Subsurface compaction a guide for WA farmers and consultants

Stephen Davies

Alison Lacey

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Subsurface compaction

A guide for WA farmers and consultants
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January 2011
Acknowledgments

This guide was produced as part of the GRDC project ‘Managing Hostile Subsoils (UWA00081)’, delivered by the Department of Agriculture and Food, Western Australia and The University of Western Australia.

The authors would like to thank Department of Agriculture and Food, Western Australia staff: Paul Blackwell, Bill Bowden, Chris Gazey, Mohammed Hamza, Jeremy Lemon and Glen Riethmuller for their assistance and Dennis Van Gool for providing the map showing soils at high risk of subsurface compaction.
Contents

Acknowledgments .......................................................... ii

Introduction ...................................................................... 1

Implications of subsurface compaction ..................... 3

Physical consequences ..................................................... 4
Soil strength ........................................................................ 4
Water movement ....................................................................... 5

Slow and restricted root growth ..................................... 7
Rooting depth ........................................................................ 7
Water and nutrient use ............................................................ 7
Vegetative biomass .................................................................. 7

Diagnosing subsurface compaction ................................. 9

Susceptible soil types .......................................................... 10

Visual identification ............................................................... 12
General observation ............................................................. 12
Soil pits ............................................................................... 12
Plant indicators ...................................................................... 15

Measuring compaction ....................................................... 16
Bulk density ........................................................................... 16
Hand probes ........................................................................... 17
Cone penetrometers ............................................................... 18
Hand-held penetrometers ...................................................... 19
Precautions ............................................................................ 19

Managing subsurface compaction .................................. 21

Deep ripping ........................................................................ 22
Machinery and techniques ................................................... 24
Timing .................................................................................. 26
Costs ................................................................................... 26
Possible disadvantages ......................................................... 27

Other soil loosening techniques ..................................... 28
Deep working at seeding ....................................................... 28
Spading and mouldboard ploughing ...................................... 29

Minimising compaction ....................................................... 30
Controlled traffic (tramline) farming ...................................... 32

Production benefits ............................................................... 34

Appendix ............................................................................. 36

Glossary .............................................................................. 36

References and further reading ....................................... 38
Introduction

For plants to grow in agricultural soils, roots and emerging shoots must be able to force their way through the soil. In soils of high strength, this growth is physically restricted. High strength soils may be due to natural soil characteristics and conditions or develop as a result of agricultural practices and may be in layers or throughout the soil profile.

In agriculture, high strength soils commonly occur as a result of compaction. Compaction of agricultural soils can be in the surface (often caused by stock trampling or rain drop splatter) or in the subsurface (usually in a layer at 10–40 cm). Subsurface compaction has a different suite of effects and management options than surface compaction, although, subsurface compaction amelioration techniques may also benefit a hard-setting profile.

Subsurface compaction can occur in most Western Australian agricultural soils. Some soils have greater capacity to resist compaction or to self-repair following compaction. However, nearly three-quarters of WA's agricultural soils are either affected by, or highly susceptible to, subsurface compaction (Figure 1).

Compacted subsurface soil restricts crop and pasture root growth with plant biomass correspondingly reduced. In most seasons this also results in grain yield reduction. The average opportunity cost of lost agricultural production is estimated at $333 million per year for the Northern, Central, Southern and South West Agricultural regions (Herbert 2009).

The most common forms of subsurface compaction in WA agricultural soils are traffic and plough hardpans caused by agricultural equipment and are the focus of this guide. In most cases these hardpans can be economically remedied and appropriate agricultural practice can minimise the reformation of hardpans.
Figure 1 Map showing the proportion of soils that are affected by, or highly susceptible to, subsurface compaction (based on Department of Agriculture and Food, Western Australia map unit database accessed May 2006). Assumptions for modelled land qualities are described in van Gool et al. 2005.
PART 1

Implications of subsurface compaction
Subsurface compaction increases the density and strength of the soil and reduces the porosity. These physical consequences are primarily responsible for the losses in production resulting from compaction.

**Soil strength**

An increase in the soil strength is the major problem of subsurface compaction. Subsurface compaction caused by farm vehicles and machinery results in a layer of higher strength soil commonly at 10–40 cm depth although on deep sands along the south coast, compacted layers are often from 20–50 cm depth. These traffic and plough hardpans may be a few millimetres to 25 cm thick, depending on soil type, agricultural practices and other environmental conditions.

In compacted layers the soil strength can be too high for roots to grow normally. Roots may grow sideways along the top of the compacted layer or be restricted to cracks and old root channels. Branching is increased as roots encounter and attempt to penetrate a compacted layer. If they are able to penetrate the compacted layer, roots grow slowly; root tips may become damaged and thickened and grow in a tortuous pattern.

Increased soil strength from a compacted layer below the usual tine depth will increase the draft force for tractors pulling deeper tined implements through the compacted soil.

**Bulk density, porosity and soil strength**

Traffic by farming vehicles and repeated cultivation by tillage implements forces soil particles and aggregates closer together by compression (downward pressure from farm machinery) and shearing/smearing (spinning or slipping of wheels and the action of tillage implements causing sideways force and realignment of the soil particles). This compacted soil then has a higher bulk density (occupies less volume) with reduced porosity (fewer and smaller pore spaces) resulting in increased soil strength. Soil particles can also ‘lock together’, further increasing soil strength and making it harder for roots to grow through.
Physical consequences

Water movement

Subsurface compaction causes slower water movement through the soil in most circumstances. Depending on soil type, the severity of compaction and the depth at which it occurs, water may not drain readily through the root zone. The risk of perched water table and waterlogging is increased, particularly on loamy sands and heavier soils (Figure 2). There is little effect on sands.

