Spread, delve, spade, invert

a best practice guide to the addition of clay to sandy soils

GRDC
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CARING FOR OUR COUNTRY

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PATHWAY TO IMPROVEMENT

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INTRODUCTION
Follow the rules to improve sandy soils with clay

Across Western and South Australia there are many millions of hectares of deep sand or sand over clay-rich subsoils that are used for agricultural production. However, these sandy soils present a range of challenges due to their poor water holding capacity, inherent low fertility, extremes of pH, low levels of microbial activity and vulnerability to wind erosion.

In addition, many sandy soils are non-wetting, which causes uneven germination resulting in poor weed control, low levels of soil cover and reduced productivity .

Sands and loamy sand soils have less than five per cent clay content. As clay protects organic material from decomposition these soils are also low in organic carbon. Raising the clay content changes the soil texture class, which increases the capacity for the soil to store water (Table 1 page 6), nutrients and soil organic carbon.

Experience has found that it is feasible and profitable to raise the percentage of clay in the soil to above five per cent. For example, adding 200t/ha of soil containing 30 per cent clay would raise the clay content in the topsoil from 0.5 to about five per cent, if incorporated to 10cm.

Provided that appropriate methods are followed, remediating sandy soils with clay-rich subsoil can result in substantial yield improvements. Trials in WA and SA have reported yield improvements of 20 to 130 per cent across cereal, lupin and canola crops in the years following clay additions.

However, achieving the correct rate of clay addition and understanding the chemical nature of the clay-rich subsoil to be used is vital, if the process is to be successful.

The depth to clay-rich subsoil determines which method of clay addition is most appropriate. Deep sands can only be addressed through spreading of clay-rich subsoil excavated from a pit, spread across the soil surface and then incorporated. Sand over clay soils (Duplex soils, Figure 1) offer the potential to provide a source of clay that can be incorporated in the upper sandy horizons. Clay at between 30 and 60cm can be brought to the surface by delving. Where clay is less than 30cm below the surface a rotary spader or possibly a mouldboard plough can be used to lift and incorporate the clay in the topsoil.

Adding clay is relatively expensive and time consuming and if done incorrectly can result in negative effects that are difficult to reverse. Consequently, detailed planning of each stage of the process and following best practice is essential.

Drawing together over 30 years of research and grower experience, this publication answers the key questions that must be addressed for a successful claying program to be achieved.

- Can the limitation be reduced by incorporating clay-rich subsoil?
- What type of clay is available on my farm and is this suitable?
- How much clay-rich subsoil is required?
- Which method of adding and incorporating clay should be used?
- What changes to management are required after clay is added?

Figure 1 An example of a typical duplex sand over clay soil.

0 - Largely organic matter (0-5 cm)

A1 - Largely mineral layer (some organic matter). Sandy. Often water repellent due to coating of particles by hydrophobic ‘waxy’ residues. (5-20cm)

A2 - Mineral layer. Bleached white sand – limited capacity to store moisture due to low surface area. Limited capacity to store nutrients due to neutral charge on particles. (20-50cm)

B – Clay layer. Stark texture contrast to A horizon. (50cm +)

Understanding the chemical nature of the subsoil to be used is vital when determining clay rates. The tape is marked 10cm increments.

QUESTION 1
Can clay help my soil?

Before claying is considered it is important to understand whether the production constraints in your soil can be reduced by the addition of clay.


CREDIT SUE KNIGHTS

Improved soil structure with clay added (right).

Sandy soils can inherently exhibit or develop the following limitations, all of which have the potential to be reduced by the addition of clay. The best outcomes can only be achieved if the properties of the clay are known and the correct rate applied.

Soil testing can help identify the degree of some of these limitations in a soil.

Non-wetting


CREDIT STEPHEN DAVIES

Eliminating non-wetting properties is a key driver behind the addition of clay-rich subsoil to sandy soils. Soils with over five percent clay are rarely non-wetting.

Soils that are non-wetting do not wet-up evenly, resulting in uneven germination of weeds and crops. This leads to patchy crop establishment and poorer weed control, especially of weeds such as brome grass, and can reduce crop access to soil nutrients that are inaccessible in dry soil. All of these can result in reduced yield.

Waxes from decaying organic matter form a water-repelling (hydrophobic) layer that causes water to bead on the surface of dry soils following rainfall. Consequently, rainfall from small rainfall events does not enter the soil but runs-off. Sands are at their most repellent at the end of summer.

Soils such as sands that have a low surface area, especially coarse sands, are susceptible to water repellence because they require less water repelling material to coat the soil particles. Water repellence is worst when soil is dry.

Non-wetting characteristics are mainly located in the top 5cm of the soil but can be found in the top 10 to 15cm of some soils. The key zone is the organically stained topsoil. Symptoms diminish with depth and after sustained rainfall - once the soil is wet water infiltration is improved.

The addition of clay-rich subsoil to non-wetting soils can greatly increase the surface area of the soil, covering the organic waxes and diluting the impact of the hydrophobic material. **Research has found that most soils with a clay content greater than five per cent (Table 1) have a very low susceptibility to water repellence.**

Approximately five million hectares of agricultural soils in Australia exhibit non-wetting characteristics. Severity of repellence should be tested as the addition of clay to weakly repellent soils may not be cost effective.

Other management options

- Wide furrow sowing (20cm) to encourage greater water harvesting (one year benefit only).
- Furrow sowing with press wheels (one year benefit only).
- In-furrow banded or blanket applied soil surfactants (soil wetters; one or two year benefit only).
- Inversion ploughing (four or more year benefits).
- Alternative land-use for example permanent pasture or fodder shrubs.

TESTING WATER REPELLENCE

Water repellence can be simply assessed by scraping off the top 2 to 3mm of soil/plant litter and placing a few drops of water on the surface. If the water remains as a bead for more than 10 seconds the soil is water repellent. Aim to test the top 10 to 20cm of soil to establish the depth of the water repellence.

In the laboratory water repellence is tested using the Molarity of Ethanol Droplet (MED) test. A field version of this test can be carried out as previously described but a mixture of industrial-grade methylated spirits and water (23.9ml methylated spirits with 200ml water) can be substituted for water or the two molar solution of ethanol used in the laboratory.

This test is useful to help gauge the degree of water repellence. On soils that are strongly water repellent and responsive to the addition of clay it will take 10 seconds for the methylated spirits mixture to be absorbed.

As water repellence can vary across a paddock a series of tests should be taken along a few representative transects in different areas in a paddock.

The test should be carried out on dry soil when soil temperatures are between 15°C and 25°C. At higher temperatures the rate of absorption will increase and decrease at lower temperatures. If the soil is not dry then the water repellence will be reduced.

When testing to assess a change in a paddocks water repellent status it is important to test at the same time of the year.

Table 1 The water holding capacity and percent clay content for the main texture groups (based on information from Better Soils Mean Better Business).

Texture	Clay %	Field capacity	Wilting point	Available water
		mm/cm of soil		
Coarse sand	0 to 5	0.6	0.2	0.4
Fine sand		1.0	0.4	0.6
Loamy sand	About 5	1.4	0.6	0.8
Sandy loam	10 to 20	2.0	0.8	1.2
Light sandy clay loam	About 25	2.3	1.0	1.3
Loam		2.7	1.2	1.5
Sandy clay loam	20 to 30	2.8	1.3	1.5
Clay loam	30 to 35	3.2	1.4	1.8
Clay	35 to 50	4.0	2.5	1.5
Self-mulching clay	Over 50	4.5	2.5	2.0

Poor water holding capacity

The low surface area of sands also limits the water holding capacity of these soils. Incorporation of clay and organic material can increase soil water holding capacity through improving soil structure, and retaining more water through increased capillary tension.

While sands have poorer water holding capacity than clays, they more readily release this water to plants. As the clay percentage increases, so does the wilting point, a measure of the residual water in the soil that cannot be extracted by a plant (Table 1). **Consequently, increasing the clay percentage of a sandy soil in a low rainfall region can result in less plant available water when rainfall is received in small amounts.**

Other management options

- Adding organic matter at depth.
- Stubble retention.

Low inherent fertility (low cation exchange capacity)

CREDIT TONY HARDING

Nutrients can be readily leached from sand. The added clay in this soil is helping to hold moisture and nutrients in the root zone.

Sandy soils have inherently low fertility levels due to low cation exchange capacity (CEC) and low levels of organic carbon. Sands generally have a neutral to weakly negative charge and therefore, have limited ability to bind with the charged particles of common nutrients. Consequently, nutrients can be readily leached from sands. Clays are more strongly negatively charged and bind easily with positively charged cations such as potassium, calcium and magnesium.

Other management options

- Introduction of nutrients and/or organic matter.
- Foliar nutrients.
- Stubble retention.

WHAT IS CATION EXCHANGE CAPACITY?

Chemical activity in the soil revolves around the colloid fraction (particles smaller than .002mm in size), which is mainly comprised of clay minerals and organic matter. Soil colloids are predominantly negatively charged (anions). Weak electrostatic forces can hold positively charged (cations) to the negatively charged sites in the soil colloids.

The greater the number of charged sites, measured by the cation exchange capacity (CEC), the greater the nutrient retention capacity of the soil.

A CEC of less than seven indicates low inherent soil fertility.

Low soil microbial activity, low organic matter and pH

Many sandy soils (particularly those with bleached A2 horizons, which is an indication of low organic matter) have low levels of microbial activity. This is generally associated with low levels of organic matter, a vital carbon source for soil biology.

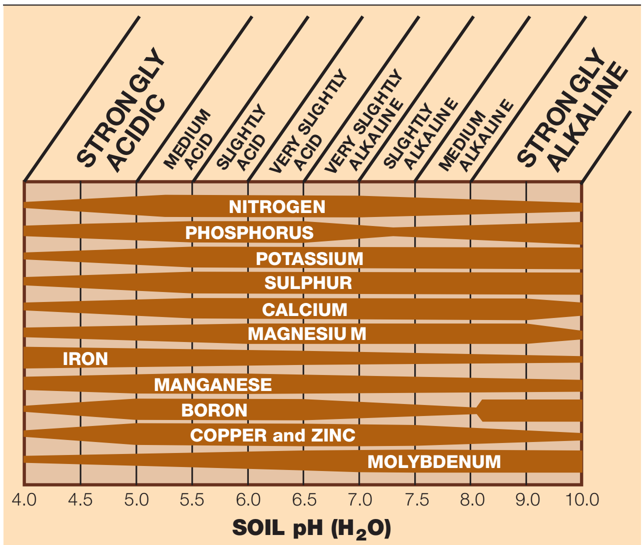
Research has indicated that the addition of clay to non-wetting soils may increase the microbial activity (Table 2). However, it is not clear whether this is a primary result of clay addition or through secondary benefits such as increased organic carbon supply, nutrient availability, water availability, improved porosity (microbial habitat) and pH. Trials at Esperance found small increases in organic carbon levels from (0.95 to 1.1) following the addition of clay-rich subsoil.

Low levels of organic matter reduce the capacity of sandy soils to buffer against rapid changes in the pH of the soil solution. This can lead to leaching of basic elements and increased availability of toxic elements such as aluminium.

Many types of clay have higher pH levels than sandy topsoils and can raise soil pH when mixed. In the sandplain soils of WA this can offer advantages by raising the pH of the acid topsoil. In SA, there are some sandy topsoils that are alkaline, introducing more high pH material can raise topsoil pH to levels hostile to some crops and reduce availability of nutrients (Figure 2).The ideal pH range for cropping soil is pH (H_2O) 6.0 to 7.5.

Understanding the pH of the topsoil and the subsoil clay that is to be added and the free lime content in each is important. **Testing the pH of material to be added or incorporated and the soil before and after the addition of clay is encouraged.** This will help predict any changes in nutrient availability that may occur after claying.

Figure 2 The effect of soil pH on the availability of plant nutrients (Source: Better Soils Mean Better Business).



Other management options

- Introduction of nutrients and/or organic matter at depth.
- Stubble retention.
- Cover crops or green manuring.
- Pasture cropping.

Table2 Data from trials in the south-east of SA demonstrate the longterm impact of delving on the organic carbon (OC) content and biological activity of the soil (source Glenn Bailey, PIRSA).

	OC-t/ha	OC-t/ha	OC-t/ha	Bacterial biomass (µg/g)	Fungal biomass (µg/g)	Mycorrhizal root score %	Total microbial biomass (µg/g)	Unknown biomass (µg/g)
Treatment	0-10cm	0-40cm	0-150cm	µg/g	µg/g	%	µg/g	
Control	25	45	60	7.29	5.1	61.5	13.85	1.46
Delved 2005	25	100	120	9.47	7.29	81	22.59	5.83
Delved 2011	24	80	100	3.64	6.56	45.9	16.76	6.56

Wind erosion

CREDIT EMMA LEONARD

Adding clay helps stabilise sandy soil making them less prone to wind erosion.

Wind erosion has been a major issue affecting sandy soils and limiting farm production systems. The main on-farm impacts of wind erosion include:

- loss of nutrients and organic matter contained in the topsoil;
- sandblasting damage to crops and pasture;
- damage to on-farm infrastructure such as burial of fences and roads; and
- development of blow outs on sand hills.

Clay supports aggregation of particles, providing some coherence between the larger sand particles. By creating some structure in the soil, the potential for particles to drift and for soil to erode is reduced. Claying also improves plant germination and vigour resulting in greater levels of surface cover.

Other management options

- Inter-row sowing into standing stubble.
- Stubble retention.
- Cover crops or green manuring.
- Pasture cropping.
- Permanent perennial pasture or fodder shrubs

Subsoil compaction

Sandy soils with low organic carbon levels are often subject to traffic compaction, resulting in a layer of low permeability. In addition, in sand over clay soils, dispersion of sodic subsoils can cause the formation of a hard crust at the boundary between the A (sand) horizon and the top of the B (clay) horizon.

Irrespective of how the hard pan is produced the result is reduced water infiltration and root penetration. Clay delving has some capacity to overcome this problem by breaking through the hard crust and depositing sand particles into the B horizon.

Other management options

- Deep ripping, inversion ploughing or spading.
- Addition of gypsum to highly sodic clay, at depth if necessary.
- Controlled traffic farming.
- Growing crops with deep tap roots, for example lucerne.

Frost

CREDIT EMMA LEONARD

There is good anecdotal evidence that soil spread with clay is warmer and less prone to frost but more research is required.

There is some evidence that the addition of clay can reduce frost damage as clayed soils can store more heat. In trials in SA, the canopy temperature was increased by 1.3°C in wheat grown in sand that had been delved for clay, compared to that growing in undelved areas.

Trials in WA have produced less conclusive results with increases in canopy temperature of only about 0.5°C, which is considered too small to reduce the impact of a frost event.

Further research on the relationship between claying, row spacing and canopy cover and their influence on frost is required.

Currently, any frost protection induced by claying is considered a supplementary benefit but is not a substantiated reason to undertake claying.

POTENTIAL BENEFITS OF CLAY APPLICATION

- More even soil wetting, reduced water repellence.
- Improved weed germination and control.
- Reduced crop damage from wind blasting and loss of soil and nutrients by wind erosion.
- Reduced nutrient leaching and greater availability, depending on soil pH.
- More microbial activity.
- Ability to manage paddocks as a more uniform unit.
- Increased crop choice and ability to increase cropping intensity.
- Greater production and return on inputs.
- Research continues to explore if adding clay to sandy soils reduces the risk of frost damage.

QUESTION 2

What type of clay is available on my farm and is this suitable?

Clay is a highly variable product and must be tested throughout the extraction depth.

CREDIT DAVID DAVENPORT

The introduction of clay-rich subsoil to the topsoil is a relatively expensive exercise, so ensuring success is important. Understanding the type of clay-rich subsoil and its chemical composition is essential if appropriate rates of clay are to be applied. The composition of the subsoil can change across a paddock and down the soil profile, so thorough testing is important to prevent costly mistakes.

Differences in soil type and chemical composition mean that target rates for subsoil addition will vary.

What is clay?

Clay is the inorganic fraction of the soil with a particle size below 0.0002mm. Clay content varies by soil type (Table 1 page 6), with sands containing between one and five per cent clay, while clay soil types have greater than 35 per cent clay.

Research suggests that subsoil with a clay percentage of at least 25 per cent provides the most cost effective and best outcomes for soil modification. However, subsoil with clay percentages as low as 15 per cent clay are known to have been used successfully.

Knowing the clay percentage of the subsoil is important for determining the rate of clay-rich subsoil required to achieve a target clay percentage in the topsoil. Obviously, only half as much is required when using a soil type containing 50 per cent clay compared to one containing only 25 per cent clay.

Clays have different characteristics, largely relating to the degree of weathering they have experienced. Highly weathered clays generally have a lower cation exchange capacity (CEC) and often lower levels of potassium, calcium and magnesium. CEC is measured as part of commercial soil nutrient tests. Particularly in Western Australia, some clays may have low pH and low potassium levels that may require nutrients or lime to be added as well.

What is the best clay type to use?

