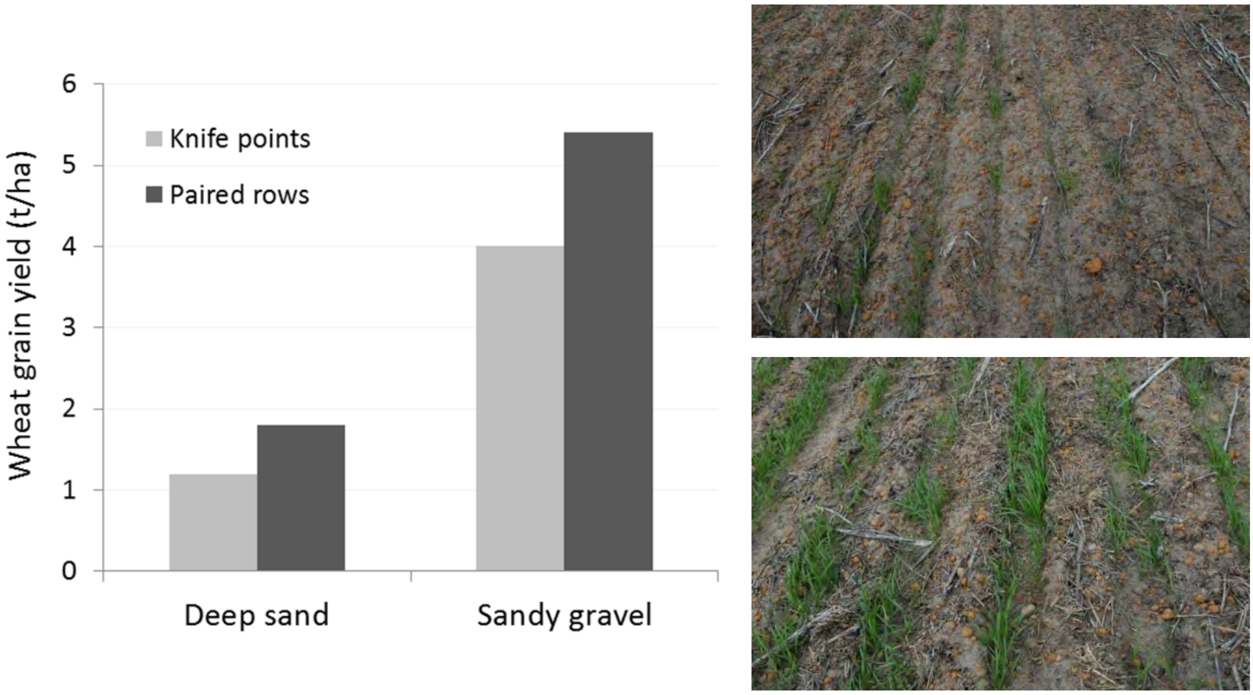

Figure 2: Comparison of paired row and knife point seeding systems and their impact on wheat grain yield in water repellent sand or sandy gravel and close up of wheat establishment with knife points (top right) and paired row seeder (bottom right), at Badgingarra WA, 2011.

In a direct comparison with standard narrow knife points, a paired row seeder on water repellent deep sands and sandy gravel improved crop establishment by 55% (+53 plants/m^2) on repellent deep sand and 75% (+71 plants/m^2) on sandy gravel (Figure 1). Soil moisture measurements on the deep sand also indicated that the furrows were wetting up better with the paired row seeder, while with the knife point seeder the furrows were ineffective being drier than the corresponding ridges (Figure 1). Grain yield was also improved with the paired row seeder, by 50% (+0.6 t/ha) on the deep sand and 35% (+1.4 t/ha) on the sandy gravel (Figure 2).

Paired row seeding systems can give substantial and reliable establishment and yield improvements compared with narrow knife points on water repellent soils. In WA they have been successfully applied to repellent sands and gravels (Figure 4) and have also been shown to improve crop competition with weeds.

The paired row seeding systems seem particularly well suited to deeper sands, on sandy gravels banded soil wetters are also an option (Figure 4).