Waterlogging and low porosity increases the chance of low oxygen (anaerobic) conditions, which leads to a significant decrease in a plant’s root function and nutrient uptake. Also, it can result in a decline in the number and activity of beneficial micro-organisms and result in the production of toxic substances such as hydrogen sulfide and ethylene as well as the evolution of nitrous oxide—a greenhouse active gas.

Figure 2 Surface ponding at North Stirling. On heavier soils where subsurface compaction has resulted in soil structural degradation and reduced porosity, the risk of perched water is increased.
Slow and restricted root growth caused by subsurface compaction often reduces farm productivity and profitability and can lead to other on- and off-farm effects such as increased wind and water erosion, dryland salinity and waterway degradation.

Where root growth is retarded or a greater amount of energy is required for roots to grow through compacted soil, production is usually reduced. The severity of the impact of subsurface compaction on root growth is dependant on many factors, primarily soil type and amount of compaction.

In sandy textured soils roots slowed by moderate compaction are less effective at keeping up with water and dissolved nutrients, particularly nitrogen, as they infiltrate through the soil profile (Table 1, Figure 3).

Occasionally, under some seasonal conditions, when water deeper in the subsoil is not used as quickly due to the slow early root growth, more water is left available in the subsoil later in the season for grain filling, thereby delaying the onset of water stress and reducing haying off.

In heavy textured soils severe compaction can restrict root growth to channels, cracks or softer parts of the soil and reduce the volume of soil available for root exploration (Figure 4).

### Table 1 Root growth rates and rooting depths of wheat grown on yellow sandy earths with and without deep ripping (Delroy and Bowden 1986, Schmidt et al. 1994)

<table>
<thead>
<tr>
<th>Location</th>
<th>Time of measurement (days after sowing)</th>
<th>Root growth rate (mm/day)</th>
<th>Rooting depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>unripped</td>
<td>ripped</td>
</tr>
<tr>
<td>East Chapman</td>
<td>28</td>
<td>5.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Wongan Hills</td>
<td>36</td>
<td>5.6</td>
<td>13.9</td>
</tr>
</tbody>
</table>

*Rooting depth assessed 35 days after sowing
Rooting depth
Restricted root growth resulting in shallow final rooting depth causes:
- reduced plant available water
  - faster onset of crop and pasture water stress during dry periods
  - rapid haying off of the crop and reduced grain fill period at the end of the season
  - reduced production
- increased risk of wind and water erosion.

Water and nutrient use
Slow root growth, unable to keep up with the movement of water and nutrients through the soil profile, results in reduced water and nutrient use by crops and pasture. The flow-on effects are:
- reduced production
- increased rate of soil acidification caused by leaching of nitrate away from the root zone
- off-site effects of dryland salinity and excess nutrients entering water waterways (eutrophication).

Vegetative biomass
Slow and restricted root growth leading to slower crop and pasture growth and less vegetative biomass results in:
- reduced production
- increased risk of wind and water erosion.

Figure 4 Roots growing preferentially through a fracture in a hardpan at Mukinbudin
PART 2

Diagnosing subsurface compaction
Most of the common agricultural soils of the WA wheatbelt are at risk of subsurface compaction.

Subsurface compaction is particularly common in the loamy and clayey sand textured wheatbelt soils which have a wide range of particle sizes. In these soils, a tightly packed (compacted) layer at 10–40 cm may develop as a result of agricultural practices, particularly if they are carried out when the soil is too wet. Deep sands are also susceptible to compaction.

Good soil structure and higher levels of organic matter may reduce the degree of compaction. However in the WA wheatbelt, higher levels of organic matter are usually only present in the surface soil and have little influence on subsurface compaction.

Medium to fine textured soils are susceptible to plough pans, which occur just below cultivation depth. These may occur in addition to traffic pans which are deeper and occur in medium to coarse textured soils.

Soils with very high levels of gravel (greater than about 50 per cent) are better at supporting agricultural machinery, however gravel soils can still compact.

<table>
<thead>
<tr>
<th>Soils with high susceptibility to compaction are characterised by having:</th>
<th>Soils that are less prone to compaction include:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• a good representation of a wide range of soil particle sizes—common in loamy and clayey sands and sandy loams</td>
<td>• high gravel content soils where the gravel helps support the weight of the machinery (greater than about 50 per cent gravel)</td>
</tr>
<tr>
<td>• soil particles that are rounded—coarser sand particles are more likely to be rounded</td>
<td>• cracking clays that are only prone to compaction when wet and are self-repairing</td>
</tr>
<tr>
<td>• low organic matter (usually less than one per cent organic carbon) in the topsoil—indicative of a sandy soil.</td>
<td>• non-cracking clays are only susceptible to compaction when wet</td>
</tr>
<tr>
<td>• poor soil structure.</td>
<td>• shallow soils that are overlying rock or cemented ironstone gravels (ferricrete) at 30 cm or less (this layer supports machinery but will also restrict root growth).</td>
</tr>
</tbody>
</table>
Susceptible soil types

