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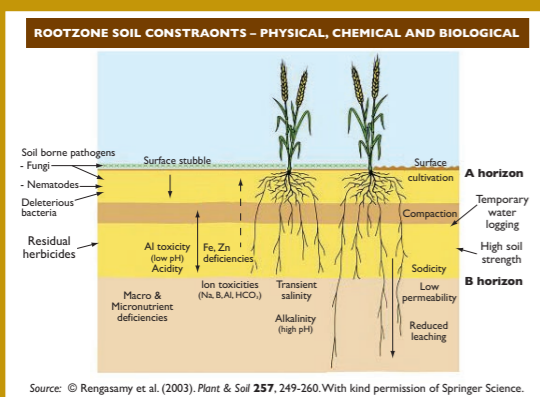
# SUBSOIL CONSTRAINTS

**limiting crop profitability  
on alkaline soils in  
South Eastern Australia**

## WHAT ARE SUBSOIL CONSTRAINTS?

Subsoil constraints (SSCs) are any soil physical or chemical characteristics located below the seedbed that limit the ability of crops or pastures to access water and nutrients. Subsoil constraints include salinity (primary or transient), sodicity, high soil strength, and toxic concentrations of boron although a range of other factors, such as aluminium, bicarbonate toxicity, nutrient deficiencies and water-logging have also been identified (Figure 1). SSCs occur naturally throughout large sections of the Australian grain belt, but are especially prevalent on the neutral and alkaline soils of south-eastern Australia (Figure 2). On some soil types eg. Sodosols of the southern Mallee of Victoria, more than 90% of the land used for cropping has SSCs.

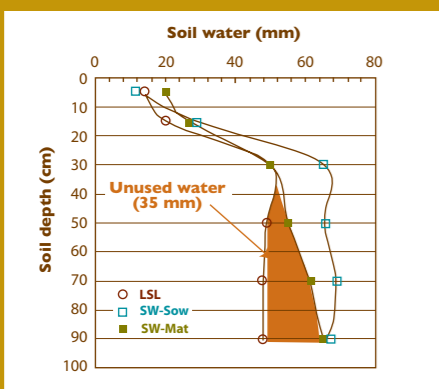
**FIGURE 1**



**Figure 1:** Conceptual outline of potential subsoil constraints to crop growth.

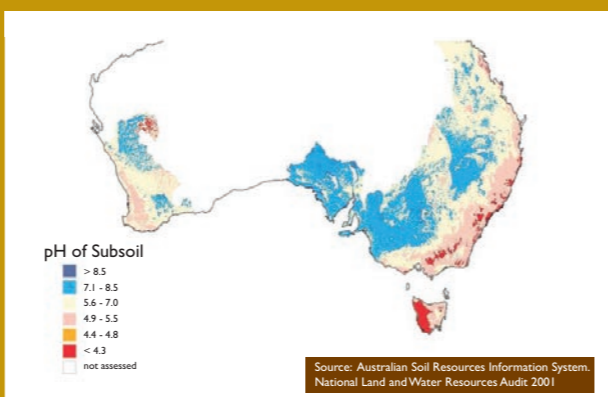
SSCs can significantly limit on-farm profitability by reducing grain yields and quality but have also been implicated in the development of secondary salinity. In many soils, more than one SSC may be operating, and the mix varies across cropping regions. Grain yields can either be directly reduced by SSCs (eg. high boron concentrations in tissues affecting cell metabolism) or indirectly (eg. when poor soil structure results in water-logging which in turn reduces crop yield). The majority of SSCs appear to have their greatest impact by inhibiting root growth, and thus limiting a crop's ability to access soil water and nutrients. The orange area in Figure 3 represents the difference between the lower storage limit (the lowest water content at which a plant can theoretically extract water from the soil) and the crop lower limit (the amount of soil water remaining in the soil at harvest). This unused soil water (ca. 35 mm) represents a significant major loss of grain yield potential (0.7 t/ha).

**FIGURE 3**



**Figure 3:** The effect of a subsoil constraint on reducing the amount of water available to a crop. LSL is the Lower Storage Limit (of plant available water), sw-s and sw-mat is the soil water at sowing and maturity respectively.