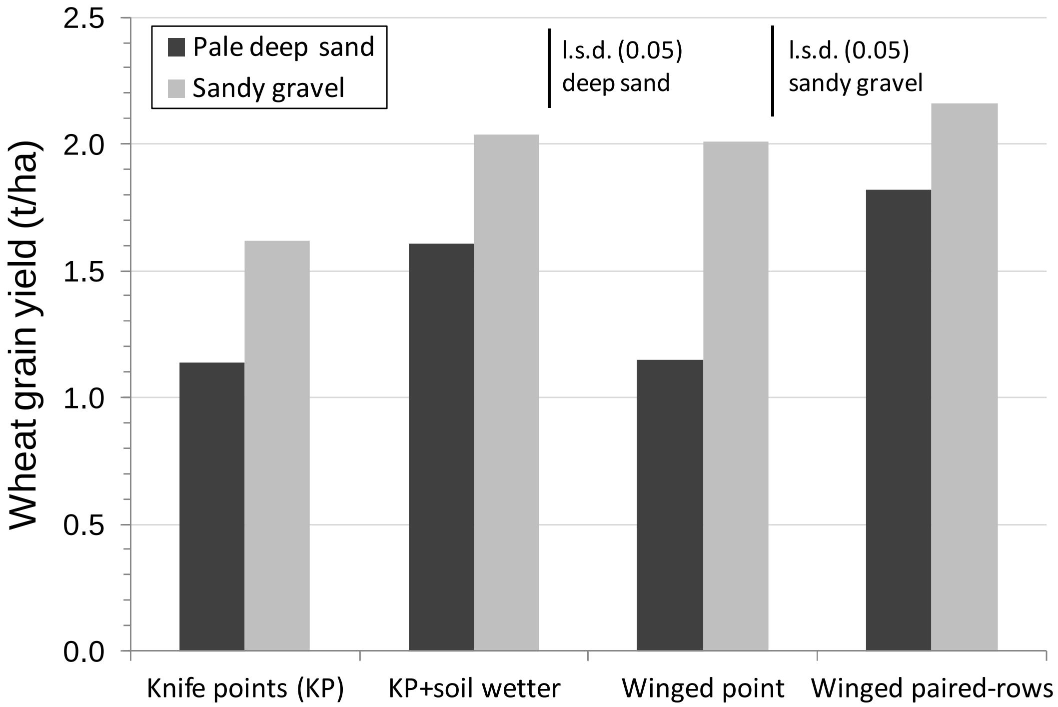

Figure 4: Impact of seeding systems on wheat grain yield at Badgingarra in 2012, sown on 17 May with dry soil over some soil moisture which was shallower on the sandy gravel. KP+soil wetter = knife points plus banded soil wetting agent.

On-row sowing

In repellent soils water infiltrates preferentially along existing and remnant root systems (Image 4), the previous seasons furrows can also retain some micro-relief which can further aid water ponding and infiltration. On-row sowing of the seed close to the previous year's crop row utilises this preferential infiltration to achieve earlier and less staggered crop establishment (Image 5). There is now evidence that the population of wax-degrading microbes is also higher in the previous year's crop row and the severity of water repellence is reduced (Ward and Roper, CSIRO).

Image 4: Preferential soil wetting in water repellent sands along the previous seasons crop rows (left) and blue dye infiltration along current root systems and the previous seasons root systems on the inter-row. Photos courtesy of P. Kelly, Mingenew (left) and M. Roper, CSIRO Perth (right).