Compaction
- induced by agriculture
- external forces rearrange soil particles and reduce pore size and number

Transient bonding
- natural process or induced by agriculture
- hard soil softens again when wet

Packing
- natural process
- particle size and shape of some sands pack densely

Cementation
- natural process
- chemical changes result in permanent hardening

Hard soils

Stock trampling ➔ SURFACE COMPACTION

Repeated action of cultivation equipment ➔ PLOUGH PANS
- compacted layer just below cultivated depth
- fine textured (clay) soil at highest risk especially if cultivated when wet
- soil aggregate structure is broken down and pores become sealed
- root penetration is restricted
- water penetration is restricted
- risk of waterlogging
- plant growth stunted

Repeated traffic by wheeled vehicles ➔ TRAFFIC PANS
- compacted layer 10–40 cm below surface
- sand to sandy loam soils at highest risk
- wet soil is more susceptible
- root penetration is restricted
- water and nutrients penetrate faster than roots
- risk of nutrient leaching
- poor use of subsoil water
- reduced production

Visual identification

General observation
Moist subsoil within 30–40 cm of the surface in cropped areas after reasonable crops in dry finish seasons indicates that there have been insufficient roots at these depths to extract water. Auger holes may provide opportunity for observation.

Tillage (to depths greater than 20 cm) when the soil is dry or only slightly wet will often bring up large dense soil clods if there is a compaction layer (Figure 5). Compacted soils may be physically difficult for the tines to penetrate and increase the draft force of the tractor.

Soil pits
Compacted layers in the soil profile can also be observed by digging a soil pit.

Compacted layers often have distinct upper and lower boundaries and a blocky appearance or structure which may or may not be fractured (Figures 6 and 7). The compacted layer will feel more dense and stronger than the soil above or below it. When pressure is applied to clods from a compacted layer they tend to crack where pressure is applied rather than on natural break lines as happens with well structured soils.

Figure 5 Clods brought to the surface after deep ripping in this dry yellow sandy earth near Kellerberrin indicate subsurface compaction.
Visual identification

Figure 6 Compacted layer in a loamy earth near Mukinbudin. Note the distinctive upper and lower boundaries of the compacted layer, blocky structure and fractures which are preferred pathways for roots to grow.

Figure 7 Compacted layer in a sandy earth exposed by erosion near Corrigin. Compacted layers usually start at 8–15 cm and vary in thickness from 8–25 cm.
Visual identification

Figure 8 This ripline (for the installation of a power cable) at Wongan Hills provides an indication of subsurface compaction in the paddock. The root structure of plants on and off the ripline (Figure 9) support the diagnosis.

This very deep ripline where topsoil may have been incorporated down the soil profile does not mimic the normal farming deep ripping process and plant responses to deep ripping the paddock may differ.
Diagnosing subsurface compaction

Visual identification

Plant indicators

The effects of slow and restricted root growth are difficult to identify by observing plant growth in the paddock because there is rarely an opportunity to observe a direct comparison between compacted and uncompacted soil. Observation of plant response to soil disturbance which would break up a compacting layer, such as water lines or power cable installation (Figure 8) gives a good indication of subsurface compaction in the paddock. Examination of the plant roots will also provide evidence (Figure 9).

**Crop and pasture indicators of soil compaction include:**

- Root growth is poor (shallow).
- Root tips become swollen as roots try to force their way through the hard soil.
- Root growth is horizontal over the hard soil layers.
- Root branching may be increased as roots try to find a way into the compacted layer.
- Root density and root branching may be reduced through (within) the compacted layer.
- Roots growing through compacted soils are often confined to pre-existing pores and soil fractures (Figure 4).
- Crops and pastures growing on compacted soil may become water stressed more quickly during dry periods and hay-off more rapidly at the end of the season. Often these areas produce pinched grain.

Figure 9 Roots of canola plants growing on (bottom) and off a ripline (Figure 8) which removed subsurface compaction as a constraint to plant growth at Wongan Hills
Bulk density

If a soil pit has been dug, it may be useful to measure soil bulk density. Bulk density is directly related to soil strength and it is the high soil strength that restricts root growth in compacted soil (page 4). Bulk density is a measure of the volume that a certain weight of soil occupies; a soil with a higher bulk density occupies less volume per weight of soil. A compacted layer of soil will have a higher bulk density than soil above and below.

Bulk density can be determined without specialised equipment (see Brown and Wherrett (2009) for detailed methodology). Together with soil type information, bulk density can provide a measure of the severity of the subsurface compaction. Care needs to be taken in interpreting results as bulk density varies depending on soil type (Table 2); bulk density may be naturally high, and not as a result of compaction. Bulk density measurements are unsuitable for indicating compaction in soils with more than 10 per cent gravel or with stones greater than 2 cm diameter (Hunt and Gilkes 1992). Be sure to take enough samples to account for spatial variation.

Sampling and then determining the bulk density is time consuming. In most cases, a simple hand probe (page 17) is sufficient to determine the presence of subsurface compaction and examination of plant root structure and depth (page 15) will indicate how this is affecting the plants.

Table 2 Rule-of-thumb bulk densities for common soil types with and without compaction (adapted from Needham et al. 1998, Hunt and Gilkes 1992).

