PROXIMAL SOIL SENSING SYSTEMS

FACT SHEET

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

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An overview of the different proximal soil sensing systems available to Australian growers, and for use in precision agriculture

Proximal soil sensing (PSS) involves on-the-go collection of information related to soil properties, often employing one or more sensors

Introduction

Soil properties vary considerably over most paddocks and farms, often leading to variable crop production. The ability of growers to understand and manage this variability in soil properties has been a considerable constraint on profitability, mainly through inefficient use of inputs.

The ability to test and analyse soils, and identify constraints to production accurately, relies on efficient sample collection and cost-effective analysis.

Proximal soil sensing offers growers and their advisers a means of assessing where to take samples from, as well as the collection of samples. Soil property data can then be analysed using a range of commercially available tools to assist with decision-making and input application.

Assessing variation in soil properties across paddocks, vineyards and orchards, and how those properties change within and between seasons in response to environmental conditions and management, can assist growers with decisions about crop and variety choice, planting time, irrigation (if available), nutrient and ameliorant application rates, and timing and the identification of constraints to production, including salinity and sodicity, compaction and biological activity.

Through a combination of soil tests, laboratory analyses and proximal soil sensing techniques, growers can increase their knowledge and understanding of soil characteristics across their farm and may choose to use variable-rate technology to apply ameliorants such as lime, gypsum and fertiliser to optimise production.

Qualitative observations of soil

Identifying and mapping soil properties can assist with farming efficiency through the reduction in variability within production units.

This can be achieved through a combination of methods including noting visual differences in surface soil characteristics, such as colour and texture, and collecting samples from representative locations using a soil auger or corer, or from soil pits. A number of field-tests allow for the assessment of pH, salinity, texture, sodicity and soil aggregate stability throughout the soil profile.

These field-tests are regarded as 'observations' (that is, a qualitative measure) rather than a quantitative measure of soil properties. Qualitative soil testing and observations do not provide sufficient information to implement accurate variable-rate application of inputs or amelioration of constraints to productivity. When combined with laboratory testing of samples representing each production zone, a grower can obtain valuable insights into the soil characteristics across the property.

Laboratory soil tests

Growers have used laboratory testing of soil samples for many years, particularly to assist with crop nutrition decisions. Although laboratory testing provides detailed analysis of the samples, the standard method of collecting soil from several locations within a paddock, combining them and then extracting a sub-sample for analysis only provides an approximation of the overall average level of the soil properties of interest in the area sampled. The cost of laboratory testing generally limits the number of samples submitted for analysis.

Using proximal soil sensing to help target soil sampling sites for subsequent laboratory analysis enables growers to more accurately identify management zones and fine-tune their management practices.

Proximal soil sensing (PSS)

Proximal soil sensing (PSS) involves the on-the-go collection of information related to soil properties, often employing one or more soil sensors. These sensors are an expanding set of tools and technologies using paddock-based sensors placed close to (within two metres) or in direct contact with the soil. The depth of soil from which a response is measured depends on the type of sensor used.

When the data from these sensors is integrated with positioning information from global navigation satellite systems (GNSS; for example, GPS), geo-referenced maps showing variation across the surveyed area