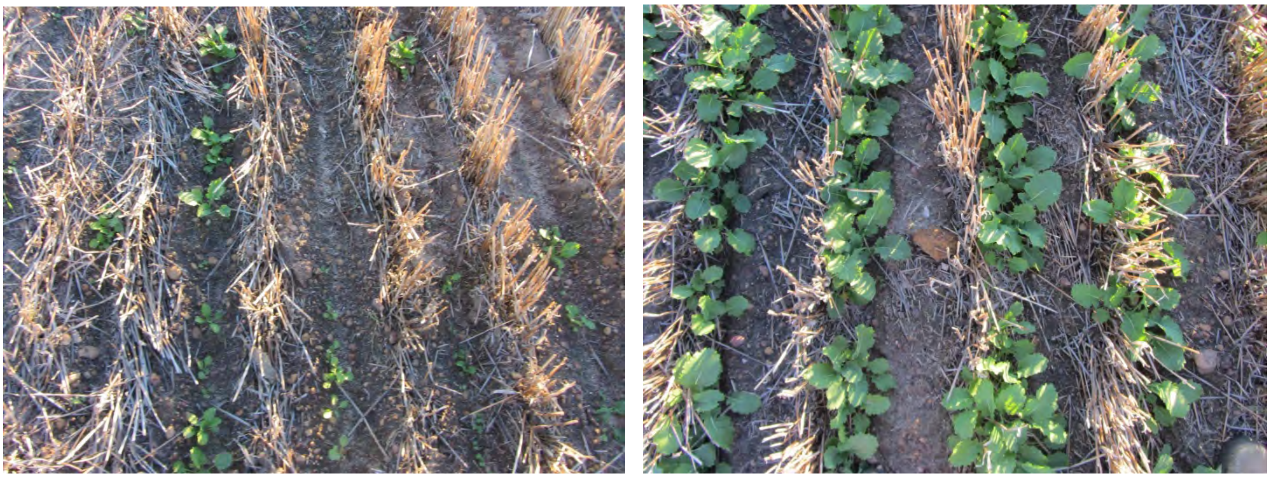

Image 5: Early canola establishment and growth in water repellent sand comparing inter-row seeding (left) with on-row seeding (right) in a side-by-side comparison sown on the same date, near Broomehill WA, 2014.

The impact of on-row seeding on crop establishment can be large (Figure 3), and in one trial on water repellent sand in the northern wheatbelt of WA on-row sowing had a bigger effect on establishment than banded soil wetting agents, which only had value when the crop was sown on the inter-row (Figure 3). Despite the establishment benefits achieved as a result of on-row sowing little data on yield benefits has been obtained. Achieving reliable on row seed placement requires accurate guidance coupled with hydraulic steering on the seeder and often different seeding points. While this requires some investment the system enables accurate placement of the seed rows not only on the row when the soil is repellent but also accurate placement on the inter-row when that is a priority.

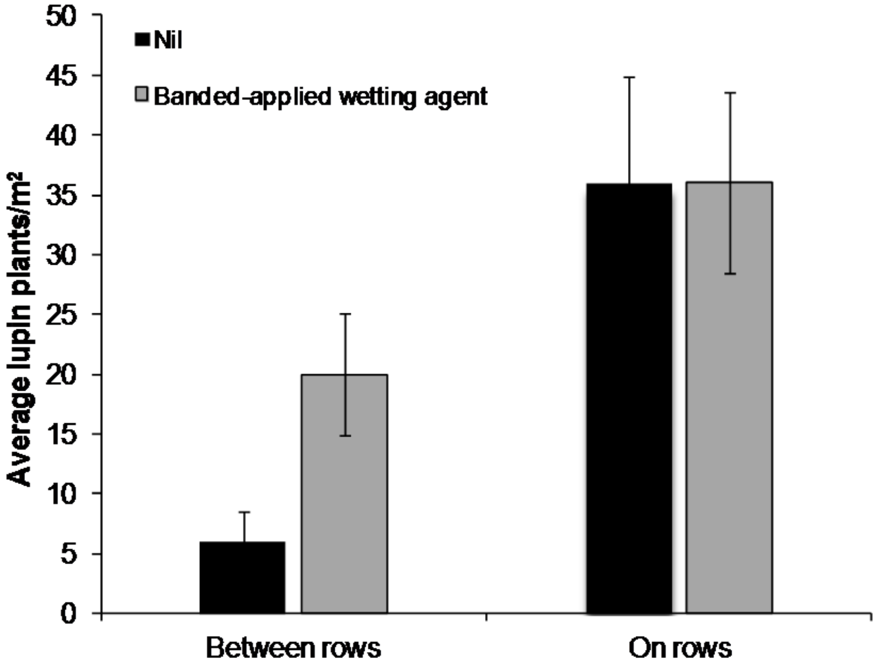

Figure 3: Lupin crop establishment (plants/m^2) when sown either between or on the previous year's row and with or without (Nil) banded wetting agent on water repellent sand, at Balla WA, 2011. Adapted from Roper *et al* 2015; source: Davies *et al* 2012.

Banded wetter

Soil wetting agents reduce the surface tension of water helping it infiltrate water repellent soils. Some soil wetters can be applied as blanket prior to sowing while others are applied as a narrow band on or in the furrow. The rates required to achieve improved infiltration and germination using a blanket application are often cost prohibitive although there is a loamy forest gravel specific soil wetting agent than can last for several seasons from the one application and can be economic. In general banding soil wetting agents are much more cost effective given the rates required and are applied during the seeding process and will be the focus of this review.

Soil wetting agents always contain a penetrant (surfactant) which aids water infiltration into repellent soil but some also contain water retention compounds (humectants) which helps retain water and possibly nutrients in the topsoil although given that wetting agents are banded at rates just 1-4 L/ha the volume of water held is very small. Given that soil wetting agents can reduce the surface tension of water they can also increase leaching, this is overcome by either giving the products a short lifespan in the soil, lasting only long enough to aid germination, or by including the water retention compounds.

