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Grains Research & Development Corporation

Managing South Coast Sandplain Soils to Yield Potential

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Department of Agriculture and Food, Western Australia (DAFWA) Funded by the Grains Research and Development Corporation GRDC

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ii



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Front Cover: Photos taken around Esperance of claying operations-from the pit to the paddock.

Contents

Acknowledgmentsi
Contributorsi
Introduction 1
Properties of sandplain soils2
Overview of geology and soils types
Physical properties of sandplain soils8
Soil chemistry 13
Soil biology
Soil properties and their management issues
Further reading23
Tools for determining yield potentials and soil production zones
Potential yield calculators25
Computer programs26
Yield monitors, maps and other spatial data
Predicting potential yields using a modified French and Schultz model – a study
Case study 1: Rebuilding sands to effectively use rainfall36
Diagnostic Tree

Water repellence
Characteristics of repellent soils in WA 49
Managing water repellent soils52
Surfactants (wetting agents)52
Furrow sowing with press wheels52
Claying53
Biological degradation of waxes56
Dilution
Case study 2: Wind erosion controlled by claying
Case study 3: Claying deep sands at Esperance trebles crop yields60
Compaction
Diagnosing soil compaction66
Causes of compaction and hardpans67
Tramline farming to prevent compaction70
Further reading70

iii

Contents

Acidification
Causes of acidification73
Management of acidification – soil testing
Preventing soil acidification and maintaining soil pH78
Correcting acidic soils with lime78
Further reading81
Case study 5: Compaction and acidification at Neridup 84
Soil organic matter, organic carbon and soil condition 86
Soil carbon materials
Soil organic matter and soil organic carbon
Dynamics of soil organic carbon
Options for south coast sandplain farmers90
Further reading91
Case study 6: Ryegrass phase increases organic carbon levels in sandy soils

Managing the hard to manage	96
Identifying unproductive areas	
When options are limited	
Spatial distribution of hard to manage areas	
Small management zones	
Case study 7: Tramlining and raised beds limit waterlogging and compaction	100
Farm 1. Orandeen (home farm)	100
Farm 2. Hogwarts	100
Farm 3. Blue Waters (40 km south of Orandeen and 15km west of Hogwarts)	101
Glossary	104
Summary	108

Introduction

David Hall, Senior Research Officer, DAFWA Esperance

Everywhere we found the soil sandy and very poor; it either supported a coarse vegetation of thin low brushwood and wiry grass, or a forest of stunted trees ... The general bright green colour of the brushwood & other plants viewed from a distance seems to bespeak fertility; a single walk will however quite dispel such an illusion; and if he thinks like me, he will never wish to walk again in so uninviting a country.



(Charles Darwin, King Georges Sound, Albany, 6 March 1836)

Darwin's appraisal of the soils and productive potential of the land along the south coast of Western Australia (WA) affirms the challenges that faced early European settlers. The soils and vegetation were totally foreign and less productive than those the early settlers had left behind in Europe. Even to the present-day observer the sandplain soils are beach sands that 'sandgropers' use to grow crops in the absence of real soils. However-to land managers and soil scientists–a wide array of soils from the sandplain and differ markedly in their productive capacity. This book is about understanding and improving the properties of soil that affect agricultural production on sandplain soils.

The low inherent fertility of the sands, coupled with highly seasonal rainfall and low water-holding capacity, held back agricultural development of the sandplain for more than 100 years. It was not until the 1950s that inorganic fertilisers, political drive and foreign capital combined to transform the sandplain from marginal extensive grazing to the productive mixed farming enterprises we see today. It is a testimony to the pioneers that they were able to foresee the potential and apply innovative solutions to land management to facilitate the transformation. While considerable progress has been made in improving the physical, chemical and biological fertility of sandplain soils, they are prone to degradation. Sandplain soils are not as 'forgiving' as many other soils, simply due to their age, chemistry and coarse texture. To improve their composition and prevent degradation requires a deep understanding of the soil resource.

This book captures both the theory and applied management of sandplain soils. In the following chapters the properties of sandplain soils are discussed along with their limitations. Methods for identifying and evaluating soil limitations are developed. Key soil management systems (claying, liming, compaction and building organic matter) are discussed in detail. Practical applications of each of these soil management techniques are developed further through farmer case studies.

Further reading

Darwin, C (1836) Beagle Diary. http://darwin-online.org.uk/content/ frameset?viewtype=text&itemID=EHBeagleDiary&pageseq=1. Shier, FL, Dunne, TC and Fitzpatrick, EN (1963) 'Agriculture on the Esperance Downs', *WA J. Agric*. 1963.

Properties of sandplain soils David Hall, Senior Research Officer, DAFWA Esperance

The south coast sandplain covers 1.8 million ha ranging from Albany in the west to Condingup in the east and extending up to 80 km inland (see Figure 1.1).



Figure 1.1. The south coast sandplain

The rainfall is winter dominant, comparatively reliable and ranges from more than 650 mm on the coast to less than 400 mm inland. Given the reliability of the rainfall the land is valued for grazing (sheep and cattle), cropping (barley, wheat, canola and lupins) and timber production (blue gum and pinaster).

Historically the sandplain was mainly used for pasture production. However in recent years there has been a shift towards cropping to the extent that currently agricultural land use is equally divided between cropping and grazing systems. The intensification of land use under cropping has resulted in farmers seeking ways of improving their soils so that they are not just sustainable but robust enough to be profitable well into the future.

In this chapter the geology and soil formation processes that have shaped the sandplain are described briefly. Key properties that affect the physical, chemical and biological fertility of sandplain soils are described in greater detail.



Overview of geology and soils types

The sandplain is underlain by ancient granites that date back to the Precambrian era, some 590–2300 million years before present (BP). These granites form the islands, coastal headlands and inland hills found throughout the area. Continental shifts and changes in sea levels resulted in the south coast being inundated during the Eocene epoch (50 million years BP). Sediments deposited within the Eocene seas subsequently formed the Werrilup and Pallinup siltstones.

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Weathering of these siltstones and illuviation of clays from more recent deposits have resulted in the formation of the predominately kaolinitic clay layer that overlies the ancient granites. Intense weathering of minerals during the Miocene (10 million years BP) and aeolian sand accessions during the Quaternary (1.6 million years BP) have shaped the sandplain as we know it today. A summary of the geological events that shaped the sandplain is given in Table 1.1.

Period/ <i>Epoch</i>	Million years before present	Event					
Precambrian	590–2300	Basement rocks (granites and gneisses) formed. Coastal headlands, islands and inland hills (ie Mt Howick and Burdett) are part of the basement.					
Cretaceous	135–64	Australia breaks away from Antarctica, resulting in continental margins sagging. Beginning of the marine transgression which inundates the south coast.					
Tertiary/Eocene	40	Marine sediments settle on the basement rocks to form the Pallinup and Werrillup siltstones.					
Oligocene	30	Uplifting associated with the formation of the Darling Plateau tilts the coastline in a southerly direction. Ancient rivers which ran east west now run north south.					
Miocene		Climate induces intense weathering of minerals resulting in laterisation.					
Quaternary/Pleistocene	1.6	Climate becomes drier. Sea recedes. Aeolian movement of sediments across the landscape. Weathering of siltstones results in the formation of sandplain soils.					
Holocene	0.000120	Farming begins.					

Table 1.1 Summary of geological development of sandplain soils (Source: WA Geological Survey)

The soils that developed from this geology are varied. However most are characterised by organically stained sands overlying highly leached white and yellow sands. These in turn overlie highly weathered kaolinitic clays. The subsoil clays often have a columnar structure with domed tops and polyhedral sides. Lateritic gravels are often embedded within the sand layer and can make up to 80 per cent of the volume. Principal sandplain soil types are given in Figure 1.2, along with their scientific classification and local names.

4

Sandy duplex, alkaline subsoil

Pale sand, usually less than 30 cm deep, over mottled clay which is often alkaline and containing free lime in the clay layer.

Some variants have sand between 30 and 80 cm deep over clay.

Most soils lack ironstone gravels but the Waychinicup series common around Bremer Bay and Jerramungup characteristically has gravels present above the clay layer.



Gravelly sandy duplex

Pale sand, less than 30 cm deep, over ironstone gravel with a clayey B horizon generally found between 40 to 60 cm. Commonly has gravel at the surface.

	Typical profile	Albany variants	Esperance variants				
1m	Dark sand Pale sand with gravel Mottled sandy clay loam to clay						
	Common names	Gairdner gravelly duplex Napier Sandy gravel	Fleming shallow Caitup (variant of Fleming shallow with gravel at surface)				
	WA soil groups	Duplex sandy gravel Grey shallow sandy duplex					
	Australian soil classification	Ferric mesonatric yellow sodosol					
	Approx. % of area in each sandplain zone	20%	23%				

Figure 1.2 Soil descriptions for key soil types on the south coast sandplain: sandy duplex with alkaline subsoil; gravelly sandy duplex; (Source P. Galloway)

5

1

6

Deep sandy duplex with gravel

Pale sand, greater than 30 cm deep, over ironstone gravel with clay below. Eastern variants tend to have more conglomerated and cemented ironstone at depth.



Deep sand

Pale sand greater than 80 cm deep, often becoming yellower with depth and occasionally with ironstone gravel or 'coffeerock' below 80 cm deep.

	Typical profile	Albany variants	Esperance variants			
1m	Dark sand Pale sand Yellow sand, sometimes with gravel					
	Local names	Kojaneerup sand Silver loam	Corinup sand			
	WA soil groups	Pale deep sand Gravelly pale deep sand				
	Australian soil classification	Yellow blead	ched tenosol			
	Approx. % of area in each sandplain zone	17%	20%			

Figure 1.2 (continued). Soil descriptions for key soil types on the south coast sandplain: deep sandy duplex with gravel; and deep sand. (Source P. Galloway)

Sand makes up more than 95 per cent of the particles within the surface horizons of sandplain soils (see Table 1.2). Within the sand fraction there is a range of particle sizes which are dominated by the very fine and fine sands. Low levels of clay and silt sized particles within the top soil layers result in the soil having a low specific surface area. For instance, the specific area of the A horizon is 550 cm²/g compared to 9500 cm²/g for the B horizon when integrated over all particle sizes.

Horizon	Clay < 2µm	Silt Very fine sand 2–20µm 20–150µm		Fine sand 150–300µm	Medium sand 300–600µm	Coarse sand 600–2000µm
А	2	1	45	45	6	1
В	47	13	19	19 12		6
*Specific area cm²/g	Opecific 20 000# 454 va cm²/g 454		227	91	45	23

Table 1.2 Particle size distribution (%) of sandplain soil at Condingup

*Foth 1979 # Kaolinite

The low surface area of sandplain soils and the range of sand sized particles have major implications for key soil properties that affect crop production. These include the three pillars of soil fertility:

- physical properties (water-holding capacity, soil strength and compaction)
- chemical properties (cation exchange, pH buffering, nutrient retention, and water repellence)
- biological properties (carbon and nutrient cycling, root channels).

Physical properties of sandplain soils

Soil water

Surface area and porosity are important for water retention. Water is held under tension as film coating the surfaces of soil particles and within fine pores (see Figure 1.3).



Figure 1.3. Diagram of the same soil with declining water contents from saturation through to field capacity (FC) and permanent wilting point (PWP). Source http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_watersoil_moisture_classification.html

At very low water contents, the film of water is bound to the soil particles at such high tensions that plant roots are unable to extract the water. The water content at which this occurs is referred to as permanent wilting point (or lower storage limit) and occurs at tensions greater than 1500 kPa. The water content corresponding to the wilting point for sands is approximately 3 per cent (by volume) compared to 15 per cent for the subsoil clays. Loosely packed gravels are even lower at 1 per cent soil water. One of the benefits of sands and gravels is that 10 mm of rainfall will wet a sand above the wilting point to a depth of 10 cm compared to 20 mm for a heavier textured soil when initially dry.

Where there is so much water that there is insufficient tension to hold water against gravity, water will begin to drain. The water content at which draining ceases is referred to as the field capacity (or drained upper limit) and occurs at tensions of 300 kPa. For sands, field capacity is in the range of 9–12 per cent volumetric soil water content (see Figure 1.4). The difference between the field capacity and wilting point is the plant available water (PAW) range. For sandplain soils the calculated PAW varies from 60 mm/m for a deep sand to 120 mm/m for a shallow sand over clay.



Figure 1.4. The effect of soil texture on volumetric water content and plant available water. For sands the available water range is 0.03-0.09 cm3/cm3 giving a plant available water content of 60 mm/m. (e.g. (0.09-0.03) *1000 mm/m = 60 mm/m)

In reality the actual plant available water levels are often lower than those calculated due to the uneven distribution of roots within the soil profile. Most roots are found in the surface soil, the percentage of roots declining rapidly with depth, resulting in less water being removed at the base of the root zone. Hence while roots at the surface will dry the soil to wilting point, deeper in the profile less water will be extracted. At depth, roots rarely extract water to the wilting point (see Figure 1.5).



Figure 1.5. Sandplain water profiles showing the wettest profile (field capacity); the driest profiles recorded for two crops (lupin, barley); and the theoretical wilting point (WP). Note that in the subsoil, crops are unable to extract water to the WP. The calculated PAW was 145 mm whereas the actual PAW was 113 mm (Lupin) and 93 mm (barley).



Although the available water range for sandplain soils is low, the sands are porous. Approximately 50 per cent of the soil by volume is solid and the remaining 50 per cent is made up of pores containing air and water. The development of periodic watertables is common in poorly drained sandplain soils. Often the water will sit at the interface between the sand and clay layers.

Shallow duplex soils are prone to waterlogging. Where water logging persists the soil eventually becomes anaerobic Most plants are highly sensitive to anaerobic conditions and will fail in soils that remain waterlogged within 30 cm of the surface for more than a week. In these conditions, roots will die within the waterlogged layer resulting in a shallow root system. In deeper sands, the perched watertable can benefit crops as the stored water can be accessed later in the season when rainfall declines. For instance, a 200 mm deep perched watertable can store up to 80 mm of water.

9

Bulk density and soil strength

Bulk density (mass of soil per unit volume) is a measure of soil compaction. Soils that are unstable and have a wide range of particle sizes will naturally compact to form dense and often impenetrable layers. Due to the wide range of sand size particles, sandplain soils are rated as moderately susceptible to compaction. Typical bulk density values for sands, gravels and clays are given in Table 1.3.

Table 1.3. Bulk density and porosity ranges commonly found in sandplain soils

Soil layer	Bulk density g cm-3	Total pore space %				
Sand – topsoil	1.2–1.4	55–48				
Sand – subsoil	1.4–1.6	48–40				
Gravel stones	2.10–2.3	20				
Clay – top of dome	1.65–1.85	38–30				
Clay – subsoil	1.60–1.75	40-4				

Bulk density values greater than 1.5 g/cm³ are indicative of compact soils which have the potential to restrict root growth. Sandplain soils often have bulk densities which exceed the 1.5 g/cm³ threshold, particularly below the organically stained topsoil. The effect of bulk density on root growth is related to higher soil strength and reduced pore space. While gravels have high densities, they may not restrict root growth due to the presence of sand filled pores between the gravel stones that allow roots to move freely through the profile. The gravels may also resist compaction due to the point to point contact of the gravel stones which form a supporting structure.



Figure 1.6. Excellent canola root growth in gravel sand, the crop yielded 2 t/ha: Jerdacuttup 2004.





Soil strength, as measured by a penetrometer, is also used to identify compaction layers in deep sands. Penetrometer values greater than 3000 kPa have the potential to inhibit root growth and are frequently recorded within 40–50 cm of the surface of sandplain soils.

'Fence line' comparisons of penetrometer resistance between native and farmed soils, measured at similar water contents,

indicate that the farmed soils have become more compact within the root zone over time (see Figure 1.7). However, plant roots have been found to penetrate subsoils with high penetration resistance by using pre-existing root channels. While bulk density and penetrometer resistance measurements indicate the degree of compaction and likely restrictions to root growth, they are no substitute for observed root growth.



Figure 1.8. Sandplain soil excavated after ponding with blue dye. Note water repellent (unstained) topsoil, concentration of staining in the permeable gravel layers above the clay, and the network of fine pores within the clay that are transmitting water beyond 100 cm depth. Almost all of these fine pores were found to contain living roots, The columns of blue dye within the sand layer represent water which is rising to the surface due to capillarity. This mechanism allows even highly water repellent soils to wet from shallow water tables.

Penetrometer measurements need to be collected at standard water content (i.e. field capacity) as strength increases as the soil dries. Furthermore, penetrometers should not be used in gravel soils as gravel stones will impede the penetrometer but not necessarily the root.

Non wetting and water flow in sandplain soils

In sandplain soils, water flow is complex due to water repellent surface layers, contrasting textures between the topsoil sands and subsoil clays, and the presence of old root channels (macro pores) which can conduct water in what would otherwise be an impermeable layer (see Figure 1.8).

Water flow rates are determined by the size and continuity of soil pores, water potential gradient and degree of saturation. A further factor, common in sandplain soils, is water repellence within the organically stained topsoil. Due to the low surface area of sands, small particles containing organic waxes, fatty acids and fungal hyphae adhere to the sand surface and render the soil water repellent. In water repellent soils the reduction in water infiltration is proportional to the area which exhibits repellence.

Because sands are coarse textured, with large continuous pores, they generally have high water infiltration rates. The hydraulic conductivity (K), a measure of steady state water infiltration, generally exceeds 20–40 mm/hr, which is moderately high. The water infiltration rate for gravels varies, depending on whether sand or clay is present within the matrix. Gravelly sands are often highly permeable, with values of K exceeding 100 mm/hr, whereas gravelly clays can be highly impermeable and are prized by road builders. In clay subsoils the hydraulic conductivities are often very low (< 1 mm/hr), and the presence of old root channels, cracks and fissures can have a marked effect on water flow, as seen in Figure 1.9.

Due to the water perching, waterlogging is common in shallow duplex sandplain soils and occurs where soils become saturated within 30 cm of the surface. Over several weeks the subsoils become anaerobic and roots die, resulting in loss of crop vigour, and in extreme cases crop death. Crops which recover invariably have pruned roots and frequently are unable to redevelop root systems that can meet the demands of a dry finish to the season.

Systems for improving drainage in sandplain soils invariably include combinations of surface water drains and raised beds. Innovations include widely spaced beds ranging in width from 3 m to multiples of machinery width which can drain into dams. Soil pits created during claying operations and natural water ways have also been developed. More details on drainage technology are given in the case studies in this book.

Soil chemistry

Cation exchange and organic carbon

Cation exchange capacity is a measure of the soil's ability to retain positively charged ions (cations). Many cations are essential nutrients (e.g. Ca²⁺, Mg²⁺, K⁺, Mn²⁺, Cu²⁺, Zn²⁺). The higher the cation exchange the greater the availability of nutrients for plants and the greater the capacity of the soil to withstand changes in soil pH.

