# Subsoil constraints in the grain cropping soils of Queensland

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## Abstract
Grain crops grown under dryland conditions in Queensland depend on the efficient use of rainfall and available water stored in the soil during fallow**.** Many soils of the region are able to store 200-250 mm water in the soil profile. However, the presence of subsoil constraints restricts the ability of the crop roots to access this stored water and nutrients. These constraints include sodicity and salinity in the cropping soils of south Queensland, acidity in Brigalow soils, and sodicity in cropping soils of central Queensland. Both the actual extent and the effects of these constraints on crop yields are difficult to quantify. Preliminary investigations of the Queensland soil database indicate that strong subsoil sodicity (ESP>15%) and high salinity ($EC_{se}$>4 dS/m) may be present in 38% and 26%, respectively of the cropping regions of southern and central Queensland. Subsoil sodicity and salinity occur simultaneously in many soils.

The variable distribution of subsoil constraints, both spatially across the landscape, and within the soil profile, and the complex interactions that exist between the constraints, necessitate site-specific management. The key toward realising potential yields is to gain a better understanding of subsoils and their limitations, then develop options for better economic and environmentally sustainable management of these soils.

## Key Words
Subsoil, spatial variability, salinity, sodicity, EM38

## Introduction
Subsoil constraints are chemical, physical or biological properties in the subsoil that limit the ability of plants to utilise soil water and nutrient resources, or otherwise have a detrimental effect on plant growth. These subsoil constraints may be salinity, acidity, alkalinity, nutrient deficiencies and/or toxicities, sodicity (chemical), inherent high bulk density, compacted or gravel layers (physical) and low microbial activities or increase in pathogen/nematodes causing diseases (biological). Several of these constraints may occur together in some soils. A number of characteristics in the subsoil interact with each other to determine the edaphic environment upon which plant roots depend at a given time. Subsoil constraints have a significant impact on soil water storage and use, nutrient regime and crop growth (Figure 1).

The presence of high salt concentrations in the soil solution (salinity) reduces plant growth, directly affecting physiological functions through increased osmotic potential and specific ion toxicity (Shaw 1997). Subsoils containing a toxic level of aluminium (Al) or deficient amounts of calcium (Ca) also restrict root proliferation (Bruce 1997). At high concentrations, chloride (Cl) and boron (B) are toxic to plants, resulting in crop loss (SalCon 1997). Nutrient deficiencies in subsoil could be a major restriction to crops, especially in dryland regions where root growth and functions depend on subsoil water and nutrients (Graham *et al.* 1992). The presence of toxic elements directly affects root functions and reduces microbial activity. Sodicity refers to a high proportion of sodium ($Na^+$) ions on the clay cation exchange complex in comparison to $Ca^{2+}$, magnesium ($Mg^{2+}$) and potassium ($K^+$) ions. Sodicity often causes a deterioration of soil physical properties, indirectly affecting plant growth, and may also induce Ca and/or K deficiency. The environmental and landscape issues concerning subsoil constraints are related to soil-water relations and can lead to structural degradation, increased drainage, runoff and erosion (Hochman *et al.* 2004), transient waterlogging, degradation of water quality and natural resources (Rengasamy *et al.* 2003) (Figure 1).