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Bulk density (g/cm³)</th>
<th>Root penetration</th>
<th>Root penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Satisfactory</td>
<td>Root penetration inhibited</td>
<td>Root penetration prevented</td>
</tr>
<tr>
<td>sand</td>
<td>&lt;1.6</td>
<td>1.66</td>
<td>1.85</td>
</tr>
<tr>
<td>loamy sands</td>
<td>&lt;1.6</td>
<td>1.61</td>
<td>1.82</td>
</tr>
<tr>
<td>sandy loam</td>
<td>&lt;1.5</td>
<td>1.60</td>
<td>1.81</td>
</tr>
<tr>
<td>sandy clay loam</td>
<td>&lt;1.4</td>
<td>1.58</td>
<td>1.80</td>
</tr>
<tr>
<td>clay loam or finer</td>
<td>&lt;1.3</td>
<td>~1.40</td>
<td>~1.60</td>
</tr>
</tbody>
</table>
Hand probes
Hand probes are metal rods that are pushed into the soil by hand (Figure 10). Compacted layers can be felt because it will be more difficult to push the probe through the compacted layer but it will become easier again once the probe has got through the compacted zone. Comparisons of resistance to the probe with similar soil in uncompacted zones such as along fence lines or in remnant vegetation areas can highlight the effect and help with the diagnosis.

Testing needs to be done when the soil is wet (preferably the drained upper limit to depth) as dry layers in the soil will feel hard regardless of compaction status.

Hand probes can be made from steel rod (about 8–10 mm diameter) sharpened to a point on one end or even heavy gauge, 3 mm, fencing wire about 40 cm long with one end looped to make a handle. In both cases depth increments can be added to the shank of the probe so that depth of the hard layer can be determined. Hand probes can also be purchased commercially from field survey and environmental suppliers.

Figure 10 Hand probes are a simple and effective way of detecting subsurface compaction.
Measuring compaction

Cone penetrometers

A cone penetrometer measures and records the force required to insert a standard-sized cone into the soil profile.

The cone penetrometer is inserted into the soil at a steady speed (commonly 30 mm/second) by hand and the instrument uses a force gauge to measure the penetration force (cone index) in megapascals (MPa) or kilopascals (kPa) required to penetrate moist soil (Figure 11). The penetrometer records the force at selected intervals (often every 20 mm) and records both the penetration resistance and depth at which it was measured at each interval. The data is stored in a data logger and can then be downloaded.

Penetration resistance measured in wet soils close to the drained upper limit (field capacity) can be related to crop root growth. In general, crop root growth starts to be restricted when the penetration resistance exceeds 1.5 MPa and is severely restricted at 2.5 MPa or more (Hunt and Gilkes 1992).

Cone penetrometers are useful for:

- assessing the effectiveness of deep ripping for reducing soil strength by comparing before and after ripping or between ripped and unripped soils
- comparing the soil strength of uncleared soil with no traffic to traffic affected soil in the paddock.

Figure 11 Penetration resistance measured using a cone penetrometer comparing ripped (to 30 cm) and unripped treatments in a deep yellow sandy earth at Northampton. In this case ripping significantly reduced soil strength to a depth of about 45 cm and to a level not restrictive to root growth to a depth of about 30 cm.
Hand-held penetrometers

A hand-held penetrometer or force gauge (Figure 12) works in the same way as a cone penetrometer.

Hand-held penetrometers can be pushed vertically or horizontally into soil surfaces, however, they can only record the soil strength to a shallow depth. For detecting subsurface compaction using a hand-held penetrometer, a soil pit would be required so that the penetrometer could be used on the vertical soil pit face to measure soil strength to depth.

Hand penetrometers are also used in the building and road making industry to check the strength of compacted foundations before pouring concrete or spreading bitumen.

Precautions

A few precautions need to be observed when using cone penetrometers and soil probes:

- Soil penetration resistance should be assessed when the soil is at field capacity (drained upper limit).
- Dry subsurface layers will also resist the penetrometer and can appear to be compacted layers.
- Soils can be wet up by applying water to a distinct area of soil before using a probe or penetrometer.
- Soil strength should only be compared between soils of the same type that have a similar water content as soils with different texture and structure or water content will give varying results.
- Higher force is required to push a penetrometer through stony and gravelly layers than if gravel was not present in the soil. Care should be taken not to mistake this for a compacted layer.
- Penetrometers are unsuitable for use in soils with more than about 10–15 per cent gravel.

Figure 12 A hand held force gauge (penetrometer) being used to measure the soil strength on a soil pit face
PART 3

Managing subsurface compaction
Deep ripping is most effective in deep sandy-textured soils where roots need to grow deep to access subsoil moisture. Deep ripping is of particular benefit when it is used to break through a compacted pan or distinct constraining layer, allowing root access to unconstrained soil beneath this layer.

If the soil below the depth of ripping contains other constraints, such as acidity, poor structure or subsoil salinity, the benefit of deep ripping will be limited (Figures 13 and 14). It is possible to inject lime into acidic subsurface soil behind deep ripping tines, however, this is a slow operation and difficult to implement on a large scale (Figure 15). Shallow leading tine rippers are ideally suited to this as they can place lime at range of depths when fitted with suitable lime distribution systems, creating a continuous seam of lime into acidic profiles.

