Manage subsoil constraints to boost crop growth

Soil limitations at depth are known as subsoil constraints and can cause significant reductions in water use efficiency and crop productivity. CSIRO Land and Water researchers Jeff Baldock, Garry O’Leary and Victor Sadras have unearthed some of the problems associated with subsoil constraints in cropping soils.

Growers are urged to take a closer look at their cropping soils from a root’s point of view as subsoil limitations can cause significant reductions in water use efficiency and grain yield.

CSIRO Land and Water research shows a range of chemical and physical changes occur in soils at depth, which can affect plant productivity and make it more difficult for roots to extract water.

Subsoil constraints include changes in soil texture, compaction, high pH, salinity, sodicity and boron toxicity.

Overcoming subsoil constraints will depend on the constraint most limiting productivity and the management costs. In many cases the cost of remedies for subsoil constraints makes dealing with the problem uneconomical.

A more productive and profitable alternative could be to identify paddock areas affected by subsoil constraints and reduce inputs at these sites.

Water-holding capacity of soils

In dryland agricultural systems of southern Australia, water is the most limiting resource.

High pasture and crop productivity depends on the efficient use of rainfall and available soil water.

The amount of water available to plants is the difference between the water held at paddock capacity (after excess water drains) and at the permanent wilting point (where water can no longer be extracted by plant roots for physical reasons). This means each soil has a specific capacity to hold water which is ‘potentially available’ to plants.

Water-holding capacity varies with soil type. Soil texture, structure, bulk density and organic carbon content all influence soil water-holding capacity.

But plants may not be able to extract all of the ‘potentially available’ water from a soil. For plants to access the water, their roots must adequately explore the soil volume in which the water is held.

In addition to water, plant roots must also efficiently extract and use other resources required for adequate growth (such as nitrogen and other nutrients).

Since water becomes limited toward the end of the growing season in most areas of southern Australia, and soils dry from the top down, optimum productivity is typically found where plants can get their roots into deeper subsoil layers containing water and nutrients.

Subsoil limitations to root growth

It is important to recognise that roots explore a volume of soil and as the soil volume they can explore increases, so will shoot productivity.

Any soil conditions which limit the volume of soil roots can explore reduce the plant’s ability to access required water, nitrogen and other nutrients.

Limitations at depth have been termed subsoil constraints and can be physical or chemical.

Physical constraints appear where the density of the soil increases.

Increases in density with depth are common in many soils and can result from natural variations in soil texture (clay content) or may be induced by compaction with machinery traffic.

As the density of a soil increases, the volume of pore space decreases and the force required by roots to push through the soil increases.

These changes can reduce the capacity of the soil to hold ‘potentially available’ water and the volume of soil explored by roots.

Chemical constraints to root development include high pH, salinity, sodicity and boron. High pH values alter nutrient availability and recent work suggests it could increase the aluminium toxicity risk to crops.

Increased salinity, while having little direct effect on plants, makes it more difficult for roots to extract water from the soil.

Sodicity will also not have a direct effect on plant productivity but makes soil more difficult for roots to penetrate and so limits the soil volume explored.

Increasing boron alters plant growth, and can slow starch formation during grain filling.

Changes in soil properties with depth

CSIRO Land and Water researchers investigated the changes in the physical and chemical properties with soil depth at Roseworthy and Marrabel, South Australia.

At Roseworthy, large increases in pH, salinity and boron occurred at soil depths of more than 600 millimetres.

But at the Marrabel site, salt levels were higher near the surface and boron levels increased and then decreased with increasing depth. These results were consistent with the site location in a water discharge zone towards the bottom of a hill slope.

At all sites, soil nutrient status (organic carbon, total nitrogen and available phosphorus) decreased significantly with increasing depth.

Reduced root length

All of the changes in soil properties indicate that the environment at depth in these soils is not favourable for root growth.

At a glance

- CSIRO research shows there is a range of soil limitations, which can occur at depth making it difficult for roots to extract water resulting in significant reductions in crop growth and yield.
- Subsoil constraints include changes in soil texture, compaction, high soil pH, salinity, sodicity and boron.
- Identify paddock areas affected by subsoil constraints and develop a management strategy, which reduces inputs on affected areas and increases inputs on productive land.
Measurements of root dry matter and root length density showed significant reductions with changes in soil properties. Decreased root length density indicates a decreased capacity to remove water from the soil.

During the three-year study, more than 90 per cent of the root biomass was located at depths of less than 600mm.

By examining the relationship between permanent wilting point and soil water content remaining at harvest, it is possible to determine the amount of water left behind by the crop.

Provided crops received adequate nutrition and were not significantly affected by disease or received excessive rainfall near harvest, the presence of significant amounts of soil water above the amount associated with permanent wilting point would indicate the existence of subsoil constraints.

**Interaction between soil constraints**

Generally, subsoil constraints do not occur independently. Where high pH values exist, there is usually high salinity and sodicity or boron.

But the relationship between various subsoil constraints is not constant across all soils.

For example, the increase in boron with increasing pH was higher in the SA and Victorian Mallee compared with the New South Wales Mallee.

Significant variability in subsoil constraints also exists within paddocks.

Recent EM38 (electromagnetic) surveys combined with yield mapping and soil sampling have indicated a link of poor soil water extraction by crops with soil chloride and boron contents at depth.

Other work shows the presence of salt affects the ability of plants to extract water from soil but not the efficiency with which extracted water is used to produce grain.