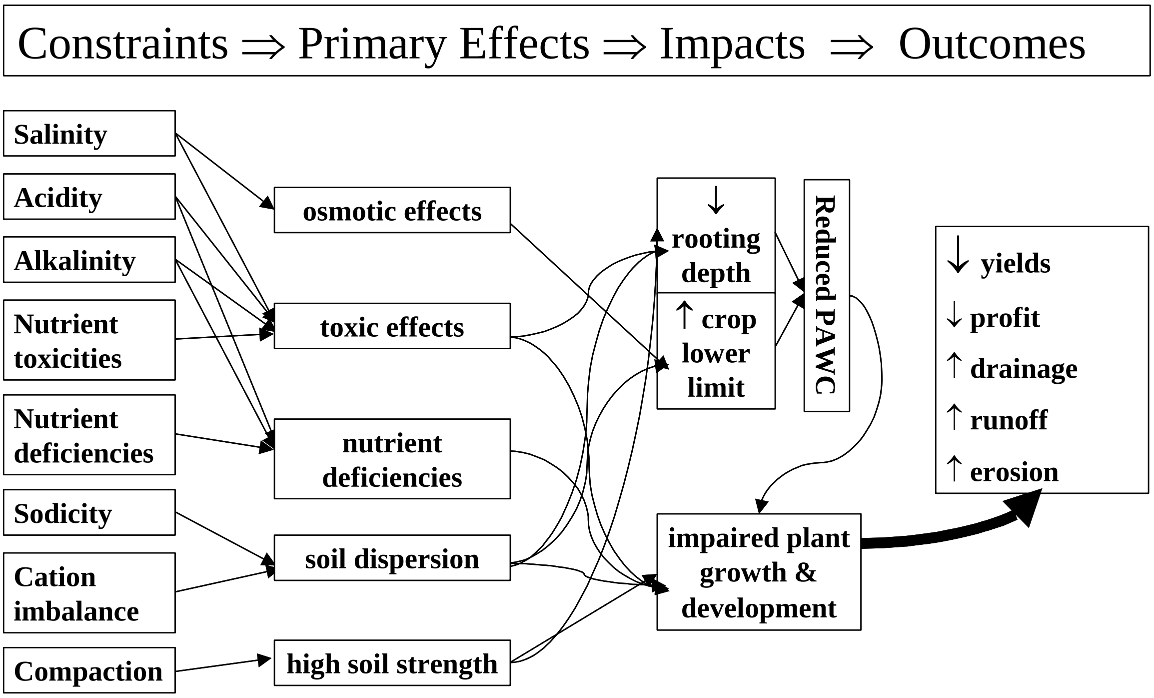

**Figure 1. Impact of subsoil constraints on soil-plant, farming, landscape and environment.**

**Subsoil constraints in the cereal cropping region of Queensland**

*Mapping of subsoil constraints*

Accurate determination of subsoil constraints requires actual field observations and/or laboratory tests. Where there is no field data, a process of estimation (or prediction) of soil properties may be used. Spatial estimation of subsoil constraints in Queensland has been derived using soil site data in the NRM Soil and Land Information (SALI) database system, and the best available land resource mapping. The polygons (from land resource survey maps) are overlayed with the point data (site information) and values (or attributes) are allocated to the polygons according to a hierarchical system of 'attribution' based on the method of Smith and Grundy (2000). The results for the grain-cropping region of Queensland (31.2 Mha) are shown in Figure 2.

On an areal basis, the spatial distribution of subsoil salinity (ECse >4 dS/m) and subsoil sodicity (exchangeable sodium percent, ESP >15) at 60 cm depth represented 26.3% and 38.5%, respectively of the total cereal grain cropping region of Queensland. In 5.8 Mha (or 18.5% of the region), both subsoil salinity and subsoil sodicity occur together.

*Subsoil sodicity*

Generally sodicity is more likely to be present in the subsoil (between 0.3 and 1.0 m depth) than in the topsoil. The occurrence of sodicity is generally related to the parent material from which the soil is formed. Sodicity within central Queensland occurs on colluvial, older alluvium and scrub soils (Irvine and Doughton 2001). On these soils, vegetation provides a good indicator of sodic conditions. Dawson Gum (*Eucalyptus cambageana*), false sandalwood (*Eremophila mitchellii*) and poplar box (*Eucalyptus populnea*) are often found on sodic soils in central Queensland. In most instances sodicity in southwest Queensland increases with depth on both Sodosols as well as Vertosols (Isbell 1996) (Figure 3).