Cations are held onto the surface soil particles via weak negative charges associated with humic and clay colloids. The cation exchange capacity of humus, kaolinitic clays and sand is approximately 200, 8 and 1 milli-equivalents/100g respectively. In sandplain soils the cation exchange capacity in the topsoil is in the range of 0.5–5 me/100g. Due to the lack of clay, most of the cation exchange capacity in sandplain soils is due to the



Figure 1.9. A) Perched water table levels and rainfall between June and October 2003. B) Blue dye used to show the development of a perched water table at the interface between the sand and an impermeable gravelly/clay layer.



Figure 1.10. Effect of soil organic matter components on soil properties for soils with differing texture. (Source: J Baldock and K Broos, 2007)



Figure 1.11. Relationship between organic carbon and cation exchange capacity (CEC) for sandplain soils.

humus and resistant fractions of organic matter (see Figure 1.10). The labile pools of organic matter, which include the soluble and particulate fractions (see Figure 1.11), while being small, are important for microbial activity and nutrient cycling.

Soil organic matter (SOM) contains 58 per cent organic carbon and approximately 3–6 per cent nitrogen. Often laboratories use organic carbon percentage (OC%) as a surrogate for SOM, where SOM = 1.72 OC%. The sandplain soils contain on average 1.2% OC (range 0.3–3.9% OC). The lowest values are generally associated with wind eroded deep sands, and the highest values with long-term perennial pastures (e.g. 25 year old kikuyu pasture) in higher rainfall (> 500 mm) regions. Generally, lower temperatures, minimal soil disturbance, plants with fast growing and prolific root systems, legumes, heavier texture (loams, clays) and higher rainfall will all increase soil organic matter levels.

Even within paddocks with the same cropping history, there can be large variations in surface organic carbon levels. For instance a paddock at Gibson sampled in 40 locations had an average organic carbon percentage value of 1.47 with a range of 0.5–2.6% OC. Similar ranges have been found at Neridup and Condingup. Hence, even where climate and management are constant, intrinsic differences in soil properties which affect organic matter accumulation can result in large differences in soil organic carbon levels at relatively small scales.

The ratio of organic carbon to total nitrogen in SOM is generally constant for a given environment. For sandplain soils the ratio is around 12:1 (range 10:1–15:1), which is equivalent to the C:N ratios of humus found throughout the world. The constancy of these ratios indicates that in order to increase, SOM requires nitrogen as well as carbon.

Soil pH

Acid is added to the soil as part of the carbon and nitrogen cycles in agricultural systems. As a part of the carbon cycle, plants take up more cations (Ca²⁺, Mg²⁺, K⁺) than anions (PO₄³⁻, NO₃⁻, SO₄⁻²). In order to maintain a neutral charge, plants excrete weak acids (H₊) from their roots, which increases soil acidity. Within the nitrogen cycle the hydrolysis of urea and ammonium fertilisers to produce nitrate results in a net increase in soil acidity. In both the carbon and nitrogen cycles, if all the plant material returns to the soil then there is no increase in acidity. However when plant materials are removed (e.g. grain and hay), or nitrates are leached before being converted into plant matter, then there is a net increase in soil acidity. While the annual increase in acidity is small, continual acid additions over time can have a profound effect, particularly in poorly buffered soils.

Sandplain soils are prone to acidification due to their poor buffering capacity. In poorly buffered soils, only small quantities of acid are required to reduce the soil pH. Poor buffering is associated with low clay and organic matter content and historical leaching from sand layers of base cations (Ca²⁺, Mg²⁺, K⁺, Na⁺). As pH declines, hydrogen, manganese and aluminium ions become more available. In highly buffered soils, large quantities of acid are required to change the soil pH. However due to the low clay and soil organic matter levels, sandplain soils tend to be poorly buffered. Consequently, smaller quantities of acid can reduce soil pH over time. The largest changes in soil acidity generally occur below the organically stained topsoil where there is little chemical buffering. Changes in soil pH between undisturbed 'native' vegetation and cropped soils are shown in Figure 1.12.



Figure 1.12. Differences in soil pH between farmed and unfarmed sites. Note the decrease in soil pH within the subsoils.

1





As the pH declines below 5 the concentrations of exchangeable hydrogen, aluminium, iron and manganese increase at the expense of the base cations (see Figure 1.13). This has two effects. Firstly, the availability of essential nutrients calcium, magnesium and potassium declines. Secondly, aluminium levels increase exponentially to the point of becoming potentially toxic (Al > 5 mg/kg). This commonly occurs at pH less than 4.3 in sandplain soils. Aluminium levels exceeding 200 mg/kg have been found in profoundly acid sandplain soils with a pH < 3.6.

While pH has a profound effect on the base cations and aluminium, there are also a number of other essential nutrients that are also affected. A generalised summary of soil pH effects on nutrient availability is shown in Figure 12. Maintaining soil pH above 5 is generally seen to be sufficient to maintain nutrient availability while preventing toxicity. Further increasing topsoil pH beyond 5.5 has benefits for maintaining subsoil pH levels above critical thresholds.



Figure 1.14. Effect of soil pH on nutrient availability. Source: http://www.traylorchemical.com/images/fags/phchart.jpg

Soil nutrition

The inherently low levels of essential nutrients continue to impede agricultural production in sandplain soils. The low nutrient retention and highly weathered nature of sands has resulted in most essential nutrients being less than optimal for crop and pasture production. Compared with native soils, considerable increases in essential nutrients have occurred with repeated fertiliser applications to meet crop demand. Considerable differences in nutrient levels can occur in 'good' and 'poor' areas of paddocks that have been managed identically since clearing.



1



Figure 1.15. Distribution of major nutrients in a deep sand profile. Soils collected from adjacent native, good performing and poor performing sites: Neridup.

Table 1.4 Differences in soil properties between the topsoil sand (0–10 cm) and the subsoil clay (80–100 cm) for a soil profile at Neridup. Note that lime (CaCO3) had been applied previously at this site.

	EC	рН	ос	N	Р	S	Ca	Mg	к	CEC	Clay%
Sand	8	4.8	0.76	0.063	48	44	48	1.79	0.15	2.3	2
Clay	38	8.5	0.2	0.013	2	540	30	2.27	5.19	13.6	36

the presence of degradable substrates (i.e. organic exudates and residues) and an active web of decomposers (bacteria, fundi protozoa nematodes slugs earthworms) and their

Carbon and nutrient cycling

fungi, protozoa, nematodes, slugs, earthworms) and their predators (amoeba, nematodes, mites). The numbers of soil organisms are large, with data from east Beverly (WA) showing approximately 800 million protozoa, 900 000 nematodes and 130 000 mites per square metre of soil under pasture. Estimates of microbial populations from some of the more fertile soils in the world are 1 billion organisms per gram of soil. Types of soil organisms and their associations are shown in Figure 1.16.

The cycling of carbon and nutrients in soils revolves around

Soil biology

The biology of sandplain soils is poorly understood. Few studies have been undertaken on the effects of soil fauna (i.e. earthworms, ants and beetles), soil flora (i.e. plant roots) and micro-organisms (i.e. fungi and bacteria) on sandplain soil fertility. With the exception of disease control and nitrogen fixation through rhizobium, there are few studies able to show definitive links between crop yields and the activities of soil organisms. Despite this, the effects of biological agents are important, particularly in terms of carbon and nutrient cycling and the development of pathways for air and water movement. The challenge for the future is to better understand these processes and harness the benefits.

Properties of sandplain soils

Increases in essential nutrient levels have mainly occurred within the 0–20 cm layer. Below 20 cm the deep sands remain 'nutritionally challenged'. The concentration of nutrients near the surface aids plant establishment, but also makes the soils more prone to drought since both water and nutrients become limiting as the surface soil dries.

The inability of plants to take up nutrients in dry topsoils has been implicated in summer crop failure on deep sands despite subsurface moisture conditions being ideal. Phosphorus (P) is the exception to the general rule, with applied P often found to have been translocated deeper into the soil profile over time. Even in these highly leached soils, residual P is still stored within the root zone and provides a continuing resource for subsequent crops.

Invariably the nutrient levels in subsurface clays are higher in sulphur and the base cations (in particular magnesium and potassium) than the surface sands (see Table 1.4). It is for this reason that potassium deficiencies are rarely found in duplex soils.

Gravel stones found in sandplain soils can have a profound effect on soil nutrition due to chemical fixation and dilution. Iron and aluminium within the gravels react with phosphorus to form insoluble compounds that reduce the availability of P to plants. The phosphate retention index (PRI) has been developed to indicate the level of P immobilisation.



Figure 1.16. Schematic diagram of soil organisms and their associations with plant matter. (Source. USDA Natural Resources Conservation Service.)

The breakdown of plant matter by soil organisms adds to the carbon pool by forming humus. Humus is relatively stable and accounts for 30–50 per cent of the soil organic matter and repository for nutrients in the ratio of 120C:10N:1P:1S. In the process of forming humus, soil nutrients are taken up by micro-organisms. Once these organisms die, the nutrients are mineralised into ions, which can be readily used by plants. Even the most resistant organic materials will eventually be mineralised as a result of enzymes produced by micro-organisms.

The quantity of microbes in soils can be assessed by determining the microbial biomass carbon (MBC). In sandplain soils the measured MBC has been found to range from 30 to 600 mg microbial C/kg soil. Values less than 100 are considered to be low and indicate low activity and levels of nutrient cycling. Definitive links between crop production and microbial biomass are elusive. Time of sampling (summer, winter), sample preparation (freezing, drying) and paddock history (stubbles, cropped) all influence MBC values. Furthermore, it can be argued that soil biology only represents the state of a soil's chemical and physical fertility. Hence soil biology cannot be managed in isolation from other soil factors.

A few specialised micro-organisms are important in harvesting nutrients from the soil and atmosphere.

- Rhizobium bacteria form symbiotic relationships with legumes producing nitrates from atmospheric nitrogen in exchange for carbon from the plant. The amount of nitrogen fixed ranges from 40 to 200 kg/ha in a growing season.
- Azotobacter are free-living, nitrogen-fixing bacteria that can produce 10–25 kg N/ha in southern WA.
- Arbuscular mycorrhizal fungi (AMF) colonise plant roots. The fungi produce mycelium which have a high surface area and are able to scavenge nutrients, in particular P and Zn. These nutrients are available to the plant in exchange for carbon compounds (sugars). In southern Australia, soils with moderate levels of P have shown no increase in crop yields as a result of AMF, whereas crops in P-deficient soils have benefited from AMF.

 Macro fauna, in particular earthworms and to lesser extent ants, are also involved in nutrient cycling. The casts produced by worms contain higher levels of nitrogen, are water stable and have low density compared to the surrounding soil. While earthworms are present in WA wheat-belt soils, their distribution is often limited to areas high in organic matter and moisture and which have minimal soil disturbance

Roots and root channels

Old root channels formed from native (pre-clearing) vegetation still have a major but declining impact on water movement in the subsoil clays of sandplain soils. Over time the large pores within the topsoil become filled with sand, reducing their diameter and hence the water flow rate. Observations of water flow into the subsoil using dyes show that almost all the water flowing into the deep subsoil is via old root channels. Often these old channels are more stable than the surrounding soil and are colonised by more recent roots, suggesting that not only is water being transmitted but also oxygen.



Figure 1.17. Old root channels transmitting dyed (blue) water from the surface to subsoil clays at a depth of 70 cm. Neridup.

Soil properties and their management issues

A11 Horizon—zone of organic matter accumulation

The sand fraction is grey in colour due to organic staining to a depth generally less than 15 cm. Most (> 80%) of the soil particles are in the fine sand category (20–200 um) and tend to be water repellent. Organic carbon values are generally less than 1.5 per cent and cation exchange capacity rarely exceeds 3 me/100g.

Management issues—Water repellence, low nutrient and water retention, wind erosion, waterlogging.

A12 Horizon—zone of clay loss

Sands are pale yellow or white and can extend to depth ranging from 0.15 to > 2 m. The whiter sands tend to be more leached of minerals and less fertile. Due to the acidic nature of the parent material and low buffering capacity of the sand, soil pH (CaCl₂) is usually < 5. Lateritic gravels are often present at the base of this layer and can make up more than 60 per cent by weight of the soil.

Management issues—Soil acidity, low nutrient and water retention, high soil strength, waterlogging.

A2 Horizon—*zone of clay and mineral loss, bleached layer Management issues*—Soil acidity, aluminium toxicity, nutrient leaching, low nutrient and water-holding capacity, waterlogging, high soil strength.

B Horizon—zone of clay accumulation

Below the sand are clays which range in clay content from 20 per cent (sandy clay loam) to more than 50 per cent (clayey sand to medium clay). The clay ranges in colour from white to yellow and red, is highly weathered and is dominated (> 80%) by the clay mineral kaolinite. Dull colours and green/ blue hues indicate reduced oxidation associated with waterlogged conditions. *Management issues*—Soil acidity, aluminium toxicity, nutrient leaching, low nutrient and waterholding capacity, waterlogging, high soil strength. The top of the column is often hard and dense. A combination of soluble silica and dispersed clay creates a hard 'enamel' layer which restricts water infiltration and root growth. Calcium carbonate nodules may be present within the clay matrix.

Management issues—Sodicity, high soil strength, poor drainage and aeration.

Summary

The south coast sandplain is made up of a range of soils with differing properties including depth to clay and presence of lateritic gravels and carbonate nodules. These soils have developed from ancient sediments that have been modified by the action of wind, vegetation, water and seasonal wetting/ drying cycles.

The low surface area of sand predisposes sandplain soils to a range of physical, chemical and biological constraints to crop production. Since clearing, major increases in soil nutrients have occurred through the addition of inorganic fertilisers. However the soils have become more acidic and compacted in the root zone than they were under native bush.

The major limitations to crop production are water repellent topsoils, compact and acidic subsoils, waterlogging, and low water and nutrient retention. Multiple limitations often exist. Identifying the magnitude of the soil constraint in terms of crop production and the need for intervention is discussed in the following chapters.

Further reading

Soilguide. A handbook for understanding and managing agricultural soils. Department of Agriculture and Food, WA. Bulletin 4343

Overheu et al. (1993). Esperance Land Resource Survey. Department of Agriculture and Food, WA. ISSN 1033-1670

McArthur (1991). Reference soils of south Western Australia. Department of Agriculture and Food, WA.

Tools for determining yield potentials and soil production zones Yvette Oliver and Michael Robertson (CSIRO), David Hall (DAFWA)

In the previous chapter a range of soil constraints to crop production were identified. Some of these may only show up in certain seasons or are relatively minor; however others will continually reduce yields and need to be rectified to optimise yield and profitability. This chapter aims to address two key questions; how do you assess when intervention is necessary and does the whole paddock need intervention or can we differentiate between soils and production zones?

Benchmarking actual yields against the rainfall limited potential yield allows farmers to assess production efficiency (actual yield/potential yield x 100) for a given crop and paddock. For paddocks which continually achieve more than 75 per cent of their potential, major intervention may not be necessary. Below 75 per cent, farmers need to know what the limiting factors to crop production are and where in the paddock they occur.

The aim of this chapter is to identify tools that can be used to benchmark crop yields, against either calculated potential yields or standout yields within paddocks. The tools vary in terms of their complexity, data requirements, number of calculations and accessibility. Some of the computer models can account for seasonal variability and spatial variation associated with soil type and subsoil constraints. We discuss how the models work, their pros and cons and their accuracy in estimating yield.

Then we go on to identify methods for strategically identifying differing zones of production, using yield maps, normalised difference vegetation index (NDVI), electromagnetic induction (EM) and radiometrics.



Potential yield calculators

In 1984 French and Schultz published their research relating wheat yields to rainfall over many seasons for various places in South Australia. They found an enormous amount of variation between yields and rainfall, and when looking at the data closely they discovered there was an upper boundary to wheat production for any given amount of growing season rainfall (GSR=April to October). They were able to show that the slope of the line for the upper boundary was 20 kg/mm/ha. They also showed that approximately 110 mm of growing season rainfall is required before crops begin to yield (see Figure 2.1).



Figure 2.1. The relationship between grain yield and April-October rainfall. Lines A, B and C represent the effects of weeds, copper and nitrogen respectively. Redrawn from French and Schultz 1984.

Based on these results, French and Schultz developed their potential yield equation:

Potential yield (kg/ha) = (GSR - 110 mm) * 20 kg/ha/mm

The equation has two components: a crop transpiration efficiency (TE) term (20 kg/ha/mm) and a soil evaporation term (110 mm). These two terms can vary between 15 and 22 kg/ha/mm and 60 and 170 mm, depending on soil type and environment.

The equation has been used widely throughout southern Australia, despite a number of limitations:

- It does not account for soil type and difference in plant available water.
- It was not calibrated for crops other than wheat.
- It does not account for sowing and harvest dates.
- It does not account for the distribution of seasonal rainfall (late season rainfall often has a larger impact on yield compared to early season rainfall).
- It assumes a linear yield response to rainfall.

Computer programs

PYCAL

PYCAL (Potential Yield Calculator) uses the principles developed by French and Schultz, but has overcome some of the limitations. PYCAL has been calibrated for a range of crops including wheat, barley, triticale, peas, lupins and canola, based on Western Australian data. It uses current and historical daily rainfall data to generate GSR, which is the sum of stored water at sowing plus rainfall from sowing through to harvest. The general equation is expressed:

Potential yield (kg/ha) = ((water stored at sowing (mm) + sowing to harvest rainfall (mm)) – soil evaporation (mm)) * transpiration efficiency (kg/ha/mm)

Stored water is calculated from daily rainfall data from the previous November to the current year's sowing date. The stored water amount is diminished with time from rainfall to simulate evaporation from the soil. The transpiration efficiency and soil evaporation terms for a range of crops grown on sandplain soils in WA are given in Table 2.1.

Table 2.1. Transpiration efficiency (TE) and soil evaporation values used in PYCAL

Crop	Wheat	Barley	Triticale	Pulses	Canola	Lupin
TE	15	18	18	12	10	12
Soil evaporation	110	110	90	115	110	125

PYCAL not only presents the potential yield at the end of the season, it also allows the user to assess the chance of achieving a certain yield as the season progresses. Expected rainfall is calculated from historical data and is presented as a decile from 1 (90 per cent chance of exceeding) to 9 (10 per cent chance of exceeding). This information is useful when farmers are making strategic fertiliser and fungicide decisions in the course of the season.



Limitations of PYCAL

- Calculated stored water can exceed the actual water storage capacity in sands.
- Like the French and Schultz model, it does not account for the distribution of seasonal rainfall.
- It does not calculate water or nitrogen stresses incurred by plants during the growing season.
- It assumes a linear yield response to rainfall and does not account for waterlogging.

PYCAL can be obtained from the Department of Agriculture and Food, Western Australia.

http://www.agric.wa.gov.au/content/fcp/tools.htm.