All clay types will assist in treating sands. The red or black clays may provide additional nutritional benefits over other clay types. Rates of highly calcareous clays have to be limited to prevent negative impacts on crop growth.

In WA, most of the kaolinitic clays used for claying will be mottled and white in colour.

There are some clays that have high levels of salt and boron, which initially can produce poor results but salt and boron levels are reduced over time by leaching. Often these clays have a green hue.

To address water repellence the most effective clays are those that break down to fine particles through the action of wetting and drying cycles. These include dispersive or slaking clays. Generally yellow, orange, brown and mottled coloured clays are more likely to be dispersive than red or black clays.

Dispersion and slaking

Dispersive or slaking clays are useful in claying as they fall apart when it rains and the clay disperses throughout the sand. The faster a clay slakes and more fully it disperses the better the clay is for improving sandy soils. However, when added at high rates dispersive and slaking clays can form a crust on the soil surface, which if allowed to dry can set like concrete. Adequate incorporation is vital in these cases.

Dispersion and slaking refer to how well clay holds together when wetted (Figure 3).

FIELD TEST – Place a lump of clay (about the size of a marble) in a saucer of distilled water or clean rainwater. (Tap water contains chemicals that may prevent dispersion or slaking). Do not shake or stir.

- Dispersive clay will dissolve, turning the water muddy as the clay spreads through the solution. Leave undisturbed for about four hours; sodic clays will remain in suspension.
- Slaking clay will slump and fall apart in the water, forming a small blob of mud on the saucer, but the water will remain clear.

It is possible for the clay to be both slaking and dispersive.

FIELD TEST – Hand texturing to estimate clay percentage

The percentage of clay in the soil (soil texture) can be estimated by making a ribbon of the wet soil and measuring the length.

1. Take a handful of soil, crumble it and add water.

2. Work the clay in your hands for one to two minutes, until it is smooth, the moisture is even and it forms a bolus

3. Squeeze the clay out into a flat ribbon two to three millimetres thick; the longer the unbroken ribbon the higher the clay content (Table 3).

CREDIT DAVID MASCHMEDT

Table 3 Per cent clay content of different clay soils predicted by hand texturing (see Table 5 for a guide to clay rates by clay percentage). (Source Describing and Interpreting Soil Profiles)

Texture – characteristics of the soil ball	Ribbon (mm)	Clay content (%)	Texture grade
Ball will not form	0	0-5	Sand
Ball just holds together	5	5	Loamy 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
Ball holds together – feels smooth and silky	25	25	Silty loam
Ball holds together – feels smooth and spongy	25	25	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
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
Ball holds together very strongly, difficult to manipulate – feels like stiff plasticine	>75	>50	Heavy clay

Hostile elements

Clays vary in clay percentage and chemical composition spatially and with depth across the paddock and within a pit. When the clay is added to the topsoil these chemical components are also introduced, which may not always be beneficial. For example, the addition of high pH, calcareous clays that increase the soil pH can lead to trace element deficiency, (particularly manganese). Although on acid sands the increase in pH could be beneficial, (Figure 2). Therefore, it is important to test the chemical components of the clay across the paddock and down the soil profile before delving and during extraction in clay pits.

pH

As a measure of the soils acid or alkalinity pH can influence crop choice, nutrient availability especially of trace elements and can change the residual behaviour of some herbicides.

Clay spreading with very acid or alkaline clay can change the pH of the topsoil by up to one unit of pH.

The pH of the clay-rich subsoil and the topsoil should be tested, especially before incorporating high rates of clay.

FIELD TEST – pH is tested using a proprietary pH test kit or in solution using a pH conductivity meter.

Carbonates

Carbonates are a group of chemicals that include calcium carbonate (lime) and magnesium carbonate. They affect soil pH and react with nutrients (particularly phosphorus and manganese) reducing their availability to plants. Using clay with high rates of carbonate has resulted in yield reductions due to manganese deficiency. These clays are sometimes referred to as having too much 'free lime'.

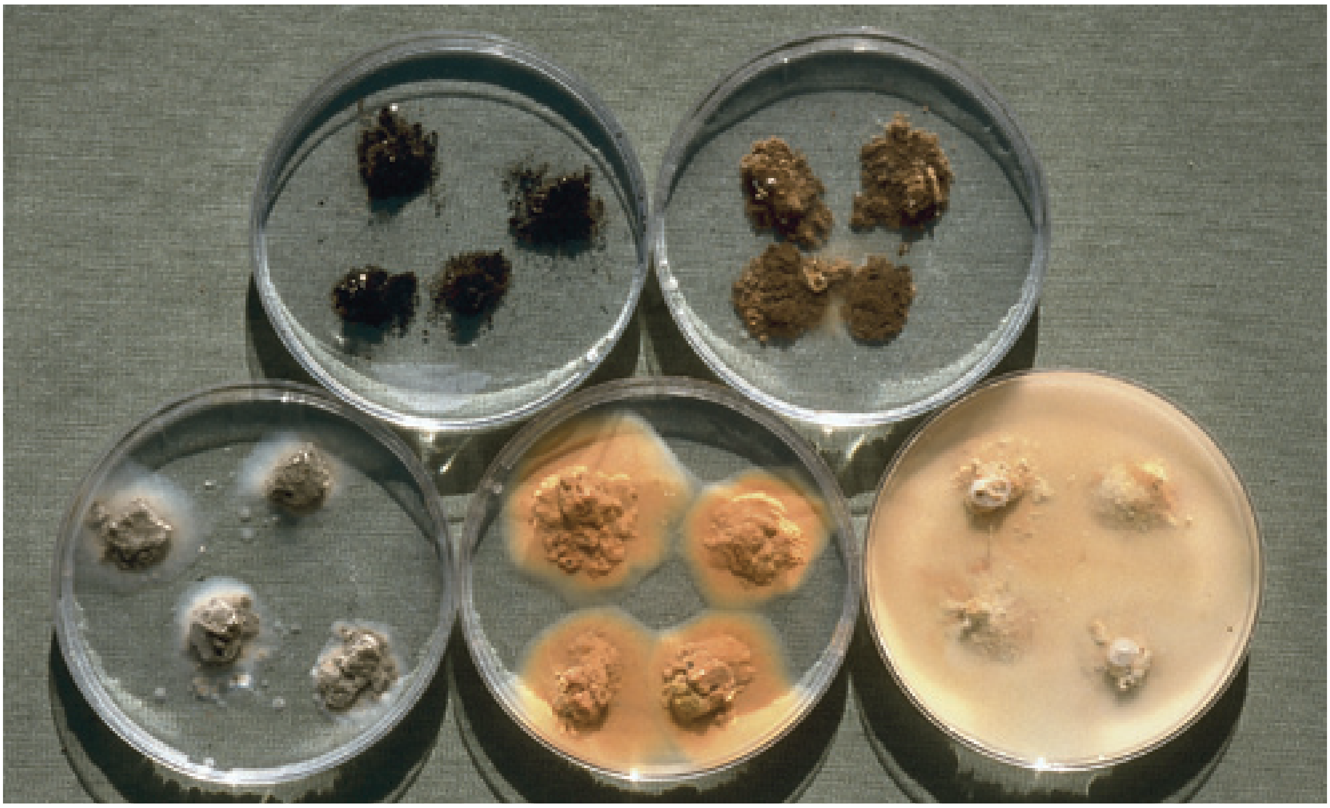
The application rate of clays with high carbonate levels should be limited to a maximum of 80t/ha. If clay spreading from a pit, layers with very high in free lime could be used on tracks rather than spreading across the paddock.

FIELD TEST – the 'Fizz Test' uses a weak hydrochloric acid solution (one part hydrochloric acid to nine parts distilled water or clean rainwater) to quantify the presence of carbonate in the soil.

1. Carefully add a few drops to a soil sample. Safety glasses and gloves should be warn and care taken as acid is hazardous.
2. Observe the level of effervescence – 'fizz'.

If the soil contains carbonate, the carbonate will dissolve, making a fizzing sound with associated release of bubbles of carbon dioxide gas; the greater the fizz, the more carbonate present (Table 4).

Figure 3: **The top two petri dishes exhibiting slaking, while the bottom three dishes show slaking and various degrees of dispersion.**



CREDIT DAVID MASCHMEDT

The colour contrast between good clay (left) and hostile calcareous clay, but looks can be deceiving. Field tests provide quick and simple guides to the level of hostile elements present.

Table 4 Evaluation of results from the 'fizz test' for soil carbonate content. (Source Describing and Interpreting Soil Profiles)

Reaction	Strength of effervescence	Approx. % carbonate
Nil	none	less than 0.5
Slight	audible	0.5 to 1.5
Moderate	audible and slightly visible	1.5 to 8
High	easily visible	1.5 to 8
Very high	strong visible fizz, bubbles jump up	more than 8

Salinity and boron or other hostile elements

Clay-rich subsoils in lower rainfall regions may also contain high levels of sodium chloride (salinity) and/or boron. There has been limited research on the implications of using clay with high levels of these hostile elements.

In soil, boron levels greater than 15mg/kg and conductivity (ECe) greater than 12dS/m have been found to negatively impact crop yield.

Following claying or delving there is obviously a dilution effect, that is; if 140t/ha of clay is incorporated to a depth of 10 to 15cm it is only roughly 10 per cent of the total soil mass. Despite this the use of high boron/saline clays at high rates may initially affect yields of sensitive crops immediately following claying.

Therefore, the use of salt or boron tolerant crops such as barley or suitable wheat varieties in the first season following claying is encouraged.

Both salts and boron will leach down the soil profile given enough rainfall and levels will probably reduce over time.

FIELD TEST – salinity can be tested using a conductivity meter, or an electromagnetic soil survey. Boron and salinity can both be requested as part of a commercial nulment soil test.

Locating clay

Landowners will generally have a good understanding of where clay-rich subsoil is to be found on their property. However, digging holes or using an electromagnetic (EM) survey can help identify the depth to clay and the depth of the clay-rich soil horizon.

Electromagnetic equipment emits electrical impulses and measures the strength and time delay of reflectance of the impulse. This provides an indication of soil water content salinity, soil texture and rockiness of the soil profile. Generally, this data is mapped with different colours representing different levels of conductivity.

Equipment can be vehicle mounted providing a relatively quick method of soil assessment for large areas. However, ground truthing is necessary to confirm what is driving any variation in conductivity. When considering delving, EM surveys can be useful for determining depth to clay in soil types where there is a high level of confidence that texture is the outstanding feature driving conductivity.

Establishing the depth to clay-rich subsoil is very important when selecting the method of clay addition.

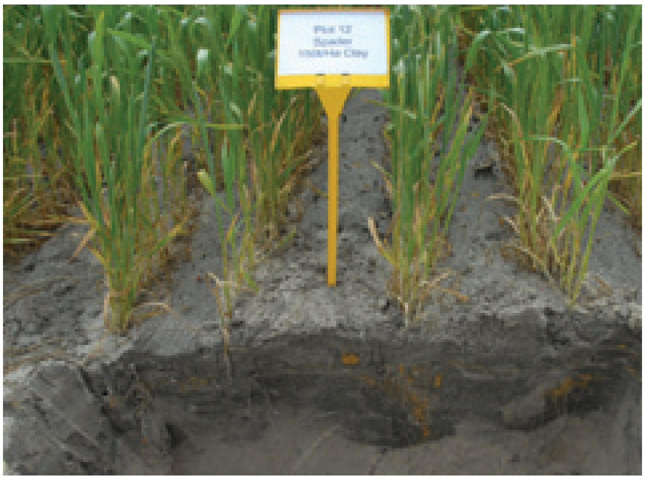
The types of vegetation present can provide an indication of the depth to clay. Vegetation such as clover, ryegrass, dock, fat hen and barley grass are used by some contractors as indicators that clay is within reach of the delving tyne.

Despite using these indicators as a guide the variability across a paddock can make judging the depth to clay-rich subsoil difficult. Each site can be different, not all sand hills have the same layers and often change in depth from the leeward to windward sides. They can also be affected by past erosion and deposition areas. Sand rises may appear even but may have lenses of calcareous rubble at shallow depth; these should be avoided if delving.

A rule of thumb that has been quoted by a number of delving contractors is "If in doubt; pull out", referring to the decision that if clay-rich subsoil is not being brought to the surface by the delver after few small test strips then there is no point continuing to try to delve and the site is best clay spread.

QUESTION 3
How much clay is required?

Before determining which method of clay introduction is appropriate for a paddock, the location and quantity of clay available needs to be understood.


CREDIT STEPHEN DAVIES

How much clay is added depends on clay type, availability, method and target result.

How much clay do I need?

When modifying soil it is important to have a clear idea what is the final soil type being targeted.

For most broadacre agriculture in 350 to 500mm rainfall areas an 'ideal' soil profile would consist of:

- topsoil - a loamy sand/sandy loam extending to at least 40cm deep:
- subsoil - a well structured sandy loam/loam from 40 to 70cm deep: and
- deep subsoil - a well structured loam/light clay below 70cm.

In higher rainfall districts, soils can be slightly heavier as rainfall tie-up by clay is not such a big issue.

This profile maximises plant available water without the risk of water logging and provides the capacity to retain adequate nutrient levels.

Determining clay rates

To achieve the 'ideal' soil profile requires a clay percentage of between seven to 12 per cent in the top 20cm and 12 to 20 per cent in the 20 to 60cm horizon. In lower rainfall areas the lower percentages should be targeted. Delving is the only method of claying that can introduce clay into the profile below about 30cm.

However, achieving the 'ideal' soil texture may not be practical, so the minimum target should be to raise the clay content in the topsoil to greater than five percent to eliminate non-wetting properties.

The rate of clay-rich subsoil required (Table 5) will vary depending on the:

- initial starting point - most sands contain between two and five per cent clay;
- clay percentage – most soils accessed for clay spreading/delving have a clay content between 15 to 50 per cent;
- depth of incorporation; and
- rainfall; rates reduce as rainfall decreases.

Table 5 A guide to safe rates of clay-rich subsoil for spreading with shallow incorporation by rainfall region and clay percentage of the material added based on experience from trials in SA (Source Rural Solutions SA).

Rainfall (mm/annum	<350		350-450		450-550		>550	
% Clay of subsoil material spread	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

Note: For clay with high carbonate levels the amount of clay spread must be limited. Clay with high fizz levels should only be spread at 50-80t/ha.

Calculating requirements

The amount of dry clay-rich subsoil required to be spread or brought to the surface can be approximately calculated using an equation:

nt – ct x (1400/pt) x d/10 = clay t/ha

Where:

- *nt* is target clay percentage;
- 1400 is clay bulk density (based on an average bulk density of dry clay of 1.4g/cm^3)
- *ct* is starting clay percentage;
- *pt* is clay percentage of the subsoil material to be spread; and
- *d* is incorporation depth in centimetres.

For example: if the target is five per cent clay content, the current topsoil contains two percent clay, the subsoil clay

A clay pit will be part of the landscape for a long time. The choice of location needs to consider on-going paddock opperations and safety.

material contains 30 per cent clay and will be incorporated to 10cm, the rate would be calculated:

(5-2) x (1400/30) x (10/10) = 139t/ha

If the material had a moisture content of 20 percent the rate would need to be increased by the same percentage.

Alternatively the change in clay percentage that will be achieved from the addition of a set rate of clay can be calculated. The following calculation assumes an incorporation depth of 10cm, with greater incorporation the change in clay percentage will be reduced:

% clay in applied material x rate applied (t/ha)/1400 = increase in clay % of clayed soil

For example: 30 x 139/1400 = 2.97%

Clay pits

Understanding how big the pit will be and its best location in the landscape is important.

Understanding the depth to clay and depth of clay is important when delving. For clay spreading knowledge of the total tonnage and capacity of the pit is required.

Pit size

To spread 100ha with 100t/ha requires 10,000t of clay subsoil. Assuming a bulk density of 1.4g/cm^3 a 7200m^3 pit is required (10,000/1.4).

For example: a pit 50m by 36m by 4m=7200m^3.

Most clay spreading machines require a pit 50m long in order to fill in one pass.

Drilling using a post hole auger can be a quick method of checking wher to locate a pit. Once clay is located it must be tested to check its suitability for spreading at the rate required.

Other options are to use clay from existing dam banks or to extend existing dams.

Pit location

To minimise transport cost and time, clay pits should be located as close as possible to the area where the material is to be spread. Work from WA suggests the optimum distance between pit and spreading area is 300m, so more than one pit may be required per paddock. Carting clay from further than 800m was reported to greatly increase the cost per hectare.

Similarly, the cost of removal of the overburden increases with depth, ideally clay should be no deeper than one meter below the surface. A pit is going to be part of the landscape for a long-time, consider on-going paddock operations and long-term farm layout plans when choosing a location.

Pit safety

Some consider locating pits at the centre of a paddock is best, others prefer corners or along a fence line. Irrespective of location pits can pose a farm safety issue, particularly if the pit is located in an area crossed by stock, vehicles and machinery.

The end and side slopes of pits should be battered to a safe angle (less than 90 degrees) and fenced-off or surrounded by the over burden to form embankments. Reflective markers attached to posts help mark the pit when working in the paddock at night and the location should be added to farm maps.

