Chapter 6

Identifying subsoil constraints using targeted analyses

Key points

- When developing a soil sampling program, the soil type/s in the paddock, number of samples, extent of bulking of samples, the depth of sampling and the number of sampling intervals all need to be considered.
- Limiting the extent of bulking – combining of samples – allows variation within a paddock to be more accurately captured however there is a trade-off between the cost of this and the value of extra data points.
- Sampling to the maximum depth of crop rooting at intervals corresponding to clear soil horizons is recommended.
- For reliable interpretations, critical levels for the various soil tests need to be calibrated for individual soil types and crops.
- Examining a soil core taken from under a flowering crop can indicate approximate maximum rooting depth.
- Field-based tests for pH, EC and dispersion (sodicity) are relatively simple to perform and allow for the identification of the presence of subsoil constraints.
- Sensing technologies, such as electrical conductivity and electromagnetic sensing, allow for paddock-scale mapping of some soil parameters.
- Calibration of results gained from sensing technologies is strongly recommended.

Why soil test?

Regular soil testing is an important part of a cropping program. Soil tests can be used to monitor soil fertility, identify soil conditions which could restrict plant production, or assist in the diagnosis of crop health or productivity problems. However, to obtain meaningful test results, soils must be sampled correctly. A soil test is not reliable if the soil sample is not representative of the paddock, is taken incorrectly, is improperly handled after collection or if the results are not interpreted carefully. If you need help taking a soil sample, consult your local agronomist for details on appropriate soil sampling methods, and for a soil sampling kit. Alternatively, get your agronomist or consultant to do the soil sampling and testing for you.

Soil sampling and analysis, using either commercial testing services or undertaking the test yourself, identifies areas which may be affected by a subsoil constraint and also the nature of that constraint. In addition to conventional soil sampling and analysis, other procedures such as electromagnetic imaging (EM 38), offer the opportunity of rapid and cheap paddock testing for variation in soil properties. This process can also highlight where samples could be taken for detailed soil analysis and help to reduce costs. The publication *Soil Matters: Monitoring soil water and nutrients in dryland farming* by Dalgliesh & Foale (1998) may be used as a reference for sampling procedures and techniques for soil characterisation and soil monitoring.

What factors need to be considered when developing a soil sampling program?

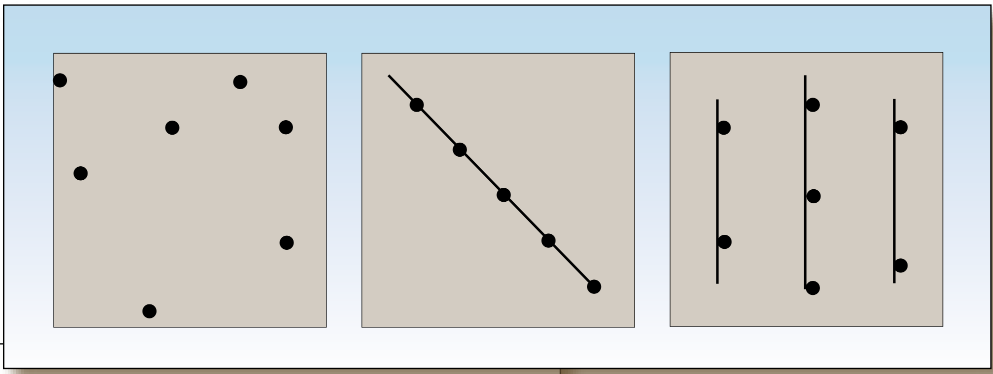
Key points that need to be addressed when constructing a sampling program are:

Sampling layout

Whole paddocks or parts of paddocks with subsoil constraints (SSC) can be identified by:

- consistently poor yields
- abundant subsoil moisture remaining under a moisture stressed mature crop
- visual crop symptoms.

Figure 6.1: Soil sampling layouts: the left hand one is random and the two right ones systematic or non-random.