**FIGURE 2**



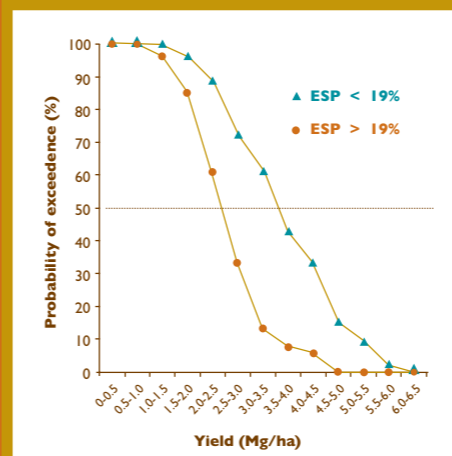
**Figure 2:** Location of neutral alkaline subsoils in the grain production regions of Australia.

## HOW DO I IDENTIFY SUBSOIL CONSTRAINTS?

Assessing the presence of SSCs and their potential impact on crop yield is difficult but very important, as it will help identify the most appropriate management strategy required and determine whether adopting each strategy is financially viable.

The severity of SSCs can vary greatly within the space of even a few metres and their impact on crops is highly seasonally dependent. Several studies have attempted to quantify the effect of SSCs on grain yields. For example, the yield of wheat near Birchip in the southern Mallee of Victoria in 1999 was significantly reduced by subsoil sodicity (ESP). The probability of getting a 3.0-3.5 t/ha grain yield that year was 60% when the ESP was less than 19% in the subsoils, but only 12% when ESP was greater than 19% (Figure 4).

**FIGURE 4**



**Figure 4:** Probability of exceeding a given grain yield for subsoils with exchangeable sodium percentage (ESP) less than or greater than 19%. (Nuttall et al. 2003, AJAR 54, 487-497)

Attributing the impact of one particular SSC on a crop is difficult because of the linkages between soil physical and chemical properties, nutrient availability and other factors such as root disease. Traditional approaches for the diagnosis of soil limitations, such as those used to detect nutrient deficiency, are generally not as effective when applied to SSCs. Visual signs of water stress by a crop eg. leaf rolling, when there is apparently adequate soil water to meet crop demand, can be a useful preliminary indicator of a SSC although these symptoms could also reflect the presence of root disease or certain nutrient deficiencies. Some chemical SSCs have distinctive plant based symptoms such as the blotches occurring on leaves of plants suffering from boron toxicity.

Soil testing can also help indicate the likely impact of a SSC. Since SSCs tend to increase with greater clay content and depth, soil samples taken from the surface are of little value. A reliable indicator of a SSC is the presence of water remaining in the soil profile at harvest, especially following a dry finish (Figure 3). Measuring soil water on samples taken for 'deep nitrogen' tests may provide an opportunity to simultaneously assess whether SSCs are present. Soil electrical conductivity (EC) is also often a reliable and relatively easy to measure indicator of some subsoil chemical constraints, such as sodicity

and, when used in conjunction with EM38 mapping, offers considerable scope to rapidly assess the presence of SSCs. However there are some areas (eg. Yorke Peninsula, SA) where SSCs appear to be purely physical and EC is not a useful diagnostic tool.

A problem limiting our ability to assess the impact of SSCs to crop production is that soil physicochemical properties can differ considerably over short distances, leading to high spatial variation in grain production within a single paddock. Yield maps can highlight much of the large variation in production that occurs as a result. Recent research in the GRDC Precision Agriculture Initiative has indicated the potential of using a surrogate measurement of harvest index (calculated as the ratio of biomass at anthesis mapped against final grain yield and normalised across the paddock) as a means of identifying areas likely to have SSCs. Other factors eg. frost, can also affect harvest index, and these factors also need to be considered when using this approach. Further, growing season rainfall patterns can strongly influence the expression of SSCs. In seasons with regular rainfall events, (especially during grain filling), crops are not as reliant on subsoil water and SSCs may have little impact on grain yields.

## WHAT CAN I DO?

There are three broad strategies for improving the profitability of cropping on soils with subsoil constraints:

1. Ameliorate the subsoil so that it is more suitable for root growth and function.
2. Grow crops and pastures that are more tolerant to the constraint/s.
3. Recognise the inherent limitation posed by these subsoils and adjusting inputs accordingly.

Choice and the effectiveness (in terms of increased profitability) of strategy depends on several factors, including the nature and severity of the constraint/s, the type of farming enterprise and the extent of seasonal and spatial variability.

## AMELIORATION OF THE SUBSOIL

Just as there are many different subsoil constraints, so there are many different methods to ameliorate SSCs. Currently there are few practical and cost effective techniques for reducing SSCs when they occur well below the surface, especially in low to medium rainfall areas where dollar returns per hectare are already low.

