Part 3: Managing soil constraints

Sustainable agricultural systems are based on managing soils according to their capabilities and constraints.

The productive capacity of a soil is determined by soil properties; some (such as texture) are inherent and cannot be changed easily, while others (such as pH) can be manipulated by management.

Once you know your soils and their inherent constraints, you can then make an informed decision on how to maximise productivity, sustainability and soil health.

Management options are provided for the following.

Physical constraints

- waterlogging and excessive/prolonged wetness
- low water-holding capacity
- hard-setting/surface sealing
- compaction.

Chemical constraints

- low nutrient retention
- acidity
- salinity
- sodicity
- alkalinity
- high phosphorus fixation
- extremely low phosphorus retention
- low organic matter content.

Biological constraints

- soil-borne diseases
- soil insect pests.

Physical constraints

Waterlogging and excessive/prolonged wetness

Excessive or prolonged soil wetness indicates limited water movement through the soil profile. This can be a result of compaction or sealing at the soil surface, subsoil compaction or a clay subsoil horizon.

A soil that previously drained well but now has a waterlogging problem may have a compacted 'hard pan' as a result of tillage and/or machinery traffic.

Waterlogging causes anaerobic (oxygen-depleted) soil conditions, which lead to denitrification (loss of nitrogen to the atmosphere as the gas nitrous oxide—a contributor to global warming), death of plant roots and favourable conditions for root pathogens.

Indicators

Things to look for that may indicate the constraint:

- low-lying position in the landscape
- clayey texture
- mottles or bleaches in the soil profile
- pale-coloured or bleached subsoil.

Measurement methods

Measurements that may indicate the constraint:

- high bulk density
- high soil resistance (see 'Drop penetrometer to measure soil resistance' on p. 33).

Management

Practices that combat hard pans and water infiltration problems will help improve internal soil drainage and reduce the risk of excessive or prolonged soil wetness. These include:

- deep ripping to break the hard pans
- changing to minimum tillage practices
- mounding of crop beds
- rotating with crops that are deep-rooted, such as forage sorghum and lucerne
- avoiding driving heavy vehicles and machinery over wet ground
- adding organic material—needs to be continued for many years. This is only a remedy in loam and clay soils where aggregation can be improved (see 'Case study 1' on p. 12).

Increasing the efficiency with which surface water is removed from paddocks will also help. This can be achieved using ground works such as:

- laser levelling
- stabilised surface drains
- subsurface drainage.

Case study 1: Dealing with waterlogging

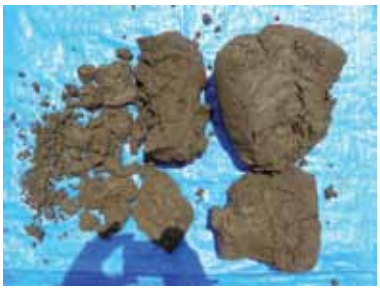
Over the past eight years, Mario Muscat has been working hard to improve soil health and soil structure at his Windsor farm in New South Wales. He has been using organic fertilisers to increase his inputs of soil carbon and reducing his tillage with the aim of finding a better way to farm.

Mario is still smiling despite the wet weather

The result has been a steady improvement in his soil structure. This was apparent when his farm experienced wet weather in December 2007. Mario's sweet corn crop did not suffer as much as a neighbouring sweet corn crop. This could be attributed largely to good soil structure, which allowed water to move through the soil profile and allowed air back into the soil.

Testing of Mario's soil showed a lower soil bulk density, which meant there were more pore spaces in the soil, and increased aggregate stability, which meant that soil pores were not being clogged with disintegrating soil particles. Mario's soil also had a higher soil nitrate reading compared to the farm next door, suggesting he may not have lost as much nitrogen during the wet weather.

Through good soil management Mario was able to offset the impacts of prolonged wet weather and maintain yield. By reducing tillage and using organic fertilisers, Mario can continue to improve the porosity of his soil. Mario knows that his efforts at maintaining a healthy soil will pay off next time he gets wet weather.

Indicator	Mario's farm	Nearby
Soil	Clay loam	Clay loam
Bulk density (g/cm^3)	1.31	1.42
Aggregate stability (%)	11	3
Organic carbon (%) (Walkley–Black method)	1.3	1.6
Labile carbon (mg/kg)	613	580
Nitrate-nitrogen (mg/kg)	12.5	3.5
Soil structure from drop test three days after heavy rain (see Soil drop test on p. 35)		

Low water-holding capacity

Low water-holding capacity indicates a sandy textured soil with low organic matter content or a clay loam soil with a high content of iron oxides (e.g. a ferrosol soil). Soils with low water-holding capacity are drought-prone and require frequent irrigation to maintain crop growth.

