FINAL GROWER REPORT

3D soil constraint diagnosis and options for on-the-go management

GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

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Title:
Final Grower Report
3D soil constraint diagnosis and options for on-the-go management

Project details: A grower-focused report on current commercially available or emerging technologies that combine 3D soil type data analysis of single/multiple soil constraints at a grower-usable scale and the value of amelioration for growers (this includes three business case studies).

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This report is the third of a series delivered to GRDC for this project. The full series is:

1. Prospecting for 3D soil diagnostic options – a technical overview of the technologies being used across the research and commercial sectors.
2. Method to estimate soil constraints costs and benefits – an economic modelling of the cost–benefit frameworks in soil constraint amelioration.
3. Developing grower options – a grower-focused report on the impact of subsoil constraints and the value of amelioration (this includes three business case studies).
4. Implementation report (to support GRDC investment decision making).

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COVER: Subsoil cross-section in Kalanie, WA.
PHOTO: Evan Collis

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Abstract

Soil amelioration needs are often variable across a paddock. At present growers have limited access to information on the locations of soil constraints at the sub-paddock level, making accurate and variable soil amelioration difficult. This project has evaluated and reported on existing and emerging technologies that provide three-dimensional (3D) multiple soil constraint data at a sub-paddock scale with potential for future on-the-go amelioration of different constraints and soils. The application of these technologies and approaches will ultimately reduce the cost and risk of incorrect soil amelioration, while significantly increasing yield and return on investment for growers.

A desktop analysis was conducted to provide insights on commercially available or emerging technologies that could deliver, or be combined to deliver, 3D soil constraint diagnostics at a sub-paddock scale.

A detailed review of the available technologies has found no one technology has all the required features or is able to provide all the diagnostics required. A combination of tools will be needed. The future almost certainly involves a combination of remote and proximally sensed data, layered over time to address computational constraints. It should step through the issues of where to look/prioritise, defining the constraint in broad terms using some form of soil testing and providing the spatial mapping of this information using proximal sensing approaches.

GRS system from Medusa Radiometrics: MS-1000 (10-15km/hour mapping speed; 90-160mm crystal; 6.3kg; deployed via drone. Photo: Medusa Radiometrics

Veris® Soil EC 3100. Photo: Veris Technologies

Summary

Growers who actively manage their soil constraints can achieve significant productivity gains. Lost productivity resulting from major soil constraints (acidity, alkalinity, water repellence, sodicity and compaction) is about $8 billion a year. For perspective, current crop production is valued at approximately $12 billion a year.

Despite the significant potential gains, there are continual challenges with diagnosis and management from the implementation and research and development (R&D) perspectives (Dang et al. 2021; Bryce and Pluske 2021).

Technology that assists growers to identify and quantify soil constraints can inform their management response. To increase grower profitability, diagnostic technology needs to be cheap and accurate enough to help a grower decide on the potential economic gain from amelioration without costing more than the amelioration itself. A one-pass system that both diagnoses and treats soil constraints must improve efficiency and effectiveness beyond current approaches for it to be commercially attractive to growers.

A commercial approach to 3D diagnostics (and real-time amelioration) would need to be built on high-level analytics (for example, digital soil mapping and/or artificial intelligence tools). These methods are actively applied in R&D, while some examples show their increasing use in current and pre-commercial activities. This includes one example that cites ongoing development of 3D soil modelling for on-farm deployment.

3D soil diagnostics will depend on the availability of useful input data. This report finds that such data is likely to come from:

- existing data sources (public and private);
- remotely sensed crop, climate and soil information;
- soil sampling and laboratory analysis to validate diagnostic models; and
- proximally sensed soil information.

The method and sequence used to bring the data together are important. The choice of remote and proximal technologies is also critical. Remote sensing is rapidly evolving in terms of what can be measured and also in the number of suppliers. Proximal sensors provide critical data but are costly to deploy. A summary of the likely technologies is given in Table 1.

The detailed review of the available technologies has found that no one technology has all the required features or is able to provide all the diagnostics required. A combination of tools will be needed.

Evidence suggests a solution is possible with short and medium-term technology development. Additional research to determine the optimal ordering and configuration of technologies is needed. This includes additional developmental work to unpack the complexities of soil constraint management into reliable algorithms that can be applied in an autonomous one-pass system.

The future almost certainly involves a combination of remote and proximally sensed data, layered over time to address computational constraints. It should step through the issues of where to look/prioritise, define the constraint in broad terms using some form of soil testing, and provide the spatial mapping of this information using proximal sensing approaches.

