Chapter 5

Physical constraints to root growth

> **Key points**
>
> - Physical constraints include compacted soil layers, layers of inherently high bulk density and layers of gravel or bedrock.
> - Like other subsoil constraints, physical constraints reduce the volume of soil explored by roots, rooting depth, and therefore, plant access to soil water and nutrients.
> - Different plant species have different abilities to penetrate hard layers.
> - Physical constraints are not easily diagnosed; the sight and touch of an experienced soils officer is still the most common diagnostic approach.
> - Objective methods of detecting physical constraints require careful interpretation.

What are physical constraints?

Physical constraints include compacted soil layers, layers of high bulk density and layers of gravel or bedrock. Root penetration through these compacted layers is restricted due to either high physical strength and/or low total porosity.

Although the terms compaction and high bulk density are often used interchangeably, determining whether a soil has a compacted layer by measuring bulk density or cone penetrometer resistance can be a crude process. Although compaction is typically measured by the amount of force (in kilopascals) required to penetrate a layer, bulk density is measured as the mass of soil per unit volume (g/cm^3). In agricultural situations, compaction typically occurs to a depth of about 30 cm due to traffic by machinery and/or animals (Figure 5.1a). The type of tyre, the air pressure in the tyre and the weight of the vehicle, and most importantly, soil moisture, all have a bearing on soil compaction by vehicles. On the other hand, high bulk density can also occur naturally in subsoils (> 50 cm) which have inherently poor structure.

Figure 5.1a: Deep compression wheel tracks, exposed after sheet erosion of topsoil, clearly showing how compaction has affected 80% of this field. (Greg Butler, NSW Dept of Agriculture (in Tullberg, J. "Driving a revolution in agriculture." ECOS, vol 118 Jan-Mar 2004).

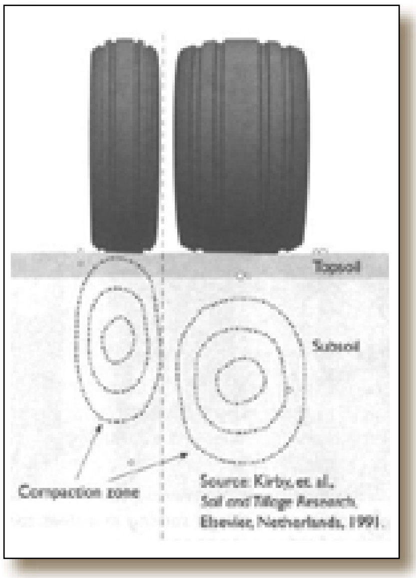

Figure 5.1b: Affect of tyre width on the shape of compaction in underlying soil.

Many of the cropping soils of southern Australia are naturally pre-disposed to compaction because the distributions of sand, silt and clay particles in these sandy or loamy soils are ideal for tight packing. Also the types of clays in these soils do not often promote strong swelling and shrinking (which helps break up compaction). These soils contrast with other soils such as the heavy grey soils of the Wimmera district, which shrink and swell during wetting/drying cycles creating large cracks down the profile. These cracks ameliorate compacted layers but may not eliminate them entirely.

Soils with low bulk density and little compaction are better suited for cropping. Bruand & Gilkes (2002) state that once bulk density exceeds 1.7 g/cm^3, physical resistance and poor aeration restrict root growth. An audit of agricultural land in Australia by the National Land and Water Resources Audit (2001) suggested that once the bulk density exceeds 1.61 – 1.8 g/cm^3 in sandy soils and above 1.4 g/cm^3 in silty and clay soils, root penetration and consequently plant growth are affected. Brady (1990) indicates that at bulk densities higher than 1.6 g/cm^3, root growth is substantially impaired due to very little macropore space.