The benefits of deep ripping can include:
- reduced compaction and soil strength
- faster early crop root growth (Figure 3)
- improved water and nitrogen use by the crop
- improved water infiltration in some soils, provided the loosened soils are not dispersive (prone to structural instability) and are not re-compacted by traffic
- crop biomass and grain yields can be increased in many instances.

![Figure 13 Root depth on and off riplines in a deep ripping and lime trial at Maya](Photo: C Gazey, DAFWA)
Deep ripping

Managing subsurface compaction

Figure 14 A compacted layer can be seen in this soil profile at Yuna where most roots have not grown through this layer. The green colour of the universal indicator stain indicates that the pH of the soil below this layer is suitable for plant growth.

If the constraints of soil acidity and compaction are removed from the 10–20 cm layer, roots would be able to grow into and utilise nutrients and water from the soil below.

Figure 15 Deep ripping and deep placing lime in one operation at Merredin. Successful treatment of acidic soil is possible, however correct distribution of the lime is difficult to achieve and an untreated acidic layer can remain as a barrier to root growth. Surface-spreading lime before deep ripping is a safer option, although amelioration takes longer.
Machinery and techniques

Deep ripping (deep tillage) involves the use of deep working strong tines which penetrate the compacted soil and mechanically break up and shatter the soil hard pan (Figure 16).

For deep ripping to be effective:

- The ripping tines must be able to penetrate just below the compacted soil layer.
- Soil must be moist enough to allow penetration of the ripping tines but not so moist that the tines cause smearing without fracturing and shattering the soil.

Some firming of the soil surface by a roller or soil packer behind the deep ripper (Figure 17) and/or attaching wings behind the tines can minimise the risk of rough or soft soil surface causing uneven seeding depth or sowing too deep resulting in poor crop establishment.

Loosened soils can be more susceptible to compaction after deep ripping if not managed carefully. Leaving deep ripped soil to settle for at least two weeks before sowing can be beneficial.

Shallow leading tine ripper

Traditionally deep rippers rip the soil with tines all set to the same depth which have to penetrate and fracture the soil to full working depth. Research has shown, however, that single shallow leading tines working in-line and ahead of the deep ripping tine reduce the draft force by up to 18 per cent with the leading tine working at 10 cm on clay-textured soil (Figure 18). On sandy-textured soils with the leading tine working at 12 cm draft force is reduced by 10 per cent (Hamza and Riethmuller 2005). The shallow leading tines loosen the upper soil layers reducing the resistance and amount of soil the ripping tine has to fracture. Shallow leading tine rippers are also ideally suited to placing lime or other soil amendments at a range of depths into the soil profile behind the tines.
Deep ripping

Figure 17 A soil roller is used at Northampton to prevent sowing too deep into loosened soil after deep ripping.

Figure 18 Shallow leading tine ripper
Deep ripping

Timing

The problem is finding the appropriate window for ripping which does not conflict with seeding but when the soil is moist (Figure 19).

The options include:

- Deep rip after seeding but early enough not to disturb establishing plants too much (generally within three days of seeding) although this can also reduce crop establishment.
- Deep rip in the inter-row of crops sown on wide rows during the growing season (Blackwell et al. 2005).
- Deep rip opportunistically after significant out of season rains.

Costs

Financial cost from fuel and machinery use is estimated at between $40–50/ha for deep ripping sandplain soils. Much of the cost of deep ripping is related to the draft force required to pull the deep working tines through the soil and the impact this has on fuel use and power requirements. This can be reduced by using a shallow leading tine ripper (Figure 18) which can reduce the draft force required to pull a deep ripper (Hamza and Riethmüller 2005).

A large time cost is usually associated with deep ripping. It is an additional operation often occurring near seeding and may compete with early sowing.

Figure 19 Rough surface on a yellow sandy earth at Kellerberrin caused by deep ripping dry soil. Deep ripping should be done when the soil is moist to avoid bringing clods of compacted soil to the surface.
Deep ripping

Possible disadvantages

One of the largest potential downsides associated with deep ripping is that it increases the risk of haying off when soil water reserves are low and the finish to the season is dry.

In some situations, faster water use and increased vegetative biomass caused by deep ripping can leave inadequate stored soil water for grain filling resulting in haying off and reduced yields.

Strategies to reduce the risk of a negative result to deep ripping may also reduce the large yield benefits that deep ripping can provide in good seasons where there is sufficient soil water to grow a large crop and fill the extra grain.

<table>
<thead>
<tr>
<th>The risk of haying off is increased in:</th>
<th>The risk of haying off can be reduced by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• dry seasons and seasons with a hot dry finish</td>
<td>• avoiding deep ripping in seasons predicted to be drier than average particularly if there is no stored subsoil moisture at the start of the growing season</td>
</tr>
<tr>
<td>• low rainfall areas/regions (less than 350 mm)</td>
<td>• reducing early crop vigour by using wider rows, later seeding, lower seeding rates or reduced early nitrogen applications</td>
</tr>
<tr>
<td>• years when there is minimal stored subsoil moisture</td>
<td>• using shorter season crop varieties after deep ripping to account for the increased rate of subsoil water use</td>
</tr>
<tr>
<td>• high input systems with high levels of applied nitrogen driving increased crop vigour and large crop biomass</td>
<td>• using water efficient, low vegetative biomass varieties in the year the soil was deep ripped</td>
</tr>
<tr>
<td>• high soil nitrogen as a result of summer rainfall can also increase crop vigour and the risk of haying off although higher subsoil moisture reserves could negate this.</td>
<td>• deep working at seeding, resulting in only partial amelioration of compacted soils and avoiding the large vegetative biomass response generally observed after deep ripping.</td>
</tr>
</tbody>
</table>
Deep working at seeding

Deep working at seeding involves the use of deeper working points during the seeding operation to cultivate below the seed and partially remove the plough pan or compacted soil that commonly occurs below the usual working depth. The deep working knife points loosen the soil a few centimetres below the seed (Figure 20), enhancing early root growth. However, this process can pose risks for sowing depth.