Image 6: Liquid kit setup on a knife-point seeder designed to band soil wetting agents on the top of the furrow behind the press wheel (right image) and in-furrow liquid banding system used to band soil wetters near the seed on a plot seeder (left image).

Historically banded soil wetters were always applied as a continuous stream to the surface of the furrow behind the press wheels, however recent research has also shown that soil wetters can also be effective when banded in the furrow near the seed (Images 6 and 7; Table 2). The soil wetter needs to banded within 20 mm of the sown seed row and appears to work by acting as a wick which helps the seed row wet up more consistently. In addition to this several of the current commercially available soil wetters are compatible with other liquid fertilisers and pesticides, and so can be applied through existing liquid kits capable of in-furrow banding.

Image 7: Barley establishment and growth in an untreated control plot (centre) with soil wetter at 1 L/ha on the left and another wetter at 2 L/ha on right (left image) and barley establishment and growth in response to soil wetter and UAN banded in-furrow (near the seed) on left compared with UAN only banded in-furrow on the right (right image). Images taken 5 August 2015.

An example of the effectiveness of soil wetters banded either on the furrow or near the seed is shown for canola growing on severely repellent forest gravel. For some of the banded wetters early crop establishment was improved by 18-23 plants/m^2 an increase of 54-70% (Table 2). This improved early establishment translated into 9-17% improvement in canola yields, an increase of 260-510 kg/ha (Table 2). Banding the soil wetters near the seed significantly improved the grain yield by an average of 190 kg/ha across the three soil wetters compared with banding the wetter on top of the furrow (Table 2). Overall the research in WA on soil wetting agents has given average grain yield increases of around 200 kg/ha for dry sown crops (Table 1), but are variable. On the repellent gravel soils, mainly loamy forest gravels in the south west, the average yield increase is higher at 400 kg/ha.

Table 2: Impact of soil wetting agents applied at 2 L/ha and their placement, banded either on the furrow surface or near the seed, on canola establishment and grain yield growing on water repellent forest gravel near Kojonup, 2015.

Treatment	Crop Establishment (plants/m^2)		Grain Yield (t/ha)	
	Furrow banded	Seed banded	Furrow banded	Seed banded
Control (Nil)	33		2.93	
Water only (Control)	34	35	2.92	3.04
Wetter 1 - 2 L/ha	45	56*	3.19*	3.37*
Wetter 2 - 2 L/ha	51*	54*	3.26*	3.44*
Wetter 3 - 2 L/ha	45	44	3.10	3.31*
LSD (P=0.05)	*15*		*0.22*	

* denotes a significant increase relative to the untreated control at 95% confidence.

Delayed sowing and seeding rate

Delaying sowing until after rain can improve crop establishment because it allows time for the soil to wet up with break-of-season rains. Seeding shortly after an intense period of significant rainfall can also result in a layer of moist surface soil being incorporated into the furrow with the seed, improving establishment (Image 8). Seeding into repellent soil when it's dry can often result in an increased expression (severity) of the water repellence, so delaying seeding until at least some of the soil is wet can help minimise this.

In addition to improving crop establishment, delaying seeding can also provide a good opportunity to use a knockdown to control weeds at or prior to sowing. In many circumstances delaying seeding can reduce the overall crop yield potential but in repellent soils the negative consequences of early sowing may be worse for overall crop productivity.

Increasing the seeding rate generally increases the plant population, even in repellent soils. It is likely that crop establishment can be further improved through the use of splitter or ribbon seeding boots in combination with a high seeding rate. On repellent sands with low yield potential, however, higher plant populations can be susceptible to haying off which can reduce yields.