When using contractors it is sensible to discuss how the pit and surrounding area is to be left on completion of the spreading.

QUESTION 4

Which method of adding and incorporating clay should be used?

Depth to clay is a determinant of which method can be used but several other factors can also influence this choice.

When considering the introduction of clay to the surface soil there are four options:

- spreading;
- delving;
- spading; and
- inversion ploughing.

Spading and inversion ploughing can also be used as a method of incorporating clay-rich subsoil following spreading or delving. Incorporation is dealt with in detail at the end of this section, while changes to management following the addition of clay are covered in Question 5.

Experience has found that whichever method is selected careful planning is required; firstly in making the correct choice and in preparing the paddock prior to claying and then ensuring adequate and timely incorporation occurs.

When using a contractor planning and good communication are also important to ensure the contractor fully understands the requirements.

Choice of method needs to consider depth to clay-rich the: subsoil; rate; area to be spread; timing of operation and the limitation(s) that the addition of clay is trying to reduce.

NOTE: It is possible to delve, spade or plough a paddock that has been spread with clay-rich subsoil but the surface of a delved paddock makes spreading virtually impossible without some significant levelling and soil compaction. Hence the delving contractors motto – *"if in doubt pull out"*.

Preparing the paddock

Incorporation of organic matter to depth is showing clear benefits in trials in SA, consequently the more organic material on the paddock prior to the addition of clay the better. However, when delving, organic matter can become bunched around the delving tynes. Contractors encourage the removal of as much organic material as possible prior to delving. Level of paddock cover should be discussed with contractors several weeks before delving is to occur.

The spader has been demonstrated to work effectively with surface dry matter in excess of 25t/ha.

Weeds and volunteers should be killed with herbicide as should summer growing perennials such as lucerne.

Heavily grazed pastures or paddocks that have been cropped to legumes or canola are considered better options for delving than those coming out of a cereal crop.

Sand blowouts should be graded before applying clay-rich subsoil to help ensure an even rate and to try and create a stable level surface.

CREDIT REBECCA TONKIN

Paddock preparation before adding clay rich subsol varies depending on the method used. Delving contractors prefer low levels of organic matter while a spader has been demonstrated to work effectively with in excess of 25t/ha of surface dry matter.

Clay spreading

Factors that can be improved by clay spreading.

Non wetting	Poor water holding capacity	Low inherent fertility, OM and biology	Wind erosion	Subsoil compaction
✓	✓	✓ (high rates of hostile clay can cause nutrition problems)	✓ (take care when incorporating)	✗

Clay spreading is the application of clay-rich subsoil from a source that is remote to the site of application. The clay source may be immediately adjacent to the application site but it is a different process to delving, spading or mould board ploughing as these methods source all clay *in situ*.

Depth

Clay spreading is really the only option if the clay-rich subsoil is deeper than 60cm below the surface, although some delvers can access material at 75cm. The level of hostile elements tends to increase with depth, so it is vital to test the soil as the depth of the pit increases.

Equipment

Clay spreading usually involves the use of one of three different machines.

Scraper - spreads the clay-rich subsoil in rows sometimes overlapping and sometimes with space between each row. This method requires the use of techniques such as smudging/spreading bars or cross working to spread the clay more evenly.

Spinner - multiple spinners crush and spread the clay-rich subsoil. This method probably achieves a more even spread of material but can be slower than the scrapers.

Laser-levelling plane - operates similarly to the scraper except that the rows can be distributed adjacent to each other due to the presence of a 'bucket' in this machine.

Regardless of the method used, the key factors to consider are evenness of application and control on the rate of clay applied. Often this is more influenced by the operator than the particular machine.

It is important to know how much the machine can transport in one pass as this can influence the efficiency and cost effectiveness of the operation.

Rates

Compared to other methods, spreading generally allows greater control of the rate of clay-rich subsoil spread.

Calibration

The spread rate can be verified on the ground by using trays or sacks. If a rate of 100t/ha is required then 10kg must be dropped on a 1m^2 tray or sack, if 200t/ha is required then 20kg must be dropped on the same area. Multiple trays/sacks should be placed across the spread width to help determine evenness of spread.

Several runs of the fully loaded machine are required to establish the speed required to achieve the correct delivery rate. Next record the distance to empty the machine at that speed and use this run length for each load to ensure a consistent rate of application.

Timing

Clay spreading is ideally completed during the summer between harvest and the break of the season. Spreading can occur providing the subsoil is not too wet and no heavy rain is expected during spreading or incorporation. Both types of moisture would result in increased soil compaction.

Post treatments

An even spread of clay across the surface should be the aim. This is because clay is hard to move laterally across the paddock. To reduce the number of passes the clay is often laid in strips up to 1.5m apart and then 'smudged' across the surface using a frame made from two railway irons. Generally, the frame is dragged across the surface twice at speed, with each pass at 45 degrees to spreading, to maximise the coverage.

If clay rows are laid further apart, increased cultivation is required to achieve an even spread, this can result in deeper incorporation of the clay-rich subsoil.

CREDIT DAVID WOODARD

Delving

Factors that can be improved by clay delving.

Non wetting	Poor water holding capacity	Low inherent fertility, OM and biology	Wind erosion	Subsoil compaction
✓	✓	✓	✓	✓

CREDIT BRETT MASTERS

Delving is about half the cost of clay spreading but leaves the surface very rough.

Delving is a process by which tyned implements are used to rip deep into the soil profile and raise clay-rich subsoil from the B horizon into the sandy A horizon. This soil mixing results in the cation exchange and water holding capacity being increased throughout the profile.

It is essential that delving is carried out in the same direction as paddock operations. After delving it is extremely difficult to work at an angle to the delve lines.

Clay delving is generally cheaper than clay spreading (up to half the cost), and has the added benefit of breaking through compacted layers within the soil profile. This reduces soil strength and improves water infiltration and rooting depth adjacent to the fracture lines.

Depth

Delvers are used where the clay-rich subsoil is shallow enough to be accessed by the delving tyne. Generally clay rich subsoil needs to be within 60cm of the soil surface.

Unlike clay spreading where the material is only placed on the surface and then incorporated, delving brings clay-rich subsoil to the surface as well as distributing it through the soil profile.

Rocks can cause significant damage to the delving machine and many contractors will not delve a site where rocks are present.

Delving can be a useful but undesirable way of finding the services crossing a paddock. As one contractor states - “no extra charge for finding poly pipes”.

CREDIT BRETT MASTERS

Improved root and crop groth can be seen in the right hand plants grown on delved soil.

Equipment

Delvers are heavy machines with very large tynes. These tynes differ from those on deep rippers, where the tyne aims to create maximum disturbance at depth without raising material to the surface.

Disused ploughs such as a blade plough are often used to provide the frame for delvers. These must be heavily reinforced in order to be strong enough to withstand the pressure of ripping through the soil profile.

The most common configuration of delving machine is three tynes, each 10 to 17.5cm wide and up to 2.5m in length. These tynes are generally spaced 80cm to 1m apart. With the same set-up, wider tyne faces bring more clay to the surface.

Studies have indicated that tyne spacing of less than 80cm provides the best results.

Although these machines are able to be inserted up to 1.5m into the soil profile, it is commonly agreed that the practical limit is to pull clay-rich subsoil up to the surface from a maximum depth of 75cm.

Delving tynes are commonly set at an angle of approximately 45 degrees, although many delvers have the ability to hydraulically adjust the working angle of the frame depending upon the depth to clay-rich subsoil.

Tractors used to pull clay delving machines require a significant amount of power, generally in excess of 400hp. Often these have tracks instead of wheels in order to increase traction.

On some machines, a set of small opening tynes similar to those of a conventional cultivator, are fitted in front of the delving tynes. These help to clear away vegetation, allowing the clay to slide the full length of the tyne to the surface. The shallow leading tynes need to be sufficiently forward of the delving tynes to allow the free flow of clay to the surface

Ideally different machines are used depending upon the depths to clay-rich subsoil.

- Greater than 60cm - a heavy deep delver fitted with two tynes is required.
- 30 to 60cm - the majority of three tyned delver machines are most effective where the clay is between 30 and 60cm from the surface.
- Less than 30cm - a heavy delving machine is likely to bring up too much clay and so a deep ripper fitted with five to nine tynes is a more appropriate machine.

Rates

The amount of clay brought to the surface will vary across a paddock depending on the depth to clay-rich subsoil, the clay percentage and the set-up of the delves. Steeper angles and wider tynes pull more clay to the surface. It is difficult to accurately determine clay rates when delving.

In deeper sand over clay soils there is a risk of not hitting the clay-rich subsoil layer. If this occurs, even in patches, the delved soil may see some benefits in the short term from addressing compaction but this is unlikely to last long. In the short term there is an increased vulnerability to wind erosion.

Where free lime (carbonates) or clay percentage are high, lower clay rates need to be applied. Achieving low rates can be difficult with delving and will largely rely on the skill of the operator.

CREDIT DAVID WOODARD

Depth to clay can vary across a paddock, so can the amount of clay brought to the surface.

It is suggested that test strips are used to assess roughly how much clay is brought to the surface however, these are only an indication as the depth to clay-rich subsoil can change across the paddock.

Timing

Delving should be conducted while the clay-rich subsoil is still wet during late spring and early summer. This helps give delved sites adequate time for the large clods of clay brought to the surface to breakdown and to give the rip line more time to stabilise before seeding.

Post treatments

Delving often brings large lumps of clay to the surface. These should be left on the surface for as long as possible before incorporation to maximise the breakdown by wetting and drying cycles. In situations where too much clay has been brought to the surface and this has been left to breakdown before incorporation, a hard clay cap can form on the surface. Therefore, where large amounts of clay are brought to the surface partial incorporation should occur before too much wetting and drying has occurred.

Following delving the clay-rich subsoil will need to be incorporated (See Incorporation) and the paddock smoothed. Generally, the clay is broken down or spread with spreader bars or rollers, incorporated with several passes of a cultivator fitted with wide shears followed by harrows and sometimes a prickle chain. Workings are generally at 45 degrees to the rip line, making these slow and bumpy operations.

Delving can result in very rough paddocks and the delve lines can remain very soft for one or two seasons. This can make paddock operations, especially spraying and seeding difficult due to poor trafficability and the creation of an uneven seeding depth. Rolling or working along controlled traffic lines can help to reduce this unevenness.

Incorporation can also be achieved using a spader providing the clay has been applied at high rates (over 200t/ha) However, if a spader is used for incorporation and the clay is less than 30cm from the surface, the spading will introduce more clay-rich subsoil from below as well of incorporating that from the surface.

Spading

Factors that can be improved by clay spading.

Non wetting	Poor water holding capacity	Low inherent fertility, OM and biology	Wind erosion	Subsoil compaction
✓	✓	✓	✓ with clay rates above	✓ if less than 30cm


CREDIT DAVID DAVENPORT

A spader can provide the sole method of clay introduction when the clay-rich subsoil is found within 30cm of the surface. It can also be a a method of incorporating spread or delved material.

There is also the potential to address other issues such as sodicity or subsoil acidity by using the spader to incorporate gypsum or lime through the profile.

Early indications are that spading following legume crops or pastures provide the best results.

Depth

Spaders have demonstrated the capability to mix clay-rich subsoil throughout the top 30 to 40cm and also to incorporate surface dry matter in excess of 25t/ha. Mixing tends to be confined to the material directly under the spade. In trials on Eyre Peninsula the spader easily incorporated the equivalent of 10t/ha of hay to a depth of 30cm.

As with delving rocks can be a problem when spading; rocks smaller than a cricket ball are generally not an issue.

Equipment

CREDIT BRETT MASTERS

The spader blades have a greater lifting action than a rotary hoe, mixing soil to up to 40cm.

Spaders are essentially a series of spade shaped blades attached to a rotating axle. They operate with a similar action to that of a rotary hoe. However, the action of the spader results in a greater lifting of subsoil and burying of topsoil, than the thorough mixing created by a rotary hoe.

Machines used in Australia are generally three to four meters wide fitted with 30cm blades. At a travel rate of about six kilometres per hour the blades rotate at 90rpm.

Rates

As the spader is able to spread the clay-rich subsoil through the top 30 to 40cm and across the whole area of the paddock, higher rates can be accommodated. This is because the clay is being diluted through a greater volume of soil.

For example, if soil that is 30 per cent clay and located at 20 to 30cm, is incorporated into a surface soil that contains only three percent clay, this will result in a clay content after spading of about 10 per cent through the top 30cm.

Timing

Spading leaves the soil very soft making accurate seed placement difficult and leaving it vulnerable to traffic compaction and wind erosion.

Working in spring provides more time for the soil to settle before seeding but increases the length of time when soil is exposed to wind erosion. Having good levels of soil cover before spading or by sowing a cover crop following the operation can be reduce the risk of erosion.

If spading is carried out in late summer the paddock should be rolled prior to seeding and sown to a pasture or crop that is less susceptible to poor seed placement, such as faba beans or peas. Some growers have successfully established cereal crops on spaded soils by broadcasting the seed and pressing it into the soil with a coil-packer or similar implement.

The use of controlled traffic farming helps minimise the area re-compacted by traffic.

In WA trials, it was found that spading when the soil was wet reduced the risk of erosion and may result in better soil inversion with more non-wettable soil buried. There is a concern that this process can move the risk of water repellence down the profile. However, this is not an issue where clay is incorporated.

Post treatments

In addition to the post treatments mentioned in 'Timing', to avoid erosion, the incorporation of heavy cereal stubbles can result in nitrogen deficiency in the following crop. Consequently topdressing fertiliser may be required.

Inversion ploughing

Factors that can be improved by inversion ploughing.

Non wetting	Poor water holding capacity	Low inherent fertility, OM and biology	Wind erosion	Subsoil compaction
✓	✗	✓	✓	✓ if less than 25cm

CREDIT STEPHEN DAVIES

Mouldboard ploughing is not suitable for soil with hostile subsoils at less than 25cm.

The spader and inversion ploughing, using a mouldboard plough, work in the same area of the soil profile. While both have been effective at reducing shallow subsoil compaction and water repellence, there are some important differences.

Inversion ploughing buries rather than mixes the topsoil with the subsoil. This means inversion ploughing is less suitable as a method of incorporating soil amendments such as gypsum or lime. When set-up to achieve full inversion, mouldboard ploughing has been found to be very effective at burying weed seeds to a depth from which they cannot germinate.

Following inversion ploughing, weed control of greater than 95 per cent has been achieved without the use of knockdown or pre-seeding herbicides. In order to maintain this weed control benefit, integrated weed management and appropriate herbicide use is still required to control surviving weeds.

As some weed seeds can remain viable for up to 10 years, inversion ploughing can only be a one-off operation and buried seed should not be disturbed for at least 10 years, particularly if it is herbicide resistant.

Due to the complete inversion of the soil, mouldboard ploughing is not suitable where the subsoil is hostile to plant growth. Inversion brings this soil to the surface as an unmixed layer that may need subsequent incorporation.

Complete inversion of shallow duplex soils should be approached very cautiously and the subsoil tested at the inversion depth. Inversion of a sodic, alkaline high clay content subsoil, possibly containing high boron or salt can result in new problems and the formation of a very hard, dense and possibly toxic crust on the soil surface.

For these reasons the duplex, texture contrast soils where the rich clay subsoil is within ploughing depth have generally been avoided in WA. However, results have been positive with mouldboard ploughing in deep sands with little clay content, and in loamy sands and sandy gravels.

Soil inversion has increased wheat yields across a range of sandplain soil types in WA by an average of 600kg/ha (range 200 to 2000kg/ha increases) in the first year.

Excellent yield improvements have often been recorded in sandy gravels that have been ploughed with a mouldboard, provided the gravel was loose and not cemented.

In the loamy sands the clay content increases gradually with depth. Typically these soils are sands at the surface then grade to loamy sands or even sandy loams at depth. Inversion ploughing can bring this higher clay content subsoil to the surface. For example, in the northern agricultural region of WA inversion ploughing of a deep, loamy sand increased the clay content of the topsoil from 3.5 per cent to 4.5 per cent without clay spreading. In the same trial rotary spading alone increased the clay content of the topsoil to 4.2 per cent.

Despite large improvements in crop establishment in the deep pale sands poor water holding capacity still limits productivity.

Mouldboard ploughs only invert the soil well when the subsoil is wet. Water gives the sand cohesion and enables it to turn on the board rather than flow around the board. Wind erosion is a big risk where only low levels of clay are being brought to the surface and this is minimised by only ploughing the soil when it is wet and immediately sowing a cereal cover crop, which is resistant to sand-blasting.

Depth

Inversion ploughing can bring clay to the surface from up to 40cm below the surface.

Equipment

Mouldboard ploughs are used to conduct soil inversion and these range in size, complexity and cost.

Mouldboard ploughs can either be one-way ploughs where each pass needs to be done in the same direction or reversible ploughs, which can plough up-and-back in both directions. In reality most commercial scale ploughs are now reversible due to ease of use and higher work rate.