**Compared to deep ripping, the benefits of deep working while seeding include:**

- lower operational costs than two separate operations
- time cost saving by deep working and seeding in one operation
- rapid early root growth and quicker establishment of the seedling root system without promoting excess early vigour which may result in rapid soil water use and early haying-off.

The disadvantage of this approach is that some compaction will still remain and yield responses in good seasons are likely to be less. Deep ripping tines working below the depth of the hard pan are likely to cause more fracturing of the hard pan and better amelioration of the compaction. Researchers have determined that in reasonable seasons in medium rainfall areas the wheat yield gained from deep ripping sandy earth soils increases by 32–50 kg/ha for each centimetre of extra soil depth ripped (Schmidt et al. 1994). For example, deep ripping tines working at a depth of 35 cm may give a wheat yield gain of 390–650 kg/ha compared with deep working knife points disturbing the soil to a depth of 22 cm.

Figure 20 Seeding tines can be modified with deep working points and adjusted for deep working to loosen the soil below the seed and provide partial amelioration of compacted soils.

Figure 21 Mouldboard ploughing at Mingenew. Although more expensive than deep ripping, additional benefits of techniques such as mouldboard ploughing and rotary spading should be considered, depending on the depth of compaction (page 29).
Spading and mouldboard ploughing

Rotary spading and mouldboard ploughing (Figure 21) will loosen soil and have a similar effect to deep ripping, provided the soil is loosened to the depth of compaction (Figure 22). These techniques are more expensive than deep ripping and so there would need to be other reasons to use them in addition to subsurface compaction.

As well as soil loosening, mouldboard ploughing and spading can have benefits in reducing weed burden, bringing up clay subsoil, burying water repellent topsoil and incorporating organic matter, agricultural lime or clay. Acidic subsurface layers commonly co-occur with compacted subsurface layers so the incorporation of agricultural lime in the same operation may be desirable. Spaders are more effective at mixing lime through the soil than mouldboard ploughs which bury rather than mix it. As with deep ripping, there is a high risk of re-compaction after spading or mouldboard ploughing unless compaction minimisation techniques (pages 30–33) are adopted.

Rotary spaders and mouldboard ploughs are able to loosen the soil to depths of 25–45 cm, depending on their size.

Figure 22 A trial at Binnu comparing different soil loosening equipment highlighted the need to work the soil to adequate depth for effective amelioration of subsurface compaction.
Implementing a controlled traffic farming system and restricting compaction to wheel tracks is the best way of preventing excessive soil compaction.

Most soils are susceptible to subsoil compaction and it is impossible to completely prevent compaction when using agricultural machinery on soils.

A number of options are available to minimise compaction:

- Restrict machinery traffic to tramlines in a controlled traffic farming system (Figure 23), which confines compaction to the wheel tracks only.
- Minimise traffic when the soil is wet and more susceptible to compaction.
- Minimise traffic when the soil has been cultivated or the subsoil has been loosened.
- Use no till sowing systems which help maintain existing soil structure.
- Keep tyre pressures as low as practically possible and consider tracked machinery.
- Minimise wheel load through the use of dual wheels. This can reduce the severity of compaction but at the expense of an increased volume of soil being compacted for a given operation.

Incorporation of organic matter into heavier textured soils can improve soil structure and soil resilience, but this can be impractical and too expensive to achieve in a broadacre context.

Figure 23 Controlled traffic (tramline) farming at Buntine restricts subsurface compaction to the vehicle wheel tracks.
Vehicle influences on traffic pans

Vehicle weight
Vehicle weight and axle load are the most important vehicle factors influencing the formation of traffic pans. Essentially, the greater the axle load, the greater the subsurface compaction. Modern agricultural machinery tends to be large and heavy, particularly when harvesting. When it is necessary to harvest on wet soil compaction is further increased. Vehicle loads of 10 t can result in subsurface compaction to 50 cm (Ashworth et al. 2010). Spreading the load by having multiple axles reduces the severity of subsurface compaction.

Traffic frequency
On loose soil, the first vehicle pass causes the most subsurface compaction. Subsequent passes increase the area and severity of compaction. In most WA agricultural soils there is little increase in subsurface compaction after four to five passes.

Tyres/tracks
Tyre size, shape and pressure are commonly selected to minimise the soil contact pressure and compaction of the surface soil, particularly if operations need to be carried out on wet soil. Tyre and track choices have less effect on subsurface compaction than vehicle weight and traffic frequency, however good solutions for surface compaction may exacerbate subsurface compaction. Larger, wider tyres result in deeper compaction and increase axle load. If close together, double and triple tyres can act as a single, very wide, tyre which protects the surface soil, but at the expense of increased subsurface compaction.