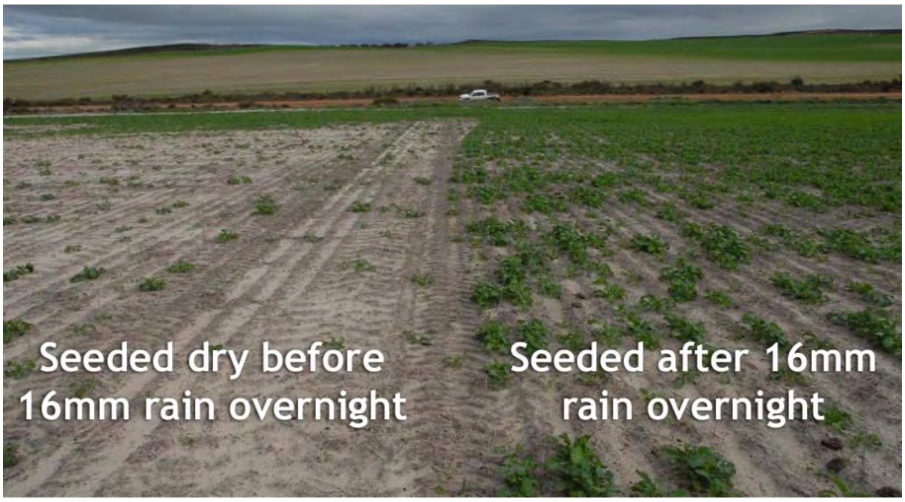

Image 8: Comparison of canola establishment either seeded dry before 16 mm rain overnight or seeded the following day after overnight rain on pale deep sand at Badgingarra, 2011.

In a series of trials on repellent soil looking at the interaction between sowing time and seeding rate on wheat performance, delaying sowing resulted in a significant increase in grain yield at two of the sites while there was a yield decrease at one site (Table 3). At Warradarge, where the yield declined, the second time of sowing occurred during a dry period and plant establishment was worse than the first time of sowing. At Cranbrook the first time of sowing was undertaken when the soil was dry and weed control was very difficult and this contributed to the very large yield increase from delaying seeding (Table 3) which provided an opportunity for effective knockdown of the weeds. Seeding rate generally had less effect, but did significantly improve emergence and grain yields at Cranbrook for the first, dry, time of sowing and also probably aided weed competition (Table 3). The results highlight how critical the interactions with season, timing of rainfall, weeds and soil-determined yield potential interact when using these agronomic approaches to try and improve crop productivity on repellent soils.

Table 3: Wheat grain yield (t/ha) for two times of sowing (TOS) and two seeding rates (SR) 60 and 120 kg/ha at four sites affected by soil water repellence in the Western Australia, 2014. GSR = growing season (April-October) rainfall.

Location (GSR)	**Soil type**	**Repellence MED (Rating)**	**Grain Yield (t/ha)**				**Least Significant Difference**
			TOS 1 60 kg/ha	**TOS 1 120 kg/ha**	**TOS 2 60 kg/ha**	**TOS 2 120 kg/ha**	
Binnu (263 mm)	Yellow deep sand	2.7 (Severe)	0.41	0.44	0.71	0.58	TOS (0.05) = 0.10
Warradarge (416 mm)	Pale deep sand	3.0 (Severe)	1.27	1.26	0.81	0.69	TOS (0.10) = 0.48
Cranbrook (426 mm)	Duplex sandy gravel	4.0 (Very Severe)	2.48	2.76	3.71	3.68	TOS (0.05) = 0.21

Developing strategies for water repellent soils

There are many options for managing water repellent sands but often a combination of mitigation and amelioration strategies will give the best returns. Economic modelling has demonstrated that while the mitigation options often do not provide such large per hectare yield gains as the amelioration approaches their low cost and capacity to be applied to large areas means whole farm returns can be high (Blackwell *et al* 2014). For farms with relatively small areas of repellent sands, fixing them using amelioration approaches is the best strategy (Blackwell *et al* 2014), particularly if the soil has reasonable yield potential. For farms where large areas are affected use of an improved furrow sowing, mitigation, option coupled with progressive amelioration over time is the best strategy. For soils with only mild repellence a mitigation option may be adequate to achieve better establishment and yield on a consistent basis while maintaining the benefit water repellence provides through increased water harvesting from the repellent ridges and from acting as a dry sandy surface mulch reducing evaporation. This can be particularly useful in drier, shorter-season environments. For soils with very severe repellence mitigation strategies may not always be adequate and while they may help with crop establishment ongoing issues with poor access to nutrients and water and poor weed control can necessitate a need for soil amelioration.

CONCLUSION

Mitigation strategies are a viable option to improve establishment and grain yield, particularly for large areas of mild to moderate water repellent soil. On sands winged boots with paired rows are one of the most reliable mitigation options, are useful for crop competition with weeds and can result in significant yield increases. Soil wetters are less reliable but can be very effective with dry seeding and for some soils and circumstances. Soil wetting agents can be easily tested and new soil wetting agent products are being developed and these need ongoing assessment to see if their efficacy is more reliable. An awareness of other soil constraints is also vital as these may limit yield potential even if establishment is improved.

Acknowledgements:

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NOTES

JANUARY 2015

CLAY SPREADING AND DELVING FACT SHEET

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EYRE PENINSULA

CLAY SPREADING AND DELVING IN LIGHT, SANDY SOILS

Clay spreading or delving can significantly improve yields of sandy soils but it is vital that the process is performed correctly.