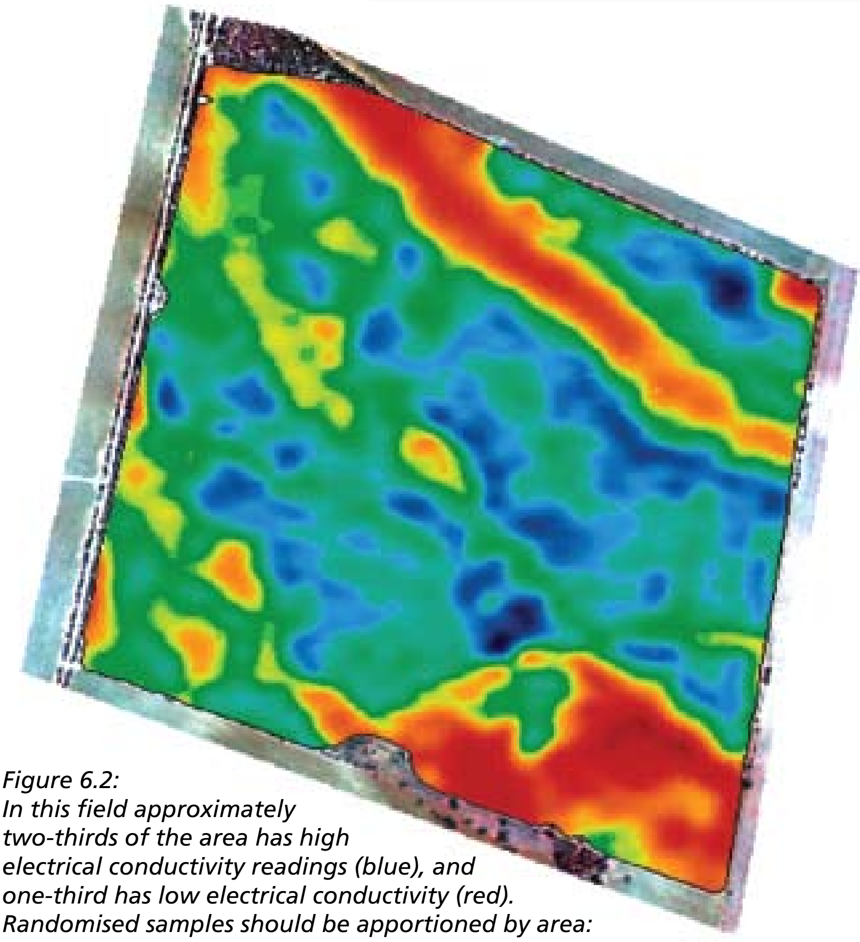


Figure 6.2: In this field approximately two-thirds of the area has high electrical conductivity readings (blue), and one-third has low electrical conductivity (red). Randomised samples should be apportioned by area: two-thirds of the 10 cores should be sampled from the larger zone, and the rest in the smaller zones.

Sampling strategies can be undertaken in a number of ways (Figure 6.1) but zones of high and low yield should be handled separately. Using a GPS device when sampling can accurately and reliably locate each specific sampling point for later reference if required. Most commercial GPS devices come with a facility to log sampling points for mapping.

The best sampling strategy is a combined approach known as stratified or directed sampling which comprises the following steps:

(i) Split the field into two to three zones based on prior information (Figure 6.2) such as a crop yield map, landscape/slope features, soil colour/texture, EM map or paddock history.

(ii) Take random samples within each zone, with the number of cores appropriate to the size of these zones. A zone comprising only a third of the field will require less intense sampling than a zone covering two-thirds of the field. Alternatively, within each zone, samples could be taken along a marked transect at regular intervals (non-randomised sampling) allowing for repeat measurements at the same points later if required (e.g. to check the effect of a particular subsoil amelioration treatment).

A diagonal transect provides good identification of the sampling line, but offers less effective coverage of soil variability. Similarly, lines provide good identification and make sample bulking easier. With a simple random system each soil core is selected separately, randomly and independently of previously drawn units. This approach covers soil variability well, but sampling points need to be marked with a GPS for location at a later date. A stratified random sample is taken from a field that has been divided into several subunits or quadrants from which simple random cores are obtained. This increases the precision for the field. The systematic sample is a further progression in an attempt to ensure complete field coverage, similar to the change from the simple random to the stratified random. Cores are taken at regularly spaced intervals in all directions. The systematic sampling plan is straightforward and potentially increases the accuracy of soil tests, however it adds considerably to costs. In a randomised sampling approach, avoid field anomalies such as fencelines or headlands, or areas close to trees.