Solutions
Reducing vehicle influences on subsurface compaction is always a compromise. Low tyre pressure and low axle loads mean less traction and load carrying ability. Vehicles set-up to reduce surface compaction may cause the subsurface compaction to be deeper. Compaction deeper in the subsurface may have less effect on plant growth but is more difficult to fix. No till and controlled traffic farming systems to maintain soil structure and restrict compaction to wheel tracks is the best solution.
Controlled traffic (tramline) farming

In controlled traffic systems the majority of soil does not have any wheel traffic on it at all. This prevents compaction and minimises soil structural degradation and hard-setting of the soil surface. Additionally, improvements in water infiltration, soil structure and increased biological activity may be seen.

The wheel tracks (tramlines) do become compacted in these systems and provide a firm and supportive foundation for machinery movement (Figure 24).

Deep ripping to remove subsoil compaction and then implementing a controlled traffic farming system to prevent re-compaction is the optimum strategy for managing subsurface compaction.

Typically, the benefits of deep ripping are considerably diminished beyond the first three years after ripping as soils begin to re-compact. Under controlled traffic systems, however, the reduced soil strength as a result of deep ripping can last beyond three years (Figure 25).

Figure 24 Compacted soil under a tramline (wheel track) in a deep yellow sand
Minimising compaction

Benefits of controlled traffic farming include:

- reduced inputs by 3–10 per cent because of reduced overlap
- reduced fuel usage, estimated to be up to a 25 per cent saving
- improved yield of the order of 5–15 per cent depending on conditions
- improved trafficability on firm tramlines when the soil is wet
- reduced driver fatigue if auto-steer systems are generally used
- more agronomic options including shielded inter-row spraying, relay planting and inter-row or on-row seed and fertiliser placement.


Figure 25 Soil strength measured on yellow sandy earth soil at Maya at field capacity three years after deep ripping to 50 cm compared with unripped soil, compacted soil under the wheel tracks and in uncropped remnant vegetation nearby. Note that there is no evidence of re-compaction of the ripped soil under a controlled traffic farming system.
Benefits from correcting and minimising subsurface compaction are best considered in terms of production lost, rather than productivity gains.

The response of crops to deep ripping (to remove subsurface compaction as a constraint to production) in research trials can give an indication of the on-farm benefits of correcting and minimising compaction (Figure 26, Tables 3 and 4).

Grain yield responses to deep ripping on the deep sands and sandy earths have tended to be large and reliable, especially in the high and medium rainfall (greater than 350 mm) areas. Benefits from deep ripping these soils appear to last for at least three years, depending on crop rotation and machinery traffic patterns.

Deep ripping of heavier textured soils such as the sandy clay loams, loams and even sodic clays has often been considered to be less reliable. More recent research has shown that the yield responses to deep ripping can be large in the year the soil is ripped although the benefits of ripping can often be short-lived in subsequent years on these soils. Incorporation of organic matter and gypsum in dispersive soils and minimising or avoiding re-compaction, especially when these soils are wet, may help maintain the soil structure and benefits of deep ripping.

Deep ripping **duplex soils** can be beneficial but only when the sandy or loamy A-horizon is deeper than the depth of ripping (Table 3). In shallow duplex soils, where the clay subsoil starts higher in the profile, nutrients and water may be held higher in the profile, allowing access by shallower roots and reducing the benefit of roots being able to explore a greater depth of soil.

![Photo: S Davies, DAFWA](image_url)

**Figure 26** Wheat response to ripping (plus lime) at east Latham can be seen down the riplines. On average, wheat yield responses to deep ripping are large, depending on soil type and whether other constraints are present.
Table 3 **Summary of published average wheat grain yield increases in response to deep ripping**

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Number of comparisons</th>
<th>Average yield response t/ha</th>
<th>%</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Various: sands–clays</td>
<td>65</td>
<td>0.48</td>
<td>25</td>
<td>Davies et al. 2006</td>
</tr>
<tr>
<td>Yellow loamy sands</td>
<td>46</td>
<td>0.65</td>
<td>37</td>
<td>Jarvis 2000</td>
</tr>
<tr>
<td>Duplex with A horizon less than 30 cm</td>
<td>13</td>
<td>0.06</td>
<td>4</td>
<td>Crabtree 1989</td>
</tr>
<tr>
<td>Duplex with A horizon greater than 30 cm</td>
<td>22</td>
<td>0.33</td>
<td>22</td>
<td>Crabtree 1989</td>
</tr>
</tbody>
</table>