KEY POINTS

- Spreading or delving involves incorporating a clay-based subsoil into a sandy top-soil that usually has less than 5 percent clay content.
- It can significantly improve the productivity of light, sandy soils by ameliorating unwanted effects of sandy soils on crop growth.
- Yields on soils which have had clay spread or have been correctly delved have increased by up to 130 percent.
- Benefits include eliminating water repellence, improved weed control, reduced erosion potential, and increased nutrient and water-holding capacity.
- Using the correct clay spreading and delving process is critical for success and to avoid any adverse impacts on productivity.

Is your soil water repellent?

To test the water repellence of a sandy soil, scrape away the top 2-3 millimetres and slowly drip a few drops of water onto the soil. If the water remains as a bead for more than 10 seconds, then the soil is water repellent.

PHOTO: BRETT MASTERS

Delving uses specially-designed machines to rip deep into the soil profile and pull up the clay-rich subsoil, incorporating it into the sandy soil.

Why spread or delve

Sandy soils have low nutrient retention and water-holding capacity. This is because of the relatively low surface area of sand grains which have a reduced ability to hold and exchange nutrients, called the soil's exchange capacity. This capacity is how cations (charged nutrients) such as calcium, magnesium and potassium move from soil to plant.

Water cannot be effectively stored in a non-wetting soil and it drains lower into the soil profile, often below the root zone of the crop. Low clay and organic carbon levels mean sandy soils have low fertility, meaning they have a low cation exchange capacity. Low organic carbon levels limit soil biological activity.

Water repulsion can be a problem in the top 5-10 centimetres of sandy soils. This effect is caused by wax residues left from decayed organic matter. In sandy soils these produce a hydrophobic surface with highly variable water infiltration. Research has shown that when the clay content is more than 5 percent, soils have a very low susceptibility to water repellence.

In addition to the negative impacts on yield, sandy soils are vulnerable to wind erosion and weed control is more difficult. Weeds tend to germinate all year round in these soils so different stages of weed maturity are present at any time.

Increasing the clay content of non-wetting soils has been shown to increase yields between 20 and 130 percent in the years following claying.

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Clay particles are less than two microns in size and when applied to a sandy soil, increase the surface area allowing it to store more water and nutrients.

The benefits of claying when performed correctly include:

- Overcome non-wetting soil properties.
- Increased nutrient levels, including organic carbon and cations.
- Increased plant available water.
- Increased microbial activity.
- Improved wettability, resulting in more even weed germination and better weed control.
- Reduced susceptibility to wind erosion.
- Reduced risk of frost, as clayed soil can store more heat.

How to delve or clay

Delving uses specially-designed machines to rip deep into the soil profile and pull up the clay-rich subsoil, incorporating it into the sandy soil. This is most effective when the subsoil is within 30-65cm of the surface. Delving should be performed in late spring/early summer while there is still moisture in the soil.

Delving is a preferred option over spreading, if there is a suitable subsoil. Delving uses the upper-most layer of subsoil, which is generally of higher quality, and results in a more even distribution of clay throughout the profile.

Spreading is the only option available if there is no clay-rich subsoil within 65cm of the surface and sources other clay – usually from a clay pit – in or near the paddock to be treated. The clay-rich soil is excavated from the pit and spread over the paddock using a scraper, spinner or laser-levelling plane. Spreading is best performed in summer, when the soil is not too wet.

Following either delving or spreading, the clay needs to be incorporated into the sandy soil. There are different methods that can be used depending on the rate at which the clay is spread, the type of clay and how long the clay is left on the soil surface. The longer it is left on the surface, the better the breakdown to small clay clods. Other amendments such as lime or gypsum can also be added before incorporation to further improve the soil.

PHOTO: DAVID WOODARD

Clay spreading is best when the clay-rich subsoil layer is more than 65 centimetres below the soil surface.

The extent of spreading depends on the depth and clay content of the sand and subsoil, with rates ranging from 100 to 260 tonnes per hectare.

Is it worth it?

Where there is a suitable clay layer less than 65cm below the sandy soil, paddocks can be delved. However, where the clay subsoil is deeper, clay spreading is required.

The cost of spreading varies with the rate of clay rich material applied and how far the pit is from the application site. Most sites are between $250-$350/ha. Delving can be as low as half the cost depending on depth and moisture levels of the clay. Additional costs may be involved in the incorporation process particularly if spaders – essentially an up-scaled rotary hoe – are used. The costs of treatments must be weighed against the benefits of the higher yields, opportunity to move to higher value production systems and reduction in costs following treatment.