Components of this have been demonstrated already (Filippi et al. 2019a, b; Filippi et al. 2020). However, a major issue still to be addressed is our understanding of the size of the soil constraint problem as related to 3D soil variability – is it large enough in financial terms to justify this approach? This desktop report suggests the western region should be prioritised simply based on the scale of the opportunity as well as the potential to recapture mapped benefits by using present amelioration methods.

Seeding of wheat in Merredin, Western Australia. Photo: Evan Collis

Background

Australian crop yields are constrained across seven million hectares of duplex soils. High spatial variability has limited the adoption of soil amelioration practices, with the issue being identified as a high priority by national GRDC grower network meetings in 2018, 2019 and 2020.

Growers have limited access to information on the location in 3D of their constraints at the sub-paddock level. This investment aims to identify and report on possible approaches, tools and technologies that can identify and create data and accurately identify soils constraints in 3D, and then enable a variable on-the-go amelioration to be undertaken.

This report summarises one part of a four-part series of reports covering a desktop analysis commissioned by the Grains Research and Development Corporation (GRDC) to provide insights on commercially available or emerging technologies that could deliver, or be combined to deliver, 3D soil constraint diagnostics at a sub-paddock scale.

Project objective

The aim of this project was to provide a thorough understanding of commercially available (or emerging) approaches, tools and technologies that combine diagnostic and amelioration practices together for a possible one-pass solution. This could allow growers in all regions of Australia to conduct accurate and timely soil amelioration on variable paddocks on-the-go and enable:

- an increased adoption of amelioration practices on soils with higher levels of variability;
- a reduction in cost of amelioration through accurate management of soil constraints, including a reduction in fuel and equipment wear;
- a reduced risk of soil structural damage and yield reduction through incorrect application of amelioration;
- optimised ameliorants and inputs (that is, lime, gypsum, fertiliser rate/type and ripping depth); and
- an increased return on investment from amelioration practices.

Multiple soil constraints on a paddock and their prioritisation are not strictly within the terms of reference for this report and therefore have limited focus. However, it is unlikely any 3D diagnostic solution could be successfully commercialised unless it considered multiple constraints.

In keeping with GRDC's prioritisation of key investment targets (KITs), this project focused on the constraints of soil acidity, alkalinity, water repellence, sodicity and subsoil compaction.

A desktop analysis was conducted to provide insights on commercially available or emerging technologies that could deliver, or be combined to deliver, 3D soil constraint diagnostics at a sub-paddock scale. It aimed to provide GRDC with the best possible advice on this important question – how can 3D soil mapping combined with variable amelioration technology be commercialised to benefit the largest number of growers and grower hectares?

The task was (1) provide a specific cost–benefit assessment of the opportunity, before (2) exploring technology options and developing business model options, (3) preparing business case study insights on leading options, and (4) providing GRDC with recommendations and an implementation plan.

Findings

The team reviewed available knowledge about current and prospective remote and proximal sensing technologies (Table 1) and how this data can be combined. The technology scan included commercial solutions with potential to deliver complete or partial 3D field-scale diagnostic solutions. The rapid ascent of sensing technologies, and Earth Observation Systems (EOS) in particular, is seen by stakeholders (for example, CSIRO, Geoscience Australia) as critical to agricultural production going forward (Jarrett and Flentje 2018). To deliver 3D diagnostics, remote and proximal sensing data (crop and soil), soil analytics and existing datasets need to be used via data fusion and modelling methods. Sensor technologies will continue to evolve with limited intervention from RD&E investment, but the use cases and data processing methods for these technologies will need specific and continued grains industry intervention if they are to be of increased value across the Australian grains industry. This should include common comparison of technologies and metadata methods across multiple sites within the northern, southern and western regions. Data fusion and statistical modelling are the enabling technology required for 3D diagnostics and real-time analysis/amelioration approaches to be realised.