Ploughs either have shear bolt or hydraulic breakout. Shear bolt machines are cheaper but hydraulic breakout is much more convenient if rocks and stumps in the subsoil disrupt the boards.

Smaller commercial scale ploughs tend to have seven to 11 boards, which cut one furrow per board, and have three-point-linkage. They require 300 to 350hp front-wheel assist tractors and tend to work as in-furrow ploughs, meaning that the tractors wheels drive in the furrow. They cut between 3.5 to 4.5m wide and work at speeds of eight to 10km/h.

Large commercial scale ploughs have 12 to 14 boards and require a 450hp tractor. Tracked tractors are ideal. These ploughs are attached using a tool carrier that allows the tractor to travel on-land, not in the furrow and have a cut width of 5 to 7m.

For optimum weed control ploughs should be fitted with skimmer blades, which are located ahead of each board and scalp the topsoil, including the weed seeds into the base of the furrow. This helps ensure weed seeds are buried deep in the furrow.

Rates

The amount of clay brought to the surface will vary across a paddock depending on the soil type, depth to clay-rich subsoil and the plough set-up.

Timing

Because the soil needs to be wet when inversion ploughing is conducted it is often carried out in autumn, during seeding or at the end of seeding and a cover crop is sown. Inversion ploughing may be able to be done in winter or early spring but it is essential to establish a cover crop to reduce the risk of wind erosion over summer.

CREDIT STEPHEN DAVIES

Burying the non-wetting topsoil with the mouldboard plough has resulted in substantially improved crop establishment.

Post treatments

Soil inversion is a technique best suited to deep loamy sand soils that gradually increase in clay content with depth. For deep loamy sand soils subsequent mixing is not required as the clay content of the subsoil brought to the surface is less than 10 percent.

In a shallow duplex soil inversion ploughing will deposit the clay-rich subsoil in a layer at the surface and the sandy topsoil in a layer underneath. This is then equivalent to clay being spread on the surface but not incorporated. Consequently further mixing and incorporation is required.

It is possible to incorporate clay with a mouldboard plough by operating it at a shallower depth and with higher speed, which will result in mixing rather than inversion. However, greater mixing is achieved with a spader.

Soil softness after inversion ploughing can make crop establishment difficult. The soil needs to be adequately rolled and firmed after inversion ploughing. Coil-packers and rock rollers have been used for this operation.

Some growers have successfully established cereal cover crops by broadcasting the seed onto inversion ploughed soil when it is wet and then pressing it in with coil packers or other rollers. Light harrows can be used to provide some coverage of loose soil.

It has been noted that because the soil is soft and wet, wheat varieties with long coleoptiles can often emerge quite successfully, even if sown deeper than normal on inversion ploughed soil.

Incorporating clay

CREDIT TONY HARDING

Spread clay on the right of the picture has been incorporated to 30cm with a mouldboard plough.

There is no silver bullet for clay incorporation; it takes work and attention to detail to ensure the best results. Lack of adequate incorporation can result in a number of issues, which can cause considerable constraints to production.

- Surface crusting – where incorporation has not been adequate or timely, soil sealing and the development of crusts may occur. These surfaces have lower rates of water infiltration with potential for run-off and water erosion.
- Poor water infiltration – inadequate infiltration will lead to patchy germination and crop growth. Incorporation of the clay should be to a depth of 10 to 15cm to ensure that clay has been placed in the non-wetting layer of the soil.
- Uneven distribution of subsoil moisture - strong texture contrasts between clayed topsoil and a lighter subsoil may result in moisture retention in the topsoil and low subsoil moisture levels.

Clay incorporation has traditionally involved levelling out the site using a heavy roller or a piece of railway H iron attached to chains to create a levelling bar. This operation is followed by several workings across the site using a tyned or offset disc cultivator.

The key to good clay incorporation is to use the appropriate method of incorporation for the clay application rate and depth of incorporation that is being targeted (Table 6).

For example, at high clay-rich subsoil application rates, incorporation with offset discs, may be inadequate and actually result in productivity decreases (Figure 4).

During incorporation check that the desired degree of spread and depth of incorporation is being achieved; if not assess and consider changing working speed, equipment set-up or equipment type.

Table 6 Suggested equipment for incorporating different rates of applied clay-rich subsoil and the incorporation depth that can be achieved. (Source Rural Solutions SA)

Rate of clay-rich subsoil applied	Suggested equipment	Maximum depth of incorporation achieved
150t/ha or less,	offset discs or tyned cultivators with wide shears	10 to 15 cm
150 to 250t/ha	rotary hoe	15 to 20cm
greater than 250t/ha	rotary spader	20 to 30 cm

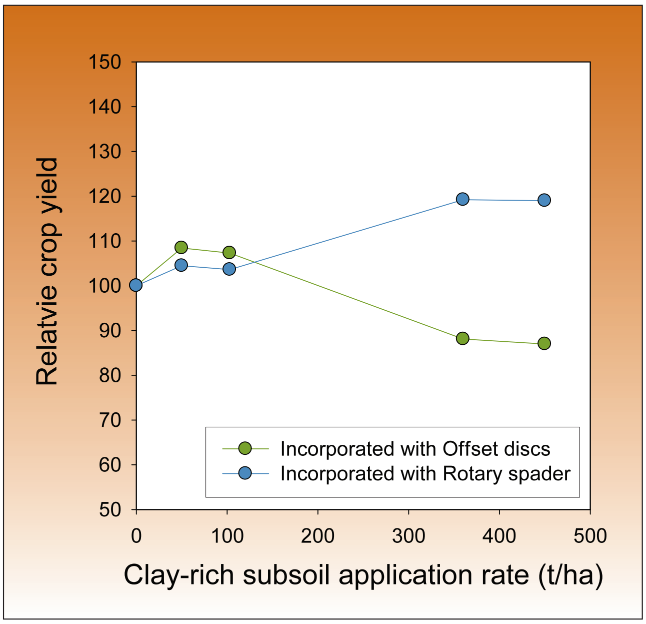


Figure 4 The change in relative crop yield derived from a clay rate by incorporation method demonstration. Data are derived from combining two years of crop responses, wheat in 2009 and canola in 2010 to demonstrate impact of clay application rate and incorporation method. (Source: West Midlands Group and DAFWA).

CREDIT

Cultivation equipment used for shallow incorporation of low rates of clay-rich subsoil.

QUESTION 5
What changes to management are required after the addition of clay?

Following the addition of clay to the topsoil some changes to management may be required.

Nutrition

Clay spreading can alter both the nutrient status of the soil and the ability of plants to uptake nutrients. Spading and deep incorporation can reduce nutrient levels in the topsoil, this may not always be offset by increased nutrient availability in the subsoil.

Soil testing for nutrients as well as the change in soil characteristics is recommended before seeding a clayed paddock.

With improved germination percentages and growth rates, nitrogen demand can increase. The use of canopy management techniques that limit nitrogen application at seeding and delay additional applications until tillering can help prevent too much early vigorous growth and crops haying-off in a dry spring.

In SA, nutrients such as potassium, calcium and magnesium are likely to increase following incorporation of clay as the majority of SA clays have high levels of these elements. The kaolinite clays mainly used in WA also result in increased potassium, as well as calcium, magnesium and sometimes sulphur.

Trace element availability, particularly manganese and zinc, may be reduced when using alkaline clays due to an increase in soil pH. Soil and/or tissue testing is recommended. Many growers in SA and Victoria use foliar nutrients to minimise these trace element deficiencies.

Herbicide activity

By addressing non-wetting following the addition of clay, it has been found that weed germination is more uniform across the paddock. This enables improved weed control as herbicides can be applied at the correct stage of weed development.

Research in WA has demonstrated better activity of residual and Group B herbicides following claying. However, if the introduction of clay results in a change in the pH of the topsoil the duration of residual herbicides can increase and may affect the following crop. For example, increasing the pH will slow the breakdown of sulfonylurea herbicides especially in low rainfall regions.

Soil compaction

While delving, spading and inversion ploughing can all help to ameliorate subsoil compaction, they can leave the soil in a soft and highly compactable state. Care must be taken to prevent re-compaction.

The use of controlled traffic farming (CTF) where machinery widths are matched enabling all paddock operations to run on the same wheel tracks, can be used to help contain soil compaction.

Unlike delving and spading, clay spreading does not reduce subsoil compaction but instead has the potential to increase compaction due to the heavy machinery driven intensively across the paddock. Such compaction is most likely to occur if operations are carried out when the soil is wet.

Consequently, deep ripping clay spread sites together with the inclusion of nutrients at depth has resulted in substantial yield improvements.

Snails


CREDIT EMMA LEONARD

When calcareous clay-rich subsoil is added growers have reported increased problems with snails.

The addition of calcareous clay to the topsoil has resulted in some growers noting an increase in conical and round snails. The higher calcium carbonate levels appear to create a more favourable environment for snails.

Crop choice post claying

Growers who have used clay spreading generally report that rotations become more flexible following the elimination of non-wetting soil properties. Cereals are a popular first crop after all methods of introducing clay-rich subsoil. Cereals provide good early vigour, substantial ground cover and large amounts of stubble that can be returned to build soil organic carbon.

Crops sensetive to poor seed placement, such as canola are generally avoided as the seedbed is uncompacted following clay incorporation. However, some growers like to grow canola after delving as they find the strong tap root is able to take advantage of pushing deeper into the rip line.

Spread, delve, spade, invert

Grower experience case studies

Case study one
Spader man a pioneer

Delving plus spading to mix clay has boosted grain yield dramatically on Roger Groocock's farm in southeast South Australia.

Felicity Pritchard

FARM DETAILS

Grower: Roger Groocock

Location: Bordertown, South Australia

Average annual rainfall: 450mm

Farm size: 1400ha, 950ha cropped area and 450ha pasture.

Enterprises: mixed farming with sheep

Soil types: bleached loamy sand over a brown mottled clay

Area clayed: the whole farm has been treated one way or the other; now just fine tuning small areas in paddocks or spading previously spread areas.

Claying history
Clay spreading began in the early 1990s and delving began on more shallow sands in 1993. Clays were mixed with a home-built 'Alabama' machine that was replaced with a spader in 2005. Spading is continuing on the property.

CREDIT FELICITY PRITCHARD

Roger Groocock's entire property has been delved or clay spread to eliminate non-wetting properties. Improved incorporation using a spader is the latest development in his on-going soil improvement program.

Roger Groocock is one of Australia's clay spreading pioneers.

In the early 1990s, Roger and his peers in the Bordertown Landcare group did all they could to overcome the scourge of non-wetting sands that were afflicting their farms. Capeweed and silvergrass dominated pastures on deep sands, while crop rotation options were unsustainable on the shallow sands, the 'good country'.

While minimum tillage and no-till with full stubble retention were tested, these did nothing to alleviate water repellence. Eventually they hit the jackpot by spreading clay over sand, after learning of this techniques success on Clem Obst's farm.

"We recognised the benefits as soon as we did the clay spreading," says Roger, who was group leader at the time.

Clay was not spread on paddocks with shallower sands, as these were considered most productive and ideal for subclover pasture. However, once continuous cropping was adopted, water repellence became an ever-increasing issue. This was due to waxes, created from the breakdown of extra organic matter produced by cereals, coating the sand particles. Wax levels after lucerne, phalaris and annual ryegrass were quite bad as well.

Realising water repellence was actually worsening with cropping, the group decided to test ripping-up the clay-rich subsoil.

The idea of delving the clay-rich subsoil was initiated by former CSIRO soil scientist Dr Bob Fawcett, after he visited a soil pit on Roger's property. Armed with this idea and information gleaned from a water repellence workshop Roger attended in Western Australia in 1993, trials were undertaken using a trench digger to 60cm depth and 1.2m spacing. They found water repellence did not return on the delved shallow sands.

Funding for the Landcare project (Operation Finetune) enabled the first clay delver to be built by University of South Australia in 1994.

"Very quickly, contractors and farmers recognised the opportunity to amend soils by delving. Within three years, it really took-off in this district," says Roger.

In 1997, Roger decided more spreading was needed on his farm. He bought a Lehman scraper to extend the area of clay spreading further down the sand hills. The expense was covered by the uplift in productivity brought about by clay spreading. Roger began contract clay spreading for an additional income stream.

Roger's entire property has now been delved or clay spread, with some paddocks spread twice where light rates were

CREDIT FELICITY PRITCHARD

Liquid trace elements are sprayed on the surface before incorporating the clay-rich subsoil with the spader.

used. Clay spreading took place on sands deeper than 40cm, while delving was used for shallow sands over clay.

He has since sold his Lehman scraper but Roger still owns a small delver. In early days, nearly all his country was delved with the small delver. In the last five years, Roger has used contractors to delve in areas with clay too deep for his small delver.

Deep incorporation

Roger built his own clay mixing 'Alabama' machine, in 1993. This created furrows about 25cm deep using V-shaped shares to mix both the spread and delved clay. A spray nozzle, mounted 30cm behind each shank and 30cm above the soil, was added to spray trace elements into the furrow. After levelling the trace elements would be located between 7.5 and 20cm deep. Liquid copper, zinc and manganese sulphate were applied at 2.5kg/ha of each element to the whole paddock. A 4.5m wide railway line was dragged behind the 'Alabama' to level soil.

Roger continues to push the boundaries of soil manipulation. In 2007, he was awarded a Churchill Fellowship and travelled to the Netherlands to research spaders. He had learnt of their existence from his Dutch farm worker, who said they were better than the 'Alabama' machine. These digging machines thoroughly mix soil to incorporate clay or other materials to a depth of about 30cm. He was so impressed with the results that he imported the first spader into Australia, to replace the 'Alabama' clay mixer. Farmax, a producer of spaders, then offered Roger the Australian agency for their machines.

Roger is in the process of spading all his delved and clay spread paddocks. After three years experience, he finds the benefits are clear. Grain and pasture yields after thorough deep mixing have increased by 70 to 80 per cent on delved paddocks. Before delving wheat yields were about 2.2t/ha now they average 3.8/ha. On clay spread areas following spading yields have doubled from 1.8 to 3.6t/ha. These paddocks can now support a more intensive crop rotation.

Roger has been fortunate, not all growers achieve such startling results from clay spreading. According to Roger, it is essential to know details of the soil profile before embarking on clay spreading or delving.

"With experience, we found we can use any clay on our farm. Some farmers have had trouble with high magnesium, chloride, carbonates or low pH in their clay," says Roger.

Types and rates

The top 30cm of Roger's clay-rich subsoil are sodic, however he considers these fine for spreading as the sodicity is readily ameliorated with gypsum. The subsoil below that layer has a higher calcium carbonate content, so rates are reduced. The clay-rich subsoil's pH (in water) ranges from 6.8 to 9.7. After delving or spreading clay, the topsoil pH is increased from about pH5.5 to ph6.5 to 7.5. Reducing topsoil acidity benefits crop growth and nutrient availability.

In the district most clay spreading and delving is undertaken after harvest. However, Roger has delved mostly in spring and spread clay in autumn, the optimal time. The spader allows more flexibility in the timing of these operations, although summer is not ideal due to the risk of erosion.

CREDIT FELICITY PRITCHARD

Orange clay brought to the surface by delving on 1.5m has been left to dry, allowing clods to break down with weathering over summer.

In the early days, Roger engaged contractors to spread on sandhills 200 to 250t/ha of clay-rich subsoil, which comprised of 35 to 40 per cent clay. This was fully incorporated to 10cm. The clay was removed from strategic points to create dams or water courses in low lying areas.

Finding his clays were 'friendly', free from major toxic elements, Roger decided to test heavier rates with deeper incorporation. Rates were doubled (400 to 500t/ha) as was the incorporation depth (20cm) resulting in the same clay percentage as the lower rate but distributed through a large volume of soil.

"About five per cent clay is adequate for long-term amelioration of water repellence. So, provided we have no more than five per cent clay, we are unlikely to create problems; the deeper we have mixed the clay, the lower the haying-off effect has been,"

Method

Roger now believes it is only worthwhile delving soil where the clay-rich subsoil is less than 30cm from the surface.

When delving with a 1 to 1.5m tyne spacing, he has found his soil is disturbed up to 90cm deep depending on depth to clay. Clay clods (football-sized or bigger) are brought to the surface. Delved soil is initially left to dry, allowing clods to break down with weathering over summer.

The ground is then levelled (smudged) with a scarifier or levelling bars. Trace elements are now sprayed before incorporating the clay-rich subsoil with the spader. Spading is carried out at between 35 and 55 degrees to the delver lines to improve clay mixing throughout the tyne inter-row area.

The rotation on delved soil is canola, wheat then barley. He believes canola provides greatest root penetration of the deep ripped layer once hardpans are removed. Pulses have been difficult in the past, but on delved and spaded soil, beans can be profitable. Balansa clover is sometimes used in lieu of a pulse. Roger is always looking for a better rotation, for example he has tried growing fodder rape as a summer forage. The addition of nitrogen through legumes is a major benefit of Roger's rotation.

On clay spread paddocks, Roger grows two cereal crops followed by long-term legume-based pasture for livestock. His aim is to raise soil organic matter levels.