On-line daily rainfall records can be obtained from: http://www.agric.wa.gov.au/content/LWE/CLI/awspages.htm http://www.bom.gov.au/climate/dwo/IDCJDW0600.shtml.



Figure 2.2. An example of a Yield Prophet agronomic report.

Yield Prophet®

Yield Prophet® (YP) is a web-based program (http://www.bcg.org.au) which evolved from the CSIRO research tool APSIM (Agricultural Production Simulator). YP was developed as a risk management tool by the Birchip Cropping Group with the main emphasis on decision support for nitrogen inputs. It models crop growth on a daily basis by simulating the soil water and nitrogen processes within the soil and crop.

YP requires soil, climate, crop and fertiliser data to run its crop growth simulations. Soil characterisation factors include plant available water, drained upper and lower limits, bulk density, organic carbon, EC, pH, chloride and nitrate. Sowing and harvesting dates, crop type, root depth and variety, fertiliser inputs and daily rainfall are also required to run simulations. Some soil data is available for various sites in Australia, including the south coast sandplain. Locations and supporting data can be viewed on Google Earth using the APSoil database (http://www.apsru.gov.au/apsru/).

YP simulations of crop growth and yields are based on long term (100 years) rainfall records. The simulations are used to rate the probability of achieving a given yield as the season progresses. Output from YP also includes water and nitrogen availability and stresses at various stages of development (see Figure 2.2). One advantage of YP is that it allows the user to assess different management options. It can also indicate reasons for poor growth, particularly if roots are limited or there is insufficient nitrogen.

Limitations of Yield Prophet

- It has a greater degree of complexity and data requirements than PYCAL.
- Output is dependent on the quality of data used in the model.
- It does not account for waterlogging.

Yield monitors, maps and other spatial data

Yield maps

Yield monitors and maps are tools farmers can use to identify areas within paddocks that are under performing. Even within the worst paddocks there will be pockets of high performing crops which are close to the yield potential. Strategically sampling soils within both the high and low yielding sites will often reveal the causes of the disparity in crop growth. Knowing the difference between potential and actual yields (yield gap) helps farmers to decide the extent and level of intervention required to improve their soils. This is illustrated in Figure 2.3 where factors including low pH (< 4.5), cation exchange (< 2.5), organic carbon (< 1%) and K (< 40 ppm) along with high penetration resistance (> 2500 kPa), are contributing to the lower yields of the pale deep sand.

Limitations of yield maps

- A yield map reflects the relationship between crop type, soils and the prevailing climatic conditions for a given year. Analysis of several years of yield data is required to identify consistently high and low performing areas.
- Higher producing areas may not always be reaching their yield potential as other agronomic factors (sowing dates, fertiliser inputs and pests) may also be limiting crop yields.

NDVI (normalised difference vegetation index) and vegetation images

NDVI is obtained from satellites that measure the absorbance and reflectance of light's wavelengths on the surface of the earth. Wavelengths in the near infra-red range are related to photosynthetic activity and hence can be used to assess crop activity and health. The combination of yield maps and within season growth using NDVI has been used to identify differences in vegetation growth.

Mid-season NDVI used with yield maps can help target areas where crop production is not reaching potential.

- Both yield and NDVI are high—no apparent constraints.
- Yield is high but NDVI is low—early constraint that has not affected yield.
- Yield is low but NDVI is high—late constraint which has affected yield.
- Both yield and NDVI are low—constrained throughout the season.

Late constraints which affect crop yield can often be related to poor root growth associated with subsoil constraints (compaction, acidity) and or drought.

Limitations of NDVI

- A lot of time is required extracting and processing data.
- Image resolution at a sub paddock scale can be low (pixel area 25 m x 25 m).
- It does not differentiate between crops and weeds.
- It cannot distinguish between healthy and unhealthy crops with low greenness (e.g. flowering canola).
- Cloud cover limits coverage and times that useful images can be obtained.

Depth	EC	рН	AI	0C	N	Р	K	S	Ca	Mg	Na	K	CEC	BSat	BD	СР
10	4	4.9	1	0.91	0.074	12	33	5	1.71	0.13	0.02	0.06	2.01	96	1.39	1020
20	2	4.2	2	0.43	0.032	13	16	3	0.52	0.04	0.02	0.04	0.88	70	1.53	1527
30	2	4.2	2		0.021	11	22	2	0.19	0.07	0.04	0.06	0.56	64	1.55	3023
40	1	4.4	1						0.12	0.04	0.02	0.03	0.36	58	1.56	3588
60	1	4.4	1						0.08	0.11	0.02	0.05	0.42	62	1.58	2721
80	2	4.5	2						0.07	0.05	0.02	0.03	0.32	53	1.63	2053
100	3	4.7	3						0.1	0.09	0.02	0.07	0.49	57	1.66	

Pale Deep Sand: Yields 40% of Potential











Sand/Grave/Clay: Yields 80% of potential

Depth	EC	pН	AI	OC	N	Р	К	S	Ca	Mg	Na	K	CEC	BSat	BD	Gravel
10	9	6	<1	1.34	0.13	32	100	11	4.11	0.51	0.02	0.21	4.9	99	1.4	11.58
20	5	5	<1	0.58	0.052	13	28	6	1.47	0.21	0.02	0.06	1.8	98	n/a	12.55
30	5	5	<1		0.021	25	21	5	0.77	0.18	0.02	0.05	1.1	93	n/a	81.01
40	5	5.1	<1		0.028	24	50	6	0.95	0.23	0.04	0.09	1.4	94	n/a	86.82
50	5	5.4	<1		0.024	14	73	11	0.97	0.25	0.06	0.15	1.5	95	n/a	88.52
60	5	5.5	<1		0.026	9	120	13	1.32	0.36	0.14	0.24	2.11	98	n/a	89.09
70	8	5.7	<1		0.022	3	180	14	1.65	0.45	0.44	0.39	2.98	98	1.68	86.95
80	5	5.7	<1		0.02	3	200	14	1.6	0.58	0.29	0.41	2.93	98	1.7	43.19

Figure 2.3. Soil chemical and physical properties associated with sites reaching 80 per cent of their potential versus 40 per cent of their water limited yield potential. Soil parameters EC (electrical conductivity (mS/m), pH (CaCl₂), OC (Organic Carbon %), N (Total N %), Al P K S (ppm), Ca Mg Na K (cmol(+)/100g), CEC (Cation exchange capacity cmol(+)/100g), Bsat (Base saturation %), BD (Bulk density g/cm³), CP (Cone penetrometer kPa) and Gravel (%).
Electromagnetic induction (EM)

Electromagnetic induction generates electrical fields to measure the apparent conductivity of soils. The depth of measurement can range from < 1 m to > 2 m, depending on the orientation and separation of the coil and receiver. Soil conductance is affected by clay, water and salt. Much of the early work with EM was directed towards mapping salinity. However EM can differentiate between soil properties and has been used to identify production zones within paddocks, mainly in heavier textured (clays) and grey alkaline shallow duplex soils. The main limitation of EM in sandplain soils is that the signal cannot distinguish between sand and gravel soils. This is illustrated in Figure 2.3 where the EM signal does not differentiate between the high producing gravel soils and the low producing pale deep sands. The main advantage of EM is that the values are stable over time.

Limitations of EM

- Crop production zones are inferred from soil properties.
- It does not differentiate between sand, gravel and rock
- It does not differentiate between clay, water and salt.
- The EM38 signal is integrated over depths to 2 m; however the signal is biased towards near surface properties.

Radiometrics

Radiometrics measures gamma rays that are naturally emitted from the ground by isotopes of potassium, thorium and uranium. The abundance and ratios between these isotopes can differentiate between near surface sand, gravel, clay and rock. For instance the ratio of Thorium to Potassium isotopes has been used to differentiate between sand and gravel in WA.

Limitations of radiometrics

- Crop production zones are inferred from soil properties that may or may not be related to crop yield.
- Gamma rays are generally detected from within the top 40 cm of the soil profile. Gravels or rock deeper within the profile may not be detected.
- Specialist knowledge is required to interpret radiometric maps.



31

Predicting potential yields using a modified French and Schultz model - a study

In this study a modified French and Schultz approach has been used to predict potential yields. The method outlined below has been modified to take into account the higher rainfall of the south coast and lower water storage of sandplain soils. The study at Gibson in 2003 was a wet year (Decile 9).

Step 1. Calculate monthly rainfall

To predict yield potential, all models require rainfall information, from a rainfall gauge located on the farm or from the closest Bureau of Meteorology rainfall station for the year of interest (see Table 2.2).

Table 2.2 Monthly rainfalls in 2003 at Gibson

Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2	45	10.4	54.2	74.9	75.6	124.5	77.3	108	53	46.6	8.2

Use monthly rainfall values to calculate:

1. Stored soil water (30% January-April rainfall) = 0.3 x 114 mm = 33 mm

2. Growing season rainfall (GSR) (May-October rainfall) = 513 mm

Step 2. Calculate yield potential

- 3. Potential grain yield (kg/ha) = (stored soil water (mm) + GSR (mm) soil evaporation (mm)) x Transpiration Efficiency kg/ha/mm
- 4. Potential wheat yield = (34 + 513 110) x 20 = 8735 kg/ha

In reality, rainfall from July to October was high, with much of it potentially lost to run-off and drainage beyond the root zone. Thus the unmodified French and Schultz model will overestimate the potential yield. Yields below the French and Schultz potential does not therefore necessarily indicate underperformance.

Once the usual agronomic factors are considered (i.e. weeds, disease, nutrients), the most common causes of not reaching the water limited yield potential is the soil type.

Step 3. Adjust model to account for soil type and plant available water capacity

To prevent the French and Schultz model from overestimating yield potential we need to take into account how much rainfall the soil can physically store. The plant available water capacity (PAWC) is a measure of the soil's ability to release and store water and is determined mainly by soil texture (percentage of sand, gravel, clay).

It is useful therefore to determine the soil types across your paddock or farm. Draw a 'mud map' defining the soils by simple soil groups and including your knowledge of constraints (see Figure 2.4). A mud map is often the best approach on sandplain soils as techniques such as EM may not differentiate between different sands or between sands and gravels (see Figure 2.3).

To allow for differences in soil type and water storage, the French and Schultz model has been adapted to define how much rainfall the soil can store. This is done by applying an upper limit to the amount of rainfall crops can use on a given soil type. Where rainfall is below the growing season rainfall (GSR) upper rainfall limit (see Table 2.3) the GSR is used to estimate yield potential. However, if GSR exceeds the upper limit, the excess will not be counted towards yield, and the upper limit is used to estimate potential.





Figure 2.4. Soil map for paddocks at Gibson. Soil types are represented by different colours. Numbers are the sampling points used to determine the soil boundaries.

Table 2.3. Upper limit to GSR used in the PARm model, for total season rainfall when the plant available water capacity is between 40–200 mm

Soil type	PAWC	GSR upper limit (mm)			
	(((((((((((((((((((((((((((((((((((((((May-Sept May-Oct			
Soils where roots	40	210	225		
are constrained due to acidity or	50	220	230		
compaction.	60	230	245		
Deep sands with no	70	240	260		
major limitations to root growth.	80	250	270		
	90	260	280		
	100	270	290		
Duplex soils with	130	305	325		
sand/gravel over clays. No root	150	325	345		
restrictions.	170	340	355		
	200	370	385		

We can write the potential yield equations as follows. If growing season rainfall is less than GSR upper limit then:

 Potential Yield (kg/ha) = (GSR (mm) + stored water (mm) – soil evaporation) * TE

If growing season rainfall is greater than GSR upper limit then:

 Potential Yield (kg/ha) = (GSR upper limit (mm) + stored water (mm) – soil evaporation) * TE

For the soils shown in Figure 2.3 the PAWC was 130 mm for the duplex soil and 80 mm for the pale deep sand. In 2003 the GSR rainfall exceeded the GSR upper limit. Consequently the GSR was adjusted to 325 mm (duplex) and 270 mm (pale deep sand), based on the values presented in Table 2.2. The potential yields were calculated as follows:

- 7. Potential yield (duplex) = (33 + 325 110) x 20 = 4960 kg/ha
- Potential yield (deep sand) = (33 + 270 110) x 20 = 3860 kg/ha

Step 4. Determine actual crop yields

Yield maps or knowledge of yield variation across paddocks can be used to determine the yield of the top 10 per cent of the paddock for the year of interest (not the *highest yield at a point* on your yield map). The yield in the highest 10 per cent of the paddock/farm is used to benchmark the yield potential for that year based on the assumption that this area is free of weeds, received enough nutrients and was on a 'good soil' which does not run off, surface seal, or exhibit subsoil constraints.

For instance, in 2003 wheat yields in a paddock at Gibson ranged from 1 t/ha to 6 t/ha with a mean of 3.4 t/ha (see Figure 2.5). The highest yielding 10 per cent of the paddock yielded more than 4.2 t/ha.





Step 5. Compare best yields with potential yields

In the Gibson example the measured yield on the duplex site was 4.5 t/ha while the predicted yield potential adjusted for rainfall was almost 5.0 t/ha. The highest yielding area of the paddock is therefore achieving 91 per cent of yield potential. However the deep white sands only achieved 64 per cent of their potential. For areas achieving less than 80 per cent of the production potential, the following questions need to be asked.

 Was there enough nitrogen and phosphorous? Calculate N and P needed to reach French and Schulz yield potential based on 30 kg/ha N and 3–4 kg P/ha for each

tonne of wheat grain.

- Were sowing dates and rates near optimal (mid May)? Late sowing affects yield potential. Use rule of thumb that 17 kg/ha per day is lost after the optimal sowing date. For a 3–4 t/ha cereal crop, planting rate needs to be 150–200 plants/sq m.
- 3. Was the crop affected by waterlogging?

Perched watertables within 30 cm of the surface will prune roots and reduce air and nutrient uptake. Canola and lupin crops are most affected.

If none of the above apply then there is likely to be a soil constraint. Common causes of underperformance are those that reduce rooting depth and soil PAWC such as acidity, salinity, sodicity and compaction, as well as those which affect water infiltration such as sodicity, water repellence and waterlogging. In this case, low pH (< 4.5), cation exchange (< 2.5), organic carbon (< 1%) and K (< 40 ppm), along with high penetration resistance (> 2500 kPa) all contributed to the lower yields achieved on the pale deep sand.

Summary

Benchmarking actual yields against the rainfall limited yield potential is the first step in identifying whether there are soil constraints. Several techniques for calculating the yield potential are given, ranging from a simple French and Schultz to more complex web based programs. To improve the predictive ability of the various techniques, and isolate areas that may need remediation, knowledge of soil types and the plant available water capacity (PAWC) of the soil is required.

Using yield maps, monitors or farmer knowledge, actual yields are compared with potential yields for the various soils types. Areas achieving less than 75 per cent of their rainfall limited yield potential often have soil constraints. The diagnosis and types of constraints commonly found are discussed in the following chapters.

Operation at a glance

Area 9000 ha

Annual rainfall 550 mm

Cropping 4000 ha

Livestock 1000 breeding cattle; 15 000 breeding ewes (up to 30 000 sheep in winter)

Soil types mainly sands—sand/gravel (the most difficult to farm), sand/gravel/clay (more prone to waterlogging) and sand/clay

History

1995 The Della Vedova family were farming at Mt Walker (central wheatbelt). Joe and Charlotte purchased 2000 ha (Welcome Downs) east of Esperance, and for the next three years they moved machinery back and forth between the two locations.

1996 Purchased a further 1500 ha (Dryandra) near Condingup.

1998 Tried claying on some of the sandy areas of the Esperance farm prone to wind erosion. Sold up at Mt Walker.

2003 Purchased a further 3200 ha (Seven Plains) and relocated the family there.

2005 Purchased another 2500 ha (Kincora) bringing the total amount of land to around 9000 ha.

2008 Erosion problems eventuated due to a dry spring and strong summer winds in the Esperance region, which resulted in Joe reassessing the value of claying to minimise further risk.

By the mid-1990s Joe and Charlotte Della Vedova had grown tired of being hit by frost and drought at their central wheatbelt Mt Walker property and so they searched Western Australia to see where else they could operate. Although their property had rich loamy soils, the inland seasons were becoming increasingly unreliable. They eventually decided that Esperance farms along the coast offered the cheapest higher rainfall land and in 1995 they purchased Welcome Downs, about 50 km east of the town and Joe and Charlotte moved their young family there soon after. They purchased other properties nearby over the next decade and in 1998 sold Mt Walker to focus completely on their coastal farms.

It took Joe some time to figure out how to manage the sandy coastal soils. The rich red loams he had learned to farm on were very different to the infertile sandplain. He soon found that most of his new farms were highly prone to non-wetting issues and although he had moved to a region that received more rain, yields often did not reflect that.



Claying and spading

Originally claying was undertaken only sporadically on the deep non-wetting sands prone to wind erosion. 'Back then we saw too many failures in dry years with paddocks which had been clayed,' Joe said. 'The band of clay was good for minimising weed germination and erosion problems, but if we only clayed the top 100 mm of the profile, then it seemed the roots tended to mostly stay in that section during the growing season. Then when there was a dry finish, the roots hadn't gone down deep enough and the crop ran out of moisture too quickly. I saw two tonne crops turn to nothing in a dry spring.'

So Joe held off on the claying until he went to a spading field day in 2007 which demonstrated that clay could be incorporated using a spader to depths of 30–40 cm. The next year, he clayed a 40 ha trial paddock to a depth of 50 cm at their Kincorra property. They aimed to achieve 6 per cent clay content (the amount of clay is subject to the percentage of clay in the material being spread), which required around





1000 t/ha to be spread, instead of the usual 200 t/ha required when claying shallower depths (10–20 cm).

'Fortunately there is pretty good clay in a lot of our coastal sandplain, so we didn't have to cart too much of it too far,' Joe said.

It was a process of soil rebuilding, with delving or carting and spading of the clay being done across the whole paddock, depending on its varying soil profiles. The paddock ranges in soil type from 15 cm of sand over clay, up to depths over 1 m, to 50 cm of sand over gravel over clay. Where the clay was close to the surface, waterlogging was more prevalent. Areas of the paddock with deep sand had clay carted and incorporated. Areas where the clay was closer to the surface were delved. But if there was a gravel layer, then the delving could not be done, so the clay needed to be carted to those areas and integrated from the surface downwards. Case study 1: Rebuilding sands to effectively use rainfall Joe and Charlotte Della Vedova, Kincora, Esperance

Tools for determining yield potentials and soil production zones



The paddock was extensively soil tested, then electromagnetics and radiometrics were used to map where the clay and gravels were, to decide on which form of earthworks to undertake (delve or spread on the surface and then integrate).

Joe is happy with initial results. In the following summer of 2009 the paddock yielded 5.65 t/ha of sorghum. That autumn it was sown to canola. 'The summer crops use the rest of the winter rainfall and consequent summer falls we usually get, so in theory we can better use all our available water and increase yields,' Joe said.