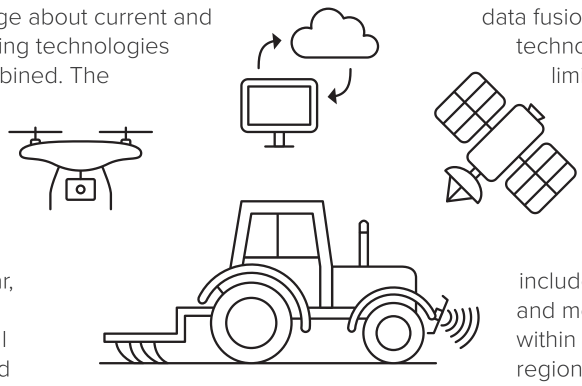


Table 1: Assessing technology fit for the diagnosis of soil compaction, soil sodicity, soil water repellence and pH (acidity and alkalinity) (TS = topsoil diagnosis, SS = subsoil diagnosis, 3D = prospect; = short term, = medium term, = long term). (The following are not listed in the table: (1) remote sensing – gamma rays [resolution too coarse to distinguish constraints directly]; SIF [provides a vegetation response and not a direct soil response]; (2) proximal sensing – NMR [method is not yet field applicable]).

Diagnostic technology	Compaction	Sodicity	Salinity	pH	Gravel	Water repellence	Comments
Remote sensing							
LiDAR	NA	NA	NA	NA	NA	TS	Soil structure and aggregation may be detectable from the soil surface (roughness). Other estimates of physical properties (e.g. density and compaction) would be a secondary derivative.
Shortwave infrared	NA	NA	NA	TS	NA	TS	Would require bare soil or presence of salinity indicator species.
Thermal infrared	TS	NA	NA	NA	TS	TS	Surface characteristics may be different for water-repellent sands. The heat signature from surface gravels may be possible to distinguish.
SAR	TS	NA	NA	NA	TS	TS	Plausible that soil moisture content can be distinguished (repellent sands). Compacted sands may be identifiable in SAR response.
Proximal sensing							
EMI	NA	3D	3D	NA	3D	NA	Proven for sodicity. Useful descriptive information but requires additional insights. 3D with multi-depth sensing and modelling.
EMR	NA	3D	3D	NA	3D	NA	
GRS	3D	NA	NA	NA	TS	TS	Includes GRS attenuation. May be linked to soil differences (e.g. texture, gravels). Useful but requires additional insights.
GPR	3D	SS	NA	NA	3D	NA	Key utility appears to be in distinguishing physical differences – likely to be useful in prediction of compaction and sodicity at depth. Gravels should be distinguishable where significant.
Cosmic ray	NA	NA	TS	NA	NA	TS	Soil water status – this may help distinguish non-wetting sands.
Electrochemical	NA	TS	TS	TS	NA	NA	pH, salinity and sodicity – chemometric methods.
Seismic acoustic	TS	NA	NA	NA	TS	NA	Prediction of physical constraints most favourable.
Gravity and magnetics	NA	NA	SS	NA	SS	NA	Magnetics have been used to detect gravels and salinity.
Mechanical	3D	NA	NA	NA	TS	NA	This would be the best direct sensor for compaction.

Glossary: EMI Electromagnetic induction; **EMR** Electromagnetic resistivity; **GPR** Ground-penetrating radar; **GRS** Gamma ray (γ-ray); **LiDAR** Light detecting and ranging; **SAR** Synthetic aperture radar; **SWIR** Shortwave infrared; **TIR** Thermal infrared; **NA** Not applicable.

Proximal sensing

Proximal soil sensing (PS) gathers descriptive data by deploying sensors within two metres of or touching the soil surface. Appropriate sensors are selected and deployed to identify specific features in the soil environment via correlation to quantitative or modelled soil data (with the basis in soil testing).

The PS options reviewed in this report are mobile in their mode of operation, rather than fixed location or scanning of point source soils. Point source scanning options are being developed as rapid methods of gathering traditional soil test data, while fixed location sensors measure properties such as soil water and temperature.

The basic premise of the approaches reviewed is that they:

- provide spatial insights and could therefore have potential as standalone or contributory data for 3D soil mapping (depth to and description of soil constraint[s]); and
- have potential for adaptation to existing machinery used in-field because the purpose is to review and frame prospective technologies for on-farm deployment (for example, sprayers, air-seeders, harvesters or tractors).

In all cases, the challenge continues to be the integration of all the crop-sensing devices and the multi-season ground-truth validation (Saiz-Rubio and Rovira-Mas 2020). We add to this the challenge of doing this in 3D across a relevant depth of soil.

Set properly, modern moldboard ploughs can have a place in soil amelioration.