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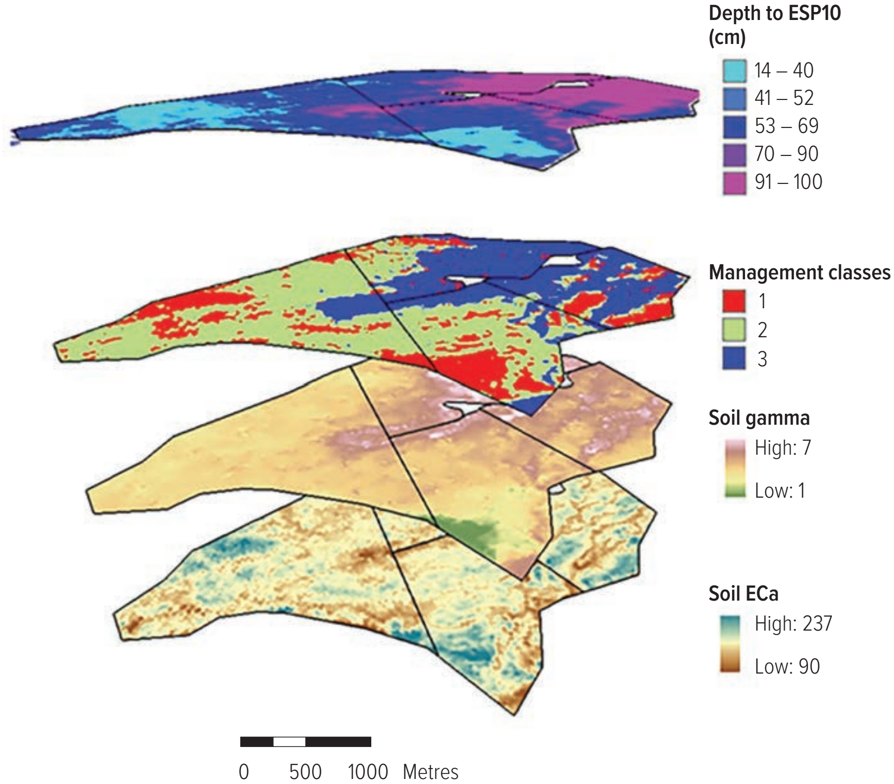
can be produced. Some commercially available soil sensors directly measure agronomically useful soil properties, although the majority measure parameters that are indirectly related to agronomically useful soil properties. If high accuracy (that is, less than two centimetres) GNSS units are used, (for example, real-time kinematic (RTK) GPS), elevation data as well as longitude and latitude coordinates can be acquired to enable the production of digital terrain maps.

The on-the-go PSS systems that are commercially available, the actual properties they measure and the soil properties that are relatable are shown in Table 1. Platforms with multiple PSS systems installed have the potential to collect data on several soil properties at the same time, allowing for more detailed assessments.

Table 1: Commercially available PSS on-the-go systems.

Sensor type	Property measured	Soil properties that influence readings
Electromagnetic induction (EMI)	Apparent soil electrical conductivity (ECa)	Clay content, moisture content, cation exchange capacity (CEC), ions in soil solution (salt and fertilisers)
Electrical resistivity (ER)	Apparent soil electrical conductivity (ECa)	Clay content, moisture content, cation exchange capacity (CEC), ions in soil solution (salt and fertilisers)
Gamma-radiometer (passive)	Natural emission of gamma rays from soil	Potassium content, texture (including gravel), soil type/parent material
Ion-selective electrode	pH	Soil chemical properties
Visible/near infrared (Vis-NIR) spectroscopy (active)	Soil reflectance of instrument source light	Colour, organic matter content, CEC, texture

Figure 1: Maps showing soil ECa, soil gamma emissions, management classes made using the two PSS data layers, and modelled depth at which the exchangeable sodium (ESP) = 10%, following strategic soil sampling across the farm.



Using PSS system data

Aside from the ion-selective on-the-go PSS instruments that directly measure a chemical property (soil pH), the majority of available on-the-go PSS systems measure properties of the soil that require ground-truthing using laboratory soil testing and calibration if the goal is to map a related agronomically useful soil property.

However, the most common use of mapped PSS data is in identification of soil sampling sites to explore the reasons for variability in crop production. The maps are either used individually or in a multitude of possible combinations with other PSS data maps, crop yield maps, terrain maps and remotely sensed images to pinpoint areas of significant soil and crop production difference.

Including PSS data in the process ensures soil information is used to corroborate evidence of any identified crop production variation. Soil sample sites can be chosen using simple map intersection processes, more sophisticated data distribution sampling techniques, or through combining the maps into a management zone map.

To date, there are no commercially available PSS tools that directly measure the available nutrient status of soils. With some paddock-specific calibrations, the soil electrical conductivity (ECa) may be used to estimate changes in soil moisture, texture and cation exchange capacity (CEC), and gamma emissions may be calibrated to site-specific total soil potassium.