After spading old pastures, he returns to two years of crop then spades in all straw. While spading works to 40cm depth, it generally mixes soils and straw to 30cm.

Three years in ten, a spring fodder rape crop has been sown pre-delving and used for finishing fat lambs through to March, then the area has been smudged and clay incorporated ready for a winter crop.

Benefits

A number of benefits have come from claying his country, these combine to help improve yield. Root penetration has increased on delved paddocks, providing entry points for roots to access previously unavailable soil moisture, increasing water use efficiency. Sandy topsoils now have better structure, trafficability, and more nutrient and water holding capacity. Soil erosion from slopes is also lower.

Weeds now germinate on the first rain providing better control with knockdown herbicides. Post-seeding weed control is better too, while less frost damage is another improvement.

Roger has seen a significant improvement due to better nutrition. The introduction of clay to the topsoil helps retain the applied nutrients in the root zone.

In nine out of 10 years Roger has covered the costs of delving and spreading after the first year. However, he knows owning his own machinery means his costs are less than the contract rate, for example $120/ha for delving.

Roger remains an advocate of clay spreading and delving. His persistence, ingenuity and enthusiasm have led to a major change in practices and attitudes of farming sandy soils in the Mallee and beyond.

"The interaction between soil scientists and farmers has been pivotal to the success of this soil amelioration process."

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Case study two
Loam creation

A bold program is underway in southern Western Australia to shift resources from depth to improve a fragile farming system.

Sue Knights

FARM DETAILS

Grower: Joe Della Vedova

Location: 50km west Esperance, Western Australia

Average annual rainfall: 550 to 600mm

Farm size: 9,000ha

Enterprises: 1,000 head of breeding cattle, 15,000 breeding ewes for wool and fat lambs, cropping a mixture of cereals, oilseeds and legumes

Soil types: Esperance sandplains

Area clayed: 300ha

Claying history
100ha of non-wetting soil was clayed 1998 to prevent soil erosion, 200ha clayed 2007 using a spader for incorporation.

The most ideal soil for agricultural is loam as it retains nutrients and water while still allowing free drainage. This is the type of soil that Joe Della Vedova is trying to create from his Esperance sandplain soil in southern Western Australia.

Starting with soil maintenance

Becoming tired of the unreliable seasons on their central wheatbelt property, the Della Vedovas relocated to near Esperance in the mid 1990's. In their search for milder seasons and more reliable rainfall, they gave up rich red loams for sandplain soil.

Joe discovered that although he had moved to an area with higher rainfall, his crop yields were well below their potential. Closer inspection of his soils showed that extensive areas were prone to non-wetting issues and wind erosion in the coastal environment.

He immediately began to experiment with clay spreading to manage these problem areas, using clay available on the farm. The material that was spread contained up to 50 per cent high grade kaolinite clay and most of it was located between 70cm to 3m from the surface. Initially, they were spreading about 200t/ha of the material and incorporating this to a depth of 10cm, which was district practice. This increased the clay proportion in the top layers to about six per cent. He found that incorporation of the clay-rich subsoil to a shallow depth in the profile was reducing weed germination

CREDIT SUE KNIGHTS, SE KNIGHTS CONSULTING

Joe (left) and Troy Della Vedova with an example of the high grade kaolinite clay used in their claying program.

and minimising erosion however, crop roots tended to stay within this clayed zone. Consequently, the crops ran out of moisture too rapidly and often hayed-off in spring. Joe was achieving an average of 2.6t/ha for cereal crops but he estimated on his average in-crop rainfall he could be achieving up to 8t/ha.

Disheartened, Joe held off any further clay spreading until a field day he attended in 2007 where he saw a spader being demonstrated. The spader could incorporate clay to a depth of 30 to 40cm without creating a hard pan and this encouraged him to give clay spreading another try.

Moving to soil building

Joe began a more comprehensive program of soil building, using spading.

Paddocks in the soil building program had soil types ranging from 15cm of sand over clay to depths of 1m of sand over gravel or clay. This subsoil material contains between 40 to 60 per cent clay.

The Della Vedovas extensively soil test their paddocks. Electromagnetics (EM) and gamma-radiometrics have been used to map the location and depth of clay and gravels in each paddock; this information is used to decide whether to spread


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The Della Vedova's use a bulldozer fitted with tracks to open up the pit and break down the material before it is gathered by the two carry graders working in tandem.

or delve. They are now able to link variable depth delving with the EM maps making a much more efficient system.

Where the clay is close to the surface waterlogging is more prevalent and these areas are delved. Paddocks are delved to a depth of 80cm and then spaded to a depth of 45cm, which incorporates the delved material.

Areas of the paddock that had deep sand have clay carted from nearby and incorporated with a spader to a depth of 45cm. Clay-rich subsoil for spreading is sourced from the lower lying areas within the paddock. Joe only considers it is economic to cart the material within a 500m radius from the pit.

Joe's standard practice is to spread 1000t/ha of the subsoil material. On poorer areas he may spread up to 2000t/ha. These rates are far in excess of the district practice. Some areas may be spaded twice to improve the tilth and friability of the soil. Spading is done when the soil is moist, because when it is too dry there is a risk of pulverizing the soil.

Gypsum and lime are applied prior to claying at the rate of 3t/ha and 2t/ha respectively. Incorporation of the clay-rich subsoil, together with the gypsum and lime has altered the pH of the soil from pH4.5 to about pH6.0 While reducing acidity has been good, crops need to be monitored for any toxicity problems which may have been introduced with the subsoil material, such as salt or boron.

At the moment, the claying process does not need to be repeated on any paddocks. Joe is now looking at building the soil nutrient levels on his property; a project he anticipates will take about 20 years. Fortunately, he has a keen member of the next generation of the Della Vedovas interested in the process, his eldest son Troy.

Results of soil building

The surface clay content of the treated paddocks has increased from about 1.5 per cent up to 12.5 per cent. Joe has found that his paddocks have become more uniform and the surface more even following the claying and spading process. With non-wetting properties eliminated, soils wet-up evenly improving weed germination and control, and timeliness of sowing; soil erosion is now a non-issue.

The major outcome from our soil building exercise is that we have soils that are easy care and have a greater production potential, making much better use of the annual rainfall," says Joe.

Average cereal crop yields are still around 2.6t/ha but yields of up to 7t/ha have been achieved. In addition, in 2009 a summer sorghum crop was sown and produced 5.65t/ha

With claying, Joe has been able to change the crop rotation from canola, wheat and two years pasture, to cereal, a summer crop or legume and canola, removing the pasture phase depending on the paddock.

With the pH change, Joe has been able to introduce alternative crops like vetch and peas, which he was unable to grow previously.

By creating a more neutral soil pH some nutrients become more available for crop growth. The clay material applied is also high in magnesium that contributes to improved crop growth. When pasture is grown on the clayed country he has noticed the pasture is more palatable to stock, this may be due to the increase in magnesium. The increase in magnesium, however, does tie-up manganese, which needs to be applied. Joe now applies less fertiliser before cropping and feeds as he goes according to the season. Clayed and spaded country is fertilised the same as delved and spaded country.

Carbon levels have been reduced to one per cent in the top 10cm because the carbon is now dispersed to a depth of 45cm. Joe has introduced tetraploid ryegrass, with its extensive root system, into his farming system. He hopes this, together with green manure crops and stubble retention will help to increase carbon levels to four to five per cent and

The texture difference between clayed (left) and unclayed (right) soil. Claying has eliminated non-wetting properties and the risk of soil erosion.

increase microbial activity within the soil. Both changes would be positive for plant growth.

Joe has found that grass weeds have nearly disappeared from his paddocks, this may be due to several reasons. Following spading, seeds may be buried to a depth where they are unable to germinate, while raising the soil pH may have created conditions that no longer favour the growth of weeds such as silvergrass. The weeds may also be outcompeted by a more vigorous crop. However, turnip weed has become more prevalent but being a broadleaf weed is manageable in the cereal phase.

In the past, frost damage has resulted in reduced crop yield. The incorporation of clay into the profile has helped to retain moisture and hold or increase temperature to mitigate frost damage in crops. Joe has been monitoring temperature and frost damage within his crops via the use of 'frost buttons' (www.thermodata.com.au). These cost effective temperature loggers recorded differences of one degree centigrade between clayed and unclayed soil. This was often enough to reduce frost severity and the risk of damage at flowering.

The pits created by the spreading operation are an issue and Joe estimates that he loses two hectares of productive land for every 200ha clayed. The pits are often dug in the lowest part of the paddocks where the clay is often closer to the surface and has a higher clay percentage. Joe is considering using the pits to harvest water during times of run-off or flood. He warns the pits can be a hazard for stock and farm workers and should be fenced.

"Ultimately we may consider a whole farm drainage plan and link the pits into an irrigation system."

Key investments for soil building

Given the scale of the earth moving operations on his property, fuel is a key input cost. Joe estimates 150 to 160L diesel/ha are used to complete all operations in the claying process. Therefore, operational efficiency is paramount.

Clay is spread at about 0.7ha/hr, it is spaded at about 3.5ha/hr and delving rates are 0.5 to 2ha/hr; the slower rate is when the operation is linked with the EM mapping. Contract clay spreaders can cost as much as $2,000/ha, whereas Joe estimates that using his own machinery and labour cost $550/ha.

Joe has purchased two John Deere ejector carry graders, each with 25t capacity, which are pulled in tandem by a 580HP John Deere tractor. He has tried to reduce the wear on the tractor, especially the rubber wheels, and uses a 400HP Caterpillar D8L bulldozer to open pits and to do the preliminary removal and break down of material. To limit soil compaction and costs, Joe does not follow the local practice of smudging and levelling. Instead the clay is dispersed in one pass and then incorporated with the Imants spader.

Joe estimates that his claying costs are recouped in two years through either the ability to produce a summer crop on the clayed country or the improved winter crop yields.

"It is important to invest in proven earth moving equipment and equipment that pays its way."

Claying as part of the farm system

Claying is part of a changing farming system to 'create loams' on the Della Vedova property to deal with non-wetting soils, improve weed management and chase increased crop yields.

Carbon building is also a challenge. In addition to the use of tetraploid ryegrass, green manure, summer crops and stubble retention, Joe now uses a stripper front to maximise the amount of standing stubble. Stock also form an integral part of the system to graze and knock down the stubble and recycle organic matter.

No-till is used to reduce the number of machinery passes and consequently compaction of the spaded country. Stubble retention helps to reduce erosion and improve soil carbon content and water infiltration.

Joe says "farming is a marriage of three systems; mechanical, biological and chemical. It is important to do the appropriate research and make decisions in light of these systems."

He uses a cautious approach and makes sure every step forward is a positive. He has worked closely with the local Department of Agriculture, together with using local knowledge, on-farm research and the world wide web.

With the recent dry seasons progress has been slowed. Joe estimates that there is sufficient clay on his property to clay all the paddocks but would like to understand more about what is happening within the whole farm system, particularly the soil biology, before he invests in further work.

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Case study three

Claying brings a farming revolution to Telopea Downs

Nine out of 10 Telopea Downs farms have been clayed to combat non-wetting soils and substantially boost production but vast areas are yet to be transformed.

Felicity Pritchard

FARM DETAILS

Grower: Darren Hards

Location: near Kaniva, between Serviceton and Telopea Downs, Victoria

Average annual rainfall: 350 to 425mm

Farm size: 4,450ha farmed; 3440ha owned comprising 3000ha cropped plus area share-farmed land and 2000ha pastures, including lucerne

Enterprises: prime lambs, merino ewes, wheat, barley, canola, lucerne and faba beans

Soil types: range from very deep sand over clay to a small area of Wimmera grey clay

Area clayed: about 3000ha on current property, plus other properties which have since been sold

Claying history
Since starting slowly in the early 1990s, a combination of spreading and delving have been used on 3000ha and a clay contracting business started. A further 800ha of new land will be clayed in the next few years.

With the ambitious goal of transforming a desert into productive agricultural country in the 1950s and 1960s, Telopea Downs in Victoria's northwest Wimmera, was cleared of its stunted, scattered vegetation.

Although fertilisers initially boosted pasture production, the local lucerne industry began to decline in the 1970s. By the 1980s, a new issue became apparent.

Clearing the sands for agriculture revealed an insidious phenomenon that native vegetation seemed to cope with: water repellent soils - a problem that worsened over time.

The extreme non-wetting nature of the sands caused many problems for local farmers. Poor germination, difficult weed control, silvergrass problems, low yields, limited crop choices and, in some parts, transient salinity. All of these made viable farming a serious challenge.

Aiming to remedy these problems, the Telopea Downs Agricultural Group formed in 1982.

Now, most Telopea Downs farmers have undertaken some claying. This ranges from five per cent of individual farms to entire properties and vast areas remain which are yet to be clayed.

CREDIT FELICITY PRITCHARD

Canola has been added to the rotation since clay delving at Darren Hards' property in Telopea Downs.

One grower who has taken on the challenge is Darren Hards. He emphasises he is not a pioneer but an example of a typical Telopea Downs grower, spurred on by the successes of claying his farm and of others around him.

By sharing his experiences, Darren is hoping it will help others contemplating claying to avoid the pitfalls and 'do it right' the first time.

Darren first heard of claying about 20 years ago, when some South Australian farmers spread clay on sand hills to prevent erosion. However, when a local farmer tried clay spreading, his initial reaction was sceptical, finding it hard to see the long-term benefit.

Now, all sandy soils on Darren's property between Serviceton and Telopea Downs have been clayed.

Darren is passionate about farming and his family's farming future, as are his wife Sharee and children – a future that may not have been possible had he not adopted spreading and delving .

"Before claying, our sand was very non-wetting, we were lucky to have 50 per cent coverage of silvergrass. An inch of rain would fall and we wondered where it had gone," says Darren.

"We were heading nowhere with the non-wetting sand."

CREDIT FELICITY PRITCHARD

One of Darren Hard's three clay spreaders. The tynes are used to rip and 'bust' the clay in the pit before picking it up. This assists more even spreading of clay over the sand and prevents the machine picking pick-up a large slabs of clay.

Clay quality

Clay-rich subsoils on the property are variable, ranging from grey clays that are less useful for spreading or delving, to lighter coloured clays that are more dispersible and better for mixing. The quality of clay nearest the surface is the best.

The majority of subsoils around Telopea Downs are sodic, meaning they disperse and incorporate readily, making them well suited to claying.

However, variability in clay quality around Telopea Downs means those considering claying need to test subsoils before claying.

Preparation

From Darren's experience, paddock preparation is particularly important for clay spreading but less so for delving. The smoother the paddock, the faster the travel - which can significantly reduce costs when using a contractor.

Chemical fallow is the best practice for producing a smooth, bare paddock. Darren suggests that if a chemical fallow is not used then spraytopping is required for paddocks coming out of long-term pasture.

Delving

After hearing of the impressive results from delving on properties near Bordertown, Darren built two delvers, the second larger than the first.

He witnessed a visible improvement in yield upon delving his first paddock. Delved paddocks now produce barley crops of 2 to 3t/ha, this is about double pre-claying yields. However, for Darren the consistency of production achieved is as valuable as the improved yield.

Tynes are spaced at 2.5m, by straddling rip lines on the return trip clay is ripped every 1.25m. The depth delved depends on the clay depth, although the maximum is generally 60 to 70cm. It can be difficult to bring-up enough clay when delving deeper. On rare occasions Darren has delved to 1m.

Although delving is possible on soils wetter than ideal for spreading, delved soil still needs time to dry out.

Spreading

Initially in about 2000, Darren bought a Lehman elevated scraper to spread clay on his property. Later, he invested in an open bowl carry grader, designed for laser levelling, which he modified to suit clay spreading.

For Darren, spreading is only undertaken on sand hills. If delving is also required, the entire paddock is delved, including clay spread areas – a practice not typical of other farmers. This is to alleviate compaction resulting from wheel tracks where clay has been hauled for spreading. The biggest downside is high fuel usage.

Darren spreads and delves all year round as part of his contracting business. He says these jobs are ideally undertaken in the drier months, between September and April, as mixing is too difficult on wet soils. However, if soil is too dry, it is hard to rip.

"I prefer to spread clay before Christmas and let nature help. Rain expands the clay, breaking it down and clods fall apart – although some larger clods do not break-up easily," he says.

When Darren started spreading clay, low rates of about 125t/ha were applied but he found clay rates of 250 to 370t/ha are optimal. Rates are determined by the clay content of the topsoil and the clay-rich subsoil being added as well as by the aggressiveness of incorporation.

Sands with lower clay content need higher clay rates and subsoil with lower clay content will need to be applied at higher rates. By testing, Darren has found the first clay layer in a pit can be up to 40 per cent clay but this can drop to 20 per cent in the next horizon and rise back to 50 per cent in a third layer.

"We worked out higher rates were better in the long-term; we can use high rates if incorporated well. With experience, exact rates are no longer measured."

The rates Darren uses are higher than those recommended about 15 years ago by the Telopea Downs Agriculture and Landcare Group. This reflects accumulated experience and the capacity of newer machinery to handle higher rates.