Doing it right

Poorly incorporating the clay can result in a number of problems including:

- Surface sealing in which the high-clay subsoil can form a crust, which prevents water infiltration into the soil and roots.
- Poor root exploration into the subsoil caused by a distinct separation between the spread/delved soil and the layer below and by not addressing fertility and low plant available water in bleached subsoils.
- If the clay is not fully incorporated, all the costs have been incurred but the benefits will not be achieved.

Choose the right clay

While most clays are suitable, a number of factors including the consistency, clay content and chemical composition should be taken into consideration.

Depth

When sampling clay, the depth as well as composition can vary in a single paddock, so a number of samples per paddock are recommended.

The depth of the clay defines which technique will be applied:

- Spread – Clay must be spread where it is further than 65cm from the surface.
- Delve – Use delving when clay is 30-65cm from the surface.
- Other methods, such as spading, can be used when clay is less than 30cm deep.

TABLE 1: Estimating soil clay content*

SOIL BALL	RIBBON LENGTH	APPROX. CLAY CONTENT	TEXTURE GRADE	BROAD GROUP
Ball will not form – clear suspension when mixed with water	0	0-5%	Sand	
Ball only just holds together – cloudy suspension when mixed with water	5	5	Loamy Sand	Sand
Sticky-ball just holds together - leaves clay stain on fingers	5-15	5-10	Clayey sand	
Ball holds together – feels very sandy but spongy	15-25	10-20	Sandy loam	Sandy Loam
Ball holds together – feels smooth and silky	25	25	Silty loam	
Ball holds together, feels smooth and spongy	25	25	Loam	Loam
Ball holds together firmly – feels sandy and plastic	25-40	20-30	Sandy clay loam	
Ball holds together firmly – feels smooth, silky and plastic	40-50	30-35	Silty clay loam	Clay Loam
Ball holds together firmly – feels smooth and plastic	40-50	30-35	Clay loam	
Ball holds together strongly – feels plastic	50-75	35-40	Light clay	
Ball holds together very strongly – feels like plasticine	>75	40-50	Medium clay	Clay
Ball holds together very strongly – difficult to mould – feels like stiff plasticine	>75	>50	Heavy clay	

* *Source: Spread, delve, spade, invert. GRDC*

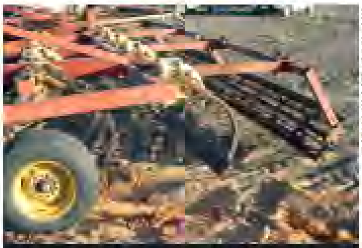

PHOTO: BRETT MASTERS

Sufficient incorporation of the clay is integral to the success of clay spreading or delving.

Clay content

The clay content of soil is a critical factor that needs to be known in order to calculate an appropriate dosage rate. Typically, 25 percent clay or higher is ideal for claying, however soils with as low as 15 percent have been used successfully.

The clay content of a soil can be estimated by taking a handful of the soil, adding water and working it into a ball until it is smooth, and then squeezing it out into a ribbon about 2-3 millimetres thick. The length of continuous ribbon can be used to estimate the clay content (see Table 1).

- **Chemical composition**

Not all clays are suitable for delving or spreading. Soils that are high in carbonates can result in a manganese deficiency and increase 'tie-up' of phosphorus. Some clays also have high salinity/boron levels that may affect yield, particularly of sensitive crops in the first few years following spreading. If using acidic clays the application of lime should also be considered.

Clays that are dispersive (they disintegrate when they get wet), – or slake (slump and fall apart in water), can be effectively used for clay application. However at high dosage rates, they can form a crust on the surface, preventing water infiltration.

- **Location**

For spreading, the location of the clay pit should be considered because transport is the highest cost involved in the process. Ideally, the source should be less than 300 metres from the paddock to be treated.

Clay application rate

The optimal clay percentage to be targeted will be from 5-10 percent, depending on rainfall – lower rainfall areas should aim for the lower end of the range. The rate of subsoil material applied can be calculated depending on the:

- Sand clay content.
- Subsoil (source soil) clay content.
- Depth of the incorporation.
- Rainfall.

Growers must avoid over-claying paddocks because clay contents that are too high can limit moisture availability to the crop and reduce yields. However, in most cases, this is due to a lack of incorporation. Recommended application levels for different rainfall zones are outlined in Table 2.

Incorporation

One of the key aspects to successful spreading or delving is adequate incorporation. If incorporation is not adequate, there are a number of consequences.