Number of samples and extent of bulking

Soil properties can vary greatly within relatively short distances (metres) within a paddock. The number of cores and the appropriate amount of bulking (combining) of samples across cores depends on the following factors:

- The amount of variation that exists within the paddock for the property being measured. Larger paddocks generally have a higher likelihood of spatial variation than smaller paddocks. Breaking the paddock up into zones based on soil type or consistent differences in crop performance based on a farmer's experience, and coring these separately, may be warranted.
- Limited bulking of samples during the initial sampling offers an insight into the variation in the paddock. Subsequent sampling strategies can be based on variation within these initial samples.
- If one soil property, such as chloride, is identified as being important in management decisions, more samples could be taken and analysed solely for this characteristic. This will decrease the costs of analysis and increase the reliability of decision-making.
- The accuracy required supporting a decision. Some variation may not be important and not influence management decisions. Variation around critical levels, for example, where things become toxic or deficient, is more important than variation around safe values. If an initial soil test indicates that a subsoil constraint is at or near an accepted threshold, then additional testing should probably be conducted to confirm the extent of the subsoil limitation and whether the area affected by the constraint needs to be managed separately.

Once a paddock has been zoned into management units, it may be efficient to bulk and sub-sample the cores from within each zone. This may reduce the proportion of total variability sampled, but also reduce costs and thus may allow for more regular testing. Around 10 cores/40 hectares is a useful rule of thumb (Dalgliesh pers. comm.), although even at this intensity of sampling, the extent of variation may not be accurately described.

Sampling depth, sampling intervals and soil horizons

There is a trade-off between the number of sampling intervals and the cost of sample analysis. Where it is physically possible, the depth of soil sampling should be set to the maximum root depth of crops grown in the soil (approximately 1.2 m), or less in severely constrained soils. Sampling depths of 0–0.1 m for the surface soil for the first 0.2 m, and then in increments of 0.2m should give an accurate picture of changing properties with depth. However, very broad depth intervals may hide the variation that occurs within the interval. If the soil displays natural horizon boundaries (for example, a obvious clay layer beneath the topsoil), then sampling regimes based around these horizons, is preferable to sampling at set depth layers. Sampling of the subsoil requires specialist equipment. However a growing number of consultants and agribusinesses are purchasing the equipment needed and offering 'deep soil testing' on a commercial basis.

Key characteristics of a soil profile

A soil profile from a soil pit, road cutting or a soil core is a convenient way to examine layers of soil from the surface down to the crop rooting depth. Key features to look for include depth and characteristics of different soil horizons or layers. These characteristics include the texture, colour, structure, pH and presence of nodules as well as the point to which plant roots are growing. The best time to look at maximum rooting depth is after crop flowering. Record the depth to which healthy roots are growing or to what depth the roots have extracted water. Take into consideration seasonal rainfall, disease and nutrition in your interpretation of what these recordings may mean. If you wish to test for soil chemical properties from lower down the profile through a laboratory, ensure that the depth of testing is relevant for the information you want to derive from the test, and ensure that the laboratory carrying out the test is accredited by the Australian Soil and Plant Analysis Council (ASPAC).

Soil pits

Soil pits do not methodically characterise an area in the same way as soil coring does, however, they do allow the rooting depth of the crop to be determined (when done in crop) and help identify potentially limiting soil horizons negatively impacting on root growth (for example, compacted layers (hard pans), carbonate layers (Figure 6.3) or calcrete (Figure 6.4)). Because most primary producers have the equipment to dig a pit, this method is useful in diagnosing the presence of chemical and physical subsoil constraints. Once identified, detailed testing is required to determine the extent of any limitations. EM maps, yield or biomass zones or other data can be used to determine the best locations to dig soil pits and to take soil samples.

Figure 6.3: Soil profile showing potential chemical constraint to rooting depth due to the presence of carbonates at 0.7m soil depth.

Figure 6.4: Soil profile showing physical limitation to rooting depth due to the presence of a calcrete layer.