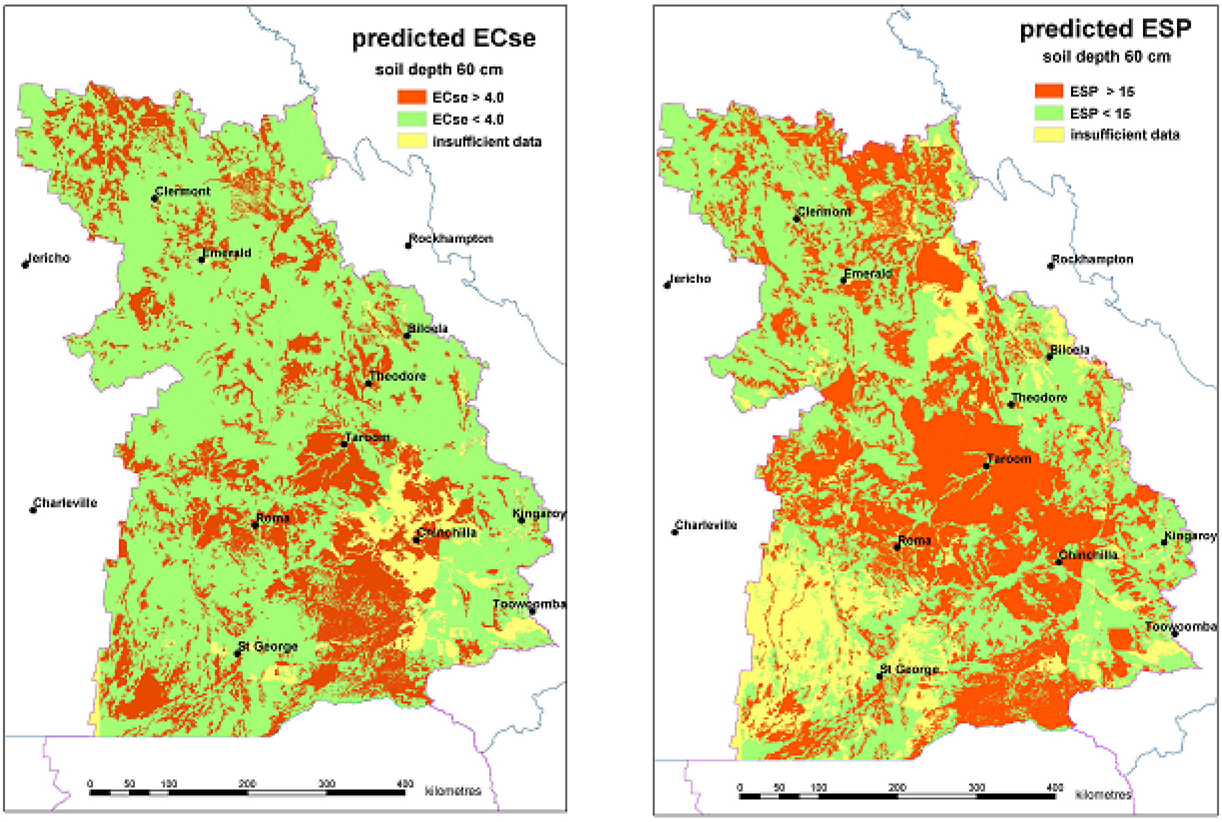


**Figure 2. Predicted distribution of high subsoil salinity (electrical conductivity of saturated extract; ECse) and strong subsoil sodicity (exchangeable sodium percentage; ESP) in the Queensland cereal-cropping region.**