Photo: Evan Collis

Remote sensing

Remote sensing (RS) insights come from sensors mounted on a remote platform (distances greater than two metres from the soil surface), usually a satellite or an unmanned aerial vehicle (UAV). By measuring the reflectance or absorption of electromagnetic energy from the Earth's surface, RS offers a range of data collection options that may reduce the overall cost of diagnostic processes. The big advantage of these platforms is the provision of spatially continuous observations while accurately capturing the temporal dynamics.

Satellite capacity is increasing because of improving technologies across multiple use cases. For example, there are estimates of 7000 to 10,000 new, small satellites in orbit by 2030 (Aglietti 2020; Behrens and Lal 2019). Similarly, machine learning and cloud computing are increasing our ability to use RS data, although the use of these sets for problems such as subsoil constraint diagnosis across a farm (Filippi et al. 2019a, b) or landscape (Filippi et al. 2020) is still emerging (that is, the fit of this information as one of many complementary datasets).

Implications of RS for subsoil constraint diagnostics in the Australian grains industry:

1. Crop monitoring information (from yield maps or RS applications) is critical to ground-truthing any diagnostic approaches (for example, Filippi et al. 2019a, b; 2020).
2. Current remote sensing technologies will continue to improve through significant global investment in R&D and commercial applications, but there are no new sensors or relevant wavelengths for investigation outside those already known.
3. Opportunity continues to be in the use of these technologies in crop monitoring applications (as per existing grains industry R&D investments).

Drones offer the ability to do proximal sensing at scale and cost effectively.

Commercial solutions

A range of partial or contributory commercial sensing solutions are available from a range of established and emerging companies (Figure 1). The team was not able to identify a complete 'plug-and-play' system for the 3D diagnosis of any soil constraint, although one group in Australia is claiming to have built software that enables 3D mapping if the 'right' input information is available. This system applies digital soil mapping approaches. The software is at the pilot development stage and has been guided through a co-design process with likely next users. It is not clear if this system allows multiple constraints to be mapped concurrently and it will not allow for constraint prioritisation.

Business case studies

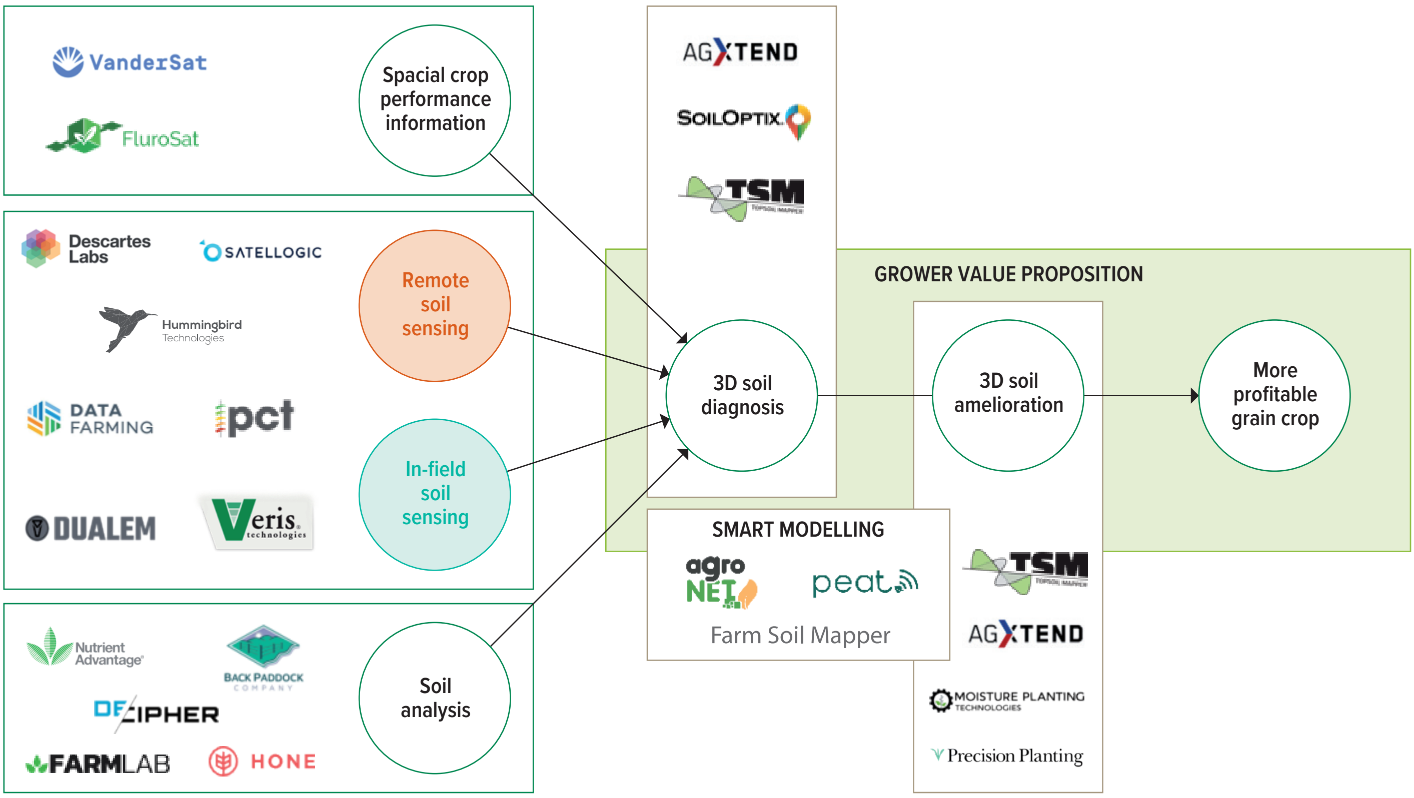
As part of the review process, three business case studies were developed and analysed to provide an insight into a practical example of combinations of technologies, issues and solutions.

