Soil structure management

The key to maintaining good soil structure over the long term is to monitor your soils. Keep comprehensive records to track your progress and assess the benefits and costs of your management actions.

KEY POINTS

- **Structure in soils is not static – it can be both created and destroyed.**
- **Some soils are naturally well structured. The structure of all soils, however, will be degraded by poor practices.**
- **Having soil with good structure will maximise water use efficiency from the rain or irrigation applied to the crop.**
- **Good soil structure is characterised by:**
  - No impediment to water entry to the soil
  - High water-holding capacity
  - Freely drained, with a range of pore sizes to ensure adequate aeration at high water content
  - Sufficient soil strength to give good structural support to the plant, but not so high that it impedes root penetration and growth.
- **Poor soil structure leads to reduced yields because of:**
  - Poor emergence and establishment
  - Low water-holding capacity and periods of crop stress through water shortage
  - Waterlogging
- **There are four principles underlying all management actions to maintain or improve soil structure:**
  - 1. Retain stubbles
  - 2. Minimise tillage
  - 3. Control traffic
  - 4. Avoid prolonged bare fallows
- **The key to maintaining good soil structure over the long term is to monitor your soils. Keep comprehensive records to track your progress and assess the benefits and costs of your management actions.**

Diagnosis and management of soil structural problems

Step 1
Determine your soil type

Step 2
Identify the problem

Step 3
Manage to improve and maintain soil structure

Step 1 – Determine your soil type

Management of soil structure depends largely on its texture (i.e. clay content). Most soils in southern NSW fit into one of two categories:

Loams over clay

Texture contrast soils have a sharp change in texture between the topsoil and subsoil, with a loam-to-clay-loam topsoil overlying a clay-to-heavy-clay subsoil (Figure 1).

Figure 1. A texture contrast (duplex) soil showing a clay loam topsoil (0-25 cm) overlying a heavy clay subsoil.

Clay soils

Uniformly textured soils have high clay contents (45-70%) throughout and are characterised by deep vertical cracks from the surface to depth when dry (Figure 2). These soils may exhibit self-mulching characteristics (Figure 3).

Figure 2. A uniform, grey clay showing the absence of any abrupt texture change within the profile.

Figure 3. A uniform, grey clay showing the crumb surface structure and cracking typical of self-mulching soils.

SOIL STRUCTURE MANAGEMENT – EXTENSION OF BEST PRACTICE PRINCIPLES FOR IDENTIFYING AND MANAGING SOIL LIMITATIONS IN SOUTHERN AND CENTRAL NSW

Step 2 - Identify the problem

Loams over clay (texture contrast soils)

Loam and clay loam topsoils are very susceptible to soil structural breakdown. Clay particles and organic matter are the primary binding agents in all soils, so the low clay content of these topsoils means that organic matter plays the major role in binding soil particles into aggregates. Excessive cultivation, particularly when the soil is dry, leads to the loss of organic matter and is the major cause of structural problems in this soil type.

PROBLEM	DIAGNOSIS	PREDISPOSING FACTORS
Surface crusting/ hardsetting Surface crusting and hardsetting seals the soil and leads to poor water infiltration and run-off. This results in less soil water in 'shedding' areas and poor growth in dry years (Figure 4), possible waterlogging in low areas in wet years, and increased erosion risk.	**Surface crusts** are distinct, often laminated, layers that are millimetres to tens of millimetres thick, which cannot be readily separated from and lifted off the soil below (Figure 5). **Hardsetting** occurs below any surface crust or flake and occurs as a compact, hard and structureless layer when dry, which is not indented by finger pressure (Figure 6).	Slaking Cultivation, particularly when too dry Organic carbon < 2%
Hardpan formation Cultivation pans (i.e. compacted or hard layers in the soil) form readily in these soils. The top of the B horizon is often a place of clay accumulation and a natural 'throttle'. This zone can be easily compacted by repeated cultivation of the overlying soil to the same depth. Hardpans can restrict root growth (Figure 7 and Figure 8) as well as water movement and nutrient availability.	**Matting of cereal roots** on top of a hard, dense layer, or **J-rooting of tap-rooted crops**, with roots failing to penetrate this dense layer, indicates a problem pan. A wet layer above the hardpan after moderate rain indicates water movement into the subsoil is being held up. A cone penetrometer (Figure 9) can show the presence of a hardpan when readings in moist soil exceed 2500 kPa.	Repeated cultivation of a soil to the same depth creates a hardpan just below the ploughed layer.