The current uses for PSS data can be summarised as:

- directing soil sampling for agronomic diagnosis;
- directly measuring topsoil pH;
- creating management classes/ zone boundaries for variable-rate input application (nutrients, ameliorants, irrigation); and
- contributing as covariate data layers for modelling processes that use data from strategic soil sampling at a site to build maps of relevant soil properties (for example, texture, CEC, soil constraints).

Table 2: Currently available, and potentially useful, techniques for proximal, on-the-go monitoring of important soil chemical properties.

Soil properties	Limitations to yield	PSS techniques that show potential	Conventional methods for calibration or ground-truthing
Soil nutrients (plant-available)	Deficiency (for example, N, P, K, S and trace elements) or toxicity (for example, Al, B)	Visible/UV/NIR/SWIR/MIR spectroscopy Ion-selective electrodes ISFET Electrophoresis	Laboratory-based soil nutrient test Laboratory-based plant tissue nutrient test Crop visual indicators
Soil pH	Nutrient availability and Al and B toxicity	Ion-selective electrodes ISFET	Laboratory-based test for soil pH
Organic matter	Low organic matter	Visible/NIR/SWIR/MIR spectroscopy	Laboratory-based test for organic carbon Laboratory-based NIR/MIR spectroscopy
Soil sodicity	High sodium content	EMI Resistivity	Laboratory-based test for soil dispersion Laboratory-based test for cation exchange capacity
Soil salinity	High salt content	EMI Resistivity Ground-penetrating radar	Laboratory-based test for electrical conductivity Crop visual indication of growth patchiness

Note: Not all the technologies listed are currently successful, and alterations to procedures and sample preparations are part of the exploration process. All techniques would require ground-truthing/calibration as noted.
Key: N (nitrogen), P (phosphorus), K (potassium), S (sulphur), Al (aluminium), B (boron), UV (ultraviolet), SWIR (short wave infrared), MIR (mid infrared), ISFET (ion selective field effect transistor), EMI (electromagnetic induction)

Table 3: Currently available, and potentially useful, techniques for proximal, on-the-go monitoring of important soil physical properties.

Soil properties	Limitations to yield	PSS techniques that show potential	Conventional methods for calibration or ground-truthing
Soil nutrients (plant-available)	Low inherent yield potential due to low: CEC, PAWC, inherent fertility	Gamma radiometrics EMI Resistivity Visible/NIR/MIR spectroscopy Ground-penetrating radar Tillage draft	Hand texturing of soil sample Laboratory-based particle size analysis (PSA)
Soil water storage capacity (PAWC)	Low water content	EMI Resistivity Visible/NIR/MIR/Thermal infrared spectroscopy Radar	Drained upper limit estimates (DUL) Crop lower limit estimates (CLL)
Soil water in season (PAW)	Low PAW	Thermal Infrared Visible/NIR/MIR spectroscopy EMI Resistivity Radar Time differential imagery	Laboratory-based mass balance measurements In situ neutron/capacitance/ time domain reflectometer moisture probes Estimate from soil texture
Water logging	Reduced oxygen availability	Elevation EMI Resistivity	Piezometers/dip wells Visual observation of crop chlorosis Surface water ponding Soil hydraulic properties
Rooting depth	Shallow rooting depth Abrupt changes to soil texture Subsurface compaction Rocks	EMI Resistivity Ground-penetrating radar	Soil pit profile description Manual push probe

Note: Not all the technologies listed are currently successful, and alterations to procedures and sample preparations are part of the exploration process. All techniques would require ground-truthing/calibration as noted.

Proximal soil sensor development

Although soil ECa, soil gamma emissions, soil pH and soil reflectance surveys can now be commercially obtained, a range of other sensing technologies continue to be explored for use in proximal, on-the-go soil property measurement.

Tables 2 and 3 list the available, and potentially useful, techniques that may be employed for on-the-go monitoring of important soil chemical (Table 2) and physical properties (Table 3).

CASE STUDY

Sensing solutions for acidic soils

In conjunction with his father Don Zwar, Russell Zwar runs a 1240 hectare winter cropping enterprise at Wirrabara in the Flinders Ranges, SA. The crop sequence includes wheat, barley, canola, faba beans and oaten hay in winter, with sunflower and maize grown as opportunistic summer crops.