Business case study 1 was developed with the Western Australian Department of Primary Industries and Regional Development (DPIRD) to test the opportunity for rapid 3D diagnosis of multiple soil constraints on WA texture-contrast soils. The technologies considered were electromagnetic induction (EMI) and ground-penetrating radar (GPR). The business case study reflected growers' need for turnkey systems that automate soil amelioration practices at a sub-paddock scale based on rapid 3D diagnostics.

KEY FINDINGS

- 5.7 million ha of texture-contrast soils would potentially benefit from soil amelioration but poor diagnostics are limiting adoption.
- Improved diagnostics in 3D would be required to realise these benefits.
- Net benefit to the grains industry of 3D diagnostics would be $120 million/year with a benefit–cost ratio of 5.0:1.
- These net benefits would focus on the Albany region ($55 million/year), with lesser benefits experienced in the Esperance ($29 million/year), Kwinana West ($27 million/year) and Geraldton ($8 million/year) regions.
- Amelioration treatments were not without risk; better diagnostics to target sites where responses were more likely could mitigate this risk.

Figure 1: Overview of the technologies being used to provide the components and their alignment to the proposed diagnostic and real-time amelioration framework.



Grower value propositions will need to be regionally specific (due to the combinations of constraints unique to each area) and seamlessly combine a range of historical data (such as soil analyses), modelled predictions, and remote and proximal sensing results to allow diagnosis and resulting prescriptive recommendations for amelioration.

Business case study 2 was developed with Agriculture Victoria and used insights from its extensive experience in the diagnosis and amelioration of subsoil constraints. The purpose was to assess the impact of variability of depth and extent of sodicity on the profitability of 3D diagnostics for ameliorating sodosols. It was focused on the deployment of 3D sensor technologies more widely in use in this region (such as EMI and GRS) to diagnose the depth of sodic subsoils.

KEY FINDINGS

- 5.6 million ha of sodosols across the southern region would potentially benefit from subsoil amelioration but poor diagnostics were limiting adoption.
- Improved diagnostics in 3D were required to support targeted subsoil amelioration strategies for growers.
- Net benefit to the grains industry of 3D diagnostics would be $120 million/year with a benefit–cost ratio of 2.5:1.
- These net benefits would be focused in north-central Victoria and south-west Victoria.

The combination of 3D soil diagnostics with subsoil amelioration appears to be a good fit in terms of enabling growers to make the most profitable investment decisions that maximise yield. A do-nothing approach may rely on other approaches using agronomists or domain experts to make judgements on depth to subsoil constraints and benefits of ameliorants.

Business case study 3 was developed using the Soil Tech Project experiences – a collaboration of AgTech Ideation, University of Sydney, AGRIvision Consultants and FarmLab. The National Landcare Program was a co-investor in this project. Farm Soil Mapping is a technology developed to address this opportunity to create 3D maps of soil characteristics. It is a prototype that requires further development and commercialisation to make it available to agronomists, growers and land managers across Australia.