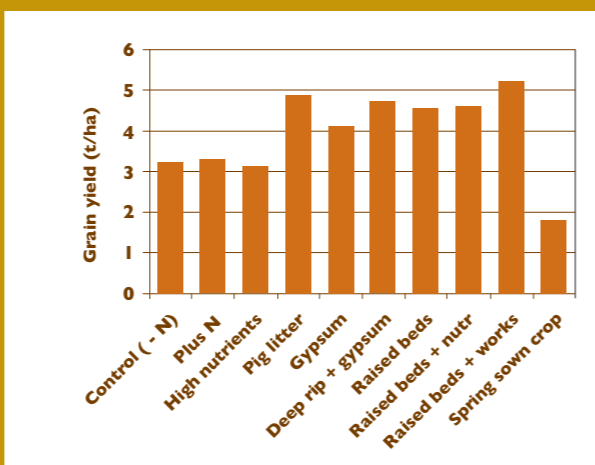
### GYPSUM

Gypsum (calcium sulphate) has been used extensively to ameliorate structural problems on sodic topsoils. Gypsum reduces dispersion of clay particles, increases porosity, structural stability and permeability and reduces soil strength. Due to the comparatively slow rate (ie. over several years) of calcium movement throughout the profile, gypsum applied to the surface generally has minimal impact on the subsoil in the short to medium term. Very large (and uneconomical) rates of gypsum are required to ameliorate subsoils with high sodicity (ESP > 15). Gypsum will provide minimal benefit where soils have high soil strength (physical limitation to root growth) but are non-sodic, e.g. soils of Yorke Peninsula.

### ORGANIC MATTER

Organic matter can improve soil structure, resulting in enhanced infiltration of water and improvements in root growth. Some forms of organic matter were found to alleviate the physical impact of sodicity. A single surface application of composted pig bedding litter derived from cereal straw (at 20t fresh weight /ha) to a highly sodic clay soil prone to water logging in the southern Wimmera region (of Victoria) significantly improved dry matter production and grain yield of wheat and several subsequent crops by an average of 40% (Figure 5). Other trials in the eastern Wimmera have recorded grain yield responses to composted organic matter of up to 138% for canola and 211% for wheat. However insufficient sources of organic matter limit the widespread use of this amelioration strategy.

**FIGURE 5**



**Figure 5:** Yield responses of Frame wheat to various amelioration practices on a Sodosol at Brimpaen, Victoria. (Source R. Armstrong, unpublished)

## DEEP RIPPING

The benefit of deep ripping on crop performance varies widely according to results reported in the scientific literature. Most studies indicate that deep ripping alone provides little or no long-term impact on the physical condition of clay subsoils. Recent research (Sadras and colleagues) has recorded yield benefits on non-sodic sandy loam soils in the northern Mallee. On dispersive (sodic) soils, ripping is unlikely to have significant long-term beneficial effects unless the structure of the soil is simultaneously stabilised through amelioration with either calcium or organic matter. Recent advances in machinery, such as 'slotting' equipment to simultaneously introduce ameliorants at depth with ripping, could increase the effectiveness of this approach to managing SSCs.

Research conducted by Hamza and Anderson in Western Australia showed yield improvements of between 52% and 159% with a combination of deep ripping, gypsum and complete nutrients. Once deep ripping and amelioration are completed, strategies such as stubble retention and controlled traffic should be considered to maintain soil structural improvements otherwise re-compaction will occur quickly on most soil types.

## PRIMER CROPS

Primer crops modify the soil and provide pathways (biopores) for the roots of following crops. Possible species that may be grown as primer crops, depending on the particular SSC present, include chicory, lucerne and sulla. A key factor in the success of this strategy will be the financial return obtained during the primer crop phase eg. from grazing, and the length of any residual benefit to subsequent crops. Growing a primer crop may have negative impacts on the performance of subsequent crops. Plant available water may actually be reduced to the following crop phase (a problem especially in low to medium rainfall zones) and the development of increased preferential flow via large pores may lead to leaching of nutrients and organic matter.

## SUBSOIL NUTRIENT APPLICATION

Deficiencies of macronutrients (eg. nitrogen and phosphorus) and micronutrients (eg. copper, manganese and zinc) are common in alkaline subsoils. Deep placement of nutrients at Edillilie, SA produced cereal yield increases of 70-135% over two years (Table 1). Different methods can be used to apply the liquid fertilisers to the subsoil, including high-pressure injection, banding from coulters and banding from knife-points.

