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Combating Subsoil Constraints: R&D for the Australian grains industry

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The contributions to this special edition of the Australian Journal of Soil Research report recent research undertaken as part of a national R&D initiative on Combating Subsoil Constraints established by the Grains Research and Development Corporation (GRDC). The Corporation is a statutory authority established to plan and invest in R&D for the Australian grains industry. Its primary objective is to support effective competition by Australian grain growers in global grain markets, through enhanced profitability and sustainability. The 'Combating Subsoil Constraints Initiative' (code: SIP08) operated as a national R&D program over the period 2002–03 to 2007–08, with projects in each of the 3 major grains regions (west, south, and north).

Much of the Australian continent is geologically very old and highly weathered. Soils in many parts of our cropping regions reflect these characteristics, without the influence of renewal processes such as volcanism, glaciation, or alluvial deposition that have formed the younger soils found elsewhere. A long period of relative aridity has also influenced the physical structure and chemical composition of many soils. As a result, many of the soils used to grow grain in Australia contain in their subsoil layers (defined here as deeper than 0.20 m) a range of factors that limit or constrain crop growth and yield.

Growers, agronomists, and researchers report that these 'hostile subsoils' are a major limiting factor to crop returns, affecting at least half of all grain farms. Abundant moisture in the subsoil at harvest after a dry finish, large yield differences between soil and crop types in the same paddock, and root growth obviously restricted to the surface soil layer are all indications of subsoil barriers to crop growth. These effects are seen in particular soil types in all cropping regions, and overall the impact on the grains industries nationally is substantial in terms of potential yield and profit foregone. Subsoil constraints act to prevent the crop from making full use of potential water and nutrients in the profile, resulting in restricted crop growth, and yield falling short of its water-limited potential. The impact can vary depending on soil type, farming system and agronomic practices, the growing season, and the farmer's response based on knowing which constraints are occurring and where.

The main subsoil constraints found in Australia's cropping regions are:

- Acidity (pH <4.8), which leads to concentrations of aluminium and other elements that are toxic to, and slow or prevent growth of, crop roots;
- Sodicity, where an excess of sodium ions allows soils to slake or 'dissolve' so that pore structure is lost and crop roots cannot penetrate the soil to reach water or nutrients—often associated with toxicity due to boron;
- Transient or root-zone salinity (not due to rising groundwater) where high salt concentrations (and osmotic potential) mean that the crop plants have to expend more energy to take up water from the saline soil solution, and in extreme cases may wilt even when the subsoil appears wet;
- High soil strength and physical impermeability (not related to sodicity) where plant roots cannot penetrate the soil structural units;
- Low nutrient levels so that the whole plant or its root system cannot obtain sufficient nutrients to enable full exploration of the deeper soil layers for water;
- Toxic concentrations of elements that are not directly linked to pH;
- Alkalinity, where the subsoil pH is $\geq$9.0, resulting in toxic concentrations of some ionic species (e.g. aluminium, bicarbonate, etc.);
- Compaction of subsoil layers caused by past land use; for example, due to repeated tillage, poor grazing management, and wheel traffic.

Research supported under this initiative aimed to provide a mix of the following outputs:

- Information on the extent, distribution, and impact on crops of subsoil constraints within each of the 3 cropping regions;
- Quantification of the effect of seasonal variation on impacts from subsoil constraints;
- Improved knowledge of major causal factors and their interactions, and how crop growth and yield are affected;
- Demonstrated effects of different farming systems and agronomic practices on subsoil constraints;
- Quantification of the economic and environmental effects of subsoil constraints;
- Development and demonstration of practical methods that growers can use to identify, avoid, and manage hostile subsoils;
- Raised awareness of subsoil constraints by growers and advisers, and effective delivery of new knowledge, methods, and decision aids.

The following papers provide a summary of just some of the results of the 'Combating Subsoil Constraints Initiative'; others

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have already been published or will be over coming months. Results have also been provided in forms that promote their adoption by growers and farm advisers, including explanatory guidelines, field days with soil pits and demonstrations, and training programs about how to recognise and then manage the common types of constraint. Grower groups within the cropping regions and some farm advisers are also active in further development, demonstration, and training in combating subsoil constraints.

In the first paper, Dang *et al.* report the results of a large, multi-organisation project undertaken in the northern grains region. They concluded that among the chemical subsoil constraints, subsoil Cl concentration was a more effective indicator of reduced water extraction and reduced grain yields than either salinity (measured as ECse) or sodicity (as ESP). At constrained sites, soil Cl concentration was the best predictor ($R^2 = 0.84$) of a wheat crop's potential water extraction rate from any subsoil layer. As might be expected, the yield penalty due to subsoil constraints is seasonally variable, with more in-crop rainfall generally reducing their effect, although the interaction can be quite complex as described later by Nuttall *et al.* The northern team also evaluated a range of plant species and cultivars for their relative tolerance to subsoil constraints, and examined the value of different techniques to help identify and map the presence of subsoil constraints at a paddock scale.

The next paper by Rengasamy examines in more detail the relative importance of ionic toxicities and osmotic effects to plant growth, as there were different results on this obtained during the Subsoils Initiative. He concluded that for Krichauff wheat growing in pots, the osmotic effect became dominant and severely restricted plant growth when the soil solution EC increased above a 'threshold value', which was 25 dS/m, corresponding to an osmotic pressure of 900 kPa. Below this EC value, ionic effects due to Na^+, Ca^{2+}, SO_4^{2-}, and Cl^- were also evident, but it could not be concluded whether these effects were due to toxicity or ion imbalance. Significantly, at EC values above the threshold, the unused water remaining in the pots was equivalent to 89–96% of the field capacity of the soil.