Incorporation

Darren advises that good incorporation of the clay is critical to success because his aim is to turn sand into loam. The spread clay is mixed with an offset disc. Sometimes a grader board is used to mix soil more finely before discing.

Effects of claying

Once clayed, cropping paddocks are sown to a cereal using minimum tillage. On the 'better country', which could previously support one barley crop every two years, grain yields have doubled and continuous cropping with wheat, barley and canola is now a reality. Faba beans have also been grown.

His results are mirrored in other parts of the Wimmera, where claying has commonly doubled crop yields.

On deep sands, lucerne is sown and establishes well; prior to claying this was a frustrating task as establishment was usually poor in non-wetting sands.

In place of spinifex and silvergrass, which fed sheep part of the year, the lush lucerne pastures have given a five-fold boost in sheep production. Darren now runs merino ewes which are mated to white Suffolk and Dorper rams for prime lamb production.

The effects of claying are most startling in dry seasons, in these years' crops on the unclayed ground die and there is nothing to harvest.

With variable seasons Darren is careful to match nitrogen rates with soil moisture, as top-dressing in August, when crops often look very promising, can quickly cause haying-off.

The benefits of claying have persisted on Darren's property, although some paddocks have required 'touching up' where clay rates were inadequate or sheep have camped. Sheep camps can result in a recurrence of water repellence.

In addition to the greater choice of crops and pastures, the benefits of claying on Darren's property are many. For example, soil-applied herbicides such as trifluralin, atrazine and simazine work more effectively as the soil dries more slowly and these chemicals require moisture to work effectively. The incidence of frost damage is lower due to better moisture retention in the soil.

The soil is now much more able to hold nutrients. Fertiliser use has increased, along with yields and the improved nutrition has resulted in a changed weed spectrum. Annual ryegrass now dominates the weed list where silvergrass once ruled on deeper sands.

A larger snail population is one of the few negatives from claying, resulting from the increased soil pH and moister soils.

Economics

While the cost of adding clay is an issue, Darren thinks in this region the cost of not claying is greater.

For Darren, claying has paid for itself in one to three years, depending on grain prices. However, delving costs have increased in recent years due to rising fuel and machinery costs, so others' experiences will differ.

Clay spreading costs about $370/ha, depending on distance of clay cartage, while delving is at around $150/ha.

To justify machinery costs, Darren runs a contracting business that spreads and delves clay.

Future claying

Darren aims to clay a further 800ha of new land over the next few years as well as maintaining the land already clayed.

Like many other farmers in his area, the future looks bright for Darren and his family. This is thanks largely to the opportunities clay spreading and delving have provided on what were previously unviable farms.

Contact details: not provided.

CREDIT FELICITY PRITCHARD

Lush lucerne pastures have supported a five-fold increase in sheep production. Lucerne establishment is much easier since clay spreading on deep sands.

Case study four
Mates rates

Less is more when highly calcareous clay is used to improve sandy soils.

Emma Leonard

FARM DETAILS

Growers: Shane and Beth Malcolm

Location: Wharminda, South Australia

Average annual rainfall: 325 to 350mm

Farm size: 1600ha in three blocks, 30km apart

Enterprises: wheat, malting barley, lupins, canola, peas, vetch (for green manure); 300 Merino ewes, plus crossbred lambs

Soil types: sand over calcareous clay, deep sand and red loam; topsoil pre-claying pH 6 to 7, subsoil pH8 plus; clay depth varies from 15cm to over 1m below the surface

Area clayed: 300 hectares

Claying history

The Malcolm's first experience of claying was in 1986 when Shane's father built a roadway through the middle on the farm. The material removed was spread over light sandy areas prone to erosion. The improved plant cover and performance seemed encouraging.

However, it was not until Shane and Beth were managing the farm that they tried their first 'true' clay spreading to reduce non-wetting properties and soil erosion. That was in 1997; fourteen years later they still have an on-going program of clay delving across the properties.

Despite the low rainfall, wheat yields of one and a half tonnes per hectare are not uncommon in the Wharminda region, providing crops are sown early and receive in-crop rainfall. However, in paddocks suffering from non-wetting sand, plant establishment is reduced leading to low soil cover and the potential for wind erosion. The non-wetting properties also result in staggered weed germination, especially of competitive weeds such as brome grass.

In pastures, stock tend to camp in these non-wetting areas causing further loss of cover and susceptibility to wind erosion.

All of these factors can substantially reduce a paddocks production and were the reasons why Shane and Beth Malcolm decided to try clay spreading.

"I hate soil erosion and drift and want to achieve timely sowing and good establishment to maximise yield potential," says Shane.


CREDIT EMMA LEONARD

Delving is now the Malcolms preferred method of claying because spreading too higher rates of calcareous clay has had a long-term negative effect in drier seasons.

Having seen the potential improvement in crop and pasture establishment on the areas spread with the clay spread from the road building process, Shane and Beth Malcolm decided to try spreading clay on patches known to be non-wetting.

Patch spreading

In 1997, a 10 tonne, Marshal belt-spreader was purchased with the aim of spreading up to 150ha across a new property the Malcolms had purchased in 1994. A CAT951 track loader with a 1.5m^3 bucket was used to extract the clay from a pit and fill the spreader.

Plastic trays were laid out across the spread width, which was up to 18m, to establish the clay rate. Roughly, the rate spread was 50t/ha with 10t/ha of clay spread per pass but much of this was as large lumps. Shane remembers this as being a very slow process.

The clay was spread during the summer and worked in at seeding by two workings with a full cut shear.

While the clayed areas did result in better establishment, not only of cereals but also of lupins and canola, these areas now suffered from two new challenges; snails and manganese deficiency.

The clay in this region can be highly calcareous (calcium carbonate) or referred to as containing free-lime. The additional calcium makes these areas especially attractive to

High calcareous clay (right) and good clay (left) brought to the surface in the same pass with the delver. Using simple on-farm tests is essential to establish the composition of the clay being added.

snails, so baiting was required. The additional carbonate can impact on nutrient availability and the residual effects of some herbicides.

The manganese deficiency is caused because the previously available nutrients become locked-up by the added calcareous clay. Over the years, Shane has established that his clayed paddocks require up to three applications of manganese sulphate (see breakout).

Paddock spreading

In the same year the Malcolms also experimented with spreading larger areas using a Landplane scraper. This contractor machine was selected as it allowed larger areas to be spread quickly, with clay rates of about 100t/ha, for the least cost per tonne.

The Landplane can spread up to 350t/ha, while the Claymate's maximum rate is about 150t/ha but the contractor rate for each machine was about $125/ha, irrespective of tonnes spread. This is approximately, the same cost as using the Marshal spreader to achieve a rate of 50t/ha.

The Landplane spread the clay in strips a little over 4m wide and left the surface very uneven. To achieve the required rate a 1m gap was left between each run. As with many operations the evenness of spread is very dependent on the operator. The clay was worked in by a wideline cultivator with a prickle chain looped behind, which smashed up the clay lumps and incorporated it to about 12cm. The clayed paddocks were cross worked about six times at work rates of about 10km/hr. Even after all these workings enough clay was left on the surface to prevent wind erosion.

The high rates of clay did result in improved crop establishment and more even germination of weeds, enabling more effective weed control after the opening rains. However, the overall yield outcomes from the high rates of clay were very seasonally dependent.

In a year with an even distribution of rainfall and adequate falls in spring, a wheat yield of 1t/ha was achieved on the un-clayed land and 2.5t/ha on the clayed. However, in a dry year these figures reverse with the un-clayed land still producing about 1t/ha but the clayed land only producing 0.4t/ha. In some situations the clayed areas in dry years resulted in complete crop failure.

"We have learnt the hard way; knowing the properties of the clay and setting the appropriate rates are essential; for our soil 100t/ha was far too high."

At this stage in their experience the Malcolms had not tested the chemical composition of the clay being applied. After the clay had been spread and the issues of snails, manganese deficiency and crop failure had been encountered they started to look for the reasons. Testing the clay from different parts of the pit established that all the clay was highly calcareous, with hostile levels of pH, free lime, boron and salt all increasing with depth.

"I encourage anyone who is going to incorporate clay into sandy topsoils to test the chemical content before they set a rate; not all clay is good for crop growth."

The high rates of clay spread using the Landplane increased the clay and the carbonate content of the topsoil sufficiently to lock-up both nutrients and available soil moisture. While the manganese deficiency is an annual problem that can be treated with foliar fertiliser, little can be done to reverse the reduced moisture availability in dry years.

"Once clay has been incorporated it is very hard to reverse the process or reduce any negative effects. Where we have the rates right we are gaining on-going benefits."

A couple of years later, the areas spread with 100t/ha of clay were worked as deeply as possible, to about 13cm with a two-way, concave disc. The aim was to distribute the clay to a greater depth and dilute the negative effects of the free lime. An application of 2.5t/ha of gypsum was also tried to help stabilise yield. The results were mixed and the tillage left the soil vulnerable to wind erosion until the next crop was established.

Minimising manganese deficiency

All cereal crops growing in clayed paddocks or clayed patches receive a foliar application of manganese sulphate (0.6 to 1.5kg/ha) at the three leaf stage. At this stage growth has not been severely checked and the plant has enough leaf area to absorb sufficient nutrient.

A second application is made when the first sign of a colour difference between the clayed and unclayed paddocks is visually observed. This is at the same rate and generally occurs about early tillering with the rest of the paddock.

If the colour difference returns later in the growing season a third application can occur.

Delving

For the Malcolms, delving is now their chosen method of introducing clay into the surface soil. Although delving is

Home built delver

Built on the frame of an old blade plough, the delver consists of three fixed tynes spaced one metre apart. The tynes, set at about 45 degrees are designed to penetrate the soil to about 50cm. The facing plate helps distribute clay through the rip line and not just bring it to the surface.

The frame is supported by two wheels located at the back of the machine fitted with hydraulic rams. Shane plans to relocate the wheels, possibly to the front, as they currently run over the ripped material making it a very rough ride. He initially fitted two pairs of wheels but found single wheels to be more stable as the pair of wheels were bouncing over more lumps.

In the current metre spacing format about 80 per cent of the surface area is ripped. The delver was originally pulled by a 245hp front wheel assist tractor; now Shane has a 275hp articulated tractor that pulls the delver at between eight to 10km/hr. With the increased power Shane could pull four tynes spaced at 60cm. He is considering modifying the delver to this layout.

relatively slow and the paddocks are left very rough, the Malcolms find this method provides an adequate clay rate and does not bring too much very hostile clay to the surface. Areas of a paddock with shallow rocks are avoided.

Following the success of some trial strips delved in 2006, Shane built his own light-weight delver, which draws clay from 50cm deep into the upper soil profile. He admits that it took four very dry years before he was convinced that delving was the correct procedure. In 2009, he recorded a half tonne per hectare difference in wheat yield between delved and un-delved ground.

"In 2010 we still saw the benefits of the original delving but without a yield monitor its hard to put a figure on the different parts of the paddock.

Shane estimates that delving and levelling a 60 hectare paddock takes approximately 100 hours. Delving is carried out in late summer, when the clay can be wet or dry. This is followed by two cross workings with a chisel plough fitted with 35cm sweep shears and trailing a prickle chain loop. The first working is in the same direction as the rip line and must be done within a day of delving while the clay still retains some moisture. The second working is at 45 degrees to the rip line.

Even after two or three workings the surface is still rough. While Shane is keen to do more delving, Beth who drives the boomspray is less enthusiastic about the prospect of more rough paddocks.

In a trial, a spader was used to incorporate the clay. While the surface was left smoother, the Malcoms were very concerned that the spader left the paddock too even and vulnerable to wind erosion.

To help retain ground cover, paddocks coming out of cereal are selected for delving. The crop following delving is usually a cereal as lupins are more susceptible to damage from the increased carbonate level.

While the negative influences have been minimal due to the lower clay rate achieved with delving, they have not found the uniformity of weed germination to be as great as with spreading. The manganese problem remains with all claying methods tested by the Malcolms, although is less extreme with delving. Shane has also noticed that where he has delved there has been an increase in the pH of the topsoil and barley has suffered more severely from net blotch. As yet he is not sure if this is also linked to a nutrient deficiency.

In February 2011, the delved paddocks were worked once with a two-way disc for further levelling and to assist seeding through thick stubbles.

The future

Shane Malcolm is keen to continue remediating the non-wetting sands using clay. Once he has delved all areas of the farm where the clay is within 50cm he will consider revisiting clay spreading, however with reduced rates perhaps 50t/ha and avoiding the use of hostile clay.

Key points from Shane and Beth Malcolm's experience with claying

- Always test the carbonate content before setting the rate and during digging. If the acid fizz test (see page 12) indicates high carbonate stop digging or reduce the rate.
- Keep clay rates to a minimum.
- Incorporate clay-rich subsoil as deep and evenly through the topsoil as possible.
- Redder clays tends to be better clay.
- Delving leaves the surface rough but results in less nutrition problems.
- All treatments have a similar cost per hectare irrespective of clay rate.
- Some leaf diseases are more prevalent on clayed country.

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Case study five

Clay spreading deals with a Pandora's box

A dramatic event forced the reassessment of the management strategy of a sandplain cropping system near Esperance.

Sue Knights

FARM DETAILS

Grower: Peter Luberda

Location: 40km west of Esperance, Western Australia

Average annual rainfall: 550mm

Farm size: Two blocks, 1,100ha in total

Enterprises: cropping, canola/wheat/barley/seradella, 1200 merino-cross ewes

Soil types: non-wetting sand and sand over gravel

Area clayed: 260ha of the home block, 300ha in total

Claying history
In 2000, 40ha clay spread; a further 260ha was clayed in 2004.Clay is too deep for delving. A further 240ha on the property requires urgent attention and will be clayed now Peter is more confident about the best method of clay addition and incorporation.

Peter Luberda likens clay spreading on his Esperance property to opening a Pandora's box.

"There is no going back once you have spread clay and you may expose some unforeseen consequences."

Peter farms with his father John, on sandplain country close to the Esperance coast, alongside the West Dalyup River. The property consists of non-wetting deep sands and sand over gravel, which can be prone to both waterlogging and erosion. The soils are generally acidic about pH5.

Over the years they have tried various soil soaker products to deal with the water repellence. These gave mixed success so, they began to experiment with clay spreading in early 2000, focusing on particularly problematic soils. This area had been cleared of banksias and was severely water repellent in the top zero to 10cm layer and contained less than one per cent organic carbon. Weed control was an issue as germination could be staggered and germination of crops was not uniform.

However in 2004, a dramatic incident occurred when a fire triggered from a electricity pole swept through the back of the Luberda's home block. The result was completed denuded paddocks that required immediate attention to ensure that the topsoil was not lost through erosion. The obvious approach was to clay spread the area and a contractor was used.


CREDIT DAVID HALL, DAFWA, ESPERANCE

Peter Luberda in a clean, vigorous wheat crop on his clayed country. Peter has found that establishing a successful claying program requires attention detail.

Determining clay rate

Since 1999, David Hall from the local Department of Agriculture and Food Western Australia (DAFWA) had been running trials on the Luberda's front paddock, funded by the GRDC and WANTFA. These included several clay rates in conjunction with deep ripping.

The claying rate for the burnt area was determined from the DAFWA experiments at the front of the Luberda's property.

These experiments had used subsoil material sourced from the property, which contained between 30 to 40 per cent clay; the clay was predominately kaolinite. The rates applied were 0, 50, 100, 200 and 300t of clay-rich subsoil/ha. The treatments were deep ripped at a later date.

The experimental site was managed as a commercial operation. Rainfall was monitored, crop emergence and biomass measurements were collected and soil samples were

Peter Luberda's property near Esperance, consists of non-wetting deep sands and sand over gravel, which can be prone to both waterlogging and wind erosion as seen by the drift.

taken. The profitability of the treatments was assessed using discounted cash flows.

The results showed that after eight years, only the treatments receiving more than 100t/ha of clay-rich subsoil, resulting in greater than three per cent clay in the topsoil, were more profitable than the control.

Peter, therefore chose the highest rate of subsoil material of between 200 to 300t/ha of clay rich subsoil to apply to his damaged back paddocks.

Further challenges

The clay was spread with a carry grader, left on the surface and further spread by smudging; this consisted of up to three passes using a railway girder. The soil was then two-way ploughed to a depth of five to 10cm. Unfortunately, Peter discovered that it is a fine line between leaving the clay-rich subsoil on the surface to be broken down by rain and the surface setting rock hard in the sun. When the latter occurred water would either puddle or run-off and after significant rainfall the paddocks would become untrafficable.

Peter soon realised that better incorporation of the clay was imperative and in 2009/10 invested in a Farmax spader. This has a power roller on the back that can further break down clods and pack down the topsoil. He chose this machine partly due to the ease of being able to replace worn parts.

The 4m wide spader is towed behind a 250hp Fendt tractor fitted with +/-10cm accuracy GPS guidance and autosteer.

"Guidance and autosteer help improve the precision of the spading operation; at 4m wide it takes many passes to cover the whole paddock."