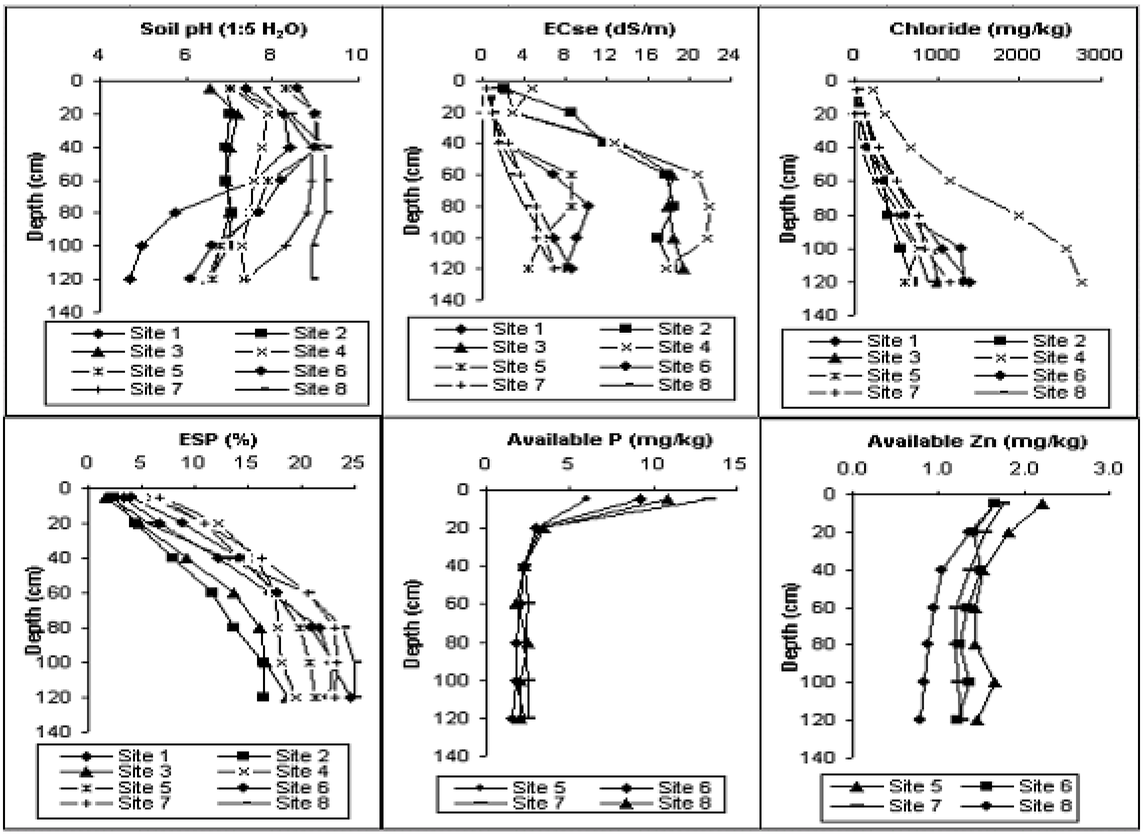


**Figure 3. Distribution of subsoil constraints in soil profiles at several sites in soils used for cereal cropping in Queensland.**

*Subsoil salinity*
Subsoil salinity is common within soils also dominated by subsoil sodicity. Shaw *et al.* (1994) found a strong logarithmic relationship between subsoil ESP and ECse (electrical conductivity of saturated extract) except for areas with less than 300 mm rainfall per year, which have a slightly higher salt concentration. Similar to sodicity, inherent subsoil salinity is also related to the soil's parent material. In most instances in central Queensland, salinity occurs at lower depth and generally increases at 0.5 or 0.7 m depths (Irvine and Doughton 2001). In southwest Queensland, subsoil salinity follows a similar pattern to subsoil sodicity (Routley 2003) (Figure 3).

*Subsoil Acidity and Alkalinity*
Subsoil acidity in the region is commonly associated with soils that once supported brigalow (*Acacia harpophylla*) and belah (*Casuarina cristata*) as the dominant vegetation (Page *et al.* 2002). These soils have the unusual characteristic of being strongly alkaline in the surface soil (up to 30-40 cm depth) grading to strongly acidic in the deep subsoil (eg Figure 3, site 1). In central Queensland, the incidence of pH less than 5.5 occurs only at depths of at 0.9 m or more (Irvine and Doughton 2001).

*Subsoil toxicities*
Many subsoils of the region are characterised by toxicities of one or more elements including Al, Na, and/or Cl. High concentrations of Cl have been reported in many soils, and there is usually an increase with depth (Figure 3). Chloride concentrations as high as 2500 mg/kg have been reported in soils at 0.9 m depth. Aluminium toxicity in low pH (<5.5) soils is well documented (Bruce 1997). Elevated concentration of Al in plants grown in high pH conditions have also been observed (Dang *et al.* 2004), which could be possibly due the predominance of anionic species such as aluminate $Al(OH)_4^-$ (Ma *et al.* 2003) although its effect on crops yield in these soils requires further investigation.

*Subsoil nutrient deficiencies*
Nutrient deficiencies in subsoils may be a major restriction to crop growth especially in dryland regions where root growth and function depend on subsoil water. Nutrient availability in the subsoil is critical during the key times of plant development. In Queensland soils, less mobile nutrients such as P and zinc (Zn) have been shown to decrease with depth (Figure 3). Highly mobile ions such as nitrate ($NO_3^-$) have been shown to concentrate deeper within the profile (Turpin *et al.* 1998). High concentration of ammonium ($NH_4^+$) has also been reported between 1.2 and 3 m in some Vertosols; however, the source of this N deposit is unknown (Page *et al.* 2002).

*Physical constraints*
Physical constraints including compacted soil layers or layers of high bulk density occur in the region. A progressive subsoil compaction is the result of increase in the weight of farm machinery operating on the farm. The presence of gravel layers or shallow depth of soil, in many cases less than 1.0 m is also common in some areas of the region (Dalgliesh and Foale 1998; Radford *et al.* 2000).