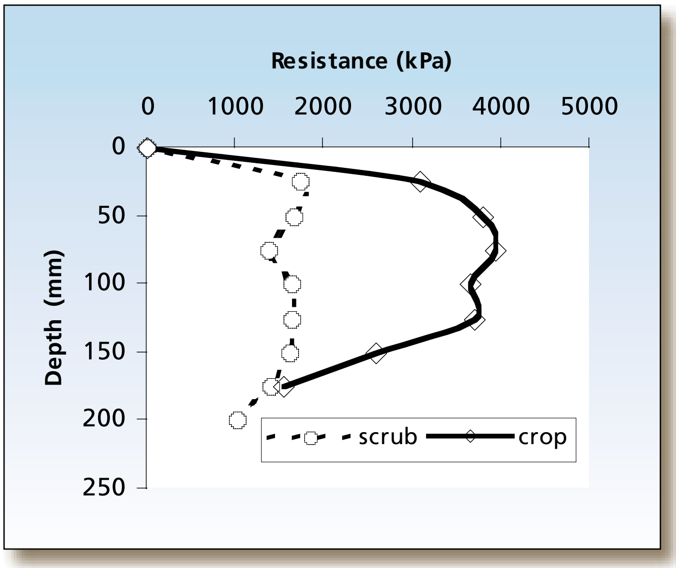

Figure 5.2: A red clay loam on upper Eyre Peninsula is more compacted under cropping than under nearby scrub (S Doudle, SARDI, Minnipa Ag Centre).

Shallow soil can itself be a physical constraint to root depth. Soil depth is an attribute just as important as soil type. Soils with calcareous origins, especially those in mallee regions, are often shallow, with limestone sheets or rubble constraining the rooting depth. Gravel and sand layers, even though porous, can also impede root growth (see Figure 6.3 & 6.4, Chapter 6).

Compacted or hard layers can also be a constraint by causing water logging within the root zone. Hard layers not only impede the growth of plant roots but can also reduce the rate of flow of water down the soil profile. If these layers provide a sufficiently tight bottleneck to water flow (commonly resulting in perched watertables), then the soil profile above the layer can become saturated, oxygen can be excluded and plant roots can eventually die. Nitrogen can also be lost as gaseous N_2 through denitrification under these conditions, which can result in large losses of N fertilizer and N-starved crops and pastures.

Although no comprehensive surveys have been undertaken to estimate the extent and severity of compacted layers in agricultural soils of southern Australia, the available evidence suggests compacted layers are a major problem. For example, in a recent sampling of major soil types on upper Eyre Peninsula (S Doudle, unpubl), 18 of the 19 soil profiles were more compacted in the farmed area compared to the nearby scrub (see Figure 5.2). Deep ripping on some of the deep sands of Western Australia has highlighted the extent and severity of compacted layers in these soils (Jarvis 1984). In Western Australia, deep ripping can increase cereal yields in areas with more than 350 mm rainfall by more than 600 kg/ha if the soils are sandy, have a compacted layer less than 30 cm deep and the subsoil is not highly acidic. Timing of ripping is critical but the response to ripping can last for many years. Deep ripping, or subsoiling, involves disturbing the soil below the normal cultivation layer, often to 40 cm, without inverting the soil. It breaks up traffic-induced or naturally occurring compacted layers. Wheat roots can penetrate the ripped soil faster and deeper to absorb more soil moisture, capture more soil nutrients and improve yield.

In other areas and on different soil types, deep ripping has been much less reliable and benefits persist for shorter periods (see Chapter 8). It is not clear whether this is due to the compacted layers having less impact on crop productivity or whether the deep ripping approaches have not been fully effective. Malinda and Darling (2002) have developed a technique for ameliorating compacted layers just below the depth of normal cultivation with deep working seeder points. This approach has produced benefits to crop and pasture productivity on a range of soil types in a diversity of environments across South Australia and Victoria.

How do you diagnose a physical constraint?

Subjective assessment of soil structure

The incidence of physical constraints can be assessed visually by digging a shallow soil pit to observe crop rooting depth, the presence of compacted soil layer and fracture planes. The occurrence of wet soil within the rooting zone at harvest also indicates the presence of a subsoil constraint/s.

You can also assess soil structure by looking at and feeling the soil. This method is subjective, and requires some practice. However, it is easier to see and feel the soil structure rather than carry out a technical measurement like bulk density and try to interpret the values.

Signs of compaction are large peds (or clods) with a platy (horizontal) shape or massive (featureless) look. In poorly structured cracking clays, ped faces are dull rather than shiny. The soil may feel puggy when wet and peds will tear apart like raw pastry. When dry, peds are not friable; they break where you apply the force, rather than parting along natural fracture faces.