Table 4 **Response of crops to deep ripping in research trials**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola</td>
<td>• Grain yield increased by 15 per cent (180 kg/ha) in response to deep ripping on average over 29 comparisons in 15 research trials.</td>
</tr>
<tr>
<td></td>
<td>• Five of the 29 comparisons for canola gave negative yield responses.</td>
</tr>
<tr>
<td></td>
<td>Negative responses were largely due to poor seeding depth control after ripping resulting in poor emergence and low plant numbers.</td>
</tr>
<tr>
<td></td>
<td>Negative responses could be prevented by either avoiding sowing canola in the year the soil is ripped or using a roller behind the deep ripper to settle the topsoil and provide a more level seedbed. Alternatively ripping can be done in the few days after sowing before full germination.</td>
</tr>
<tr>
<td>Barley</td>
<td>• Barley grain yield increased by an average of 49 per cent (540 kg/ha) in response to deep ripping over 11 research trials.</td>
</tr>
<tr>
<td></td>
<td>• No negative barley yield responses to deep ripping have been reported although several showed small non-significant responses.</td>
</tr>
<tr>
<td>Field pea</td>
<td>• Field peas were responsive to deep ripping in 3 out of 5 trials with an average yield increase over the 5 trials of 11 per cent (120 kg/ha).</td>
</tr>
<tr>
<td>Other crops</td>
<td>• Positive yield responses have been observed in a limited number of research trials with oats and chickpeas.</td>
</tr>
<tr>
<td></td>
<td>• Responses to deep ripping have been observed for narrow-leafed lupin but the responses have tended to be smaller and less consistent than for wheat.</td>
</tr>
</tbody>
</table>
A-horizon (topsoil or surface horizon) The top layer of soil, immediately above the B-horizon. Commonly at 0–10 cm, it contains more organic matter, nutrients and soil organisms than the B-horizon and is usually visually distinguishable by its darker colour.

Agricultural lime Used to treat acidic soil. In WA usually a natural mined product—limesand from coastal dunes, crushed limestone from coastal deposits or crushed dolomitic lime from ancient inland waterways. It is comprised primarily of calcium carbonate with varying amounts of magnesium carbonate which are the active ingredients.

Bulk density Weight of soil per unit of volume (g/cm³). Soils with a high bulk density are harder for plant roots to penetrate.

Cation exchange capacity (CEC) A measure of the ability of soil to hold cations which is important for nutrient availability, good soil structure and ability to resist acidification. Soils with high clay and organic matter content generally have high CEC.

Cementation Permanent bonding of soil material into rock-like form.

Cracking clays Fine textured clay surface soils at least 30 cm deep which exhibit three dimensional swelling and shrinkage, resulting in cracks greater than 5 mm wide.

Dispersive soil Soil where the attractive forces between particles are insufficient to hold them together leading to the breakdown of soil aggregates.

Deep sand Sandy textured soil to a depth of at least 80 cm.

Dryland salinity (secondary salinity) Salinity which develops after clearing of natural vegetation leads to salt being brought to the surface by groundwater.

Duplex soil; sandy or loamy duplex Sandy or loamy surface soil over a distinct texture contrast layer at least 10 cm thick and occurring up to 80 cm depth.

Eutrophication Influx of nutrients to waterways leading to rapid increase in aquatic plant and algal production resulting in waterway degradation.

Gravel Soil particles greater than 2 mm diameter.

Gypsum Hydrated calcium sulfate mined in WA from sand dunes or the edges of salt lakes. Used to improve and maintain structure of dispersive soils by assisting with aggregate formation.

Hardpans Layers within the soil profile of high strength (hard) soil.

Plough pan (cultivation pan) High strength layer of soil just below the cultivation depth caused by the action of tillage implements.

Traffic pan High strength layer of soil caused by agricultural vehicle traffic, typically deeper than plough pans.

Non-wetting (water repellency) The tendency of soil particles to repel water (hydrophobic) as a result of waxy organic compounds coating the particles. Leads to water ponding on the soil surface and uneven distribution of moisture in the soil profile.

Organic matter Component of the soil that has been derived from once-living organisms. Occurs in higher quantities in the topsoil.

Packing Arrangement of soil particles such that there is the smallest possible pore space and soil volume and
determined by the shape and size distribution of the particles.

**Perched water table** Occurs where a less permeable soil layer prevents water draining to the natural level.

**pH** A measure of the acidity or alkalinity of soil. Ideal soil pH for plant growth is 5.5–7.5.

**Porosity/pore space** The air-filled spaces between soil particles.

**Root zone** The area of soil occupied by plant roots.

**Rooting depth/maximum rooting depth** The maximum depth reached by plant roots at the end of the growing season.

**Soil acidity** Soil with pH too low for optimum plant growth.

**Soil structure** How the soil particles are arranged. Soil structure good for plant growth has stable aggregates of soil particles allowing adequate pore space.

**Soil strength** The ability of soil to resist penetration. High strength soils have high bulk density and restrict root growth.

**Soil texture** Soils are classified into three main texture groups—sand, loam and clay—according to the proportions of sand, clay and silt in the fine earth (< 2 mm) fraction of the soil.

- **Light textured soils** - sands and loamy sands.
- **Medium textured soils** - loamy sands, clayey sands and sandy loams
- **Heavy textured soils** - loams, clay loams and clay soils.

**Subsoil (or B-horizon)** The soil below the topsoil or A-horizon. Commonly contains less organic matter and more clay than topsoil and may consist of more than one layer.

**Subsurface soil** Soil below the top 10 cm of soil, independent of the depth of topsoil or a change in horizon.

**Subsurface compaction** Soil compaction occurring below 10 cm depth.

**Surface compaction** Soil compaction in the top 10 cm of soil.

**Topsoil** see A-horizon

**Transient bonding** Temporary bonding of soil constituents increasing the strength of the soil but softening again with wetting.

**Universal indicator** A chemical pH indicator that changes colour with change in pH from red (strong acid) through orange/yellow, green (neutral), blue and purple (strong base). Comprised of several chemical compounds.

**Waterlogging** Occurs when excess water in the soil results in insufficient oxygen in the pore space for plant root respiration. Waterlogging may occur without surface inundation.
References and further reading


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