Soil chemical characteristics

Simple screening for some of the chemical indicators of subsoil constraints using field-based tests prior to sending samples to the laboratory will help reduce costs of intensive chemical analysis. The chemical analyses in Table 6.1 provide information that can be used to determine the type of subsoil constraint that might be present in a paddock. For details on some of these methods refer to Chapter 7, *Field Diagnostics*.

Diagnosing subsoil constraints

Soil chemical testing provides valuable information about the chemical fertility of the soil, such as the presence of any nutrient toxicities or deficiencies, as well as providing some indication of the soil's potential physical condition. Unlike some plant nutrients, which may vary greatly with time, subsoil constraints tend to be more constant, so having a comprehensive measure done should provide relevant information for many years. Generally, chemical subsoil constraints can be identified by five key parameters:

- Soil pH
- Electrical conductivity (EC, dS/m)
- Exchangeable Sodium Percentage (ESP, %)
- Boron (B, mg/kg)
- Chloride (Cl, mg/kg)

Soil pH

For a detailed description of measuring soil pH refer to Chapter 7.

Electrical conductivity (EC)

Recent research in Victoria indicates that high EC is a reliable indicator of subsoil constraints so if you examine no other soil property, EC should be measured.

Critical values: 1:5 soil:water extract ($EC_{1:5}$) = 1-2 dS/m
saturated extract (EC_{se}) = 6-12 dS/m

For every 1 dS/m increase above the threshold, productivity decreases by approximately 5 – 7% in barley and wheat (refer to Table 4.4 a & b for other crops and pastures).

Table 6.1. Chemical analyses for subsoil constraints

Sampling for:	Technique#	Unit
pH	1:5 in water (*#4A1)	pH (0-14)
Electrical conductivity	1:5 soil solution extract (*#3A1)	dS/m
Chloride	*#5A1	mg/kg
Boron		mg/kg
CEC	Alkaline soils: alcoholic ammonium chloride at pH 8.5 with pre-treatment for soluble salts (*# 15C1) Neutral and acid soils: *#15A2	cmol(+)/kg
Exchangeable Cations	As for CEC	cmol(+)/kg
ESP	Calculated from CEC and exchangeable cations	%

* *refers to a technical procedure contained in Rayment & Higginson (1992).*

\# *Note: Not all of these chemical tests can be conducted in the field. Testing for specific elements (e.g. boron) or measuring cation exchange capacity (CEC) needs to be done in a laboratory.*

Exchangeable Sodium Percentage (ESP)

Critical values:	Non-sodic	< 6 %
	Sodic	6 – 15%
	Highly sodic	> 15%

A detailed description of the measurement of ESP is described in Chapter 7 and assistance with interpretation of results can be found in Chapter 4.

Boron (B)

Critical values:	Risk	>3 mg/kg
	Toxic	15-50 mg/kg

High Boron (B) concentrations below 10 – 30cm occur naturally in southern Australia and are often associated with sodic soils. Boron toxicity appears to interact with seasonal rainfall. The incidence and severity of B toxicity appears to be greater in dry years (Yau 2002) when crop roots explore deeper into the soil profile for subsoil moisture. The range of toxic values reported vary from 15 – 50 mg/kg, reflecting crop and cultivar differences and the association between B toxicity and other potential subsoil constraints such as salinity and sodicity. No clear correlations have been developed between B toxicity and ESP, clay content or CEC, so it is difficult to determine if B toxicity alone is the cause of yield reductions.

Chloride (Cl)

Critical values:	Adequate	<300 mg/kg
	Marginal	300 – 600 mg/kg
	Toxic	>600 mg/kg

Chloride concentrations in surface soil are usually low, however in the subsoil, chloride concentrations can often be within the toxic range. High concentrations of chloride in the subsoil limit water extraction by increasing osmotic potential, and chloride can accumulate to toxic concentrations in the shoots of plants.

Using sensing technologies to identify subsoil constraints

The recent introduction of precision agriculture technologies has made the capacity to monitor and quantify subsoil constraints more accurate. Sensors coupled with a GPS device can produce maps of some subsoil constraints (SSC), such as salinity.

This subsection discusses some of these technologies – how they work – and the way they should be used when attempting to identify and manage SSC.