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Step 2 - Identify the problem

Clay soils (uniformly textured soils)

The clay mineral fraction (45-75%) dominates these soils. The plate-like structure of clay minerals and their chemistry allows water to move into the space between these 'plates' when clays are wet, increasing the inter-plate distance and weakening the forces that bind the clay particles into aggregates. Consequently, these soils are particularly susceptible to deformation (squashing) from compressive forces when wet. The net negative charge on the surface of clay 'plates' also attract charged atoms such as sodium and calcium. As the proportion of sodium on exchange sites increases relative to that of all other cations, the attractive forces between clays weaken and aggregate stability decreases. See the Sodicity and alkalinity Factsheet for more information. http://www.farmlink.com.au/project/grdc-soils-extension

Self-mulching clays (Figure 3) have a greater surface area and higher charge density than non-self-mulching clays and this gives them greater aggregate stability (better subbing, higher water holding) and an ability to 'self-repair' if they are deeply dried. However their structure will still be degraded by poor management practices.

PROBLEM	DIAGNOSIS	PREDISPOSING FACTORS
Compaction When soil is compressed, its pore volume is reduced and it becomes denser. This makes it harder for roots to grow, reducing access to both water and nutrients. There is also less oxygen in the soil, and infiltration and water holding are reduced so rainfall is less effective and erosion risk is greater.	J-rooting of canola or small, clumped roots in cereal crops are symptomatic of compaction in clay soils. Test using a cone penetrometer. Values > 2500 kPa in moist soil indicate compaction, as do bulk densities > 1.6 g/cm^3. In irrigated paddocks, clay soils coalescence as a result of frequent irrigation with very fresh water. This should not be confused with traffic-induced compaction.	Trafficking and cultivating when the soil is wet (Figure 10) Multiple machinery passes Uncontrolled trafficking Heavy machinery and animals can compact soils to 70 cm
Sodic soils Sodic soils suffer from: a) poor crop emergence b) poor water infiltration, waterlogging and run-off c) poor root growth Topsoil dispersion causes problems (a) and (b) (Figure 11). Dispersed clays in sodic subsoil blocks pores and restricts internal drainage and contributes to problems (b) and (c).	Soils are considered sodic when the amount of sodium affects structure. This is seen as dispersion (Figure 11). Sodic soils seal when wet and set hard when dry. Dispersed surface soils form a surface flake on drying (Figure 12). Conduct a test. Send soil away for analysis to test for EC, ESP, CEC and organic C if dispersion is observed. Seek advice as to management actions. See the Sodicity and alkalinity Factsheet for more information. http://www.farmlink.com.au/project/grdc-soils-extension	High levels of sodium on exchange sites Low salinity The problem is aggravated by: 1. low soil organic matter 2. cultivation

Figure 4. Surface crusting and hardsetting in a red, texture contrast soil resulting in water-shedding and death of wheat from drought on high knobs under a pivot irrigator.

Figure 5. Surface crusting following irrigation of a cultivated texture contrast soil.

Figure 6. A hardset soil horizon on the left compared to a well structured sample of the same soil on the right.

Figure 7. The top surface of a hardpan (a depth of 10 cm from the surface) showing fine cereal roots growing horizontally on the pan.

Figure 8. The same hardpan seen in side-profile. Note the absence of roots in the pan.