The research indicated boron does not reduce water extraction by plants but does reduce the efficiency with which extracted water is used for grain production.

**Identify potential subsoil constraints**

To identify areas which could be affected by subsoil constraints, firstly check areas of low crop yield which are not due to disease or inadequate nutrition.

Collect soil samples from depth (600mm up to one-metre) in these areas and in nearby areas of high production.

Determine the relative difference in water content of the soil samples by measuring the amount of water present. A rough idea of this can be obtained by measuring the change in mass when the soil is dried.

If soils from low production areas contain more water after harvest than those collected from high production areas, the crops in the low producing areas did not extract as much water from depth and the potential for subsoil constraints exists.

Having the soils tested for electrical conductivity, sodium concentration, boron concentration and pH can identify the presence of chemical constraints.

The presence of a physical constraint can be determined by deep ripping a portion of the low producing area and looking for a yield improvement and reduced residual soil water at depth at harvest compared with an adjacent area not deep ripped.

**Electromagnetic paddock surveys**

Areas of a paddock which have the potential to be affected by subsoil constraints can also be identified with an EM38 meter.

CSIRO researchers have combined a Global Positioning System unit with a portable EM38 meter to produce a paddock map of EM38 readings.

Soil sampling at known points within the paddock are then used to check the relationship between EM38 values and soil electrical conductivity (a measure of salt concentration in the soil).

Using this information, it is possible to generate a map of soil electrical conductivity based on the EM38 measurements (see Figure 1a).

EM38 readings can also be used to obtain a map of soil water content immediately after harvest (see Figure 1b).

By performing EM38 measurements immediately after harvest, as was carried out for the maps in Figure 1, areas which show high residual water content indicate where crops could not effectively extract water from the soil.

The strong agreement between areas of high residual soil water content and high electrical conductivity suggests the presence of subsoil constraints.

**Influence on crop yield**

The influence of low soil water efficiency and high electrical conductivity on crop performance could be shown by comparing residual water content and soil electrical conductivity maps with crop yield maps from a yield monitor (see Figure 2, page 39).

But it is important to recognise several major limitations to this approach.

Firstly, the soil EM survey used to obtain a map of electrical conductivity (see Figure 2a) is a static soil measurement taken at only one time (in this case, just before harvest).

Crop yield variations (see Figure 2b) also result from the effect of many soil, climate and management factors experienced by growing crops through the growing season.

So, the spatial variation in soil electrical conductivity is just one of the factors which could influence yield.

To obtain a relationship between electrical conductivity measured after harvest and crop yield, electrical conductivity would have to be the major factor limiting crop growth.

In a dry year, this may occur because crop yield is highly dependent on accessing water located in deeper soil layers with high electrical conductivity.

But in a wet year, crop yields may not be influenced by soil electrical conductivity because crop water requirements can be met without extracting water from deeper soil layers.

**Disease and nutrition factors**

Other factors, for example root disease and poor nutrition, can account for variations in yield maps.

These must also be considered when defining the influence of subsoil constraints on crop yields.

Disease may depress yield across an entire paddock so the effects of subsoil constraints, even though they may exist, are unimportant.

**FIGURE 1 Identifying the presence of subsoil constraints**

Maps of A electrical conductivity (progressing from blue through yellow to red corresponds to increasing electrical conductivity) and B residual soil water content after harvest (progressing from white to blue corresponds to increasing water content). These measurements were obtained from a EM38 survey for a 100 hectare portion of a paddock at Balranald, New South Wales.

Source: CSIRO Land and Water.
Alternatively, patchy areas of disease may produce yield maps that are not related to the variations in subsoil constraints within a paddock.

Therefore, when attempting to map areas of a paddock subject to subsoil constraints based on yield monitoring, take care to consider other factors which may limit the expression of the constraint on grain yield. Also determine whether the constraints are exhibited every year or whether they are worse in wet or dry years.

Despite the limitations identified, maps of electrical conductivity or residual water obtained from EM38 surveys can be useful in defining variations in soil properties, which can potentially influence crop yield, and indicating where inefficiencies in crop production (indicated by lower water extraction) exist within the paddock.

**Subsoil management**

Overcoming subsoil constraints will depend on what constraint is most limiting production and the remedy costs. In many situations the costs or feasibility of amelioration make it uneconomical.

Compacted layers near the soil surface can be ripped and gypsum applied to reduce sodicity near the surface.

But as the depth of the constraining soil layer increases or the magnitude of the subsoil constraint increases even these management options become impractical.

An alternative is to live with the subsoil constraints and build a management strategy around them.

After areas affected by subsoil constraints are identified, a management regime which reduces inputs on affected areas and increases inputs on unaffected areas is likely to result in the biggest improvement in productivity and profitability. In areas identified as having subsoil constraints, consider growing crop varieties known to have a higher tolerance to the constraint.

Acknowledgement: Grains Research and Development Corporation.

*For more information contact Jeff Baldock, CSIRO Land and Water, by email on Jeff.Baldock@csiro.au, phone (08) 8303 8537 or fax (08) 8303 8550.*

---

**FIGURE 2 Influence of electrical conductivity and soil water on crop yield**

Maps of electrical conductivity were obtained from a EM38 meter (progressing from purple through blue and green to yellow corresponds to increasing electrical conductivity) and barley yield were obtained from a yield monitor (progressing from red through yellow and light green to dark green corresponds to increasing yield) for a 50-hectare portion of a paddock at Wemen, Victoria, at the end of the growing season.

Source: CSIRO Land and Water.