Sensors used to identify subsoil constraints

Two main types of sensors have been developed to identify SSC. These are the Electrical Conductivity (EC) sensors, and the electromagnetic induction (EM) sensor.

Electromagnetic induction sensing

Electromagnetic induction (EM) sensing is a well-established geophysical technique that relies on electromagnetic pulses to indirectly sense the salt load/s within a soil. Depending on the scale of mapping, EM sensing is termed proximal (such as mounted on the side of a tractor or all-terrain vehicle but within proximity of the soil) or aerial (mounted under a light aircraft).

An example of a proximal platform includes the Geonics EM31 and EM38 instruments (www.geonics.com). These are non-contact (or indirect) sensors that measure apparent soil EC using the principles of EM.

EM maps can be used to identify soil types within a field, usually on the basis of clay content. These soil maps are useful to direct soil sampling, and help to produce an accurate map of SSC without having to take too many cores.

Field research in Victoria suggests that a post-harvest measurement by EM can reveal where SSC impair root growth and thus reduce the uptake of soil moisture (O'Leary *et al*. 2003). Reduced rates of nitrogen fertiliser could then be applied at these sites (Pedler *et al*. 2003). However, a good calibration must be obtained between the EM results and the feature of interest. Check with your EM provider that the equipment has been calibrated at varying ground speeds. The EM38 also requires daily calibration to ensure that factors like air temperature, humidity and atmospheric electricity are not destabilising the measurements. It is important to confirm that these calibration readings are being done to get the best measurements from the instrument. To ensure the accuracy of EM surveys, the GRDC commissioned the development of guidelines for the proper set up and use of equipment for EM survey in grain cropping systems (O'leary *et al* 2006).

Electrical conductivity sensing

Technologies that measure EC are essentially recording the ability of the soil to transmit an electrical charge. A direct field measurement can be obtained with a soil conductivity meter. The charge transmitted between the two electrodes depends on the concentration of salts in the soil. More salts mean more conductivity and a higher EC value. Scaled-up versions of the conductivity meter have been developed to measure soil EC in the field. The VERIS 3100 Soil EC Mapping System uses a series of coulters arranged on a drawbar to transmit electrical pulses into the soil profile (Figure 6.5). The paired arrangement allows two EC readings to be made, one down 0 – 30 cm and the other 0 – 90 cm. When linked to a GPS device, EC maps can then be produced. Handheld EM devices are also available and easy to use (Figure 6.6). For example, the EM38 provides rapid surveys with excellent lateral resolution. Measurements are normally made by placing this instrument on the ground and recording the meter reading. Digital meters are located on the top and the side of the EM38 for the horizontal and vertical dipole measurements.

Readings of soil EC from these test types of devices depend on a number of soil-related properties:

- **Salinity.** As expected, more salt gives higher EC readings. Note the sensor will not distinguish between salts, and the salinity may equally be due to sodium or chloride. Ground-truthing is recommended in these hot spots to confirm the cause of the high readings.

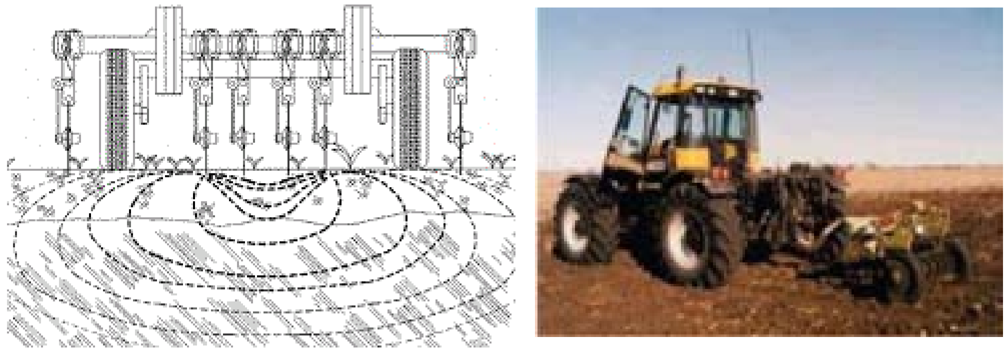


Figure 6.5: A cross-sectional representation of the VERIS 3100 in operation (www.veristech.com). Electrical arrays are created by pulsing a current through the coulters to record the average concentration of salts to 30 and 90 cm.