**TABLE 1**

2001 (Treatment)	2002 Yield (t/ha)	Yield benefit (t/ha)
<b>N, P normal sowing</b>	<b>1.52</b>	<b>0</b>
<b>N, P @ 20 cm</b>	<b>1.96</b>	<b>+ 0.44</b>
<b>N, P, Cu, Zn, Mn @ 20 cm</b>	<b>2.24</b>	<b>+ 0.72</b>

**Table 1:** Yield responses of Keel barley to shallow and deep (20 cm) nutrient application on a Sodosol at Edillilie, SA (Davenport and Cordon 2003).

## AGRONOMIC MANAGEMENT

Agronomic management, in theory, should reduce the impacts of subsoil constraints. Simple practices such as early sowing and enhanced nutrient supply can boost localised root density, thus increasing the volume of topsoil exploited by crop roots and reducing the reliance on water and nutrients from the subsoil.

Fallowing is a widely used strategy to minimise risk in environments characterised by terminal drought, especially where grain yield depends heavily on water use between flowering and grain maturity. The value of fallowing is questionable, given that it is now recognised as a major contributor to increased recharge and the development of dryland salinity as well as wind erosion and that severe subsoil constraints often limit the ability of a crop to exploit deep soil water reserves. However, leaching associated with fallowing may provide a means of moving constraints such as salts deeper into the profile, thus increasing the effective rooting depth for crops.

## RAISED BEDS

Overcoming waterlogging is critical to improving grain yields in the higher rainfall zones of southern Australia. Even in lower rainfall zones (350 – 550 mm annual rainfall), grain yields may be reduced significantly by temporary waterlogging from perched water tables overlaying poorly structured (sodic) clay subsoils with low porosity. Research has shown that raised beds have greater infiltration, lower bulk density, lower shear strength and lower penetration resistance compared to conventional treatments. Some paddocks, however, are not suited to raised beds because of inappropriate soil types or insufficient slope.

## SELECTING MORE TOLERANT CROPS

Plants (on a crop type and cultivar basis) vary significantly in their tolerance to many SSCs, and plant breeding may ultimately provide the most feasible long-term economic solution for overcoming subsoil constraints. Pulses and oilseeds are generally regarded as much more sensitive to subsoil constraints such as salinity and high boron than cereals. Recently released wheat and barley varieties targeted for the low to medium rainfall areas, especially those with alkaline soils in south-eastern Australia, now possess boron tolerance. Cereal germplasm with tolerance to a range of SSCs such as salinity, aluminium, water-logging and bicarbonate toxicity have been identified so that cultivars with tolerance to these particular subsoil constraints are likely to be commercially available in the future. Similar genetic solutions are being sought for pulses (especially lentils) and oilseeds.

## ISSUES TO CONSIDER

Amelioration of SSCs is usually expensive and often not economically feasible, especially in low to medium rainfall areas where financial returns per hectare are low. Before any subsoil management practices are undertaken, cost-benefit analysis needs to consider the issues associated with particular treatment options. These include relative yield improvement, residual impact of the treatment, ameliorant cost, transport cost, machinery cost, additional fuel cost, erosion risk, trafficability of the paddock after subsoil operations and the opportunity cost of alternative investment.

Management strategies used will depend on the nature and extent of constraints that are present and the relative cost of these strategies compared to potential improvement in financial returns (via higher grain yields). Crops are always constrained by the most limiting factor. When several potential SSCs exist in combination (which is the norm on neutral-alkaline soils in southern Australia), overcoming the primary constraint will then require the next most limiting constraint to be dealt with and so on. A pyramiding of solutions will thus be necessary if the full yield potential is to be achieved. For example, soil structure may first need to be improved by deep ripping and ameliorating sodicity. Once the structure is improved, and adequate drainage is established, salinity and boron may be reduced to non-critical levels through leaching or alternatively crops/cultivars with boron and salinity tolerance may need to be grown.

## THE FUTURE

The highly variable nature of SSCs in the field, both temporally and spatially, is recognised as a barrier to the identification of appropriate management strategies. Recent field research has, however, demonstrated the potential benefits of particular operations. Current research will facilitate the development of appropriate decision tools to identify, understand and manage subsoil constraints across south-eastern Australia. Such tools will help to deliver major increases in productivity, sustainability and profitability.

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