Indicators

Things to look for that may indicate the constraint:

- light-coloured soil with a sandy texture
- red clay loam soil (ferrosol)
- crop wilts only a short time after rain or irrigation
- high water infiltration rate.

Measurement methods

Measurements that may indicate the constraint:

- low soil organic carbon (SOC) level (see 'Soil organic carbon (SOC) and labile carbon' on p. 24).

Management

Increasing soil organic matter content will improve the water-holding capacity of the soil (see 'Low organic matter content' on p. 20). Applying clay minerals or water-retaining compounds is also possible, although the economics of these options need to be carefully assessed.

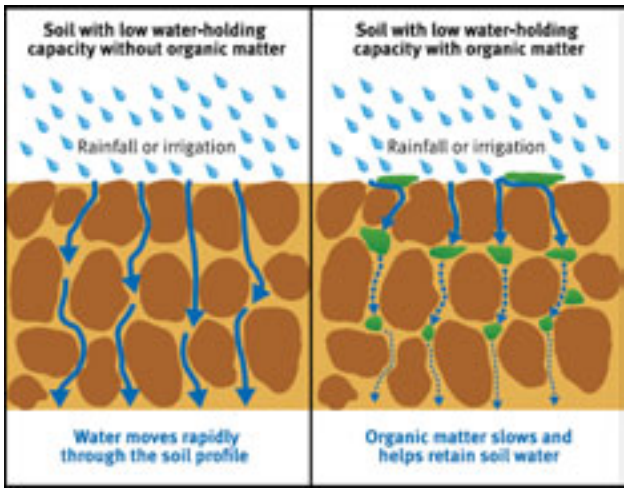


Figure 1. Water moves quickly through soils with low water-holding capacity. With higher organic matter levels, water movement is slowed and soils retain more moisture

Hard-setting/surface sealing

A hard-setting soil or a soil that has a surface seal is often the result of dispersed clay particles and indicates poor soil structure and/or possible sodicity problems (see 'Sodicity' on p. 18).

Another cause of surface sealing is raindrop impact on weak soil aggregates, causing them to disintegrate and allowing small particles to seal off soil pores. Too much cultivation, reduced soil carbon levels or a bare soil surface increases the risk of surface sealing problems.

Surface seals (or surface crusts) impede seedling emergence and increase run-off from rainfall or irrigation, thus increasing the potential for erosion. Silty soils and sandy soils with a high proportion of fine sand are prone to hard-setting.

Indicators

Things to look for that may indicate the constraint:

- visible surface crust or clay 'skin'.

Measurement methods

Measurements that may indicate the constraint:

- high penetrometer resistance (see 'Drop penetrometer to measure soil resistance' on p. 33)
- dispersion and/or slaking (see 'Emerson dispersion test' on p. 6).

Management

By increasing soil organic matter content and reducing tillage, soil surface crusting can be minimised. The most important factor is to maintain some surface cover on the soil at all times. This reduces the force with which raindrops hit the soil surface and keeps the soil surface open, allowing water and air to enter the soil profile.

Short-term remedial practices such as tillage are able to physically loosen the soil surface but this is only temporary—the next rainfall or irrigation event will again result in surface crusting. In the long term, reduced tillage, controlled traffic, maintaining soil surface cover and adding organic matter will all help to reduce soil surface crusting.

Practices that reduce the risk of compaction, such as increasing soil organic matter content and reducing tillage, are useful for managing hard-setting soils.