In 2009 the paddock was in Year 2 of the three year trial he wanted to complete prior to purchasing earthmoving machinery to tackle substantial areas of his properties as part of a major whole farm claying program.

In brief

- No-till had always been used to minimise erosion problems, but big wind events in 2008 'frightened' the Della Vedova family into reviewing amelioration options to reduce the risk of erosion.
- Targeted claying at greater depths has been used to improve waterlogging issues.
- Carbon building is a challenge for the sandplain. Joe wanted to link biological management techniques with chemical options to increase yields and minimise inputs. He would like to increase carbon content from the sandplain average of around 1 per cent to closer to 4 per cent.
- Green manure (summer crops such as sorghum and stubble retention) is being trialled to increase carbon content.
- The no-till concept is being retained on top of spading, to minimise compaction on designated continual cropping paddocks.





Key lessons

- Clay needs to be a minimum of 6 per cent in content to a depth of 30 to 50 cm within the profile.
- The claying has changed the pH of the soil from 4 to around 7. Crops are being monitored closely for any toxicity issues.
- More nutrients are needed post claying. Around 600-700 kg/ha of copper, zinc and molybdenum were applied prior to delving. Five tonne/ha of lime was applied, along with 100 kg/ha of manganese and 2 t/ha of gypsum, post preparation.
- Fuel and labour are the biggest overall costs. If a whole farm operation is undertaken, then large machinery will be purchased, big enough to handle the massive amounts of earthwork required.

Diagnostic Tree Modified Misc. Bulletin 20/2003 by Daya Patabendige, Dept. Agriculture and Food, Western Australia.

Decision tree for diagnosing and ameliorating problem soils in poor-performing paddock zones

Most cropping paddocks in Western Australia have areas that consistently perform poorly. If your agronomy and management practices are good, then the poor yields are usually due to soil-related problems. Some of these problems can be corrected or reduced by adopting certain proven practices. However, it is important to identify and quantify the problem so that you can decide whether amelioration is possible and worth the cost.

Remember to eliminate any agronomic and management problems for poor yield before using this diagnostic key on your soil problems.

This decision tree has been colour-coded with corresponding chapters in the book. You can get more information on managing water repellence, waterlogging, soil acidity and soil compaction once you diagnose which of these problems you have by working through the following steps and then going to the relevant chapter.

Index for the diagnostic key on soil problems



Step 1

For more information –go to Chapter 3

Non-wetting sandy soils and poor pale deep sands











Water repellence David Hall, Senior Research Officer, DAFWA, Esperance

Water repellence or non-wetting describes soils that have hydrophobic properties. It is a worldwide phenomenon and not restricted to any one climate or soil type. In southern Australia between 2 and 5 million hectares of agricultural land exhibits water repellence tendencies. Often, but not always, the affected soils are sands. The sandplain soils that cover the coastal fringes of the WA and SA wheatbelts are especially prone to this condition.

In water repellent soils, long chain organic substancesincluding waxes and polymers-coat the soil particles resulting in hydrophobic properties. The waxes and polymers are derived from plants and fungi and are most evident in the organically stained layers in the upper A horizon. Water repellence may be used by certain plants to suppress germination of competitors and improve soil water relations by reducing surface evaporation and channelling rainfall deeper into the profile via 'finger flow'. However, in broadacre cropping systems, water repellence reduces grain yields by directly preventing seeds from germinating. Staggered germination results in poor crop establishment, poor weed control, soil erosion and uneven crop maturation.

Considerable progress has been made in identifying management options for water-repellent soils. Often these solutions are based on introducing hydrophilic agents to the soil (e.g. wetting agents and clay); creating mini-catchments within seeding rows in order to 'harvest' rainfall more effectively; and more recently identifying and using micro-organisms to break down the organic materials that cause water repellence.



Characteristics of repellent soils in WA

Water repellent soils are found throughout the world over a wide range of climates and soil types. No single vegetation type or management system can explain the occurrence of water repellence over such a wide geographical area.



Figure 3.1. Risk level and distribution of water repellent soils in Western Australia. Source: D Van Gool DAFWA.

Distribution

In southern Western Australia, water-repellent soils are commonly found in association with the coastal sandplain (see Figure 3.1). The areas affected include the northern wheatbelt, south of the Stirling Ranges and the Esperance sandplain. In total there are 3.2 million hectares which are classified as having greater than 70 per cent of the area at high risk of being water repellent. Water-repellent soils are usually sands that have more than 0.5 per cent organic carbon and less than 3 per cent clay. A strong relationship exits between organic carbon levels (0.3–1% OC) and water repellence in sands (1–2% clay) on the south coast of WA. Soils with increasing clay content generally have reduced repellence. However, where there is an abundance of hydrophobic organic residues then soils with more than 20 per cent clay can become repellent. The repellent zone is confined to the organically stained topsoil (0–15 cm).

Causes of non-wetting

Direct relationships have been found between fungal hyphae, the production of hydrophobic compounds (amino acids) and water repellence in sands and clay soils. Waxes from plants (eucalyptus, acacia, clover, lupin) will also confer hydrophobic properties to soils. Often the hydrophobic compounds are found in isolated organic particles mixed within the soil hydrophobic organic matter derived from fungal hyphae, root exudates and leaf waxes. Repellence is a by-product of organic residues that have been sequentially broken down to smaller particles. A range of organic compounds, and more than 50 plant species, have been implicated in water repellence (see Figure 3.2).

The waxes in particulate organic matter are adsorbed to soil particles as they diffuse out of the organic matter in the course of wetting–drying–heating–cooling cycles. Often this organic matter contains a higher proportion of waxes relative to the original organic residues.



Figure 3.2. Schematic diagram of causal agents and the development of water repellent soils. Source: http://www.alterra-research.nl/pls/ portal30/docs/folder/water repellency/

The amount of organic matter required to inhibit water infiltration in sands is relatively small due to their low surface area and charge. Generally, the coarser the sand the less particulate organic material is required to produce repellence. A few hydrophobic sand grains (1–3%) will inhibit water absorption and infiltration in an otherwise wettable soil. As the surface area and charge increase, as in the case of clay soils, more hydrophobic grains will be required to inhibit water absorption and infiltration.

Repellence and water infiltration

Water repellence alters the way in which water is absorbed and distributed within the soil. Firstly, repellence reduces water infiltration with the reduction being proportional to the area of repellent soil. Secondly, repellence causes water to infiltrate along preferred pathways associated with less repellent regions and old root channels. Small changes in topography in repellent soils result in run-off collecting and ponding in localised depressions. Where head pressure of ponded water exceeds the water entry pressure of the repellent soil, then water will infiltrate. 'Finger flow' is characteristic of the wetting pattern found in repellent soils where water moves into the profile within wettable zones interspersed with dry soil (see Figure 3.3).



Figure 3.3. (A) Finger flow in a water repellent soil from Geraldton WA as shown by the darker (saturated) areas where water has infiltrated. Photo taken after 75 mm rainfall had fallen in 4 hours. (Source: Doerr et al. 2000). (B) Wetting pattern in a non-wetting soil at Esperance.

Water repellence occurs in dry soils, not in wet soils. As the soil moisture content rises beyond field capacity to saturation, the hydrophobic properties are diminished. The critical water content appears to be related to water movement occurring in the vapour as opposed to droplet or film phases. On drying, the soils often remain hydrophobic, with 'finger flow' paths redeveloping in the same locations following successive rainfall

events. With sufficient rainfall, most repellent soils wet fully. In duplex soils, perched watertables can wet the soil from the bottom up, including the repellent layer.

Managing water repellent soils

The management of repellent sands can take several forms including surface tension reduction (surfactants), water harvesting (furrow sowing), masking (claying and delving), decomposition of waxes by soil microbes, avoidance (sowing plants which can tolerate repellence) and dilution (mixing repellent soils with non-repellent soil). There is almost no information on dilution as a management technique for repellent soils.

Surfactants (wetting agents)

Surfactants are wetting agents that reduce repellence by lowering surface water tension and lowering the critical water content below which soils show symptoms of repellence. Surfactants have a hydrophilic polar head and a hydrophobic long carbon chain tail. The tail of the surfactant molecule can bind with waxes. In theory the binding of surfactants to soil particles should aid in re-wetting the soil surfaces. The combination of improved water penetration and bonding with oils and waxes can result in partial dissolution of waxes. Surfactants can be cationic, anionic or non-ionic. Non-ionic surfactants have the advantage of remaining effective when diluted with dam or bore water containing higher levels of dissolved salts and minerals. Surfactants are commonly applied at seeding and banded within the sowing lines. Crop responses to surfactants have been variable with the largest responses occurring when moisture has been limiting at seeding. Trials conducted in a dry season (1988) at Condingup, Neridup and Dalyup showed yield increases of up to 50 per cent as a result of banded wetting agent being applied at rates ranging from 0 to 16 L/ha. Much of the increase in yields occurred at rates of 1–2 L/ha. Where press wheels were used, the yield responses to wetting agents dropped to 10–15 per cent. The results of other trials on south coastal sandplain soils have been mixed, with yield responses and declines attributed to the application of wetting agents.

The cost of the surfactant is approximately \$9/L, applied at a rate of 1 L/ha in banded strips over the sowing lines. It is interesting to note that very little surfactant is currently sold in the Esperance region for the purpose of alleviating non-wetting. There is a perception that wetting agents have only a shortterm benefit and that other techniques, including furrow sowing with press wheels and claying, are more effective.

Furrow sowing with press wheels

Furrow sowing produces a series of small ridges and furrows. The microrelief of the ridges generates run-off which collects near the seed at the base of the furrow (see Figure 3.4). Approximately 5 mm of rainfall can wet 70 per cent of the sown area for furrows compared to only 20 per cent of the area when sown level (Blackwell et al. 1994a). Initial research into furrow sowing concentrated on wide seeding rows (> 350 mm) and relatively deep furrows (40–80 mm) in order to maximise water harvesting. In the northern wheatbelt, significant increases in grain yields (> 40%) were found compared with level sowing.



Figure 3.4. Furrow sowing on water repellent soils. Source: Blackwell, Dept Agriculture WA Farmnote 11 January 1996.

On the south coast of WA, longer growing season conditions have resulted in smaller benefits or yield reductions from wide furrow sowing. Although improving water infiltration, furrows that are deep and wide increase the chance of deep seed burial and herbicide damage caused by chemicals concentrating at the base of the furrow. Row spacing trials at Esperance showed that the highest cereal yields were achieved at a spacing of 250 mm when furrow-sown. In a further development, press wheels were found to create and maintain furrows but also to aid in soil water retention. In the absence of a wetting agent, press wheels have shown dramatic increases in crop emergence and grain yields (see Figure 3.5). Further improvements in yields have been achieved when banded wetting agents are applied to furrow-sown crops on repellent soils. There has been almost universal adoption of press wheels by south coast sandplain farmers, while surfactants are rarely used.



Figure 3.5. Effect of press wheels (♦) and rates of banded wetting agents (■) on barley yields (Crabtree and Henderson 1999). Dramatic increases were achieved in yields when banded wetting agents were applied, however press wheels overcome most water repellence issues.

Claying

Small amounts of particulate organic matter covering the surface of sands can cause repellence. The low surface area of sands renders them more susceptible to repellence than soils with a higher surface area such as clays. In theory, increasing the surface area of a soil by adding clay will 'dilute' and 'mask' the particulate organic matter to the extent that water infiltration is no longer retarded.

The addition of clay to repellent soils has been practised by farmers in the Netherlands since the 1940s and in South Australia since the 1960s. Clay is applied to the topsoil by spreading or by delving. Clay spreading involves exposing a clay 'pit' within a 1 km radius of where it is to be applied. Scrapers or carry graders collect and deposit the clay material. The subsoil material is either laid out in strips or as a complete

layer. The strips are spread with iron bars ('smudged') and tined implements to break down clods and evenly incorporate the clay across the paddock. The cost of applying clay ranges from \$500 to \$800/ha.

Alternatively the clay can be delved. The delving blade, which is approximately 150 mm wide and set at an angle of 45 degrees, lifts subsoil clays to the surface. Clay needs to be within 50 cm of the surface for most delving operations to be effective. Delving can bring to the surface as much as 150 t/ha of subsoil at a lower cost than spreading. Because of the cost differential, electromagnetic induction maps have been used to identify areas suitable for delving within paddocks that would otherwise have been clay spread.

Clay types differ in their ability to reduce repellence. The efficacy of clay in ameliorating repellent soils depends on specific surface area, mineralogy and dispersion. Clays that readily disperse and bind to sand grains and organic waxes as a thin coating 'mask' the hydrophobic sites. Sodium-dominated kaolinitic and illitic clays will reduce water repellence in sands



Figure 3.6. Relationship between water repellence (MED) and clay percentage for soils with differing organic carbon contents from the south coast of WA.

to a greater extent than other clay types (e.g. smectite). Sodic kaolinitic clays are ideally suited to masking water repellence given that they readily disperse, have a low width to thickness ratio and a comparatively high surface area of 40 m2/g. It is fortuitous that most of the subsoils on the south coast of WA associated with repellent sands are sodic kaolinitic clays.

Relationships between non-wetting and dispersive kaolinitic clay content invariably show an exponential decline in repellence with increasing clay content, as seen in Figure 3.6. Repellence is often negated above 3–5 per cent clay for sandplain soils on the south coast. The amount of organic carbon within the soil will also affect the amount of clay needed to be applied.

Higher levels of clay are required to ameliorate repellent soils with higher organic carbon contents (see Figure 3.7). Farmers with extensive experience in claying aim for 4–7 per cent clay. The amount of clay subsoil required to achieve this can be calculated based on the clay and water content of the applied material and depth of incorporation. For instance the amount of subsoil required to raise the clay content in the 0-10 cm layer from 0.5 to 5 per cent will be 180 t/ha for subsoils with 20 per cent clay, and 140 t/ha if 30 per cent clay.

Clay rates vary according to the depth of incorporation and to the clay content of the claying material. A simple tool (Claycalc) has been developed for calculating clay rates required to achieve 4–7 per cent clay. In southern WA and parts of South Australia various experiments have been devised to determine clay rates from 0 to 6 per cent. Most of the published experiments have shown substantial reductions in repellence and increases in biomass and crop yields where the surface clay content of the topsoil was increased beyond 3 per cent (see Table 3.2).



Figure 3.7. (A) Clay spreading at Dalyup (Steve and Dave Marshall) using a carry grader to collect and spread clay subsoil. (B) Bringing clay to the surface using a delver at Condingup.

Table 3.2	Effect of clay rates (0, 150-200 t/ha) on Water repellence (MED), Relative dry matter (%), and Relative yield (%) for sites in SA and WA.
	Figures in brackets are clay %. Data from the Border Town and Woogenellup sites are from Cann 2003 and Carter and Hetherington 1997
	respectively

	Water repelle	ence (MED)	Relative	eDM %	Relative	YLD %
Rate t/ha	0	100-150	0	100-150	0	100-150
Border town SA	3.4	1.2	100	193-226		
Woogenellup	3.7 (0.9)	0.7 (3-5)			100	127-193
Dalyup	2.5-3 (0.4)	0.2 (4)	100	155	100	185
Esperance Downs	2.5 (3.3)	0.5 (6.6)			100	85
Dalyup 2	3.2 (0.2)	1.4 (1.5)	100	108	100	123



Figure 3.8. Stunted canola roots where clay has been poorly incorporated and resulted in premature senescence.

The improvements in crop yields are principally attributed to even wetting and greater water storage within the surface soils. Other benefits from clay include increased cation exchange, pH, potassium, organic carbon and strength resulting in reduced wind erosion.

While claying has been shown to be beneficial in most cases, a number of farmers have had only minor yield increases, or yield declines following claying water repellent sands. There several reasons for this. Firstly, crop yield increases from clay addition are most likely to occur where sands are deep (> 60 cm), soils are highly repellent (MED > 2.5), cation exchange capacity (CEC) is low (< 3) and potassium is marginal or deficient (< 50 ppm). Where some or all of these conditions are not met, clay may not result in significant yield improvements. Secondly, some clay is naturally low in potassium (< 50 ppm) and has little nutrient benefit. Thirdly, subsoil compaction will occur

during the claying operation as a result of heavy equipment (axle loads > 15 t) and repeated passes during the 'smudging' and incorporation operations. Finally, crop yield reduction often occurs where high rates of clay have been applied without adequate incorporation. This has resulted in surface sealing, poor seedling emergence, stunted root growth and inadequate water infiltration. The combination of reduced water infiltration and root growth results in crops 'haying off' prematurely.

Biological degradation of waxes

Current research into using micro-organisms to break down repellent waxes has taken two paths. The first path has been to assume that wax degrading organisms are already present in the soil, but at populations limited by the inherent infertility of the medium they are growing in. The second path has been to isolate and inoculate soils with 'superior' wax degrading organisms.

Improving the fertility of the sand medium using slow release fertilisers has led to a reduction in the time required for micro-organisms to break down waxes. The application of slow release fertiliser has been shown to significantly reduce repellence in laboratory studies from severe (MED 2.6) to moderate (MED 2.2) in the absence of plants. However, in the presence of plants the initial reduction in repellence could not be sustained.

Laboratory studies selecting micro-organisms based on their ability to degrade waxes has resulted in the isolation of bacteria capable of reducing water repellence. Specific strains of actinomycetes have been found to significantly reduce the repellence from severe to low levels in laboratory experiments. However, reducing repellence by inoculating paddocks with 'superior' wax degrading organisms is limited by competition from other micro-organisms and insufficient soil moisture to maintain effective populations throughout the year.

Dilution

Water repellence is mainly confined to the organically stained topsoil. In theory mixing topsoil and subsoil sands has the potential to reduce repellence. However, mixing sand layers is rarely practices due to the unevenness of mixing and increased likelihood of wind erosion. However new systems of tillage such as spading machines can evenly mix repellent and non-repellent subsoils using low speed rotary tillage. Currently farmers are testing the spading machine as a means to incorporate high levels of clay to depths of 20–40 cm. However there may be potential to use spading alone to dilute water repellent layers.

Summary

Water-repellent sands are common throughout the wheatbelt, covering approximately 5 million ha. Repellence is caused by small quantities of particulate organic matter derived from a wide range of plants and micro-organisms.

Management systems involve reducing water tension (surfactants/wetting agents), water harvesting (furrow sowing with press wheels), masking (claying), decomposition of waxes (microorganisms) and dilution (mixing sand layers). Press wheels and furrow sowing are the most widely used methods to manage soils that are moderately repellent, but claying is the only treatment to permanently ameliorate water-repellent soils. Increasing the clay content to 4–7 per cent will ameliorate water repellence in most sandplain soils, but heavy rates of clay and poor incorporation can result in surface sealing and reduced yields.