*Biological constraints*
Biological constraints in the region are related either to an increase in pathogens/nematodes causing soil-borne diseases such as crown rot, common root rot, root-lesion nematode and yellow spot (Wildermuth *et al.* 1997), or the reduced activities of beneficial microbes such as vesicular-arbuscular mycorrhizae (VAM) and earthworms (Thompson 1987).

**Spatial characteristics of subsoil constraints**
Soil properties vary both horizontally and vertically (McBratney and Pringle 1999). For example, soil cores 1-6 for each of the 2 soil types (Figure 4) were taken at <25 m apart within a paddock. The analyses of soil profiles revealed large spatial differences both between soil types and within soil types. For example, soil pH trends for Vertosol were near neutral throughout the soil profile with topsoil pH ranging from 6.3-7.3 (6.8±0.4) whereas subsoil pH ranged between 5.5-8.0 (7.2±0.5). There was large variation within soil type for the ESP in the surface soil (4.3±2.9) as well as in the subsoil 2.9-22.2 (15.0±4.6). Salinity levels (ECse) were 2.0±0.6 dS/m in the surface soil and 15.6±7.2 dS/m in subsoil with similar variability in Cl levels ranging from 25-374 (123±118) mg/kg in the surface soil and 49-3009 (1079±899) mg/kg in subsoil. Similar variability was observed in Sodosols as well as in 6 other soils surveyed at various locations (data not shown). These examples showed that intra-site variability in soil properties can be greater than at inter-site level which will correspond to marked differences in crop growth and water

use. This provides opportunities to manage such variability in subsoil constraints with emerging precision agriculture technologies.

**Sensing technologies to identify subsoil constraints**

Grid sampling of soil to test for variable distribution of possible subsoil constraints, both spatially across the landscape, and within the soil profile would be time consuming and expensive. However, sensing technologies have made feasible and practical the capacity to monitor and quantify some of the subsoil constraints (O'Leary *et al.* 2003). There are three types of sensors developed to identify subsoil constraints, viz. electrical conductivity sensor, electromagnetic (EM) induction sensors and gamma radiometric sensor.  We examined the feasibility of using mobile EM38 coupled with yield map to identify areas with possible subsoil constraints on a paddock in southwest Queensland. EM38 technology uses electromagnetic induction to provide measurements of bulk soil EC (apparent), which is related to salt content, soil water, and texture of soil. As expected, more salt gives higher EC readings, higher moisture content will bring more salts into solution and a clay soil has more sites that can store salts and moisture and will give higher EC reading than a sandier soil with same moisture content. Interpreting EM maps can be confusing and can be avoided by taking samples when the soil moisture profile is close to drained upper limit. Soil texture is often the governing factor in yield potential due to its effects on water-holding capacity and nutrient movements. The EM38 readings would be function of both texture and salt effects, so ground-truthing is necessary.  Further, seasonal climatic conditions can also have a profound influence on the EM38 results. For example, in dry years, the EM38 map could match with the yield map however, in wet years, the effect of subsoil constraints on roots growth may be less severe so the EM38 map may not correspond with yield map.