Objective measurements of soil structure

Here is a checklist of objective measurements that have been used to assess physical constraints:

- stability changes (wet sieving, Emerson's test)
- porosity changes – total and air-filled (moisture release curve)
- soil strength (moisture dependent)
- bulk density
- infiltration, water movement
- air/oxygen flux
- shrinkage (resilience)
- cation exchange capacity (resilience)

Penetrometer

An accurate and rapid method for determining soil strength (to depths of >450 mm) is to use a cone penetrometer. High penetration resistance may reveal a compacted layer but the measurement is strongly affected by soil moisture. Soil water content can have a bigger influence than compaction on penetration resistance. The most successful technique for using penetration resistance is to compare it with a known uncompacted site, at the same soil water content.

Plant symptoms

Identifying plant symptoms that are directly caused by compacted subsoil horizons is difficult because other factors can cause similar symptoms. Overall, compacted horizons impede rooting depth, causing reduced plant vigour and poorer water-use efficiency (roots have limited access to water and nutrients). Other symptoms include a lack of roots present below a certain depth (shallow root system) and, in some cases, roots turning or branching to grow horizontally above the compacted layer (see Figure 5.3). This latter phenomenon can often be easily observed in pulse and oilseed crops by excavating a few plants with a shovel.

Figure 5.3. A compacted soil layer diverting the roots of canola (Malinda 2003).

Soil and land type

As mentioned previously, sandy soils tend to have higher bulk densities compared to clay soils, so awareness of soil type will help you diagnose high bulk density. Also, specific soil classes may be predisposed to high bulk density compared to others. Knowing these classes will assist your diagnosis but obviously requires comprehensive knowledge of soil types.

How do physical constraints impact on crop production?

Reduced PAWC and root depth

Compacted layers affect crops directly as plant roots encounter high physical resistance in these areas. Compacted layers also affect crops indirectly, by causing poor soil aeration, lowering the access of plants to soil water and increasing water logging. A well-structured soil has many large pores to allow the rapid transmission of water and easy root penetration so roots can easily exploit water and nutrients. Large pores also drain to create air-filled passages within the soil. A compacted soil has few large pores, which impedes root development and water movement throughout the profile.

Lack of large pores means that there are few air spaces within the soil and what little air there is, is not connected to the atmosphere; oxygen is used up in respiration by roots and soil organisms and the soil then becomes anaerobic. Roots and the organisms involved in healthy soil processes then suffer. Under these conditions, anaerobic organisms thrive and produce toxic substances such as ethylene and hydrogen sulfide (resulting in the raw sewage smell of waterlogged soils). Ethylene can impede root growth at concentrations of less than one part per million. Anaerobic conditions are also conducive to denitrification of nitrate. This can cause losses from the soil because the nitrogen is converted to a gas, which can easily escape from the soil profile.

Plant tolerance ranges

The diameter of plant roots determines their ability to penetrate layers of high bulk density. Crops with thick taproots (such as safflower, lupin or canola) can better penetrate layers of high bulk density than crops with fibrous root systems (such as wheat or barley) (Materechera *et al*. 1991, Materechera *et al*. 1992). Among cereals, the larger diameter roots of the tropical species such as sorghum and maize would suggest that these crops should be able to penetrate into dense subsoils with more vigour than the roots of wheat and barley, although useful data on this is lacking. However, in cases where the compacted layer is very strong, all annual crop roots will fail to penetrate the layer and will end up growing across the face of the layer. Perennial crops tend to penetrate to greater depths in compacted soils than can annual crops but this is more to do with the extra time they have to exploit naturally weak zones in the profile than an innate ability to better penetrate hard soils.

Using primer crops is a relatively new concept whereby by paddocks may be sown with plants for the specific purpose of improving the porosity of soils that have naturally high bulk density at depth, for the benfit of following crops. Such '*primer plants*' may not necessarily be economic crops in their own right. Many alkaline subsoils of south-eastern Australia also have high levels of B, salinity and sodicity, in addition to high bulk density. Considerable variation exists in root growth of a range of potential primer-plants to high levels of soil B and salinity. Although lucerne is commonly used in farming systems as a break crop, its effectiveness at creating biopores in many alkaline soils may be limited given its poor capacity to tolerate salinity. If primer-plants are to be used for physically ameliorating subsoils, then tolerance to a range of subsoil constraints needs to exist. Other species such as tall fescue and phalaris may be better adapted to alkaline soils and the presence of multiple physicochemical constraints. (See Chapter 8).

References and further reading

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