Further Reading

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Case study 2: Wind erosion controlled by claying

John and Kerry Smeeton at Korraling, Jerdacuttup

Water repellence

Operation at a glance

Area 4917 ha

Annual rainfall 500 mm

Soil types deep sand, sand/gravel, shallow sand/clay

Livestock 2000 sheep and 150 cattle

Cropping (80 per cent of arable area) 620 ha wheat, 829 ha barley, 978 ha canola, 421 ha lupins

History

1984 Purchased original block (1900 ha).

1986 Began planting trees.

1994 Planted mass tree shelter belts and received a government grant to support the plantings.

1995 Started increasing cropping program.

2000 Received a grant for claying a small section (100 ha) of problematic deep sands.

2002 Clayed a further 100 ha.

2003 Clayed a further 50 ha.

John and Kerry Smeeton's property Korraling is located 30 km from the coast and receives strong north-westerly winds and sea breezes. They have planted masses of saltbush and trees since 1985 to combat salinity and wind erosion. Although these shelterbelts have had some positive effects, the trees have also caused problems. They can create wind tunnels, and in the drier years they can rob the pasture of moisture. In some years, lovegrass in the tree lines can also pose a fire hazard.



John and Kerry Smeeton at Korraling, Jerdacuttup

Water repellence

The Smeetons started looking into claying as a means of controlling erosion on some of the worst affected deep sand areas and in 2000 they received a grant to clay some of their very deep and unfertile sand areas. They employed a contractor to dig the clay and spread it, and they incorporated it themselves.

They have found that the clay can be incorporated dry as it doesn't blow, which means it can be spread in summer when it is easier to get contractors, and then incorporated any time before April.

Much of the Jerdacuttup area is prone to non-wetting and the clay has in areas helped to alleviate this. The Smeetons say their soils are highly variable and so the claying to date has targeted the non-wetting areas and the sandy areas prone to wind erosion.

Yields have increased in parts, in some areas by as much as 2 t/ha, but the Smeetons say the best benefit has been that wind erosion has been halted. Paddocks that were unable to carry stock over summer can now be grazed, enabling them to keep a greater number of livestock on hand throughout the year.

'So by halting the erosion problems, the paddocks have become more useful and we can put stock on them, where before they were too fragile,' Kerry said.

The Smeetons would like to do more claying and more liming of their paddocks in the next few years and they have considered purchasing their own machinery to clay whole paddocks rather than the small sections they have clayed to date. The clay is sourced from dams and their catchments and is then incorporated with a 'mung grader', which so far seems to be working.

Key lessons

- During the drier years, they have noticed that the clayed areas put under crop hay off faster.
- When it is a wet year, the plant roots don't go down as deep into the sand, and they seem to stay in the clay zone, especially if the clay is quite thick. Therefore the plant isn't strong enough to cope with the last stages of development once the soil profile starts to dry out.
- You can put too much clay in and then not incorporate it well enough. Less is sometimes better than more.

Operation at a glance

Area 2450 ha

Annual rainfall 570 mm

Soil types sand, sand over gravel, and sand over gravel over clay

Livestock 3000 mated ewes and replacements, 150 cows mated including replacements

Cropping 1100-1200 ha

History

1956 Acquired Olimarena, 800 ha virgin block at Gibson

1960s A decade of mainly livestock production with excellent annual pasture production.

1970s Cropping at Scaddan. A decade of poor wool, lamb, mutton, cereal and beef prices.

1980s Improved farm production and profitability until the collapse of wool prices. Minimum tillage became widely accepted.

1995 Began claying.

1990s A decade of greater seasonal variability, with improved yields due to addressing soil constraints and claying.

2000 onwards Recognition that south coast soils are unique and dissimilar from WA's northern sandplain region. Due to improved technology, cropping yields rose dramatically and sheep numbers dropped to less than a third of what they were in the 90s.



Nils Blumann has been farming the Esperance sandplain since 1956 when at the age of 22 he acquired 800 ha of conditional purchase leasehold land near Gibson. Once the virgin scrubland was cleared and pastured, cattle and sheep were the primary enterprises for the first two decades as cropping the sandy topsoil using traditional cultivation methods led to massive wind and water erosion. Mechanical weed control was difficult in most years, with non-wetting soils and waterlogging being other major constraints to profitable cropping.

In 1969 Nils began growing cereals on a mallee farm at Scaddan. The focus on livestock at Olimarena changed in the 1990s when wool prices collapsed and farmers had to turn to cropping. The Blumanns now run an integrated livestock and cropping operation on 2500 ha of land 20 km north of Esperance.

The farm at Scaddan had to be sold after a devastating fire in November 1993 ripped through the Gibson property causing huge losses in infrastructure, stock and machinery. After the fire there also came the loss of fertile topsoil from subsequent wind erosion.

The two big advances in cropping the sandplain that had taken place since the 1960s-when most of the Esperance Downs was cleared and developed-were the use of herbicides and minimum tillage. These two practices made cropping viable on shallow duplex soil but were ineffective on non-wetting deep sands. Nils was aware that yields per millimetre of rainfall on all soil types fell well short of their potential.

It was obvious that this was due to poor soil water relationships which in turn led to patchy seed germination and ineffective plant nutrient uptake. The practice of using a wetting agent became popular but did not appeal to the Blumanns as it was only a short-term expedient. It was a solution that would overcome the symptom but not the cause of the problem.

Claying

'When looking at the physical, chemical and biological components of any soil it became clear that to increase production we needed to improve the soil's physical aspects,' Nils says. 'By adding clay to what is an inherently infertile fossil and fragile soil we have overcome some of the physical constraints.'

There have been multiple benefits from claying which have dramatically increased productivity. Claying combined with the practice of minimum tillage has minimised the risks of wind and water erosion; overcome staggered seed germination which makes herbicides more effective; allowed a more efficient use of fertiliser; increased soil organic carbon; led to greater soil flora and fauna activity; trebled yields on deep sands; and increased cereal yields on duplex soils by over 1 t/ha.

Nils says all of this has made it possible to transform the farm from a 100 per cent livestock operation into a highly profitable integrated cropping and livestock enterprise.

Claying the deepest sands was the first step to overcoming the non-wetting problem and instantly it increased nutrient uptake. It did not take long before overall soil health was improved. The rewards from claying exceeded expectation and where shallow duplex soils were inadvertently clayed it became obvious that these soils would also benefit from claying.

Claying began in 1995 and has continued since then to now cover the entire farm.



Claying techniques

Nils warns that claying is an expensive operation and should not be undertaken lightly. 'Farmers must ask themselves why they are doing it, what the benefits are and what the downstream consequences of claying are,' he says.

There is no linear relationship between soil clay content and plant growth and production. Consequently there are many who have clayed and failed to reap the rewards. Too much clay applied to the top soil will have disastrous effects and be counterproductive. It is so easy to fall into the trap of thinking that if a relatively small amount of clay improves the soil, then more clay must be even better. But there are failures from applying too much rather than too little clay.

There is a clear message to all thinking about claying—it is vital to have the right amount of clay in the soil profile. Once having understood the principles about claying, ensure the correct amount of clay is effectively incorporated to the appropriate depth. The aim is to have between 3 and 6 per cent of clay in the topsoil irrespective of the depth of corporation.

Nearly all clay available in the south coast sandplain subsoils is kaolinite derived from granite. The clay content of material used in claying varies greatly. Some of the clay pits on Olimarena varied greatly both across as well as down the pit. From what at first glance looked to be satisfactory, the clay fraction could be as low as 10 per cent with the highest being 80 per cent. The biggest mistake leading to unprofitable amounts being applied can be due to this huge variability.

Nils warns that it is important to spread the clay material evenly over the paddock. If the material from the clay pit is not dropped on the ground evenly, 'smudging' is essential.



If a 'carry grader' is used and the clay material is moist, smudging three times is essential. (This should be done twice at 45 degrees to the parallel runs, and once around the entire paddock). Not only is the material spread evenly, but often a significant amount of incorporation with the sandy topsoil results from the smudging.

Nils says there is less need of smudging if something like a Lehmann scraper spreads the clay material. It is important that the appropriate tonnes of clay (not material per hectare) are applied to have the right percentage of clay incorporated to a target depth of topsoil.

The next important step in the claying process is to incorporate the clay. The preferred method is to use a 30-foot 50-tine scarifier with extra wide points except for the back row of tines. Instead of points, grader blades are welded to tines some 110 mm above the base of the points forward of the last row.

Working depth should be deep enough to ensure the clay is incorporated and then levelled by the grader blades with material flowing over the top of the blades. Lumps of clay will then be on the surface, which will ensure no wind erosion.

Fertilising

The next important element in claying is to apply fertiliser appropriate to the new physical and chemical characteristics of the soil. Because mixing clay with the soil leads to a higher cation exchange capacity and higher phosphorus sorption as well as a much larger soil particle surface area, there is stronger adsorption of soil nutrients to the soil particles. Yield potential will have increased dramatically through the claying process, so more nutrients need to be added to reap the rewards of higher potential yields.

'We learned very quickly after we began claying that it is important to increase a number of plant nutrients-particularly phosphorous and nitrogen,' Nils said. Consequently on deep sands, the first crop following claying is lupins. On duplex soils, canola is the first crop by choice.

There has been a substantial amount of research done on Olimarena for many decades by DAFWA with GRDC funding and Nils believes that all of his management decisions are backed up by science. The research is ongoing.



Compaction Jeremy Lemon, Senior Development Officer, DAFWA Albany



Compaction

Hard soil conditions caused by soil compaction significantly impedes the root growth of agricultural crops and pastures. On loam and clay soils, compaction causes poor structure leading to reduced water infiltration and lower moisture-holding ability. On sandy soils, subsoil compaction leads to dense hard layers which impede root growth but have little effect on infiltration and water-holding ability. On sandy soils in northern agricultural areas of WA, peak soil compaction from wheeled machinery occurs at about 30 cm depth, but on deep sands of the south coast sandplain, high soil strength can extend from 30 to 50 cm depth. Figure 4.1 shows penetrometer profiles on typical deep sand paddocks near Esperance.





Gravel soils generally don't compact from machinery but can be naturally hard with cementation of laterite or ironstone. Loose gravelly soils (more than 60–70 per cent gravel by weight) tend to support the weight of machinery on the gravel matrix, leaving the soil porosity intact with reasonable aeration and root growth. Figure 4.2 shows healthy root growth in such a soil. At gravel contents lower than about 60 per cent, the soil component (less than 2 mm particle size) bears machinery weight and can be compacted by traffic. 4

Figure 4.1. Typical soil strength profiles for deep sands near Esperance. The clayed and unclayed profiles are adjacent along a claying boundary within a paddock. The continuous crop profile is from a paddock cropped with large machinery for 14 years. Profiles were wet when measured.

Compaction



Figure 4.2. Healthy root growth in a gravel soil at 40 cm depth.

Diagnosing soil compaction

Soil strength and bulk density can be used to measure compaction, but visual observation of root growth for shape and form as well as depth can indicate the layers of compaction, especially in gravelly subsoils where physical measurement is difficult. A cone penetrometer is commonly used to measure soil strength but because strength varies with moisture content penetrometers are only reliable when the soil is near field capacity and there are no rocks in the profile. Measuring soil bulk density is a skilled procedure and the presence of rocks prevents accurate assessment.

With experience, simple tools such as hand probes made from steel rod or wire can identify compaction. Sometimes compaction pans are visible with distinct boundaries and a blocky appearance when viewed in a soil pit. Symptoms of compaction include suppressed growth because of poor nutrition and premature maturity from terminal drought as a result of poor root access to subsoil moisture. Compaction is often difficult to assess without a healthy comparison nearby. Figure 4.3 illustrates below-ground symptoms on lucerne, showing thickened roots with dense branching and twisting indicating compaction at 25 cm and below.



Figure 4.3. Lucerne roots showing the effect of a compacted soil layer. The roots grow normally to 25 cm but become thickened, intensely branched and distorted in response to a hard layer in a deep sand profile.
Causes of compaction and hardpans

Hardpans in the soil can be a natural condition. It can also be caused by packing of the soil particles and cementation or compaction induced by agricultural activities. Most often compaction is associated with agricultural machinery operations and to a lesser degree by stock trampling. Stock compaction only influences the top 10–15 cm of soil, is generally not severe, and can be easily remedied with cultivation and root growth. Wheeled machinery compacts soil to depths of 30–50 cm. Severity and depth of compaction is related to soil type, soil moisture, axle load and the size of the tyre 'footprint' related to tyre pressure.

Soils with a range of particle sizes are more prone to compaction than soils with uniform particle size, but the latter are rare. Like most sandy soils, sand on the south coast has a range of grain sizes which can pack together to form hard layers. Sandy soils with no clay will compact to greater depth than soils with some clay content, such as northern wheatbelt loamy sands. Soils compact more when they are moist. Even if the surface is dry the subsoil, which is susceptible to compaction, can remain moist during the summer period.

Tyre pressure and design

There is a lot of discussion about the influence of tyre design and pressure on soil compaction. While low tyre pressures and tracks can reduce ground pressure, an increased surface contact area means more soil is affected at each pass and peak compressive forces are transferred to greater depths. Tyre pressures should be as low as practicable but axle loading is an over-riding factor. Axle loads over 8 tonnes compact soil severely and need to be restricted to already compacted areas such as tramlines in a controlled traffic system.



Figure 4.4. Tramline farming restricts machinery compaction to permanent traffic lines.

Moderate compaction slows the rate of root growth, leading to shallower root systems at maturity and lower root density at depth. Severe compaction can prevent root growth altogether, leading to very shallow root systems.

Remediating compaction

Sandy soils do not shrink and swell through wetting and drying cycles and so do not loosen themselves through time. Mechanical and biological softening can occur. Roots only grow freely through soil when soil strength (as measured by a cone penetrometer when the soil is at field capacity) is less than about 2.0 MPa. At 2.5–3.0 MPa root growth is slowed and in soil layers stronger than these values, root growth is effectively stopped. Root observations in deep sands show that in compact conditions at depths more than 25 cm roots almost only grow through old root channels and ant holes rather than through the bulk soil matrix. It is important to retain these channels and preferential pathways for root growth (see Figure 4.5).

Ripping

Ripping or deep cultivation has long been used to soften subsoils. Ripping tines commonly work to a depth of between 30 and 45 cm. Ripping has been the subject of a lot of research over many years but gives variable results. Other soil factors, seasonal conditions and crop types interact with the effects of ripping, making results unpredictable. In a review of deep cultivation experiments in the southern agricultural area of WA, 9 out of 18 experiments showed grain yield increases in response to ripping. Positive ripping responses attributable to soil loosening have been observed in cereals and canola but not in lupins. Nil and negative results have been associated with dry springs, shallow and gravelly soils and poor seed placement in soft soil, though some remain unexplained except to say the site was not responsive. Research has found that ripping responses are unlikely if the sand depth over clay and/ or gravel is less than 30 cm.



Figure 4.5. New roots growing through old root channels in sand.

The aim of ripping or soil loosening is to allow more rapid root growth to depth allowing a greater volume of soil to be explored by roots for water and nutrients. With a larger volume of soil, there is more plant-available water capacity (PAWC) for growth and grain fill. Responses to ripping in northern areas of WA have also been associated with more rapid root growth keeping pace with the downward movement of leachable nutrients, largely nitrate. Nitrate leaching can be better managed by a split application of fertiliser so that roots are established before the main application of nitrogen. There is still a risk of nitrogen, mineralised from organic sources during autumn, leaching faster than root growth on deep soils with low water-holding capacity.

Ripping gives the best results when soil volume for root growth is increased significantly. This may be from loosening a narrow compacted layer that is restricting root access, or loosening a larger volume of soft soil at depth, or it may be from deepening the root zone in a situation where there is very restricted root depth. Increasing root depth from 30 cm to 35 cm, for example, is unlikely to sufficiently increase the volume of soil explored by the roots to give a significant response. Figure 4.6 illustrates the distribution of compacted layers in profiles that influence the likely responses to ripping.



Figure 4.6. Likely response to ripping soils with various compacted layers. The coloured section of profile indicates the layer of compaction. Profile A is likely to respond to deep cultivation as the hard layer is removed allowing roots to explore soft subsoil to depth. Profile B is likely to respond as the volume of soft soil is significantly increased. Profiles C and D are unlikely to respond as there will only be a small increase in volume of soft soil for C while D does not have a restricting layer.

Limitations of ripping

Following ripping, a leafy canopy develops from increased root growth. This results in greater water use early in the season, which may result in there being insufficient water to support grain filling in a dry spring. Under these conditions ripping gives no grain yield response, only a vegetative response or even a negative response.

Ripping is an expensive operation—up to \$80/ha depending on the depth of ripping and machinery costs. Given unreliable and seasonally dependent results, it is difficult to value the economic return.

Other constraints to root growth may prevent a response to ripping. Soils with acid subsoils restricting root growth will often not respond to deep ripping. On many deep sands in WA, including the south coast, compaction and subsoil acidity occur together.

Biological remediation of compacted sands may be possible using perennial plants with robust root systems. There has been some research to investigate this but results are inconclusive. While annual plants have only 4–6 months to develop a root system, perennials, including lucerne and trees, have several seasons to penetrate hard subsoils and open new root channels. Rapid root growth of perennials generally occurs in previous root channels, largely from bush that has been cleared. Even blue gum plantings on deep sands rely on fresh ripping to 50 cm or more to ensure rapid tree growth. At the end of the plantation phase, new and enlarged root channels may provide improved root access for annual crop and pasture species.

Tramline farming to prevent compaction

Since heavy machinery is the main cause of severe subsoil compaction, restricting machinery movement on paddocks is the best way to prevent compaction or re-compaction after ripping. Residual effectiveness of ripping diminishes over two to three seasons and is largely attributed to further machinery movement and natural hardening processes, such as packing and cementation. Tramline or controlled traffic farming allows machinery access to paddocks for timely operations but restricts wheel and track compaction to defined tramlines. In addition to reduced compaction of the crop root zone, benefits of greater tractive efficiency and reduced fuel use result from wheels running on compacted tramlines.

Further reading

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West of Law diseases in

Stephen Davies, Chris Gazey, Paul Galloway (DAFWA)

5

Deep sand, sandy gravel and sandy duplex soils make up 66 and 75 per cent of Albany and Esperance sandplain, respectively. DAFWA analyses of south coast soil-landscape data estimates that 607 000 ha of farmland in Esperance sandplain (88%), and 365 000 ha of farmland in Albany sandplain (63%) is either currently acidic or at imminent risk of subsurface acidification.



Overall 2.64 million ha or 65 per cent of the agricultural area of the south coast is considered to be acidic or at high risk of developing subsurface acidity with a further 8 per cent at moderate risk if left untreated.

Current status of the pH of south coast sandplain soils was reviewed at 2340 sites across the south coast, including about 650 sites from Esperance sandplain and 800 sites from the Albany sandplain. The results are alarming, with half of the Albany sandplain samples having pH less than 4.5, throughout the topsoil, midsoil and subsoil (Figure 5.1). Only between 2–3 per cent of Albany sandplain soils were considered to have 'good' pH (5.5 or above in the topsoil and 4.8 in the subsurface), requiring maintenance liming only.