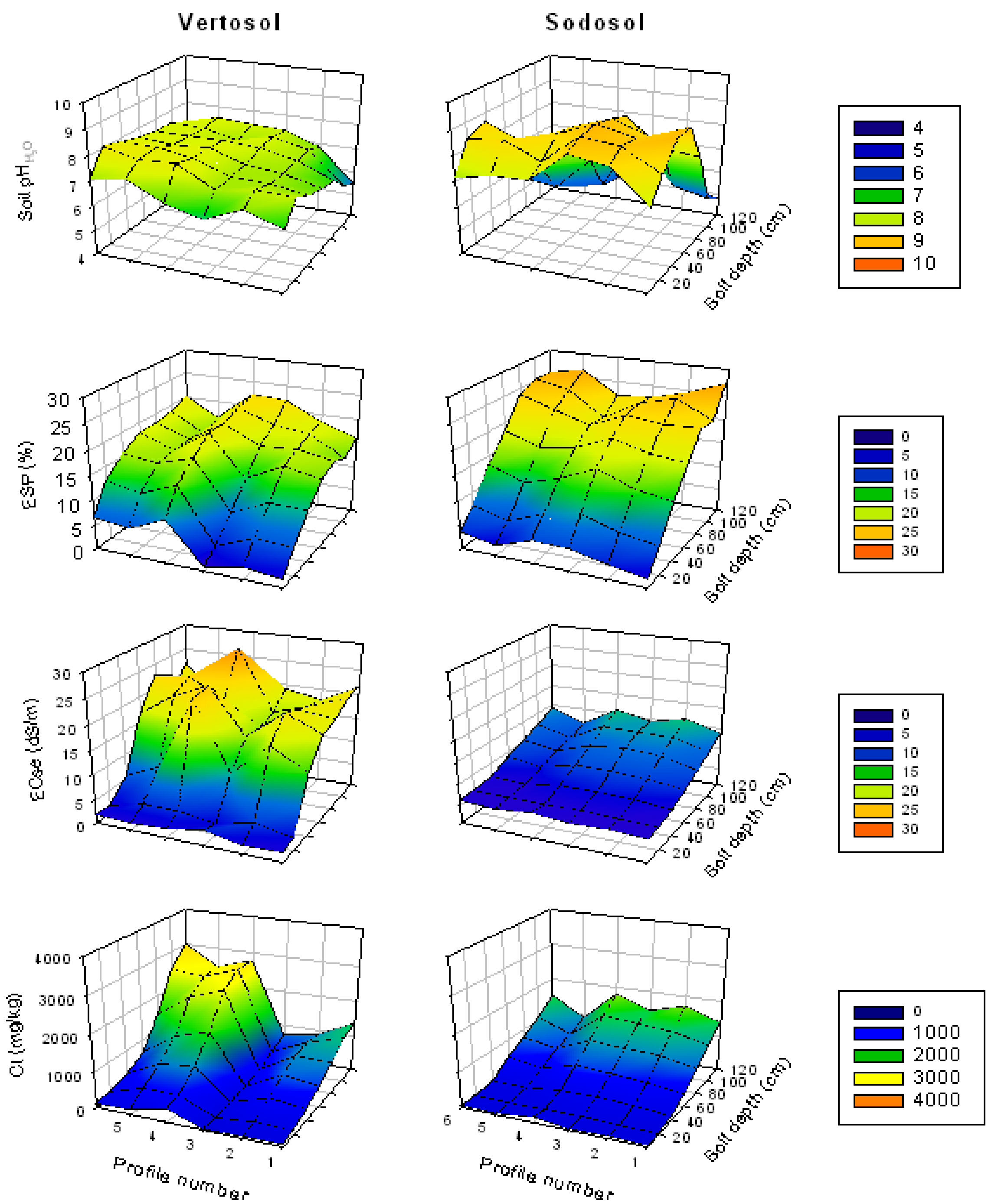


**Figure 4. Variability in pH ($H_2O$), exchangeable sodium percentage (ESP), electrical conductivity (ECse dS/m) and soluble chloride (Cl mg/kg) at 6 profile points across a paddock for two soil types at two different locations.**

Sorghum yield on a 137 ha paddock in southwest Queensland ranged from <0.5 t/ha to 3.0 t/ha whereas apparent electrical conductivity on EM38 map varied between 80 and 220 (Figure 5). The sorghum yield analysis showed negative linear relationship with EM38 readings ($R^2$= 057, $P$<0.05). Soil water, clay contents, ECse, chloride and ESP were determined on soil samples taken at 30 cm intervals to 1.2 m depths at selected positions determined from the EM38 map to cover the full range of EM38 measurements. EM38 readings showed linear relationships with average soil profile ECse ($R^2$=0.57, $P$<0.05), Cl ($R^2$=0.58, $P$<0.05) and ESP ($R^2$=0.49, $P$<0.05). However, the relationship of EM38 readings was linear but non-significant with soil water ($R^2$=0.41) and clay content ($R^2$=0.42). Preliminary results suggest that using EM38 maps together with yield map may offer more realistic economic opportunities to map out large areas of paddock with suspected subsoil constraints. However, significant relationships of EM38 with more than one causal factor of subsoil constraints warrants further analysis so as to identify the major limiting factor to root growth, yield and hence possible options for combating subsoil constraints.