Figure 9. A cone penetrometer that has been pushed into the soil to collect soil strength readings under a wheat crop.

Figure 10. Smearing and compaction of a clay soil as a result of sowing when the soil was too wet

Figure 11. Dispersion of a sodic grey clay leading to waterlogging and poor establishment of wheat.

Figure 12. Typical surface flake formation seen in a sodic clay following rainfall

SOIL STRUCTURE MANAGEMENT – EXTENSION OF BEST PRACTICE PRINCIPLES FOR IDENTIFYING AND MANAGING SOIL LIMITATIONS IN SOUTHERN AND CENTRAL NSW

Step 3 - Manage to improve and maintain soil structure

1. Where a hardpan or compaction has been identified, deconsolidate the soil

While deep tillage can be used to reduce soil compaction and break up hardpans, it is not suited to all soil types. GRDC's Deep Ripping Factsheet has more information.

The critical consideration for all clay subsoils is that the soil is relatively dry so that it shatters (see Assessing soil moisture for tillage).

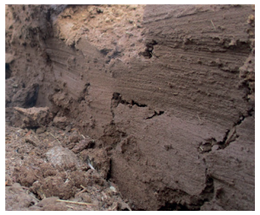

Figure 13. Smearing of clay subsoil as a result of deep ripping when too wet.

Take a handful of soil and try to squeeze it into a ball. A dry soil will not form a ball. A very compact lump or a dry clod of heavy clay will not break.

If the soil breaks into powder:		If the soil crumbles but does not powder:
Sand, silts and loams – are too dry to till and will pulverise.	**Clay soils –** can be safely tilled.	**All soils –** this is a good moisture content to till.

If the soil forms a ball, then it is moist. Place the ball between your thumb and forefinger and squeeze, sliding your thumb across the soil.

If it the soil does not form a ribbon:	If the soil forms a ribbon:	
All soils – the soil is at a good moisture content to till.	**Sand, silts and loams –** can be tilled, but may smear if they are too wet (i.e. if they ribbon easily). Test by trying to roll the soil into a 3 mm rod. • If the soil forms a 3 mm rod, then it is too wet to till. • If it can only form a crumbly rod, it is dry enough to till	**Clay soils –** are too wet and will smear at this moisture content; they should not be tilled.

The right water content for deep tillage

Deep tillage in moist clay subsoils causes further compaction and smearing of the soil (Figure 13).

Deep tillage **is not recommended where subsoils are sodic**. While ripping can reduce soil compaction in sodic subsoils, its effects are not likely to be long-lasting.

The situation can be made worse by deep tillage if:

1. Sodic subsoil is brought to the surface
2. Blocks of hard subsoil are brought to the surface that need repeat workings to break them down to form a seedbed.

Loams over clay – use progressive tillage

- **If a hardpan has been identified** – tillage need only be to a depth just under the pan. Going deeper has no additional benefit and is expensive.
- **Progressive tillage and tillage rotation** – is a proven, low-cost and effective technique for breaking up hardpans and improving the rooting depth and water-holding capacity of these soils.

Self-mulching clays – use deep drying

- These soils are 'self-repairing' if passed through a drying phase that allows clays to re-aggregate.
- Natural remedies to break hard pans and compaction, such as using deep-rooted rotation crops to dry and crack the subsoil, should be used where possible in soils that are self-mulching (see Cotton Info SOILpak for more information)

2. Prevent soil consolidation – adopt the following practices

2.1. Controlled traffic

- Reconfigure machinery to fit the tractor wheel spacing and either mark out tramlines or use GPS guidance.
- Leaving the header out of the system makes controlling traffic easier to do and more affordable. Harvesting on a 15-20° angle to tramlines helps spread trash and makes it easier to sow into stubbles for following crops.
- Remove stock from cropping paddocks when wet conditions are forecast to avoid compaction.