As very early adopters of no-till farming and stubble retention, the Zwar family is aware of the potential risk of increasing soil acidity due to the leaching of unused nitrate from the rootzone. This effect is particularly evident in soils with marginal pH levels, and within high production zones. Over the years they have conducted annual soil testing within a number of paddocks and have monitored changes in pH over time. With pH testing indicating that soils on the farm ranged from pH 4.5 in lower areas to pH 7.5 on the rises, Russell was confident farm productivity would respond to lime applications on the more acidic soils.

To more accurately measure, map and monitor pH, Russell employed his brother Michael (AgTech Services) to progressively map the pH status of his farm since 2015. Initially, samples were collected at a rate of one sample/ha, but this was increased to two samples/ha due to the variability in pH across the farm.

The on-the-go pH sensor machine assesses the soil pH of small soil cores collected on a grid sampling pattern.

CASE STUDY (CONT.)

During the soil survey, Michael also collects representative samples from each pH zone, which he sends away for independent laboratory testing. The field-test results are then calibrated to the laboratory-derived pH ($CaCl_2$) analysis. These results also show the soil's cation exchange capacity (CEC), which can be used to further fine-tune lime application calculations. The CEC and buffering capacity of the soil make a large difference to the rate of lime required to cause a desired shift in soil pH.

In 2015-16, a 300ha area of the farm was mapped and 150ha was identified as having a soil pH less than 5.5, indicating there should be a crop response to lime applications if lime was applied to the lower pH area. In another 35ha paddock, which Russell had never considered to be affected by acidity, one quarter of the paddock was found to be below the pH 5.5 threshold. Applying lime to the 9ha of this paddock that required amelioration, rather than the whole 35ha, saved Russell $2380 (see Table 4) while also evening out germination and yield across the paddock and achieving stronger crop competition with weeds.

Using the paddock-generated pH maps, Russell only applies lime where it is needed the most. In zones where the pH is below 5.5 ($CaCl_2$), he applies lime at a rate of three tonnes per ha. His aim is to increase the soil pH across the farm to above pH 5.5.

Lime is applied to dry soil in March using a Marshall spreader. This spreader does not have variable-rate capacity, so Russell uploads the pH map to a Topcon X20 GPS console unit and simply shuts the spreader off when it moves out of a zone that requires lime. This allows him to apply lime at 3t/ha in low pH zones and no lime in zones where the pH is above 5.5. Being a no-till farming system, Russell relies on some minor incorporation during the disc seeding operation and natural movement of the lime through rainfall and biological activity.

Table 4: Cost–benefit of pH mapping and patching out liming.

	Uniform paddock application	Application area based on pH mapping
Area limed (ha)	35	9
Amount of lime required (t) applied @ 3t/ha	105	27
Cost of lime ($15/t)	$1575	$405
Cost of freight and spreading ($20/t)	$2100	$540
Cost of mapping ($10/ha)	-	$350
Total cost	$3675	$1295
Saving		**$2380**

Russell has observed positive production responses in all crops sown immediately after lime application. However, the yield response in faba bean crops is the greatest, so lime is generally applied to paddocks that are to be sown to this crop.

Two years after liming some highly acidic (pH 4.5) grey silt soil, a faba bean crop yielded 3.2t/ha and Russell now budgets on yields of about 3t/ha for faba beans, now that the acidity constraint on production has been addressed.

When choosing between lime sources, Russell takes into account the cost of lime and freight, the neutralising value and the particle size (preferably less than 0.25 millimetres or 250 microns). Along with the soil's buffering capacity, the neutralising value and particle size of the lime also influence the rate of lime applied to achieve a change in pH.

Now that the soil pH status of the farm has been completely mapped, Russell plans to re-map it over the next few years to assess the impact of the liming program. He expects to continue monitoring as required, to monitor pH levels and assess the long-term efficacy of lime application. In the future, he hopes to include mapping of other production constraints, such as potassium variability, in the same pass.

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