In 2010, the damaged paddocks were spaded to a depth of 25 to 45cm to better incorporate the spread clay.

Unfortunately, the spading operation brought iron stone rocks from the subsoil material to the surface, which had to be removed to avoid damaging the harvester later in the season. A Mungie rake was used to clear the rocks.

Logistics of clay spreading

Clay spreading is only economic when the clay-rich subsoil is sourced from within the property. On the Luberda's property suitable material is found at depths from 90cm to 5.5m, usually at the lowest point in the lanscape. Holes were bored to determine the presence and depth of appropriate quality clay for the operation. Delving is not feasible on the property as the clay is too deep. Deep ripping may be necessary on some areas to alleviate compaction and waterlogging problems. This is usually repeated every six to seven years.

Peter only considers it economic to spread subsoil in a 400m radius from the pit. Once a pit is opened it is important to use it completely, because if it fills with water it becomes unusable. Any excess water in the material being spread can slow the speed of the operation and increase the cost.

"To minimise the cost of clay spreading it is important to consider opening a pit, on a pit to area basis rather than pit to paddock basis, says Peter.

Clay spreading is a very slow operation, usually undertaken at 2ha/hr. Peter says it is akin to clearing virgin land and only so much can be done each year. From Peter's experience the evenness of application is important as an uneven surface can damage the harvester and cause wear on his machinery. Peter's decision to clay areas is made after considering the farm budget and the operation is undertaken in summer.

Paddocks are prepared for clay spreading by burning stubble or grazing hard with stock, this may expose the paddocks to erosion but Peter says it is a small step backwards for a bigger gain. Lime and gypsum are applied together to the paddocks after clay spreading and before spading, at the rate of one or 1.5t/ha of each product.

Positive outcomes of clay spreading

Peter avoided a significant erosion problem after the fire on his property by spreading clay. He learnt the hard way that it is vital to thoroughly incorporate the clay to make the soil manageable for cropping. However, since undertaking the spading Peter's cropping system has become more productive and flexible.

As the spading was only carried out in 2010, it is early days to assess the changes in the Luberda's system. However, cereal yields on clayed areas have increased from 2.5t/ha up to 4.6t/ha and Peter suspects this could be due to many changes.

"The improved yield could be due to better water retention and aeration of the soil and I have recorded an increase in fungal activity and earthworms in the soil."

The spader also incorporated some crop residue to depth which may be contributing to the increased biological activity.

A change in the availability of soil nutrients may also be playing a part in the improved yield. The Luberda's soils are potassium deficient and the clay material applied is high in this element. More nitrogen may be mineralised in the first year following the spading process. Improving the clay content of the topsoil is also reducing the leaching of fertiliser.

"Mixing the clay material through the profile is like adding a 'blotting agent', which absorbs nutrients that have previously leached through the sandy profile."

Peter has not changed his nutrient regime significantly since incorporating the clay with the spader. A 50:50 mix of potassium and urea is broadcast to cereal and broadleaf crops at 100kg/ha, four weeks after sowing.

Problem weeds in Peter's system are ryegrass, radish, brome grass and silvergrass and this spectrum has not changed with the claying of the soil. However, weed populations and consequently herbicide use has decreased as most of the weed seeds are buried in the operation and those that remain now germinate more uniformly. As the majority of weeds now germinate at the break of the season a single herbicide application usually achieves acceptable control.

CREDIT SUE KNIGHTS

One of the reasons Peter Luberda's selected a Farmax spader was because the parts are replaceable.

Since claying, Peter's crop rotations are more flexible and he may re-introduce lupins, depending upon returns. Crops appear healthier as they can out-compete diseases. He is considering introducing green or brown manure crops to improve the organic matter levels of his paddocks.

Peter has observed his crops' response to the clay treatment and now plans to expand his clay spreading program. Rather than rely on contractors he has invested in clay spreading

CREDIT SUE KNIGHTS

Once opened a clay pit needs to be used as they fill with water. Peter Luberda demonstrates the quality of the clay pit water after treatment with barley stubble, making it a source of stock water.

equipment with the purchase of a second hand JR carry grader, which has a capacity of 15t. This will be hauled by a 410hp Caterpillar tractor to reduce some of the compaction of paddocks.

The future

Peter is determined to continue with the clay spreading and spading program and says there are a further 240ha on the property that requires urgent attention. To do this he would like to obtain more in-depth information particularly on the topography of the paddock. He is considering using electromagnetic (EM) mapping or gamma-radiometrics to obtain this information. He also wants to understand how the crops are responding and is working with a local fertiliser company to quantify crop responses to nutrients.

Management of the many soil pits on the property is currently an unresolved issue. At present they form a drainage pond and stock water supply. Peter has experimented with clearing the water with barley stubble, which releases chemicals that breakdown the algae and has seen water-life develop. He says in the longer term he must consider the pits in a whole of farm context and he would like to take a more holistic approach to improving the property.

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Case study six

A recipe nearly perfected and a farm transformed

A conservative approach, over nearly 20 years, has allowed Steve Jaeschke to come close to perfecting the recipe for claying on his family's property near Keith, South Australia.

Felicity Pritchard

FARM DETAILS

Grower: Steven and Robynne Jaeschke

Location: Sherwood, 25km north east of Keith, South Australia

Average annual rainfall: 440mm

Farm size: 5000ha

Enterprises: grain and fodder crops, merino base flock for wool and prime lambs and first cross ewe lambs.

Soil types: mostly sandy soil, including non-wetting sands and deep sand on hills; the flats contain a heavier clay or loamy sand over clay, about 10cm deep

Area clayed: 3400ha

Claying history
Claying has occurred since the mid 1990s, with spreading, delving, spading and a combination of treatments used. The Jaeschke's are continually changing the system as paddock conditions and equipment evolve.

Steve Jaeschke's property is mostly on sandy soil, including non-wetting sands and deep sand on hills. The flats contain a heavier clay or loamy sand over clay, located at about 10cm deep.

The farm was cleared in the early 1960s and at the time was typical of others, with grazing and some fodder crops. The demise of lucerne in the 1970s saw silvergrass and rabbits begin to take over the area, while farm profits declined.

Now, thanks to claying and other progressive farming practices, Steve and his wife Robynne, along with brother Anthony and his wife Judy, grow a number of summer and winter crops and pastures. Crops include wheat, barley, canola, lupins, faba beans, vetch, and millet, while pastures include lucerne, clover and ryegrass, some oats and grazing barley. Summer growing plants are included to capitalise on the 75 to 100mm average summer rain.

Although minimum tillage is used for cropping systems, Steve employs a variety of cultivation methods to improve his soils. Methods include clay spreading, delving with big and small delvers, deep ripping and spading.
About 70 per cent of the property has been treated over the past 20 years.

CREDIT FELICITY PRITCHARD

Steve Jaeschke's Mandelup lupins grown in a paddock which has been spread with clay, delved and spaded, show strong root growth. He encourages others to take a conservative approach and work out the methods, rates and management best suited to their farm.

In 2004, Steve completed a Nuffield Farming Scholarship to study how farms on sandy soils can fulfil their potential. About 2000 hectares have been clay spread, 1200ha delved and around 200ha have received the 'full package' of spreading, delving and spading.

"We are lucky the clays on the property are relatively benign and free from toxic levels of boron and salt, this has been a great help," says Steve

Steve and his family own a small Vermeeren delver, a Lehman scraper for clay spreading, a deep ripper and a spader. Initially a Caterpillar Challenger 55 tractor was used to haul the clay spreader, small delver and deep ripper. Now, a contractor is


CREDIT FELICITY PRITCHARD

Thoroughly mixed clay. While the soil still looks very sandy it now wets-up, holds nutrients and moisture, and encourages root growth.

engaged to spread clay and for some delving with a bigger delver, due to the partnership's heavy workload.

The cost of using the bigger delver is $120/ha, while the small delver is more economical at about $100/ha. For spreading, Steve uses a rule of thumb of about $1/t to spread clay, although this is dependent on the proximity to the clay pit. That price excludes any smudging or incorporation costs. Although expensive, for Steve these costs are all paid back within one to three years, depending on the season and grain prices.

"Delving provides a better return on investment than spreading, but the aim is to improve all our soils, and clay is not always close enough to the surface to delve".

Clay spreading was first undertaken on deep sand hills, but over time Steve now spreads clay on more shallow sands (20cm deep) further down the hills and flats. This ensures when delving the sides of sand hills, there are no missed patches. Clay is spread at around 250t/ha. Double this rate has been trialled but results are still unknown.

Delving and incorporation

Steve has found that delving is most easily done when the subsoil is slightly wet but is more convenient after harvest or in new country after heavy grazing and killing weeds the preceding year.

The two tynes on the small delver are set at 3m apart on a 45 degree angle and can rip clay to 90cm; this implement is used on the shallower clays. By straddling the previous rip line soil can be delved every 1.5m.

A big delver is used by contractors for deeper sands where Steve's machine is unable to bring-up enough clay. This delver has tynes at 1.5m spacing.

Both of these delvers are only able to bring clay to the surface from a maximum of 50cm depth but can disturb soil to 1.5m deep. Steve is seeing production gains from using the big delver on deeper sand over clay soils, which have previously been spread with clay-rich subsoil. This is most likely to be a deep ripping affect from disturbing the soil up to 1.5m depth, even where clay is not brought to the surface.

After delving, soils are left for as long as possible before incorporation. Some paddocks are 'cross worked' with a deep ripper at a 45 degree angle from the delve lines, ripping to about 30cm with tynes 40cm apart. The aim is to loosen soil between delve lines, break through the clay hardpan and bringing clods to the surface. Two more cultivations at 45 degrees using conventional tillage drag and smooth the soil to complete the job.

In 2011, delving was undertaken with a four tyned machine set at 1m spacing. This scattered the inter-row better than wider spacing and removed the need for deep-ripping. Instead, the paddock was disced and cultivated.

"We are changing the system all the time to trial new ideas," says Steve.

About three years ago, the family bought an Imants spader. They have spaded about 200ha so far and are trying to measure the benefits to ensure it is cost-effective. When possible, spading is undertaken in spring but can be very time-consuming.

"It is imperative to mix clay thoroughly when it is dry," says Steve. "It looks very sandy but done correctly the soil is right forever".

The desire for change was driven by the desire to minimise non-wetting sands and erosion. Steve reports that incorporating clay-rich subsoil in the topsoil has fixed the non-wetting sands. This has been achieved over 20 years and he has taken the process slowly to avoid making major mistakes, which may otherwise never be remedied.


CREDIT FELICITY PRITCHARD

About 70 per cent of the Jaeschke's is property has been clayed over the past 20 years. A paddock acquired in 2010, was delved and grew its first crop yielding an impressive 4.7t/ha of wheat.

New management

The addition of clay-rich subsoil and the benefits it has brought have enabled the Jaeschke's to make tremendous changes in their management. Before claying, the non-wetting soil had to be cultivated before seeding to enable adequate germination; this created a major erosion issues. Having eliminated non-wetting, Steve is now using no-till and retained stubble to maximise water use efficiency and build soil organic matter.

"I abhor dust coming off paddocks because that is organic material you are losing; being able to retain stubble and no-till has helped stop this soil loss".

Paddocks are grazed hard and sprayed before delving the following year. This paddock was delved with the 'small' delver at varying depths. Clay clods are left to breakdown in the weather before incorporation.

Steve has noted how his soil's ability to wet-up and hold moisture has improved since claying. This not only helps crop growth but ensures fertiliser enters the root-zone rather than remaining unused on the surface.

The improved moisture allows lucerne to be direct drilled into standing stubble and results in more rapid establishment. Similarly, cereals are sown on the first rains, grazed to delay flowering, providing both winter feed and later grain.

"Paddocks are now more even, weed management across the whole farm has improved and more robust rotations have been established."

With improved soil moisture across the paddocks, Steve has found that weeds germinate more evenly and moisture active herbicides, like simazine, work far more effectively, providing much better weed control.

With good weed control, cereal root diseases are likely to be lower as host species are removed.

The opportunity to use a range of chemicals effectively allows a broader and more sustainable rotation to be grown. The family has been vigilant in keeping out wild radish and salvation jane, which has enabled conventional canola to be grown. However, inclusion of a pulse in the rotation is a challenge for Steve, as input costs can be prohibitive.

Since 2009, vetch has been grown for nitrogen on clayed sand. Faba beans and lupins can be successfully grown in the same paddock, with lupins on sand hills and faba beans on heavier flats. Steve hopes to use precision agriculture to sow the two crops in one pass, noting the same herbicides can be used in both so no crop damage should occur. When achieved the work load at sowing will reduce as they currently sow patches of different crops all over the place.

In contrast to others who have clayed, lupins can still be grown effectively as the topsoil has not become too alkaline. The topsoil's pH(Ca) has lifted from pH4.8 prior to claying up to pH6.0.

Steve encourages others to ensure they monitor trace elements closely after claying. Most of his crops receive trace

CREDIT FELICITY PRITCHARD

Spaced at 3m and on angle of 45 degrees the two tynes of the small delver can pull clay from 90cm and produce a rip line every 1.5m by straddling the previous line.

elements in solid form at sowing. Copper, manganese and zinc are applied in the sulphate form as a foliar spray to the growing crop. Trace elements are also applied as liquid during cultivation and clay incorporation.

A paddock acquired in 2010, was delved, ripped and cultivated and then grew its first crop using this nutrient management package. The yield was an impressive 4.7t/ha of wheat. Previously this paddock had only grown pastures or silvergrass and was lost to erosion.

Livestock benefit from claying through increased production of fodder crops and pastures. Where ryegrass numbers have built-up, pastures are used as a break. They are grazed by ewes and pasture-topped with herbicide to control weed burdens.

The biggest drawback with the system is the provision of an ideal environment for snails. Claying is also suspected by Steve to be a factor in increasing mouse populations after harvest; this may be due to changed soil structure for burrows but is most likely due to increased grain production.

Steve still gives claying a glowing report card and is pleased with the progress achieved from about 20 years of trial, error and experience. He encourages others to take a conservative approach and work out the methods, rates and management best suited to their farm.

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Case study seven

Clay benefits through trial and error

Trevor Hancock has learnt through experience the benefits and pitfalls of clay spreading and delving.

Felicity Pritchard

FARM DETAILS

Grower: Trevor Hancock

Location: Parilla, South Australia

Average annual rainfall: 350mm

Farm size: 900ha cropped area

Enterprises: cereals, vetch/oaten hay, canola and lupins

Soil types: heavy loam to infertile sand; six to seven soil types on the property; subsoils range from 'friendly' sandy clays with just over 20 per cent clay to 'hostile', very heavy soils with toxic levels of boron and sodium and high pH

Area clayed: 120ha clay spread and about 100ha clay delved

Claying history
Clay spreading began in 2000; delving and some more spreading took place in 2007. The program is on-going until all non-wetting sands are treated.


CREDIT FELICITY PRITCHARD

In the best delved treatment on a trial on Trevor Hancock's property wheat yields improved by 60 per cent. Rebecca Tonkin of Rural Solutions provided technical support for the trials.

Clay delving and spreading have provided an advantage for southern Mallee grain grower, Trevor Hancock, boosting yields by up to 60 per cent and making farm management much easier. However, Trevor advocates that growers considering claying should test their clay before taking any other steps.

Despite turning his back on clay spreading after poor results in the first year, Trevor has finally found a method that works to remediate his non-wetting sands. He is now undergoing the final phase of a claying program and will continue until the remaining 200 hectares of sandy soils are treated.

Trevor was unimpressed with initial results from clay spreading in 2000.

The crop died in a dry spring with lack of moisture, it was better where no spreading was undertaken," Trevor says.

Within five years, however, it was apparent to Trevor that something needed to change. His non-wetting sands were a continual source of frustration as they did not readily wet-up and dried rapidly. This left a very narrow sowing window, and caused uneven crop establishment and weed control challenges. The sand struggled to hold nutrients and was more affected by frosts, due to low moisture holding capacity and heat reflection.

Non-wetting sands created other logistical problems, requiring different crop types in the one paddock.

"Years ago, I would grow rye and/or barley on the non-wetting sands and wheat on the better soils in the one paddock. Now, in clayed paddocks, I have one crop over the whole paddock."

He aims to one day no-till the entire farm. On non-wetting sand, he sometimes cultivates to improve establishment using an offset disc, followed by harrows, to mix wet and dry components.

In 2005, Trevor, with a group of local farmers, made contact with Rod Eldridge of Rural Solutions SA and decided to undertake trials to determine if claying was feasible in the region and the best methods to use. The Southern Mallee Ag Bureau was re-formed and succeeded in obtaining a Natural Resource Management grant.

Four years of trials found delving increased growth, germination and most importantly, consistently increased yield, by up to 60 per cent in some years.

Rural Solutions SA consultant, Rebecca Tonkin, found as long as nutrition was maintained, the yield bonuses were continued.

Delving creates deep furrows (above), which can be seen even after incorporation. Delving should be done in the working direction of cropping machenery or at a slight angle.