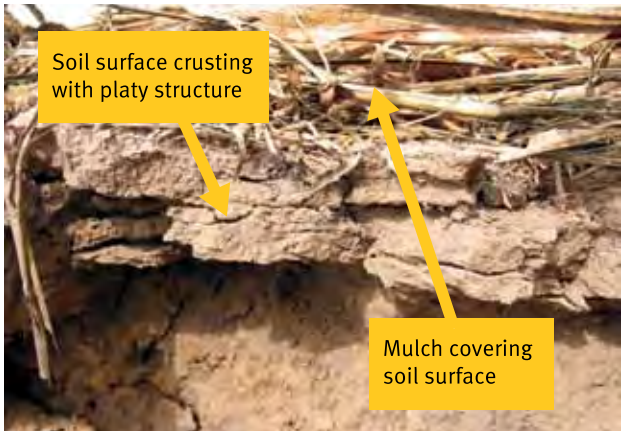


Figure 2. This soil with surface crusting shows a 'platey' structure (the soil compacted into layers), which slows the movement of air and water into the soil. Surface mulch retains moisture and reduces the impact of the surface crusting on plant growth

Compaction

Compaction is caused by applying stress to a soil with a moisture content wetter than its plastic limit (see 'Determining the plastic limit' breakout box below). This stress causes the soil to deform (or smear in the case of tillage) and form a layer with very few pore spaces (i.e. it has a high bulk density). Both aggressive tillage and wheeled traffic apply stress to a soil and can result in compaction if the soil is wet. The soil can become compacted on the soil surface or in the subsoil just below the cultivation depth (a 'plough pan').

Compacted soils are less permeable to air and water. When water is unable to infiltrate into the soil it will run off the soil surface, causing erosion problems. Compacted subsoils restrict water movement through the profile, resulting in a perched watertable and anaerobic conditions.

The volume of soil that plant roots are able to explore is also reduced in compacted soil, making it harder for plants to take up water and nutrients. The pore spaces are smaller in compacted soil and plants have more difficulty extracting water from small pore spaces than large ones. Therefore, compacted soils have lower plant-available water even when they have more total water compared to non-compacted soils. Compacted soils also offer greater resistance to tillage implements, thus requiring greater horsepower and higher fuel consumption for tillage operations.

Determining the plastic limit

How to assess if a soil is wetter or drier than its plastic limit:

- Collect some soil (about the size of a golf ball) from at least 10 cm below the proposed depth of cultivation.
- Roll the soil between the palms of the hands and attempt to form a rod or cylinder about 50 mm long and 4 mm thick.
- If cracks appear in the cylinder, the soil is drier than its plastic limit and is therefore suitable for cultivation.
- If the cylinder stays intact, then the soil is wetter than its plastic limit and cultivation will cause compaction.

This technique is very useful for assessing your soil's readiness for cultivation, thus reducing the risk of compaction.

Indicators

Things to look for that may indicate the constraint:

- silty soil texture or a soil with a high content of fine sand
- a soil layer exhibiting 'platey' structure, especially at the usual depth of tillage
- plants showing sudden water stress.

Measurement methods

Measurements that may indicate the constraint:

- Bulk density will identify generalised soil compaction but not specific compaction layers.
- Abrupt increase in penetrometer resistance with depth identifies compaction layers (see 'Drop penetrometer to measure soil resistance' on p. 33).

Management

Deep ripping is the first option to correct subsoil compaction as it can break the plough layer, but this is only a temporary solution. Once the soil receives rainfall, and with normal irrigation and cropping practices, it will return to a compacted state.

Rotating crops between plants with a fine, fibrous root system and deep tap roots can help to break apart compacted soil, allowing air and water to move down the old root channels into the soil profile.

Tillage of wet soils will lead to subsurface compaction due to compression and smearing caused by implements. Therefore, the soil should only be tilled when it is drier than its plastic limit just below the depth of cultivation (see 'Determining the plastic limit' breakout box). Rotary hoes, mouldboard ploughs and disked implements are more likely to cause compaction than tyned implements because they are more disruptive to the soil.

Tillage and its impact on soil health are discussed in more detail in Part 5.

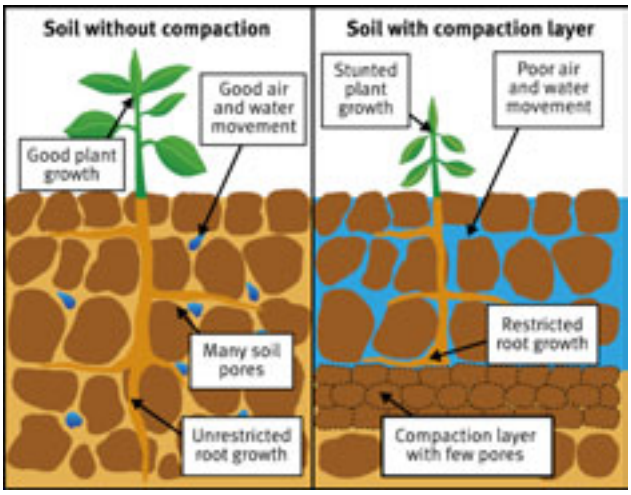


Figure 3. Excessive tillage or traffic when the soil is above its plastic limit can lead to a compaction layer, which limits root development and air and water movement through the soil

Chemical constraints

Low nutrient retention

Soils with a low cation exchange capacity (CEC less than 4 cmol(+)/kg) have a very limited ability to hold nutrient cations such as potassium (K^+), calcium (Ca^{++}) and magnesium (Mg^{++}).