Esperance sandplain fared slightly better, with one quarter of soils having pH less than 4.5 throughout the topsoil, midsoil and subsoil, and about 15 per cent were considered to have 'good' pH throughout the profile, requiring maintenance liming only.

Causes of acidification

Soil acidification is an inevitable consequence of productive agriculture. Agricultural soils acidify because of:

- inefficient use of nitrogen
 – when nitrate not taken up
 by plant roots leaches away from the root zone, excess
 hydrogen ions remain.
- product removal–all agricultural produce, including grain, hay and livestock, is slightly alkaline and its removal from the farm or redistribution on the farm results in a net removal of alkalinity.

These processes result in an increase in the concentration of hydrogen ions in the soil, measured as a decline in the soil pH. Soils vary in their capacity to resist change in pH—this is known as their buffering capacity. Sands have low buffering capacity, and therefore a low capacity to resist the pH change. However, while this makes them susceptible to acidification, these sands also require lower amounts of lime to neutralise the acidity and increase the soil pH.



Figure 5.1 Soil pH ranges of sites at three depths for Esperance and Albany sandplain, and whole south coast. Soils are generally acidic in the topsoil and deeper soil layers, with yellow to red colours indicating a pH level detrimental to yield potential.

Implications of acidification

Acidity (low soil pH) increases aluminium (Al) soil to levels potentially toxic to crop root growth. The consequences of reduced root growth and water use can include:

- increased groundwater recharge
- reduced crop and pasture biomass and crop grain yield
- fewer crop and pasture options as acid-sensitive species cannot be grown.

Acidification is an ongoing process. If left unchecked it will worsen and threaten the long-term sustainability of the farming system. Crop and pasture species sensitive to acidity cannot be grown in strongly acid soils and productivity will continue to decline. Acidity also has an impact on soil health, reducing the availability of some plant nutrients and soil microbial activity.

Subsurface acidity is a bigger problem than topsoil acidity. It requires deeper subsurface and subsoil sampling to identify and takes much longer to correct. Subsurface acidity commonly occurs between 10 and 40 cm. Topsoils are often less acidic because some alkalinity in the stubble and straw is returned to the topsoil even though some is removed in the grain. Surface applied lime quite rapidly corrects and maintains the pH of the topsoil. Consequently subsurface acidity cannot be identified by measuring the pH of a 0–10 cm soil sample– deeper soil testing is required.

Sample depth	Soil texture	Soil pH (CaCl ₂)	State and the
0–10 cm	Sand	5.3	2ª 41
10–20 cm	Sand	4.1	60
20–30 cm	Sand	4.1	80
30–40 cm	Sand	4.2	100

Figure 5.2. Subsurface and subsoil acidity in a pale deep sand near Gibson, Esperance Shire, WA.



Figure 5.3. Relationship between soil pH and extractable aluminium levels for four depth intervals for a pale deep sand near Gibson, Esperance Shire, WA.

Examples of acidification in Esperance sandplain soils

Acidification can affect the topsoil (0–10 cm), subsurface (10–20 cm) and the subsoil (> 20 cm) of pale deep sands (see Figures 5.2 and 5.3) and sandy layers above the clay subsoil of the sandy duplex soils (Figure 5.4) in the Esperance sandplain.

Sample depth	Soil texture	Soil pH (CaCl ₂)	
0–10 cm	Fine loamy sand	4.2	10
10–20 cm	Fine sand	4.3	
20–30 cm	Fine sand	4.7	
50 cm+	Fine sandy clay	Not measured	

Figure 5.4. Acidity in the sandy soil above the clay subsoil of a grey deep sandy duplex soil near Munglinup, Ravensthorpe Shire, WA.

Management of acidification - soil testing

Subsurface acidity in sandy soils cannot be identified by measuring the pH of a 0–10 cm soil sample. Deeper soil testing is required.

1. Laboratory measurement

1) Sample 0–10, 10–20 and 20–30 cm depths for subsurface acidity. Sampling should take into account the variability of paddock soil type. Care must be taken to avoid contamination of subsurface soil samples with soil from the layers above.

2) Send your samples to an accredited lab. The standard and best practice for Western Australia is to measure soil pH in 0.01M CaCl₂ (pH_{Ca}). Soil pH can also be measured in a 1:5 soil:water solution (pH_w). This will give a higher reading than a soil pH measured in CaCl₂. Soil pH_{water} can be converted to an approximate equivalent pH_{Ca} by subtracting approximately 0.8 from the measurement.

Lists of accredited labs are available from the Australasian Soil and Plant Analysis Council Inc. www.aspac-australasia.com or the National Association of Testing Authorities www.nata.asn.au.

3) A laboratory measure of extractable aluminium can help you determine whether your soil has toxic levels of aluminium. Extractable aluminium levels greater than 4 mg/kg are toxic to most agricultural crops. (Note: aluminium measurement in topsoil 0–10 cm can be unreliable due to the influence of organic matter reducing the toxicity effect of aluminium on root growth). See Table 5.1.

Table 5.1 Toxicity ratings for a range of extractable aluminium levels and sensitivity of the major agricultural crops

Extractable aluminium	Toxicity rating	Crop species affected
< 2 mg/kg	Non toxic	N/A
2–4 mg/kg	Moderately toxic	Sensitive crops affected: barley, canola and the pulse crops
> 4 mg/kg	Highly toxic	Sensitive crops and wheat affected
>> 4mg/kg?	Very highly toxic	Highly tolerant crops (triticale, lupins and acid tolerant pasture species) affected

4) Use the following guide (Table 5.2) to determine your general pH rating (adapted from Van Gool et al. 2005)

	Soil pH rating						
	Very strongly acid	Strongly acid	Acid	Slightly acid	Neutral	Alkaline	Strongly alkaline
рН _{са}	< 4.2	4.2–4.5	4.5–5.0	5.0-5.5	5.5–7.0	7.0–8.0	> 8.0
pH	< 5.3	5.3–5.6	5.6–6.0	6.0–6.5	6.5–8.0	8.0–9.0	>9.0

Table 5.2 Soil pH ratings for determining level of acidity or alkalinity. Source: Van Gool et al. 2005

2. Field measurement

Several methods are available to test the pH of soil samples in the field. These are less accurate than laboratory testing but are cheaper and can give an indication of where further laboratory testing may be required.

- Colour pH indicator test kit—mix up a soil paste as per instructions and use universal pH indicator to obtain a colour reaction. This gives an indication of the pH accurate to 0.5 of a pH unit. If a soil pH of 4.5 or 5.0 or below is recorded, further laboratory testing may be necessary.
- Hand-held electronic pH meter—a Hanna Instruments Model HI 98130 Combo pH, Electrical Conductivity and Total Dissolved Salts is an example of a robust waterproof meter.
- Soil pH test strips—strips are dipped into a 1:5 soil water solution colour develops depending on pH of solution, and this is compared to a colour chart. This is quick and easy to use and accurate to 0.5 of a pH unit. If a soil pH of 5.0 or below is recorded further laboratory testing may be necessary.



Figure 5.5. Average increase in soil pH at two soil depths over time in response to lime applied at 1 or 2 t/ha. Data are based on the average pH response for 88 Department of Agriculture and Food field trials conducted in the WA wheatbelt.



Preventing soil acidification and maintaining soil pH

Aim is to keep the surface soil pH > 5.5 as this will also prevent acidification of the subsurface soil. Paddocks should be resampled approximately every three years to monitor change in pH and refinements to the liming schedule.

Nitrate leaching can be minimised through careful N management such as splitting N applications. Be aware of the effects of product removal on acidification rate and replace exported alkalinity. Burning windrows or use of chaff carts can concentrate alkalinity in a specific location and increase the rate of acidification of the soil where the hay and straw have been removed.

Correcting acidic soils with lime

Correction or prevention of soil acidification using lime is a proven way of maintaining high crop and pasture production.

If your soil is already acidic, with a topsoil pH < 5.0 or subsoil pH < 4.5, sufficient lime needs to be applied to increase the surface soil pH to 5.5 or more (see rule-of-thumb liming guide in Table 5.3). Surface-applied lime can take 3–5 years to significantly increase pH below 10 cm (Figure 5.5). Any incorporation of lime can assist downward movement and amelioration of soil acidity deeper in the profile. Use acid tolerant crops and pastures until the subsoil pH is corrected.

Rule-of-thumb liming guide

Rates of lime application are best determined in consultation with an adviser/agronomist or may be provided by a lime supplier and based on soil pH test results. Apply lime and soil test again in 3–5 years. Remember that liming is part of an ongoing farm practice and it is better to lime to maintain soil pH rather than try to ameliorate soil that has acidified.

Table 5.3 Approximate amounts of lime required to correct and prevent soil acidity depending on the starting soil pH at various depths in the soil profile. Actual amounts required will vary depending on soil type, rainfall and farming practice

Soil depth	pH (CaCl ₂)	Lime amount over 5 years*
0–10 cm	< 5	2 t/ha
	<5.5	1 t/ha
		plus
10–20 cm	< 4.5	2 t/ha
	< 4.8	1 t/ha
		plus
20–30 cm	< 4.5	1 t/ha
	< 4.8	measure pH in 3 years

* These rates represent an increase above the old 'one tonne every 10 years' because the majority of soils, particularly subsurface soils, have become more acidic over the past decade. Rates are for high quality agricultural lime.

Lime quality

Neutralising value (NV), as a percentage of pure calcium carbonate (100%), and particle size distribution are the key indicators of agricultural lime quality, regardless of the source of the lime. Lime with a high neutralising value will neutralise more of the acid in the soil. Limes with a high proportion of fine particles will react more quickly to neutralise the acid in the soil, which is beneficial when liming to recover acidic soil.

Because agricultural limes vary in quality, it is important to calculate the cost per tonne of NV landed and spread on the farm.

The easy-to-use calculator at http://www.soilquality.org.au/ calculator/lime_comparison is ideal for determining the most cost-effective lime for any situation. Product information sheets detailing independent test results of lime quality are available online at www.limewa.com.au or directly from suppliers who belong to the voluntary WA lime industry association, Lime WA Incorporated.



Benefits of liming

Correction or prevention of soil acidification using lime is a proven way of maintaining high crop and pasture production. DAFWA lime trials on acid soils (mostly sandplain soils) show that, on average, responses of acid sensitive crops to lime are significant. As indicated in Table 5.4, the sensitivity of crops to soil acidity varies. This difference in sensitivity affects both the timing and magnitude of a specific crop species response to liming as summarised in Table 5.5.

Table 5.4 Average crop grain yield responses to surface lime applications shown as the % yield change compared to unlimed plots with time. The number of trials included in each average is shown in parentheses

Crop	Lime rate (t/ha)	Years after lime application			
		0	1–4	5+	
Wheat	1.0–1.5	1 (16)	8 (34)	6 (11)	
Wheat	2.0–2.5	2 (19)	13 (35)	12 (18)	
Canola	1.0–3.0	21 (3)	15 (18)	12 (7)	
Barley	1.0–3.2	-4 (1)	7 (18)	47 (5)	

Table 5.5 Summary of the sensitivity to soil acidity and time to and magnitude of the maximum response to a surface application of 2 t/ lime/ha for the common broadacre agricultural crops grown on acid sandplain soils in Western Australia

Crop species	Sensitivity to soil acidity and aluminium toxicity	Time to maximum response to an application of 2 t lime/ha	Approximate magnitude of maximum grain yield response to 2 t lime/ha
Wheat	Moderately sensitive	3–4 years	10–15%
Barley	Highly sensitive, particularly to subsoil acidity	5 or more years	> 20%
Canola	Highly sensitive, particularly to topsoil acidity	0–2 years	10–20%
Lupins	Nil to very low sensitivity	Unresponsive	Negative responses (2– 10% decline) possible in first few years after liming*

¹ Negative responses in lupins have been shown to be caused by induced manganese deficiency causing split seed. This can be overcome with application of fertilisers containing manganese applied to the soil or as foliar applications (See Department of Agriculture and Food, Western Australia Farmnotes 214; 45/2002; 70/1993; 71/1993).

The differing response levels and timings of response shown in Table 5.6 have important implications for determining crop rotations when correcting an acid soil. Rotations can be ordered to maximise benefits and more rapidly cover the cost of liming while minimising the possibility of negative impacts.

Table 5.6 Preferred crop options for sowing after liming to correct subsurface acidity

Time after liming	Preferred crop options
0–2 years	Wheat (particularly acid tolerant varieties), triticale, canola and lupins
3–4 years	Wheat, lupins and canola
5+ years	Wheat, barley, lupins and canola

Acid tolerant wheat varieties and canola are good options in the first few years after liming. Canola yield response to liming can occur quickly and be quite large (10–20%), which can help offset the cost of liming. While lupins are tolerant of acidity it is necessary to ensure that micronutrient deficiencies (in particular manganese) which may be induced by liming, are not limiting. Where subsurface acidity is a problem, barley is best avoided until five or more years after liming, when there has been some movement of lime to increase the subsoil pH. Large yield gains are then more likely.

Further reading

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Operation at a glance

Area 4800 arable hectares across 6 blocks Annual rainfall 375 – 450 mm Soil types shallow sand over gravel over clay soils Livestock 3500 ewes mated

History

1985 Baum family settled in Wellstead.

1993 Began liming paddocks.

2002 Began using precision-farming methods of management.

Darren Baum, his father and brother moved to the Wellstead area from the lower north of South Australia in 1985. They brought their experience of intensive cropping from SA to the largely grazing area. Darren has always practised no-till cropping, being involved with WA No Till Farming Association (WANTFA) from its early years.

Darren now farms with his wife Nola across six blocks, some owned and some leased. They crop about 4000 ha in a canola–wheat–canola–barley rotation with a year of sown Cadiz serradella between each four year sequence. Lupins have been grown in the past as a legume break year but have not been grown recently as yields have been unreliable. Darren is now trying lupins again as newer varieties are showing promising results.

He uses a DBS seeder with 30 cm tine spacing for all sowing operations, including 1000 ha of sown Cadiz each season. Darren considers that continuous cropping is not sustainable in his environment and a pasture phase provides many benefits to his system for a variety of reasons.



'The Cadiz year is good for weed control,' he says. 'It allows another year of grass weed control combined with other techniques such as spraytopping and sheep grazing as well as being a competitive pasture.' Darren sees the residual benefit of legume nitrogen from Cadiz for at least two seasons.

Weed control is an important part of the management operation. Brome grass has been reduced to very low levels through selective herbicides in the non-cereal phases. Summer weed control is also a priority to conserve soil moisture for sowing and retain any nitrogen mineralised over summer. Consistent summer weed control over several seasons means that weeds like fleabane are not a serious issue, even in the 2008–09 summer. Sheep improve the control of summer weeds by follow-up grazing.

Darren aims to achieve optimum productivity through increasing topsoil pH to 5.3, managing plant nutrition and maintaining groundcover at all times. Weaker areas of the farm were clayed about six years ago to improve plant growth and groundcover to reduce wind erosion risk. Areas that once were non-wetting with poor groundcover now have solid cover, much the same as the rest of the paddock.

Soil testing has been an integral part of his operation, alerting him to topsoil pH values as low as 4.3 in the early years. Such low pH was a great concern, so he has been liming since 1993. To date, all paddocks on the initial property have been limed twice at 1 t/ha and this year he is starting on the third application, aiming to raise pH to 5.5 in time.

Darren observes that, 'Applying lime in a canola year really seems to help the crop. I'm not sure if it's the pH or calcium, but it boosts the crop.' He has used a variety of lime sources from south coast pits and even Lancelin lime as back loads from Perth. Transport cost is a big consideration for the lime program so effective neutralising value and transport distance are considered carefully.

1992 was a very wet season after which Darren constructed a series of surface drains to control flooding. The drainage together with liming and serradella phase pasture has increased the productivity and sustainability of Darren's farming system.

Darren has been using guidance and matching machinery widths since 2002 but currently the header does not match the seeder. The shallow sand over gravel soils do not show any signs of compaction, so the main benefit of matching machinery widths is accuracy of operations and restricting in-crop wheeling to tramlines. Lime is spread by a contractor using GPS autosteering to ensure even application across the paddock. At this stage, while pH is still being lifted across the whole operation, a blanket rate of lime is used across all paddocks.



Operation at a glance

Area 3200ha

Annual rainfall 500mm

Soil types sand, sand/gravel, sand/gravel/clay

Livestock cattle-500 trade steers

Cropping 3000 ha of canola, wheat, barley, hay and triticale

History

1992 Purchased the family partnership.

1993-94 Started liming trials. Lime was difficult to purchase.

1994 Compaction was observed in some areas.

1998 Purchased second property and expanded the cropping program.

1999 Purchased an agro plough and started an extensive deep-ripping program.

2004 David awarded a Nuffield Scholarship.

David and Sally Cox have made great inroads with their cropping program in the past decade, with yields dramatically increased as a result of dedicated liming and deep ripping management techniques. David was awarded a 2004 Nuffield Scholarship to study the production and management of high yielding crops. Their Neridup property is situated on the sandplain and receives 'anywhere between 300 mm and 700 mm' annually. Soil types are typical of the region, mostly varying depths of sand over gravel and clay. The Cox family was originally located in Capel in the southwest, where part of the family still runs a dairy operation. In the early 1990s David moved to Esperance, originally to buy cheaper land to fatten weaned steers from the dairy operation and to grow grain and hay to send back to provide supplementary feed for the dairy.

Grain prices started to increase soon after David arrived in the area and he quickly developed an interest in the grain industry. His management techniques started to focus on trying to increase grain yields. It became obvious early on that acidification could only increase with intensive cropping, which would limit his yields. The availability of lime was a problem for several years and only small amounts could be purchased due to the expense associated with carting it 800 km from Perth. However, enough lime was purchased in 1993 to lime the occasional paddock. At that time also, DAFWA developed and monitored lime trials.



Dave started having severe traffic problems and an agro plough was purchased to deep rip some of the more badly affected paddocks. Controlled traffic farming was implemented to minimise compaction. The focus was on improving the chemical structure of the soil through liming and increasing plant growth through deep ripping, which enables roots to penetrate deeper in the soil profile. Controlled traffic maintains the effectiveness of these two programs for as long as possible.

Over the next four years the Coxes limed 4000 ha at a rate of 1 t/ha. In those years, the crop's nutrient requirements changed and potash and sulfate inputs were increased in line with the higher yields being achieved.

Deep ripping

Only certain soil types are deep ripped, as a hardpan is only found on those soils that have a depth greater than 500 mm over gravel and/or clay. The very deep sands show the highest response to ripping.

'Basically we went from sandhills which more or less harvested nothing, to achieving quite respectable yields,' David said.