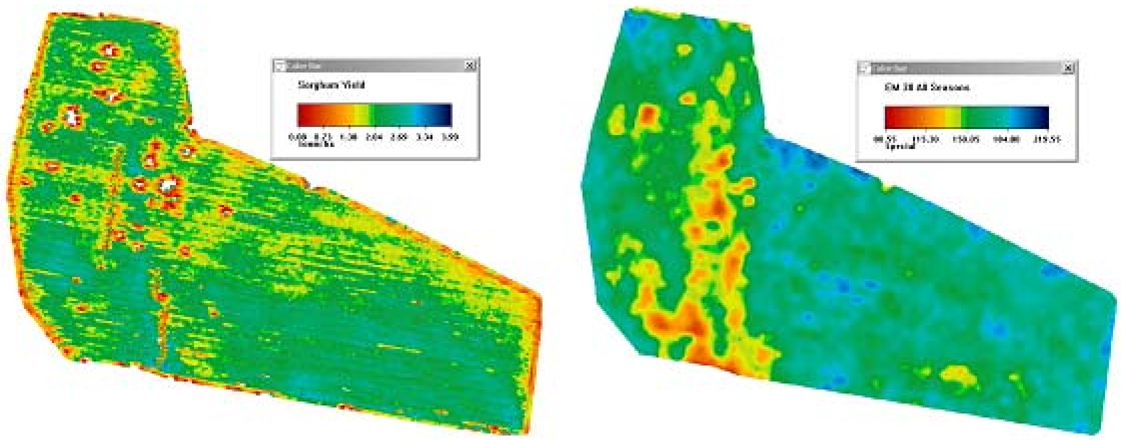


**Figure 5. Yield and EM38 maps from the 136.9 ha field near Goondiwindi showing areas of low and high sorghum yield in relation to EM38 measurements.**

### On-farm identification of subsoil constraints

The identification of the most limiting subsoil constraint and its interaction with other factors is a first step to plan for site-specific management. For in-field soil testing, a soil profile from a pit or soil core can be used to examine layers of soil and maximum rooting depth. Field based tests for salinity, sodicity, acidity and alkalinity are relatively simple to perform and allow for the identification of the presence of a subsoil constraint in different layers of a soil profile.

In field, soil EC (surrogate of salinity) and pH (measure of acidity and alkalinity) can be carried out in 1:5 air-dry soil: water (distilled or rain water) solution using hand-held conductivity and pH meters, respectively. $EC_{1:5}$ need to be converted to $EC_{se}$ (electrical conductivity of saturated extract), to interpret threshold in terms of plant growth, using soil texture conversion factor, which ranges from 22.7 for sands to 5.8 for heavy clays (Slavich and Petterson 1993). Semi-quantitative tests can give the presence of predominant salt in the paddock by observing precipitation in soil solution with $AgNO_3$ and $BaCl_2$. If chloride salts were dominant, the soil solution would precipitate with $AgNO_3$ whereas the precipitate with $BaCl_2$ would indicate the presence of sulphate salts (Rayment and Higginson 1992).

The sodic behaviour of soils is defined by dispersion and swelling of soil clay and can be assessed in field using scoring system for dispersion (Emerson 1967). The test needs to be performed in two steps: (i) dispersion on wetting indicates that a soil is sodic, and (ii) dispersion on remoulding indicates that soil is likely to disperse after cultivation, under wet conditions. The test can be perform by placing air-dry aggregates (3-5 mm diameter) in a dish and cover them with rainwater or distilled water. Assess the degree of dispersion after 10 minutes and 2 h (0: no dispersion; 4: complete dispersion). Further, carry out dispersion test for 10 minutes and 2 hours with pieces of soil aggregates that have been remoulded. Add the dispersion scores for both air-dry clods and remoulded pieces for 10 minutes and 2 h (Daniells *et al.* 1994). Although the test is sensitive in highly sodic soils but where sodic effects are only slight, other factors such as salinity level, organic matter, pH and clay content influence dispersion (Murphy 1995).

Rarely, do the various subsoil constraints occur independently. The various combinations of these may occur in many subsoils of the region, which makes management complex. However, using the decision tree (Figure 6) one can identify the most limiting constraint. The $EC_{se}$ > 4 dS/m would indicate salinity as the dominant constraints to majority of grain crops grown in Queensland (SalCon 1999; Dang *et al.* 2004), however, the effect on plant growth may vary with the presence of dominant anion (i.e. chloride, Cl and/or sulphate, $SO_4$). The presence of Cl salts would indicate osmotic effect and/or Cl toxicity, however, the effect of $SO_4$ salts on crop growth is not clearly understood and is under investigation. Dispersion score >7 would indicate sodicity as the dominant constraints and score between 2-6 indicate moderate dispersion suggesting not to work the soil when it is moist (Daniells *et al.* 1994), a pH value <5.5 would indicate acidity and a pH value >8.5 would indicate sodicity and/or alkalinity as the dominant constraint (Rengasamy and Bourne 1997). This is a conceptual framework, and would require testing over a wide range of cropping soils.