Under such circumstances, these nutrients leach with the movement of water through the soil profile. Sandy soils typically have a low nutrient holding capacity because the soil particles are large, with a limited amount of charged surface area to attract and hold onto nutrient cations.

Indicators

Things to look for that may indicate the constraint:

- light-coloured soil with a sandy texture.

Measurement methods

Measurements that may indicate the constraint:

- low CEC value from standard nutrient soil test. Note that CEC can be expressed as cmol(+)/kg or as meq/100 g. For all practical purposes these units are the same.

Management

Management of soils with low nutrient retention must focus on increasing the CEC of the soil. CEC can be improved by increasing soil organic matter content (see 'Low organic matter content' on p. 20) or adding high-activity clay minerals (if economically feasible).

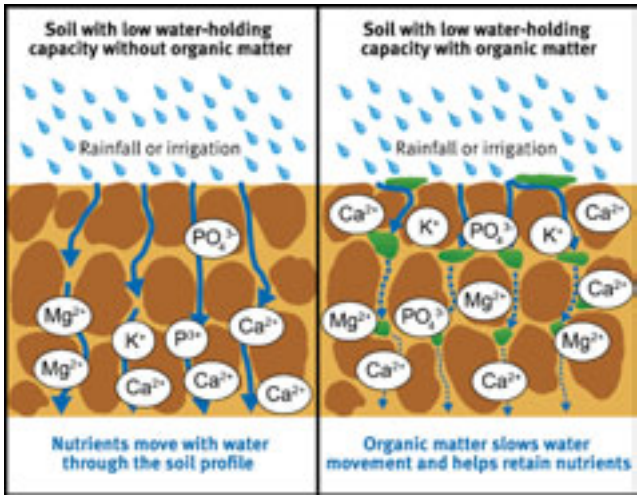


Figure 4. Adding organic matter to the soil can increase its CEC (a measure of the soil's ability to hold onto nutrients) and increase the water-holding capacity of the soil

Case study 2: Dealing with soils that have low nutrient retention

Two brothers started growing loose-leaf lettuce on adjacent blocks near Gingin, north of Perth, in the late 1990s. They adopted two different management approaches. At one site they focused on applying best fertiliser and irrigation management practices, while management at the other site focused on using organic amendments to improve soil performance. The organic amendments included regular use of manures and some use of compost.

As part of a national soil health project, areas of similar soil and crop rotations were selected and the soils tested to compare the impacts of the treatments on soil health.

These tests showed that regular use of organic amendments has increased soil organic carbon (SOC) almost three-fold and as a result, soil water-holding capacity and nutrient holding capacity have similarly increased. The amended soil has a higher phosphorus buffering capacity (a measure of the soil's ability to hold onto phosphorus) and improved nitrate retention. Soil pH has also increased. Best practice fertiliser and irrigation management would be expected to amend the very low pH on this site with lime or dolomite guided by a 'lime requirement' soil test.

As well as an increase in SOC, the use of organic amendments has increased the amount of labile carbon, which is the active form of carbon readily used by microbes in the soil. Adding organic matter has lowered the bulk density of the soil, probably due to improved soil aggregation. This results in increased porosity and aeration, making it easier for roots to explore the soil.

Sandy soils tend to have limited buffering capacity, meaning that they quickly run out of available nutrients. By regularly adding organic matter, the soil was better able to retain nutrients.

Indicator	With organic inputs	Without organic inputs
Texture	Loamy sand	Loamy sand
Organic carbon (%) (Walkley–Black method)	1.95	0.67
Labile carbon (mg/kg)	720	584
CEC (meq/100 g)	10.6	2.7
Nitrate-nitrogen (mg/kg)	31.2	12.0
Phosphorus buffer index	85	35
Soil pH	6.8	4.6
Bulk density (g/cm3)	1.11	1.40