TABLE 2: Application rates for clay spreading and delving (higher rates need to be applied where deep incorporation is undertaken)*

ANNUAL RAINFALL (mm)	<350		350-450		450-550		>550	
Clay in subsoil (%)	15-25	>25	15-25	>25	15-25	>25	15-25	>25
Rate (t/ha)	100-150	70-100	120-180	100-150	150-250	150-200	250-300	200-250

**Source: Spread, delve, spade, invert. GRDC*

page 3

TABLE 3: Methods of incorporation		
RATE OF CLAY RICH SUBSOIL ADDED	SUGGESTED EQUIPMENT	MAXIMUM DEPTH OF INCORPORATION ACHIEVED
150t/ha or less	Offset discs or tyned cultivators with wide shears	10-15cm
150-250t/ha	Rotary hoe	15-20cm
Greater than 250t/ha	Rotary spader	20-30cm

* Source: Spread, delve, spade, invert. GRDC

If the non-wetting layer has not been fully treated, poor water infiltration will continue, reducing the benefits of the process. If the contrast between the treated layer and the soil below is too great, the clayed topsoil can retain much more water than the subsoil, resulting in poor root growth into the subsoil. Inadequate incorporation can also cause a crust to form on the surface which reduces water infiltration.

There are a number of different methods to incorporate the clay (see Table 3).

Management after claying

A number of areas need to be assessed and monitored following claying to ensure a successful season.

Nutrient management
Nutrient management is important after claying a paddock. As the topsoil composition has changed, a nutrient deficiency is possible. It is recommended that nutrient levels are tested before seeding, and appropriate nutrient management – such as applying fertiliser and/or foliar spray – is applied.

Pest management
In some instances, use of calcareous clays has resulted in an increase in snail populations, which needs to be addressed (see Useful Resources).

Crop selection
Claying increases the flexibility of crop selection by eliminating repellent properties. Cereals are considered a good choice in the season following claying. If sowing canola in the first season, care has to be taken with seeding depth where the incorporation of the clay has resulted in a soft seed bed. Lupins and other crops sensitive to increased soil pH may not be the best choices in the first years following claying.

Checklist: Is delving or spreading right for you?

Is there a valid reason?
Consider the unique challenges of the property and whether claying the soil will be able to address these challenges.

Are spreading or delving the best options?
There are cheaper options available to improve sandy soils such as wide furrow sowing, wetting agents, rotary spading and inversion ploughing. These may not be as effective, treat the entire range of symptoms or have the longevity of spreading or delving, but should be considered as options before committing to a plan of action.

Is there a clay-rich subsoil within 65cm of the surface?
If so, delving is a suitable option if the clay has the right properties. If not, spreading may be the only choice.

Is the clay source suitable?
Matching the clay content, composition and location to the soil to be treated are all critical to ensuring the process is successful.

Other simpler and cheaper options are available for treating non-wetting soils, such as rotary spading or soil inversion, however none have the longevity of spreading or delving.

PHOTO: SUE KNIGHTS

Spreading is more cost-effective when the clay pit is close to the area to be treated.

FREQUENTLY ASKED QUESTIONS

How long does claying continue to have positive effects?
Claying delivers a long-term change to soil characteristics. To date, experts have not seen any reduction of clay or its impact on soil texture characteristics in sites treated 20 years ago. This suggests the benefits are permanent.

How much does clay spreading and delving cost?
While costs are different for every site, most sites cost between $250-$350/ha for spreading, and delving can be as low as half the cost of spreading.

What clay properties are ideal?
Ideally, the clay soil would be:

- Clay content of about 30 percent.
- Low in carbonates, salinity and boron.
- pH matched to topsoil – alkaline if the topsoil is acidic or vice versa.
- Less than 65cm from the surface (delving) or close to the paddock to be clayed (spreading).

However in reality, it is not always possible to get all the ideal properties and compromises can be made.

What happens if the clays on a property are not ideal, can it still be spread or delved?
It is sometimes possible to successfully clay a paddock with non-ideal clays. For instance the dosing rate can be increased or decreased to manage the variance in clay content. For non-ideal circumstances, it is recommended to engage an adviser to set up a spreading or delving program.

USEFUL RESOURCES

Spread, Delve, Spade, Invert – a best practice guide to the addition of clay to sandy soils (GRDC651)
GRDC Bookshop
Free phone: 1800 11 00 44
Email: ground-cover-direct@canprint.com.au

Snail Management
GRDC Fact Sheet
www.grdc.com.au/GRDC-FS-SnailManagement

MORE INFORMATION

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