Ripping is done post-seeding, pre-emergent and after the pasture phase in canola. The process of ripping is very time dependent. 'We wait four days for the seed to become wet and germinate, and then we rip the paddock to 300 mm using controlled traffic. We have 600 mm tine spacings and target to get under the hardpan, which is 100 mm down and 75 mm thick. The root development after ripping is amazing. The responses vary in different years from 800 kg of canola in a year where waterlogging is an issue, to dry years where there is not as much of a response.'

The drawbacks with ripping are all in the timing. It has to be done within 4 to 6 days after seeding, which leaves only a small window of opportunity. Each year, the most potentially responsive areas are identified for ripping.

DAFWA trials on the property have found that barley yields increased by up to a 1 t/ha as a result of deep ripping. David estimated ripping costs (in 1998) at around \$25/ha for diesel, point wear and labour.

Liming

Liming goes hand in hand with improving the subsoil. It allows the roots to go deeper and limits the formation of a chemical and physical hardpan in the subsoil. If the pH is more favourable, then the plants will more readily penetrate the subsoil, which then stops the hardpan from forming.

In 2002 David imported a 12 tonne Bredal Multi Spreader to spread the lime. The entire property was limed over four years at a rate of 1 t/ha. Most of the liming happened in earnest from 2002, after the purchase of the spreader and the opening of a lime pit in the Esperance area made lime cheaper and more readily accessible.

David estimates that around 2 t/ha of lime is needed on his soils and he is targeting around 1 t/ha to be spread every 10 years to maintain soil health on the property and to offset the acidifying nature of his ongoing intensive cropping program.

The cost of liming in 2008 was \$10/ha for freight, \$10/t for lime and \$10/ha to spread.

Lime trials to date have not shown a direct yield increase, but David believes that by setting a good pH in the subsoils he can maintain optimum production through good soil and plant health.

Dr Craig Russell, DAFWA Albany

The composition and behaviour of soil organic matter (SOM) has been an active field of international agricultural research for more than 50 years, and its importance to crop productivity and soil condition was common knowledge well before this. With the increase of cropping, a major threat to the productivity and sustainability of our agro-ecosystems is the decline in fertility attributed to diminishing amounts of SOM. Maintaining or increasing SOM is good farming practice.



SOM is a complex mixture of materials that play a critical role in a variety of soil processes that have a major impact on soil health. SOM binds soil particles together, thereby enhancing soil structure, water infiltration, water-holding capacity and resilience to erosion. SOM is also a store of nutrients, with over 90 per cent of the soil nitrogen in organic forms. The biological breakdown of SOM is an important source of mineral nitrogen for crops and pastures. SOM is also the primary energy source that supports biological functions in the soil that impact on productivity. In a sandy soil the relative contribution of the organic fraction to cation exchange and moisture retention is higher than loams because of the low clay content. In soils with more than 5 per cent clay the organic fraction can improve soil stability by reducing slaking and dispersion through binding particles together into aggregates. Bacterial excretions, root exudates, fungal hyphae and plant roots all contribute to better soil structure.

Of the fresh organic material returned to the soil, anywhere between 50 and 85 per cent is lost to the atmosphere as carbon dioxide in the first year. Knowing the decay rates of plant and animal residues, soil biota, and other organic carbon pools is necessary to understanding the cycling and availability of nutrients such as carbon, nitrogen, sulfur and phosphorus, all of which contribute to plant requirements.

Soil carbon materials

Definitions and terms used to describe the carbon fractions of soils can be confusing as they are not always consistent. Some commonly used terms are explained below.

There are three basic forms of carbon in a soil: elemental carbon, inorganic carbon and organic carbon.

Elemental carbon is of little importance in most soils, and is in the form of charcoal or graphite—the combustion products of organic materials.

Inorganic carbon refers to carbonate and bicarbonate minerals derived from either soil parent minerals, or amendments of lime. Calcite (CaCO₃) and dolomite (CaMg(CO₃)₂) are the two most common carbonate minerals found in soils, and are frequently added to ameliorate soil acidity.

Organic carbon is derived from plant and animal materials. It is both capable of decay and the product of decay. Organic compounds have a fundamental molecular structure that is a combination of carbon, oxygen, and hydrogen. These compounds will combine with other elements, especially nitrogen, phosphorus and sulfur.

It is important to note that the terms total organic carbon, soil organic carbon and organic carbon are interchangeable. Microbial biomass carbon and labile carbon, although they are organic carbon materials, are a small fraction of the larger organic carbon pool.

Total carbon is the sum of elemental, inorganic and organic carbon. It differs from organic carbon, which refers specifically to the organic carbon fraction. In sandy soils the analysis of total carbon can be very similar to organic carbon, due to only minor contributions from elemental and inorganic carbon forms.

Soil organic matter and soil organic carbon

A more comprehensive description of SOM is that it consists of the partially decayed plant residues that are no longer recognisable as plant material, thereby excluding the highly visible organic residues. This includes the micro-organisms, the small fauna involved in decomposition and the by-products of decomposition. These products undergo a process called humification which forms humus—a dark substance that has a higher carbon and lower oxygen content than most animal and plant residues. Humus is approximately 50–55 per cent carbon, 4.5 per cent nitrogen, and 1 per cent sulfur, with varying amounts of phosphorus and nutrient metals. This composition applies to soil humus worldwide, with the ratio of carbon to nitrogen being constant at about 12:1.

The standard commercial measures of SOM involve the analysis of carbon, which is expressed as a percentage of a soil's dry weight. When results are presented and interpreted, care should be taken to note whether organic matter or organic carbon levels are indicated. SOM is approximated from a measure of soil organic carbon (SOC), a measure that most analytical laboratories include in their soil test reports.

Organic matter (%) = organic carbon (%) \times 1.72

The factor of 1.72 is based on the assumption that the organic matter in the soil has a constant carbon composition of about 58 per cent.

SOC exists in several distinct chemical and physical fractions, four of which are currently areas of active investigation.

- **Coarse residues** are organic carbon materials larger than 2 mm, on or in the soil (rarely measured except for detailed research investigations).
- **Particulate organic carbon** consists of individual pieces of organic material smaller than 2 mm but larger than 0.053 mm.
- Humus is decomposed materials less than 0.053 mm that adhere to soil minerals.
- Recalcitrant organic carbon consists mainly of charcoal.

As the coarse residues and particulate organic carbon are readily decomposed, and the recalcitrant carbon accumulates very slowly, the best way to enhance and maintain soil organic carbon over the long term is to increase humus.

Soil sampling to estimate soil organic carbon

The key to any successful sampling is adequate representation of the management unit being measured. Consistent depth of sampling is important, especially as reduced tillage practices and extended pasture phases promote a significant layering of organic carbon in the soil surface, as opposed to the more uniform distribution in the 0–10 cm layer that results from tillage.

Commercial testing is typically performed on a soil samples fine fraction (i.e. those particles < 2 mm in diameter). When comparing soil analyses across sites, the laboratory concentration value must be adjusted for differences in density and stones.

Although SOC is concentrated in the surface soil, its concentration can be highly variable across short distances, making it expensive to quantify at the paddock scale (see Figure 6.1). As SOC changes slowly, yet with distinct seasonal fluctuations, it may require several years or even decades to quantify the effects of management treatments. With much current research focused on quantifying a labile organic matter pool, such as the particulate organic carbon fraction, this more dynamic carbon pool might be useful as an early indicator of future changes in SOC in response to changes in management.

Dynamics of soil organic carbon

SOC levels are dynamic and heavily influenced by climate, land use, vegetation, productivity, soil type, and stubble management. The quantity of SOC at any given time depends on the balance between carbon inputs and the rate of decomposition. Carbon inputs are determined by the type and amount of plant residues added to the soil. Factors influencing this include climate, fertility, vegetation type and residue management.



Figure 6.1. Temporal trend in SOC from just after clearing to the end of a seven year phase of clover dominant pasture, with a comparison of the same system converted to continuous cropping at four different times throughout the pasture phase. (Data adapted from Rowlands 1986 who measured total soil nitrogen levels. SOM has been inferred from these data using a C:N ratio of 12.) Each year of pasture gave a SOC% increase of about 0.05%, therefore requiring 20 years to raise the SOC by 1%.

Decomposition rates are largely driven by temperature and moisture. The highest accumulations of organic carbon are found in cold climates and in swamps and marshes where decomposition is inhibited by a lack of oxygen. Silt and clay in the soil generally decrease decomposition rates of humus, thereby increasing SOC levels.

There is a definite limit to the amount of carbon that a soil can accumulate. While management affects how close a soil comes to its potential, the potential is little influenced by management and varies among soils within a climate zone according to their clay and gravel contents, soil depth and bulk density. Due to the enhanced fertility, surface area and physical protection of organic matter in clay soils, the carbon storage potential is much greater for a clay soil than a sandy soil.

SOC will generally increase under any practice that enhances productivity and returns plant residue to the soil, and this increase will be most pronounced the lower the SOC level compared to its potential maximum. Conversely, SOC can be lost under intensive cropping systems due to the removal of a large portion of biomass as grain. These increases and losses have been observed to occur rapidly in Western Australian sandy soils (see Figure 6.2), due to their very low initial carbon levels. They are also predicted from our current understanding of SOC dynamics as described in the Rothamsted carbon model, a tool that has been successfully used to model soil carbon fractions and total SOC dynamics in Australian soils.

The simulation presented in Figure 6.3 shows that management practices such as claying and enhanced residue retention produce very little increase in SOC in 10–50 years compared with significant increases in SOC over the same period resulting from enhancing productivity to the yield potential of the region. The increase is most pronounced where the SOC is low, such that a SOC at 0.35 per cent will be doubled in 10 years, while SOC starting at 1 and 2 per cent will only increase by 25 and 5 per cent respectively, over the same period.

Options for south coast sandplain farmers

There is a wide range of SOC concentration in surface soils across the grain-growing region of WA's south coast, with 0.2 to 4.0 per cent recorded across the Fitzgerald River catchment alone. Many sandy surfaced soils have less than 1 per cent SOC and should be responsive to changes in land management such as claying, full stubble retention and increased productivity, through either amelioration of soil constraints or growing perennial pastures.



Figure 6.2. Within paddock variability of SOC. Results from a grid sampling of 65 sites within a paddock near Esperance (data courtesy of D. Hall, DAFWA). Each sample is the analysis of SOC in the 0–10 cm layer. The size of the bubbles is relative to the determination of SOC%, the range being 0.79 to 1.89. Statistical analysis of this data estimates that 42 samples are required to estimate SOC across this paddock within 5% of the true value (i.e. population mean) 95% of the time. These data have not been corrected for gravel or soil density.



Figure 6.3. Modelled response of soil organic carbon to management actions on a typical sandy south coast soil.

It is widely believed that tillage reduces SOC, and that soil carbon can be increased with minimum tillage. However, several studies now conclude that this is not the case, and while tillage may promote organic matter decomposition in the short term (days to weeks), in the long term there is no difference in SOC between the two systems. While there are other good reasons to implement conservation tillage, evidence that it promotes carbon sequestration is not strong.

While some cropping practices reduce SOC, appropriate changes to land management may reverse this trend and allow some soils to store carbon. Although it is well known that SOC accumulation is limited by climatic and soil (physical and chemical) factors, and that some management practices are better than others, there is insufficient information on how much organic carbon Western Australian soils can accumulate. Practices that increase plant biomass productivity and retain residues will increase SOC. While this will help to improve soil condition, reduce wind erosion and retain soil moisture, excessive retention of residues can pose problems for weed, disease and insect pest control.

Soil organic carbon as a commodity?

Current interest in climate change believed to be due to greenhouse gas emissions has led to debate on mitigation, including the potential role of soils to sequester carbon.

Soil carbon could potentially provide a low-cost abatement option to manage emissions, with many agricultural soils possibly having the capacity to build soil carbon. A number of issues require resolution for soil carbon to be considered a viable commodity in a formal emissions trading scheme, including:

- a lack of reliable and comparable data on the capacity of south coast farming systems to sequester carbon
- the stability of soil carbon pools under different farming systems
- the ability to cost effectively verify and audit changes in soil carbon.

Regardless of carbon trading issues, good farming practices that increase productivity will produce financial rewards and should increase soil carbon levels.

The management of soil organic carbon has additional benefits in the chemical, physical and biological functioning of soils. It is an important component of the resilience of soil in resisting stress and is involved in a number of important ecosystem services. Management which increases soil organic carbon such as perennial and improved annual pastures, residue retention, grazing management, green manure, enhanced productivity through optimal fertilisation and amelioration of soil constraints—should be promoted within the context of profitable and viable farming systems.

Further reading

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Baldock, JA (2007) Soil Organic Matter, Soil Health and Soil Resilience.

Soil Quality Interactive Web Site—http://www.soilquality.org.au

Summers, R, and Rivers, M (2002) Soil testing: a guide to fertiliser use. Farmnote 69/2002. Western Australian Department of Agriculture.

Operation at a glance

Area 14000 ha

Annual rainfall 550 mm

Soil types traditional sandplain (40%), shallow duplex (40%), non-cropping—deep sand or heavy clay (20%)

Livestock 1400 breeding cattle, steers and heifers; 25 000 ewes and weaner sheep

Cropping 6100 ha (around half of the arable land)

History

1969 Andrew's father Richard took up a Conditional Purchase block at Condingup and formed the family company which now includes brothers Andrew, Simon and Tim.

1995 Dramatically increased the size of the cropping program and began continuous cropping using no-till method.

2000 Soil tests showed a decline in soil organic carbon levels.

2004 Planted 130 ha of Winterstar ryegrass.

2008 Began silage production.

Incorporating a ryegrass phase into their cropping program has been useful in increasing the organic carbon content of the Fowler family's soils. They now plant around 500 ha annually of a tetraploid Italian annual ryegrass which stays in production for between two and five years before the paddock is returned to a cropping phase with canola the first rotation.





In the early 2000s Andrew Fowler says it was becoming evident that a continuous cropping program was depleting the sandy soils on his Condingup property. The organic carbon content was dropping and the soils were becoming more prone to waterlogging. Profitability was falling and higher inputs of fertiliser were consequently required, which was increasing the financial risks associated with crop overheads.

The first ryegrass planting was in 2004, following a wet year in 2003 which had resulted in instances of poor crops and water erosion on the sloping country. Andrew's aim was to grow good feed and stabilise the soil. And In what was a relatively dry year, the Fowlers found that the 130 ha of ryegrass remained green until the end of December.

Soil tests on that original paddock showed that the organic carbon content after its ryegrass phase had increased from 2 per cent to over 3 per cent. A canola crop in the following year yielded 2.6 t/ha—when cropped previously that same paddock had only yielded around 800 kg/ha.

"We found that by increasing the organic carbon content, structure was added to the soil and there was then more ability for it to retain nitrogen which became bound in the organic mat," Andrew said. "This also allowed the soil to hold more oxygen."



Tips for planting ryegrass

Time of sowing: usually scheduled around the seasonal cropping program.

Sowing rate: 20 kg/ha of Winterstar if seed is purchased, or 30 kg/ha if it is their own seed.

Method: Double disk opener previously, but knife points from 2008.

Spacing: 25 cm

Fertiliser: 50–100 L Flexi N and 150 kg Super Phosphate

Andrew says that controlled grazing is the key to success with ryegrass in order to allow it to actively set seed. The Fowlers have found that the ryegrass phase has allowed their clover to thrive also.

Grazing management

Grazing management is important and fundamental to getting the most out of the pasture. The Fowlers rotationally graze with high stocking rates. They find that in a three-year phase, the first two years are mainly ryegrass in the pasture, while the third year is mainly clover. The organic carbon in 2008 was around 2.7 per cent and the average for the rest of the farm around 1.7 per cent.

The stocking rate is around 13 dry sheep equivalent (DSE) winter grazed per hectare and the Fowlers would like to lift that to around 20.

'We get three grazings with high stocking rates and we also cut the pasture for silage at around 8 t/ha of dry matter,' Andrew said. 'We then get another grazing from that and let it set seed. We then graze it over summer at around 100 DSE/ha for two weeks each time, which all up is around four times a year.'

The Fowlers plan to plant more perennials such as lucerne and kikuyu, with the aim of preventing wind erosion and providing feed over summer. They are also building more dams to ensure they won't run out of water.





Costs in 2008

Pasture costs: around \$30/ha for seed spraying; \$20/ha for chemical; \$220/ha for fertiliser (500kg/ha total, comprising compound fertiliser with seed, flexi N and NKS which is applied before silage harvest).

Silage costs: \$300/ha by the time it goes into the pits for mowing, chopping, transport and stack cover. The ryegrass pasture will cut 24 t/ha of silage which is the cheapest form of supplementary feeding and it lasts at a high quality for a long period, ensuring that the property is drought proof.

The silage is valued at \$60/t when it is used in feedlots; the value is \$180/t of dry matter, which is similar to the cost of good quality hay. The Fowlers have been making ryegrass hay for the past few years, but will switch to silage in 2008.



Key points

- Closely monitor the grazing you can't set stock until after 3-leaf stage if you want maximum productivity. Rotational grazing will ensure maximum productivity.
- Too much N when trying to graze can make the pasture too high in protein and livestock will stop putting on condition as they will require more energy to bypass the protein.
- The ryegrass needs to be grazed low and the N should be applied at about 4–6 weeks after seeding.
- If you want ryegrass to persist, then you need it to set seed. It is very tempting when everything else is brown to leave livestock on it—but don't!
- Because the ryegrass is a tetraploid, if it flowers at the same time as the diploid ryegrass the seeds will be sterile, so it can be used to help eliminate resistance.

- Cutting the pasture for silage helps to control weeds and so fewer chemicals are needed.
- Because there is a relatively high investment in fertiliser, it is important to be sure you will use the feed that you grow, so no plant is using extra fertiliser that is going to waste. A holistic approach is required in order to lift stocking rates over the farm, which can be more challenging. Grazing management should always be the first change to improving stocking rates rather than increasing fertiliser rates.
- Winterstar acts like a biannual and will stay green deep into summer if there is moisture in the soil. The second year is the most productive after seeding.
- You can seed ryegrass with clover but in the Fowlers' case there is enough of a bank to allow the clover to rebuild during the pasture phase.
- Ryegrass is quite a versatile pasture and grows well in a range of soil types. Andrew typically chooses paddocks that have been in crop for several years where clover production was especially low.
- Weed control in pastures is vital prior to sowing, as weed competition is a major cause of establishment failure and production loss. If unmanaged, capeweed can dominate ryegrass at establishment.

Managing the hard to manage Jeremy Lemon, Senior Development Officer, DAFWA Albany

7



Despite our increased understanding of soil constraints to production and their amelioration, there remain areas that perform so poorly that they cannot be economically amended for usual cropping practices. Increasing returns from cropping may alter the economics so crop returns into the future need to be considered to calculate time to breakeven when deciding what returns there will be on any amelioration investment.