"Higher yields due to increased moisture availability mean more nutrients are removed. You need to increase inputs to ensure reserves are not run down," says Rebecca.

However, the amount of clay brought to the surface is important, too much can reduce yields. In 2008, delving over shallow clay at 0.7m spacing lifted excessive clay to the surface resulting in a yield of only 0.2t/ha. This excess clay in the topsoil limited moisture availability to plants, a problem that was worse in a dry year. Conversely, delving at double the width, 1.4m, created excessive gaps between the brought-up clay. This made it difficult to spread evenly and create a uniform topsoil across the area delved.

In 2007, the highest yielding delved treatment produced 3.2t/ha of barley, in stark contrast to cultivated 'control' plots, which averaged 2.0t/ha. In 2008, a very dry season, the yield benefit was more modest, with control plots of wheat yielding 1.2t/ha and the best delved treatment yielding 1.4t/ha.

These results led Trevor to embark on a clay delving program for all his non-wetting sands, except those with sand too deep for delving, which are spread with clay.

Delving

One advantage of delving over spreading relates to clay quality. Delving normally brings-up clay from the top 20 or 30cm of the clay layer, whereas clay used for spreading is extracted from up to 2m. On Trevor's property, the deeper clays for spreading are highly variable, often sodic with toxic boron levels and very high pH – leading to nutrient tie-up.

Unlike clay-spread paddocks, Trevor has no issues with manganese deficiency or boron toxicity in his delved paddocks.

"Delving is more forgiving, you can use clays with higher carbonate levels than those used for spreading. When clay spreading, you need to search for decent clay".

However, Trevor does not suggest farmers delve high carbonate clays and warns that really high carbonate levels can result in disaster.

While delving increases the topsoil's clay content, probably permanently, it also deep rips. Trevor has found roots grow deep into the rip lines, while in the clay spread areas they are confined to the depth of incorporation, about 13cm for his system. This improved root growth is possibly why bringing carbonate rich clay subsoil to the surface by delving, is more forgiving than spreading similar material. The longevity of this benefit is unknown.

Trevor is happy with the delving results and engages a contractor. Four ripper tynes, 90cm apart, are dragged through the non-wetting sand at 45 degrees. Clay is delved at five to 6km/hr. The tynes are 10cm wide, modified with 2.5cm 'wings' welded to each side to prevent clay slipping around the tyne, which otherwise can be a problem.

The delver uses hydraulics to alter tyne depth, ensuring excess clay is not moved into the topsoil, however, actual rates of clay are unknown. Trevor recommends using a contractor with autosteer on the tractor so they can concentrate on the job behind.

On deep sands (more than 60cm deep), delving can bring pure sand (dead sand) to the surface causing machinery to sink during subsequent seeding and spraying operations.

Delving duplex soils can bring football-sized clay clods to the surface. These begin to breakdown after two or more rainfall events, allowing easier spreading across the paddock. Trevor uses a cultivator to begin levelling and shallow incorporation, with the first and second passes in the same direction as the furrows. Grader blades are then fitted along the back row of the cultivator to drag clay and the ground is worked at right angles to spread clay.

After delving the paddock is very uneven and heavy rainfall events can cause problems when travelling directly along a delve line, if it becomes saturated. Trevor encourages those contemplating clay delving, to delve in the same direction as cropping machinery works, or even better at a slight angle but not at right angles.

"You cannot really cross a delved paddock with a boomspray, it is too rough."

While some people delve in spring, for Trevor, delving occurs in autumn to fit his continuous cropping program. The delved paddocks are then farmed with no-till practices as Trevor has found no other management is needed.

Spreading

Although delving is the preferred and more reliable option for improving the sandy topsoil, it is not possible where the clay-rich subsoil is more than 50cm from the surface, so clay is spread instead.

Trevor has experimented with several clay rates and now spreads about 125t/ha but this will depend on the percentage clay in the subsoil material. At this rate he does not have too many problems with boron and sodium. The clay content of Trevor's subsoils can vary from 10 to 40 per cent. The heavy flats have the highest percentage of clay but also of boron, salt and sodium. All Trevor's clays are sodic, so they disperse easily and cover the sand particles.

From Trevor's experience applying the correct rate and using good quality clay is extremely important.

"I started spreading 250t/ha and found it was too much clay, this was reduced to 185t/ha which was a bit too much; now I use 125t/ha and that is a fairly safe rate."

Clay is scooped and spread with a landplane, by a contractor, who also calculates the rate. Grader blades on a cultivator or railway irons are used to even-out the clay across the surface.

Trevor has tried a spader on delved as well as clay spread ground. He found this very useful on soils where high rates of clay are spread, requiring deeper incorporation to dilute the clay. Paddocks clayed years ago with excessive rates have particularly benefited from spading.

Ideally, the clay needs testing before spreading and growers new to claying are encouraged to try a small area first. In this region the Ag Bureau hires an excavator to dig pits and obtain clay samples for a number of local farms. Rebecca Tonkin collects and analyses samples at different depths and these are sent to Western Australia for further testing.

CREDIT FELICITY PRITCHARD

Sands more than 60cm deep can be spread with clay but are too deep for delving.

Management post claying

Clay quality varies considerably with depth, particularly salt content. In spread but not delved paddocks, foliar manganese is applied once or twice a season at 3kg/ha of manganese sulphate, to overcome manganese deficiency. Copper and zinc are also applied at 1.5 kg/ha zinc heptahydrate and 400g/ha copper sulphate. Trevor believes boron tolerant varieties may have an advantage in some situations.

Crop and weed germination is better and frost incidence lower where clay is spread or delved.

However, haying-off is an issue on clay spread paddocks in seasons with dry springs. This is worst with high clay rates and is possibly a permanent effect. Trevor is careful to manage nitrogen to reduce the risk of haying-off; applying some at sowing (20kg N/ha for wheat) and topdressing (50 to 60 kg N/ha for wheat) if needed.

The results from extensive trials on Trevor's farm support similar work on the properties of Wayne Hayward's and Strawb Walker's properties also part of the Ag Bureau project.

"Work by Rural Solutions SA staff, Rod Eldridge, Brian Hughes, Linden Masters and Rebecca Tonkin, as well as farmer Roger Groocock, has been invaluable in helping to improve techniques at a local level," says Trevor.

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Case study eight

Inversion produces results in sandplain soil

From a failed clay spreading event, Tony Harding has successfully adopted mouldboard ploughing to manage non-wetting sand and weeds.

Sue Knights

FARM DETAILS

Grower: Tony Harding

Location: Mingenew, Western Australia

Average annual rainfall: 425mm

Farm size: 6253ha, 3500ha cropped on average

Enterprises: wheat, lupins, canola, multipurpose merinos

Soil types: sandplain

Area clayed: 150ha

Claying history
2002 clayed 30ha, 2005 clayed 120ha; 2009 mouldboard ploughed 180ha and only 80ha in 2010 (due to dry conditions).

Tony Harding farms what he describes as inert, non-wetting sands in the Mingenew region of Western Australia. At depth, clay is found in abundance on Tony's property; it is degraded kaolinite clay, white or pink in colour.

Aiming to address the non-wetting properties and to improve weed control in a notoriously difficult to manage sandy soil, Tony used contractors to spread clay with carry graders to 120ha. The spreading rate was supposed to be about 250t/ha but ended up being anywhere from zero to 500t/ha. Trainee drivers, he considered caused much of this problem.

This clay was spread in 2005 and smudged across the paddock immediately. However, it was left sitting on the surface until April 2006, when incorporation was planned. Unfortunately this was too long, by the time Tony returned the clay had set like cement increasing the cost and effort of incorporation. Some eight passes with various machines were required. A heavy roller, large set of offset discs, a set of rotary harrows and a deep ripper all made two passes over the clayed area in an attempt to turn a 'gravel road' back into a paddock.

The initial cost to clay was $600/ha, plus $150 to $200/ha for cultivation and levelling to try and even out the clay.

An oat crop sown on the clayed paddock in 2006 failed, 2007 saw lupins yield about 400kg/ha, 2008 was wheat that yielded around 500kg/ha, comparative unclayed white sand under the same conditions yielded 800 to 1000kg/ha. All three years experienced a period of low soil moisture and the crop 'ran out of water' faster than that on the unclayed sands.

CREDIT KEN WILSON, FARM WEEKLY

Tony has changed from in-furrow sowing to broadcasting of seed to avoid the wind tunnel effect created by in-furrow planting.

"The clay rates were very variable and application uneven; production from the clayed area has been disappointing with the crops failing in dry years," says Tony.

Tony calculates the yield penalty from claying has exceeded $600/ha, since 2006. He now believes it would have been more economic to have spent the equivalent money to purchase additional land at approximately $1350/ha.

However, all has not been lost as an interest in using a mouldboard plough was born from his disappointing clay spreading experience.

Learning from experience

Prior to 2008, Tony had paid little attention to the mouldboard research being carried out by the Department of Agriculture and Food Western Australia (DAFWA). However, after three successive poor crops on the clayed areas Tony was starting to become interested in investing in a plough. Having spent

Tony Harding's original nine furrow mouldboard plough in action inverting the non-wetting topsoil and burying weed seeds to about 30cm.

a year working on a farm in the United Kingdom, Tony was familiar with the workings of the mouldboard plough.

Initially, he had considered buying a spader or large rotary hoe but one of Tony's staff had used one regularly in New Zealand. His comment was "if you buy a spader do not expect me to be driving," and he went on to explain that both machines are slow and expensive to run.

Tony had not considered the other benefits of the mouldboard plough in the beginning but they soon became apparent when he looked at the results from the local DAFWA trials, particularly the improved weed management.

The decision was made and he sourced two second-hand ploughs from New Zealand, eight furrow and nine furrow machines for himself and a neighbour.

Multipurpose tool

In 2009, pasture oats were sown in the paddock clay spread in 2005 and a mouldboard test strip was done here. The area was harvested after grazing and the ploughed trial yielded roughly 600kg/ha more than the rest of the paddock. Tony plans to plough all paddocks that were clayed in 2005 to turn the clay under.

In the same year, a good paddock with a bad history was chosen to be ploughed to a depth of 30cm, bringing the coarse sand subsoil with slightly higher clay content to the surface and burying weed seeds and the surface organic matter. This paddock had a high weed burden and the top 10cm of soil was water repellent. The grass weeds had become particularly difficult to control due to delayed germinations caused by the non-wetting nature of the sand. After ploughing, the paddock was no longer non-wetting and the weed seedbank had been reduced by about 98 per cent.

By changing the working speed and machine set-up the mouldboard plough was used to incorporate this material through the top 15cm. Ploughing increased the topsoil clay content from about 0.3 per cent to between two and 10 per cent

"A mouldboard plough is quite versatile as it not only can invert soil but can also mix the soil depending on the speed and depth of working.".

Wind erosion was an issue when establishing the initial crop in 2009. A DBS seeding bar with 300mm spacing was used to sow the crop in an east-west direction. At the three to four leaf stage, a westerly wind of 90km/hr significantly damaged the crop. Fortunately it recovered and still out yielded the control by several hundred kilos. An adjoining ploughed section that had been sown with a spreader and harrowed did not suffer nearly as badly.

Following inversion ploughing, Tony has also found that his weed management has become more efficient and he can save almost $70 a hectare on herbicide costs in the first year alone. Ryegrass and radish are his most problematic weeds, followed by brome grass and blue lupins. Inverting the soil can bury the weed seeds to a depth from which they cannot germinate and reduce weed populations.

Weed counts have revealed more than 2000 brome grass plants per square metre on non-wetting soil and about one brome plant per 10/m^2 on the ploughed area. Tony has also found that simazine activity is more aggressive on the inverted soil due to the higher clay content, so a lower rate needs to be used to prevent crop damage.

In addition to the improved weed control and increased topsoil clay content, using a mouldboard plough may break any hardpans within the soil profile. A sub-soiling attachment is also available to rip below the working depth of the

Ploughing sandplain soil is best done when the soil is saturated so, this is the last operation in the seeding program.

The orange clay and dark organic layer hold moisture at depth.

mouldboard cancelling out any plough pan effect. Tony does not have the subsoiling attachment but says they are a simple knife point attachment that bolts on to the bottom of the mouldboard.

Perfecting the process

Tony has now progressed to a combination Kverneland plough consisting of two parts with a maximum 14 furrows. This is pulled by a tractor that provides 30hp per board. Furrow width can vary from 30 to 50cm and the boards invert soil to a depth of 30cm. The 14 furrow plough can be operated at 6ha/hr but Tony emphasises that the soil conditions need to be conducive for the operation, this is when the profile is saturated.

"The greater the non-wetting properties and the weed burden, the deeper I plough because I want to ensure the repellent soil and weed seeds are completely buried."

After ploughing the soil needs to be packed with either a coil-packer or rubber tyre rollers. Rather than using a second tillage pass to place the seed in a furrow, Tony broadcasts seed over the furrows with a Multispreader and covers the seed by harrowing. He has found that an erratic seed pattern can avoid wind damage in the growing crop.

Wheat is usually sown as the first crop after ploughing as it has the best early vigour. Tony also recommends a cereal crop in the second year to build-up stubble cover.

His crop establishment is a four pass operation, plough, incorporate, spread and harrow and Tony wants to evolve to a two pass operation, plough and seed. To achieve this he is building a machine able to seed, level and pack in one pass.

Subsoil pH is acid; prior to ploughing, lime is usually applied with the Multispreader at the rate of 1 to 2t/ha depending on pH. His objective is to achieve a topsoil of pH5.8 to 6.0.

Burying all the organic matter with mouldboard means the crop needs extra fertiliser in the early growth stages. Root development is much more aggressive and as the crops grow they access the nutrients buried with the organic matter and former topsoil. The ploughed land tends to be the last to suffer moisture stress, possibly due to the inverted organic layer holding moisture at depth.

At this stage ploughing is undertaken at the end of seeding, usually the last paddock or two is ploughed and then the crop is sown into wet sand, this can be difficult in a year with a late break. Ploughing in winter and sowing a cover crop has also worked well and perennials established vigorously when sown on ploughed ground in spring.

Tony considers that non-wetting soil is by far the biggest issue facing sandplain farmers in WA. Introducing high rates of clay may reduce the soil's non-wetting properties but Tony believes it also increases the loses to evaporation by holding the moisture in the clayed surface layer. This may not be the case in the southern parts of WA where the winters are cooler.

"In very sandy soil that has very little water holding capacity I think adding large quantities of clay results in less water being available to the plant, virtually cancelling out the benefits."

Tony says that the use of a mouldboard plough must be considered in the context of the whole farming system and the issues that need to be addressed. It is just another tool for managing broadacre farming systems.

Tony suggests ploughing may be more productive on good sandplain country that has fallen behind rather than in poorer country.

There are still many questions to be answered and the system is not perfect. Ideal soil moisture and crop establishment techniques require further investigation but from his experience the concept of using the mouldboard plough on sandplains is very sound.

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Check list

Thinking and planning are cheaper than doing and fixing.

Why clay – is there a valid reason?

- ✓ Overcome non-wetting sands.
- ✓ Stabilise sand hills, reduce wind erosion.
- ✓ Increase water holding capacity (small).
- ✓ Improve nutrient retention (depends on type of clay).
- ✓ Reduce frost risk (not consistent).
- ✗ The neighbours have added clay to their paddocks.

Do some investigations

- Dig some holes, to locate clay-rich subsoil.
- Establish how deep the applied clay-rich subsoil needs to be incorporated
- Use an EM survey to assess variation in depth to the clay-rich subsoil, if considering delving, spading or mouldboard ploughing.
- Test the clay percentage and chemical composition of the clay-rich subsoil.

Do some numbers

- How much do you want to increase the clay percent of the topsoil and subsoil?
- How much of your clay-rich subsoil is required to achieve this change taking into account the clay percentage and incorporation depth?
- Can this rate be achieved?
- What area do you have the time and money to remediate?
- If spreading, how far away will the pits be located?

Choose the method

- What methods can be chosen for this site?
- Who will spread/delve the clay?
- What equipment is required and what is available?
- Who will incorporate the clay, how and to what depth?
- Consider the timing of the operation and how this impacts on current and future production/rotations.

Executing the plan

- Draw a paddock plan; mark areas to be spread/ delved/spaded or mouldboard (inversion) ploughed.
- If delving and spreading are to occur in the same paddock, in the same year, spread first.
- Mark the locations of clay pits on the plan and highlight potential hazards.
- Mark the direction of delving, spading or mouldboard ploughing on the plan.
- Ensure the paddock is levelled and the amount of organic matter can be dealt with by the chosen equipment.
- Smudge and incorporate spread clay promptly but allow delved, spaded or mouldboard ploughed clay time to breakdown before incorporation.

After claying

- Soil test to identify changes in soil characteristics and nutrient availability.
- Grow crops that will not be impacted by issues including; if carbonate or salt is present in the added soil, do not grow sensitive crops such as lupins. If the seed bed is soft following incorporation do not select crops that need accurate sowing depth.
- Yield map to assess changes in production and the return on investment.

CREDIT STEPHEN DAVIES

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