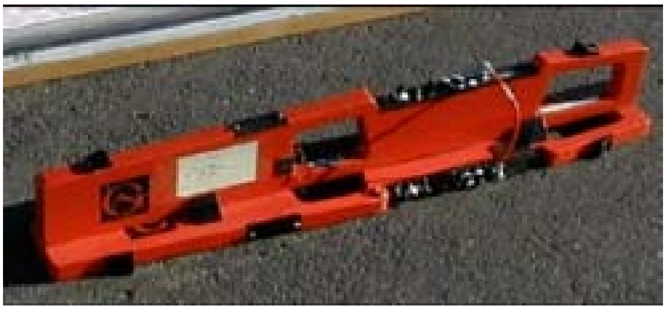


Figure 6.6: Geonics EM38 conductivity meter (www.ussl.ars.usda.gov).

- **Moisture.** Higher moisture content will bring more salts into solution and produce higher readings. Conversely, dry soil will prevent proper conduction between soil layers, so EC will be underestimated. The connectivity of moisture within the profile will influence the conductivity between the layers.
- **Texture.** A clay soil has more sites that can store salts and moisture and will give higher EC readings than a sandier soil with the same moisture status.

Interpreting EC maps can thus be confusing: the high readings can be due to high concentrations of salts, more soil moisture, or simply a heavier soil type (greater clay content). Avoid this confusion by taking samples at the time of the EC survey. In non-saline situations (that is, apparent EC values of <1500 dS/m), an EC map will then provide a surrogate measure of soil texture. Soil texture is often the governing factor in yield potential due to its affects on water-holding capacity and nutrient movement. In saline situations, the readings will be a function of both texture and salt effects, so ground-truthing is recommended.

NB: The EC values reported by a sensing device and those from laboratory analysis of soil samples are measured in different ways and hence cannot be compared directly. However, comparisons could be made if the sensor is calibrated against laboratory analysis of matched soil samples.

Considerations when using sensing technologies

As with the application of any new technology, a range of factors should be considered, namely correct calibration as previously mentioned, and the costs and benefits associated with gathering soil EC information. For example, a basic survey would run the sensors up and down the field at distances of approximately every 50 m. The points can be filled in using interpolation of these data. However, a more detailed survey – for example, if variability in EC (or texture) is anticipated to be higher or the yield map indicates significant variation – might be carried out using 25 – 30 m passes. Obviously, these changes will double the costs per hectare. For airborne detectors, surveys can be taken at 100 m lines where multiple soils are likely to be featured, or at 400 m lines for regional surveying (although this will not identify sub-field features).

It is important to remember that EM measurements will be most valuable where it complements existing knowledge, and thus it is still very useful to collect biomass data and/or yield maps to identify areas of potential subsoil constraints, followed by field inspections. Jones and O'Halloran (2005) have produced a useful guide, detailing the costs and benefits of farming with GPS guidance for the Mallee region. It can be sourced online by typing Farming the Mallee with GPS Guidance into your search engine, alternatively the full link is: http://www.dpi.vic.gov.au/dpi/nrenfa.nsf/LinkView/6EDC7749CA334A70CA257188002048E859DAA7AF7FB30E974A256DEA0012302A

References and further reading

Dalgliesh, N. and Foale, M. (1998). Soil Matters: Monitoring soil water and nutrients in dryland farming. APSRU. (Cranbrook Press, Toowoomba) This manual is available from Queensland DPI (ph: 07 46 881415). Alternatively, a web-based version is available online at: http://www.apsru.gov.au/apsru/Products/APSoil/SoilMatters/Default.htm

O'Leary, G., Peters, J. and Roget, D. (2006). A new standard for electromagnetic induction mapping of soils for the grains industry. In: Turner N.C., Acuna T. and Johnson, R.C. (2006). "Ground-breaking stuff". Proceedings of the 13th Australian Agronomy Conference, 10-14 September 2006, Perth, Western Australia. Australian Society of Agronomy. http://www.regional.org.au/au/asa/2006/poster/soil/4586_oleary.htm Internet address verified 19 November 2008.