Examples of areas with low prospects for economic amelioration include deep coarse sands with low water-holding capacity (less than 40 mm plant available water), often with very low cation exchange capacity, and waterlogged areas with little prospect of drainage due to landform and position in the landscape. Soils with acid subsoil from 30–60 cm depth can be amended with large applications of lime (with or without deep placement) but the time taken for effective change in the subsoil will reduce the value of the investment. It takes several years for alkalinity to move down the profile and neutralise subsoil acidity; meanwhile crop performance remains constrained for many years. Careful selection of plant species—such as acid tolerant wheat varieties rather than barley—will reduce the effect of subsoil acidity.

Identifying unproductive areas

There are many ways to identify hard to manage areas. Direct observation of crop performance and groundcover is an initial indication. This can be confirmed with yield maps, satellite biomass images or aerial photography from selected seasons, or better still, from a series of seasons to ensure the reliability of the observations. Before defining the extent of hard to manage areas, consider whether the extent of the problem area changes with seasonal conditions—is it likely to remain constant or is it increasing? Some problems only show in certain seasonal conditions, so the frequency or risk of poor results needs to be considered. Is the loss on small areas infrequent enough to ignore?

97

When options are limited

Once poor areas have been defined, the cause of the poor performance needs to be identified so that amelioration can be assessed for likely benefit. Use this book and obtain professional help to identify likely causes of poor production.

There are limited land use options available for areas that are not suited to cropping. Generally options relate to selecting plant species adapted to the low land resource capability.

Livestock grazing on annual and perennial pastures and even fodder shrubs are traditional ways to use land unsuited to cropping. Woody perennials for a range of purposes are also possible. Deep sands can be used for timber production, with many options for ownership and management of the plantation. Waterlogging tolerant species can also be explored for timber. Finally, areas can be planted for conservation purposes with no commercial purpose in mind. Future possibilities may emerge with energy and carbon sequestration planting.

Spatial distribution of hard to manage areas

Size and distribution of variability will influence the way that poor performing areas can be managed. Changing paddock layout and land use are ways to manage areas with low yield potential that cannot be economically farmed with current normal farming systems. Small scattered areas which total less than 5 or 10 per cent of the paddock area are unlikely to be worth isolating and managing separately. Larger areas that can be amalgamated with similar areas in adjacent paddocks or isolated within the existing paddock can be managed separately for alternative land uses. Non-cropping land uses need to be carefully fitted into the whole farm with consideration of the desired mix of enterprises and resources to manage these effectively. This is management at a paddock and farm level.

Small-scale variability of soil properties over short distances is very difficult to manage, even with paddock zoning and variable rate technology (VRT). In VRT, inputs are generally targeted for the average of each management zone, recognising that there is variability within the zone but at a scale that is difficult to measure or manage practically. There will be a scale at which the cost of more intensive monitoring and management is not justified by extra returns. As technology develops for rapid ground-based sensing such as 'on the go' spectral scanning for variable rate nitrogen application, management of the various zones will be fine-tuned.

Small management zones

Current technology allows management of some inputs for zones as small as 2–5 ha within paddocks. A difficulty arises when zones that have a constraint that is uneconomical to amend, are small and scattered so that it is impractical to isolate these areas for a different land use. The considerations for leaving poor areas in a paddock include the effect on average zone yield and effect on grain quality. Abandoning small areas within a paddock is not desirable as these can harbour weeds if not sown and need sufficient groundcover for water use and erosion protection. One strategy with VRT is to crop through these areas but with minimal inputs to maintain cover only. Another possibility is to sow a perennial grass that will maintain cover, compete with weeds and can be traversed with machinery to retain machinery working patterns. Revegetation of any areas needs to be planned carefully to ensure practical machinery operation.

Many factors need to be considered to 'manage the hard to manage'. Ultimately, decisions will be based on individual preferences and confidence in alternate management options given the circumstances unique to each property and land manager.

Table 7.1 Hard to manage issues and management responses. Some problems are not economic to ameliorate. Alternative land uses can be undertaken if amelioration is not a good option

Problem	Economic to ameliorate?	Standard approach	Alternative land uses
Subsoil acidity	Yes	High rates of lime and time is needed to move alkalinity into the profile.	Acid tolerant species of crop or pasture.
Subsoil compaction	Uncertain	Deep ripping, then tramline farming.	
Gutless sand – low water and nutrient holding	No	Ignore small areas. Drive around larger areas.	Timber production. Conservation planting.
Impermeable subsoil	No		Annual and perennial pastures.
Undrainable waterlogging	No		Fodder shrubs.

Table 7.2 Some responses to size and distribution of hard to manage areas

Size of hard to manage areas	Number of hard to manage areas	Possible responses
Larger (> 2ha)	Few	Segregate from cropped areas, manage separately.
Larger (> 2ha)	Many	Combine with other similar areas inside or alongside the paddock.
Small (0.5–2 ha)	Few	Ignore, wear the loss.
Small (0.5–2 ha)	Many	Stabilise and crop with reduced inputs.

Farm 1. Orandeen (home farm)

Operation at a glance

Area 2000 ha

Annual rainfall 510 mm

Soil types sand/gravel, sand/gravel/clay

Livestock none

Cropping 50 per cent raised beds cropped in a canolacereal rotation

History

1986 Purchased Orandeen.

1992 Downsized sheep and increased cropping enterprise.

1994 Sold last sheep, pulled all fences out and began cropping using no tillage.

1998 Changed to discs.

2000 Turned to raised beds.

2002 Began autosteer tramlining.

2003 Created 3 m raised beds and 3 m tramlines.

Farm 2. Hogwarts

Operation at a glance

Area 1000 ha

Annual rainfall 425 mm

Soil types grey clays, duplex sand/clay

Livestock none

Cropping 920 ha in canola-cereal rotation

History

2004 Purchased property and immediately removed all fences and created tramlines. Whole farm tramlined.



Doc Fetherstonhaugh

Farm 3. Blue Waters (40 km south of Orandeen and 15km west of Hogwarts)

Operation at a glance

Area 1200 ha

Annual rainfall 625 mm

Soil mostly sand/gravel, some heavy clay areas, some deep sand and some red loams/sandy loams

Livestock 500 breeding cows

Cropping mixed over the remainder of the property

History

2005 Purchased property and pulled out all fences. Digitally contour mapped, contour drained all cropping country and built raised beds over 900 ha.

2006 Put cattle on areas of the property not able to be cropped. Replaced all fencing with electric fences and now rotationally graze the pastures.

Doc Fetherstonhaugh and his brother Barn run a tight operation involving three properties, supporting mostly mixed cropping enterprises on 4200 ha of arable land around the Munglinup area. The brothers have been farming the sandplain since 1986, when they moved from their family-run business in South Australia.

Doc says it wasn't until the families 'nearly went broke' with the decline in wool prices in 1992 that they decided to put their energy into cropping. Compaction and water erosion issues have been dealt with since then by a steady transition into tramline farming with the use of raised beds on low-lying areas.



View downslope along raised beds across drive over grade banks with undrainable (uncroppable) area at the base of the slope in background. (photo D Fetherstonhaugh)

For the first two years of moving to precision cropping on one line, the brothers had mechanical markers and used a 12 m seeder and 24 m boomspray and spreader with a normal 10 m header (which of course didn't fit).

'So at first we weren't on 3 m spacings, but after those first two years we threw away the mechanical markers and bought a 2 cm GPS,' Doc said. 'We went to 3 m spaces on tractor wheels with the spreader and we bought a seeder bar with 3 m spacings. We then redesigned the discs to go from 1.86 m to 3 m spacings and bought a header (Case 80/10) to have a 12 m front. So now everything runs into 12 m and we now also have a 36 m sprayer.'



Section of 'Blue Waters' showing paddock of poor deep sand sown to perennial pasture (A), section of cropped paddock left out of crop due to deep erodible sand (B) and marginal area of paddock cropped with lower inputs (C). Drive over grade banks show clearly (D). Image provided by Western Australian Land Information Authority, January 2007.

All of their cropping land has now been digitally contour mapped (Landlogic) and contour drained and raised beds have been built on the country prone to waterlogging.

On the hostile deep sand country along the coast, not able to be cropped, around 500 breeding cows graze perennial pastures, clovers and ryegrass which in 2006 were planted to halt soil erosion and increase productivity.

Benefits of tramlining and raised beds

Problems associated with compaction have been substantially minimised. Before tramlining, the crops in a dry season often suffered lower yields because of machinery compaction. Better germination is now achieved through nudging a couple of centimetres each season and inter-row sowing. This avoids sowing into stubbles left in place from the previous year.

Retained stubbles minimise soil erosion during the summer months and increase vegetative matter supplies put back into the soil, helping to raise organic carbon.

Soil testing and EM38 surveys are combined with yield maps to get a good understanding of the paddock's strengths and weaknesses. The data helps to decide on variable rate phosphorous and potassium applications at seeding time.

Yields in wet years in the region can be very low, but raised beds have reduced the risks associated with waterlogging on the properties to almost nothing. A Gessner 6 m raised bed former was purchased almost a decade ago to construct the beds (at a cost of \$40 to \$50 per hectare). It usually takes around 3 ha per hour to form them and they last for around 4 to 5 years before needing to be reworked in places. They are built in March once strong winds are less prevalent, to reduce the chances of wind erosion on the bare earth.
Managing the hard to manage

Lessons learned

In future Doc will topography map using EM38 prior to making management decisions such as constructing raised beds, to allow for best drainage options. He has learned that getting the pH right is essential to eliminate yield constraints, and gypsum is regularly applied where needed.

Lime is also applied until the pH is above 5. The home farm (Orandeen) has had lime blanket-applied twice. The EM38 surveys combined with soil tests now show where to place variable rates as required.

EM38 and extensive soil testing have also enabled correct applications of potassium, phosphorous and trace elements in order to increase yields where needed, dependent on current and previous seasonal conditions.

Acidic Soils with a pH < 5.5 in water. Soils with pH < 4.5 are considered very acidic

Acidification The process whereby soils become acidic over time as a result of (a) the parent material; (b) the addition of nitrogen to the soil by either fertiliser or legumes (where nitrogen is converted to nitrate); (c) the leaching of cations down the soil profile by rainfall

Aggregate Cluster of soil particles (sand, silt, clay) that forms a discrete unit

Anion A negatively charged ion such as nitrate, sulphate, chloride

Base saturation percentage (BSP) Percentage of the cation exchange capacity (CEC) consisting of the base cations (Ca, Mg, Na, K)

Bulk density The mass of dry soil per unit volume, commonly used to assess compaction. Values > 1.5 g/cm³ can restrict root growth, water infiltration and aeration in sand and clay soils

Buffering capacity A measure of the soil's ability to resist chemical changes. Often used in relation to soil pH

Cation A positively charged ion (e.g. H+, Na+, K+, Ca²⁺, Mg2⁺, Mn²⁺, Al³⁺)

Cation exchange capacity (CEC) A measure of the soil's ability to adsorb and exchange cations. Expressed as milli-equivalents (me)per 100 g of soil. Important in nutrient retention, CEC represents the total negative charge per unit quantity of soil. Soil colloids including clay and humus have high CEC

Clay Soil particles < 0.002 mm in diameter

Claying The process of adding clay to a soil, often to ameliorate water repellent topsoils

Compaction Increased soil density due to vehicle and animal traffic, resulting in reduced pore space. See **bulk density** and **soil strength**

Soil constraint Any property of the soil within the root zone which prevents the crop or pasture from achieving its rainfall limited yield potential. Constraints can be chemical (salinity, acidity, toxicity, deficiency), physical (impenetrable, nonporous) and biological (nutrient and carbon cycling)

Deep ripping Tillage using rigid tines that physically disrupt ('breaks out') compacted layers in subsoils. Used to improve water infiltration and root growth

Dispersion Process whereby soil aggregates separate into their primary particles (clay, silt and sand) when immersed in water. Dispersion is commonly associated with sodic clays

Drained upper limit See field capacity

Duplex Soils that have a distinct texture contrast between layers within the soil profile (i.e. sand over clay)

Electromagnetic induction (EM) Technique for indirectly measuring and mapping soil conductance. EM uses a coil to generate an electromagnetic field and a receiver to measure the induced current. The induced current is directly related to the conductivity of the soil and is affected by salinity, clay and water. The Geonics EM38 is the industry standard for EM mapping. The EM38 integrates soil conductivity to depths of 1 m in its horizontal mode and up to 2 m in its vertical mode. Dual EM is the measurement of EM in both horizontal and vertical modes

Electrical conductivity (EC) A measure of soils ability to conduct electricity. Affected by soluble salts (salinity) and clay content. ECe is the electrical conductivity adjusted for texture and is used in salinity tolerance recommendations for differing plant species

Exchangeable anion A negatively charged ion (i.e. Cl-, SO4, NO2) held on or near the surface of a mineral or organic particle by a positive surface charge. These ions are available to plants

Exchangeable cation A positively charged ion (Na, K, Ca, Mg, Cu, Zn etc) held on or near the surface of a mineral or organic particle by a negative surface and which may be replaced by other positively charged ions in the soil solution. These ions are available to plants

Exchangeable sodium percentage (ESP) Percentage of the cation exchange capacity occupied by sodium ions. Sodic soils have an ESP > 6%. Used to evaluate the level of sodicity within a soil

Field capacity Amount of water remaining in an initially saturated soil horizon 2–3 days after free drainage has ceased. Also known as the drained upper limit (DUL)

Gravimetric soil water Soil water content expressed as grams of water per gram of oven dry soil. Gravimetric water content = (wet soil-dry soil)/(dry soil)

Gypsum (CaSO4.2H2O) Hydrated form of calcium sulphate, used as a fertiliser and soil conditioner. Most commonly used as a soil conditioner to reduce dispersion in sodic clay soils that crust and set hard **Horizon** Horizontal soil layer that differs from layers above or below because of physical, chemical or biological properties

Ap Horizon (surface organic layer) the zone of maximum organic matter accumulation. Comprises mineral layer with fresh and decomposed organic matter

A Horizon (topsoil) layer from which clays, mineral and salts have been leached to form the B horizon

B Horizon (subsoil) the zone where clay or other minerals have accumulated through illuviation or weathering of the A horizon

C Horizon (parent material) Material from which the A and B horizons have formed. Not necessarily bedrock

Humus Fraction of organic matter that is a by-product of microbial degradation and is relatively stable. Properties include high water retention and cation exchange capacity. Ratios of nutrients in humus are constant—100C:12N:1P

Infiltration Movement of water into soil. Rate of entry is affected by sorption (the blotting paper effect) and pore size distribution and continuity

Leaching The removal in solution of cations and anions as water moves through the profile

Lime A highly alkaline compound of calcium and carbonate (CaCO3, pH>8), commonly used to increase soil pH in acid soils. Lime quality is assessed based on neutralising value (NV) and fineness

Lower storage limit (LSL) See Permanent wilting point

Macronutrient Essential nutrients required in high quantities for plant growth (e.g. N, P, K, Ca, Mg and S)

Molarity of ethanol droplet test (MED) Measure of water repellence. MED is the dilution (molarity) of ethanol, that when applied as a drop, takes less than 10 seconds to be absorbed by the soil.

Micronutrient Essential nutrients required by plants in relatively small amounts (e.g. B, Cl, Cu, Fe, Mn, Mo, Ni, Co and Zn)

Mycorrhizae Soil fungi that infect plant roots, increasing the root surface area for taking up nutrients including phosphorus and zinc. Lack of mycorrhiza is associated with long fallow disorders in sorghum crops in Queensland. Can be important in cereal crops where soils are P deficient

Organic carbon Carbon fraction of soil organic matter (OM) expressed as a percentage. Commonly measured in soil analyses with topsoil values of 1–2 per cent. Organic carbon is widely used as a surrogate for organic matter with OC = 0.57 OM

Organic matter Fraction of the soil that contains residues of plant and animal matter at various stages of decomposition. See also **humus**

Penetrometer Used to assess soil strength. A cone penetrometer consists of a cylindrical rod with a cone-shaped tip attached to a strain gauge

Permanent wilting point Water content at which plants can no longer extract water due to the soil being too dry. Often measured at a tension of 1500 kPa but can also be measured beneath plants that have wilted. Also known as the lower storage limit (LSL)

Perched watertable Body of water that is held above the main watertable by an impervious clay layer. Commonly associated with duplex soils

pH A measure of soil acidity and alkalinity. Defined as the concentration of hydrogen (H⁺) and hydroxyl ions (OH⁻) on a negative log scale from 0 to 14. A pH of 3 has 10^{-3} H⁺ ions and 10^{-11} OH⁻ ions. A pH of 11 has 10^{-11} H⁺ ions and 10^{-3} OH- ions

Plant available water capacity (PAWC) The amount of water (expressed in mm) held in a soil that can be extracted by a plant. The PAWC is affected mainly by soil texture, crop type and root depth. Soil texture has the greatest effect on PAWC, with sands having PAWC of 60–100 mm compared to loams (180–220 mm) and clays (150–200 mm)

Porosity Measure of pore space in a soil. Defined as the volume of air within a known volume of mineral + air + water. Porosities less than 10% are associated with limited aeration

Profile A vertical section of soil often extending to the base of the root zone. Mainly used to describe soil properties

Radiometrics Measure of gamma particles emitted by isotopes of uranium, potassium and thorium that can be used to interpret soil properties including parent material, gravel, clay and bedrock. Used to map areas of potential mineralisation

Root zone Zone in which roots are found in a soil profile. The depth of the root zone is affected by any factor that limits root growth and function

Sand Soil particle greater than 0.05 mm

Salinity Measure of the total soluble salts in a soil. A saline soil is one with an accumulation of free salts at the soil surface and/ or within the profile affecting plant growth. Salinity levels of soil or water can be tested using **electrical conductivity**

Slaking Breakdown of aggregates into micro-aggregates when immersed in water, slaking is a measure of aggregate instability. Soils that slake are prone to hardsetting, crusting and erosion. May also be associated with dispersive soils

Smudging Process of spreading surface applied clay across a paddock using lengths of iron trailed behind a tractor

Sodic See exchangeable sodium percentage

Soil Unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for plant growth. See **topsoil** and **subsoil**

Soil strength Measure of a soil's ability to resist deformation by roots or tillage implements. Consists of cohesive and frictional forces. Often measured in megapascals **(MPa)** using a penetrometer

Soil water Amount of water stored in the soil. Expressed either on a gravimetric or volumetric basis. See plant available water capacity

Subsoil The soil layer below the topsoil; it does not include the C horizon. See horizon

Topsoil The uppermost part of the soil, often organically stained. Frequently designated as the plough layer, surface layer, **Ap horizon**

Volumetric soil water Soil water content expressed as volume of water per volume of oven dry soil. volumetric water content = wet soil-dry soil)/(dry soil) x bulk density

Summary

This book has been written to help farmers reach their rainfall-limited yield potential. It comes from a need to understand the properties and management options for grain production on sandplain soils.

It also seeks to address concerns that crop yields on sandplain soils are not increasing at the rate experienced on soils elsewhere in the south coast region of Western Australia.