2.2. Reduce cultivations – adopt direct drill and minimum/strategic till

Soil structure is preserved by using:

- Herbicides and direct drilling to reduce the number of cultivations
- Tyned implements instead of disc implements when sowing
- Offset scalloped discs instead of one-way disc ploughs when fallowing
- Herbicides are an invaluable tool to increase flexibility, but rotations and the use of strategic cultivation are essential to avoid a build-up of herbicide resistance. (See GRDC Strategic Tillage work.)

Loams over clay

- Too much cultivation when too dry is the major cause of soil structure problems in this soil type.
- **Minimum till and direct drill should be standard practice in these soil types.**

2.3. Cultivate at the correct moisture content

Test your soil is at the right moisture content for cultivating (see Assessing soil moisture for tillage).

Loams over clay

- The moisture content at which these soils are cultivated is critical for maintaining good structure.
- **These soils should not be cultivated when too dry** as they will pulverise.

Clay soils

- It is best to work clay soils on the dry side.
- Clay particle cohesion gives these soils greater resistance to structural breakdown if cultivated dry, but their plasticity makes them susceptible to compaction, slabbing and smearing if cultivated when too wet (Figure 10).

2.4. Gypsum and/or lime amendment

- All cropping soils require lime to maintain soil pH – see the Soil Acidity Fact Sheet http://www.farmlink.com.au/project/grdc-soils-extension
- Only soils that are sodic AND dispersive require gypsum
- Test for dispersion using the slaking and dispersion test. If soils disperse, collect samples and send them away for analysis. Seek advice on appropriate gypsum rates based on the resulting cation exchange capacity (CEC) and exchangeable sodium percent (ESP) of the tested soil.
- **Lime** has very low solubility and should only be used in soils where pH_{water} is less than 5.5 and the desired effect is to supply both calcium for sodicity and carbonate for pH amelioration. In these cases, combinations of both lime and gypsum are most effective.

Loams over clay

- Crusting and hardsetting in these soils is an indication of low organic matter, NOT sodicity.
- **Slaking** without dispersion shows there is not enough **organic matter** to stabilise aggregates.
- **Gypsum is only needed if soil disperses in fresh water**

Uniform clays

- Clay soils that **disperse** are likely to be **sodic**.
- If dispersive, conduct soil tests for ESP and pH.
- Seek advice on appropriate gypsum rates for sodic, dispersive soils. Rates should be based on the CEC, bulk density, and desired change in ESP over desired depth of treatment.

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Step 3 - Manage to improve and maintain soil structure

3. Build soil organic matter – grow something

3.1. Avoid bare fallows and retain stubbles

- Retaining crop residues and stubbles conserves soil moisture, protects the soil surface from erosion (wind, water), increases the amount of organic matter, and encourages earthworms.
- **Organic matter is very important in loam over clay soils** as it cements soil particles together and is crucial for structure maintenance. It also holds a high reserve of nutrients and aids water holding.
- **Target an organic carbon level of 2% to ensure water stable aggregates** in lighter-textured soils.

3.2. Include pastures in crop rotations

- Inclusion of a vigorous pasture phase in the cropping rotation is ideal for rebuilding structure. Legume pastures will build organic matter levels and soil stability.
- Stock grazing these pastures should be managed to maintain around 70% ground cover, which will prevent water run-off and soil erosion.
- Remove stock from cropping paddocks if wet conditions are forecast, to avoid compaction.

A simple slaking and dispersion test for sodicity

1) Take some dry crumbs of soil from the depth of interest and put them in a dish of rainwater.
2) Observe the soil after about 10 minutes has elapsed and assess its stability (Figure 14).
   a) Stable aggregates (bottom left) – the attractive forces between soil particles are greater than the repulsive forces when the soil is wet, so aggregates remain intact. This is indicative of good soil structure.
   b) Slaked aggregates (bottom right) – the forces acting to separate soil particles when the soil is wet are greater than the attractive forces, so the soil loses coherence and aggregates 'melt'. This is indicative of low organic matter.
   c) Dispersed aggregates (top) – the bonds between clay particles are broken and the clays are separated from each other and form a suspension in water. This is indicative of sodicity.
3) A laboratory soil test that includes exchangeable cations can confirm sodicity.