Nuttall and Armstrong also examine the importance of a range of subsoil constraints, and the effects of seasonal rainfall, to growth and yield of wheat, barley, canola, and lentil, but this time in the alkaline soils of the Victorian Wimmera and Mallee. There were significant associations between several of the constraints studied (i.e. they often occur together), but although subsoil constraints affected canola (high ESP) and lentil (salinity) crops, this was not the case for wheat or barley. The authors attribute the latter to the lack of available soil water at depth, and the cereal crops' tolerance of the physicochemical conditions encountered in the shallow subsoil, where plant-available water was more likely to occur. They suggest that if climate change results in lower rainfall in these districts, agronomic management for subsoil constraints may become less important.

A lack of nutrients in the subsoil can affect root proliferation and uptake of deeper water, a topic investigated by McBeath *et al.* Past work had shown that deep-ripping with addition of subsoil nutrients could increase crop yield substantially and that the effects could last for several seasons. These authors tested whether this response was related to an increase in the use of water and nutrients located in the subsoil by measuring the effects of deep-ripping with and without amendments on the physical and chemical properties of the A and upper B horizons of 2 South Australian soils. They found that deep-ripping and deep-placement of nutrients increased grain harvest weight even in an exceptionally dry season, and this was accompanied by significantly lower field-penetration resistance to 0.35–0.50 m depth, which they hypothesise enabled the crop to better access stored soil water and deep placed nutrients in the subsoil.

Subsoils can thus restrict plant growth due to physical factors as well as chemical. MacEwan *et al.* report on the range of subsoil constraints that occur in the high rainfall zone (mean annual rainfall 500 mm or more) of south-eastern Australia, a region where cropping is expanding into areas previously used for grazing. Subsoils in this region are spatially variable, but most contain a high proportion of clay. Subsoil acidity and sodicity are significant constraints in some areas, but bulk density (mean value 1.6 t/m^3) is likely to be the most pervasive limitation to plant growth; the growth-limiting bulk density for clay lies, theoretically, between 1.4 and 1.6 t/m^3. In these subsoils, the transmission pores that provide a ready pathway for root extension are not common and are often widely spaced, principally occurring as fissures between large structural units. Mechanical loosening of the soil to a depth of 0.30–0.60 m is widely recognised as one means to address physical impediments to plant growth in subsoils, the more recent expanded use of raised beds for cropping is another.

In Western Australia, crop yield in the sandy soils of the wheatbelt is influenced strongly by the plant-available water and soil strength of subsoils, and adjacent subsoils with broadly similar texture (around 20% clay) are known to vary widely in their crop production potential. Kew *et al*. report on the differences in particle size, shape, and degree of sorting, and the density of associated clay minerals, in hard subsoils derived from transported (by wind or water) material compared with those derived *in situ* from saprolite. The hard subsoils were found to contain rounded quartz grains and transported, rounded aggregates of clay (spherites), while saprolite contained angular quartz grains in a more porous kaolin clay matrix. At all matric potentials there were large differences in water retention between hard subsoils and saprolite. A soil fabric classification is presented that is predictive for both water retention and soil strength.

Sandplain soils on the south coast of Western Australia have multiple limitations to crop production, and in severe cases achieve <40% of their rainfall limited yield potential. Incorporating subsoil clay from an adjacent pit into the sandy topsoil has been shown to provide an excellent financial return in some but not all situations, and deep ripping can also increase yield. Hall *et al.* quantify the effects of claying and deep ripping on soil properties, crop growth, and profitability. Although claying to a rate of 3–6% alleviated water repellence as well as adding valuable potassium to K-deficient soils, and the effects of claying and ripping were additive, only some of the treatments were more profitable than untreated areas over an 8-year period. Claying and ripping alone do not overcome all the major constraints at low-productivity sites.

Nuttall *et al.* point out that there are few financially viable amelioration options for cropping on soils with significant subsoil constraints, and that this has raised interest in 'genetic solutions' through crop types and cultivars that are more tolerant of the common constraints. They examined the performance of closely related genotypes differing in boron and/or sodium tolerance on typical Calcarosol soil types that were either 'benign' or 'hostile' in terms of their level of subsoil constraint. They concluded that for the cereal lines tested, there was no obvious benefit in those with potentially improved tolerance for a single subsoil constraint where multiple potential constraints exist but that for lentils, incorporating tolerance to sodium and boron does show promise.

The work of the Combating Subsoil Constraints R&D Initiative, part of which is reported in this special edition, contributes to the GRDC goal to develop optimal farm management practices that, when used to grow superior, high-yielding varieties, will lead to increased productivity from sustainable grain production systems. Better farming practices contribute to increased productivity by enabling grain growers to obtain the maximum return from their inputs, while at the same time minimising losses and off-site effects. Improved management resulting from this research is being combined with new knowledge from other GRDC R&D initiatives that enables growers to identify soil constraints at a paddock scale, and to select suitable pasture or crop plants based on the known types and levels of constraint. They are also now better able to consider the potential influence of seasonal conditions on subsoil constraint effects, and to vary fertilizer and other inputs across the farm or paddock according to estimated crop demand. Action learning and agronomic packages that incorporate the subsoils R&D results have been tailored to suit each major grain region, and are being tested and further developed under local conditions by grower groups.