KEY FINDINGS

- The Farm Soil Mapping technology combination has yet to be completed and commercialised but shows technical promise.
- The requirement for extensive soil sampling to ground-truth the modelling and RS data may be extensive on more complicated sites.
- 2D maps produced for trial farms to date have provided immediate opportunities for practice change.
- The ability to visualise and specify multiple soil constraints (rather than just a single soil constraint) simultaneously was a significant benefit as soil amelioration of individual constraints would lead to reduced yield responses if other soil constraints remained unaddressed.
- Farm Soil Mapping uses data from soil tests. The more soil tests conducted, the more accurate the 3D maps.
- The business case study suggests that Farm Soil Mapping is cost-effective where an individual constraint has a moderate to high impact on yields, or when there is more than one constraint limiting yield.

Knowledge gaps in developing 3D diagnostics

Sensor technology is developing rapidly and there are many research groups evaluating and adapting it for agricultural purposes. To deliver 3D diagnostics, remote and proximal sensing data (crop and soil), soil analytics and existing datasets need to be used via data fusion and modelling methods. The clearly identified gap from the review was the ability to bring these multiple sources of data and modelling together into reliable and cost-effective packages designed to provide the specific output we require. Soil scientists have long applied statistical methods that combine multiple datasets to develop soil maps or field management zones. These methods have continued to develop alongside sensing tools and computing capabilities.

So while the sensor technologies continue to evolve and improve, the specific needs of the grains industry may require investment to adapt those technologies to be of value across the Australian grains industry.

A leading example of R&D being undertaken in this technology combination and its practical use is the Digital Soil Mapping (DSM) project (GRDC Code COG2009-001CAX). DSM combines geographically referenced soil databases (based on quantitative relationships between spatially explicit environmental data) and measurements made in the field and laboratory to provide insights at field scale (McBratney et al. 2003). While it is not real-time, has limited spatial accuracy and is limited in the constraints being measured, it provides an insight into the potential of this type of toolbox.

The major commercial gaps appear to be in:

- incremental improvement and maturity of electromagnetic induction, electromagnetic resistivity and gamma-ray sensing systems and their specific fit to measure soil constraints in real-time;
- development of field-ready (robust and cost-effective) proximal sensors with promise (for example, ground-penetrating radar); and
- integration, analysis and modelling of complex data sources to deliver diagnostic results (R&D providers are working on this problem).

Prospective future

The prospective revenue benefit for grain growers will come from managing soil constraints that vary with soil type, soil variability, the nature of the constraint(s) present, climate, crop choice, farming system, grain prices and longevity of the yield response post-amelioration. This vast complexity hinders grower decision-making. Having commercially available technology packages that provide paddock-specific recommendations on the cost–benefit of amelioration options could help growers unlock the estimated $8 billion in lost revenue.

It is noted that grower adoption of any prospective 3D diagnostic approaches does face the technical barriers (such as connectivity and real time data management) and financial limitations common to most of these types of technology introductions. However, as with previous introductions such as GPS steering, the expectation is that once it is made available the subsequent integration into common systems and scale of industry potential will make it more affordable.

Emerging expectations

- 3D soil constraint diagnostic approaches are emerging through the use of data fusion, where data from historic sources, remote and proximal sensors and soil testing are combined (for example, Filippi et al. 2019a, b; 2020).
- 3D diagnostic approaches will benefit from:
  - continued development of statistical models and digital mapping software to make use of multiple data streams and sensing platforms (transformational change); and
  - improvements in remote and proximal sensing technologies (stepwise change), but 'new' sensing technologies were not found.
- The expected timeline for delivery of 3D diagnosis of soil constraints with GRDC investment, beyond simple management zones with constraints mapped based on soil testing, is shown in Figure 2.

Figure 2: Expected timeline for delivery of 3D diagnosis of soil constraints with GRDC investment.

Short-term (<2yrs)	Medium-term (3–5yrs)	Long-term (>5yrs)
No reliable grower options Current technologies provide partial solutions in select soil constraints (e.g. multi-depth EM) when linked with soil analytics and 3D modelling.	**Emerging grower diagnostics** Proximal, remote sensing and other data are combined** using digital soil mapping for specific soil constraint scenarios.	**Scaled grower deployment** 3D soil constraint diagnostics are probable** across major soil constraints in Australia, available for pre or at amelioration*** diagnostics.

** Data processing and modelling are the key gaps. This timeline depends on the progress and suitability of an existing digital soil mapping project (and further development/testing).
*** If appropriate for the management strategy deployed in each farm business.

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