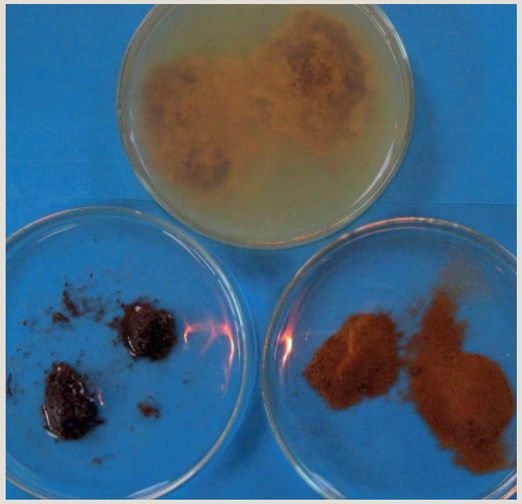

Figure 14. Dispersed (top), slaked (bottom right) and stable (bottom left) soil aggregates in water.

Assessing soil moisture for tillage

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- **Clay soils –** can be safely tilled.

If the soil crumbles but does not powder:

- **All soils –** this is a good moisture content to till.

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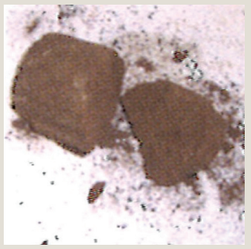
  - If it can only form a crumbly rod, it is dry enough to till
- **Clay soils –** are too wet and will smear at this moisture content; they should not be tilled.

The right water content for deep tillage

Dig down to the hardpan or compacted layer you wish to break up. Take a spade-full of the soil from this hard, compacted layer and drop it from a height of one metre onto a tarp spread on the ground. Use the pictures below to see if the soil is the right moisture content to ensure deep tillage will be effective.

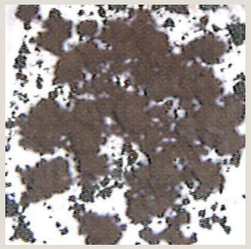


If the soil remains in a few large clods or does not break up at all, the soil is too dry for deep tillage to do the best job.

There is a high probability of bringing large, possibly sodic, clods to the surface that will require repeat working to break down and form an adequate seed bed.

This is also an indicator of high bulk density.

If the soil lands in a 'splat' it is too wet for any tillage.



If the soil is tested when moist and it ends up in lots of small, discrete, but relatively soft clods, this is ideal for deep tillage. Compacted wet soil when subjected to impact stress will shatter into small aggregates.

If the soil is tested when dry and it ends up in small discrete clods, the bulk density will be low. Deep tillage is not likely to be useful because compaction or hardpans are probably not present.

More information

Cotton Info SOILpak

https://www.cottoninfo.com.au/publications/soilpak

Strategic Tillage Fact Sheet

www.grdc.com.au/GRDC-FS-StrategicTillage

Sodicity and Alkalinity Fact Sheet

http://www.farmlink.com.au/project/grdc-soils-extension

All Figures Sam North, NSW DPI except:

Figure 1 & 2: Justin Hughes – Southern Irrigation SoilPak, NSW Agriculture

Figure 6: source: Dr Richard Doyle, Senior Lecturer in Soil Science, Tasmanian Institute of Agriculture, School of Land and Food, University of Tasmania)

"Right water content for tillage" – three photos – David Malinda, SAARDI

This factsheet was written by Sam North and Abigail Jenkins from NSW DPI as part of the **Extension of best practice principles for identifying and managing soil limitations in southern and central NSW** (GRDC Project code FLR1909-001SAX).

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