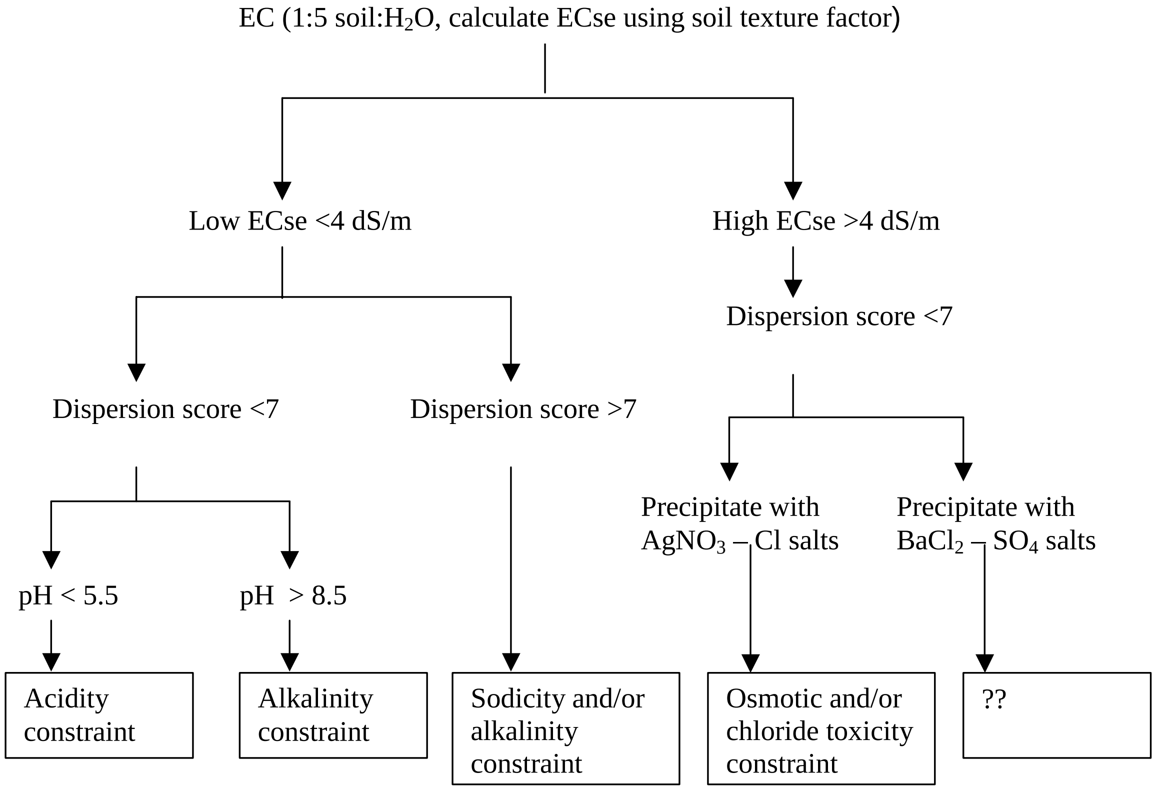


**Figure 6. Decision tree for the identification and interpretation of subsoil constraints for grain cropping (modified after Scott Irvine, personal communication).**

For interpretation of soil pit or core examination couple with chemical test values of soil, we should also consider seasonal rainfall, disease, nutrition and any other relevant information that can help in identifying root growth limiting properties and then plan for site- specific management thereafter. The key toward realising potential yields on these soils would be to gain better understanding of these subsoils, their limitations and the interaction among the causal factors of subsoil constraints, then develop options to manage them practically and economically in an environmentally sustainable system.

## Conclusions

Single or multiple factors of subsoil constraints are present in many Queensland soils. The identification of the most limiting subsoil constraint and its interaction with other factors is a first step. Soil properties vary spatially and temporally. Preliminary results suggest that using EM38 maps together with yield map may offer more realistic economic opportunities to map out large areas of paddock with suspected subsoil constraints. Interpretation of EM maps can be confusing due to texture, moisture and salt effect, so ground-truthing is necessary. Simple on-farm tests are useful as a screening device to identify subsoil constraints.

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