Manaaki Whenua
Landcare Research

S-map Farm Test: Summary report on proof of concept

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Manaaki Whenua – Landcare Research

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Contents

Summary

Project and client

The Fertiliser Association of New Zealand funded Manaaki Whenua – Landcare Research to complete a proof-of-concept project on a proposed workflow for developing an S-map farm test. The vision is to develop a method by which a range of consultants, who may have limited soil expertise, can cost-effectively characterise a broad range of soil profile attributes at the farm or paddock scale.

Objectives

1 Develop a proposed workflow of the steps involved in the S-map farm-test.

2 Demonstrate the workflow on four farms as a proof of concept.

3 Recommend key areas needed in a stage two scaled-up project.

4 Deliver a detailed assessment report to the Fertiliser Association of New Zealand.

Methods

- A proposed workflow was developed, covering key steps from on-farm soil sampling through to the delivery of customised soil information to different end users.
- The options for each workflow step were described and reviewed.
- Four case study farms were used to test the feasibility of the S-map farm test workflow.

Results

- The workflow proved to be flexible for the case study farms, which were located in different parts of New Zealand. Each farm had different levels of base soil information and different questions for the S-map farm test to answer.
- A simple-to-use sampling method for consultants was identified, which involved stratifying sampling by existing map units, and then randomly selecting paddocks and sampling locations within those map units. About 10 different on-farm locations were able to be sampled in 1 day, although we believe more would be possible if the range of attributes predicted by future spectral models means that soil morphological and classification features do not need to be described during the sampling process.
- Currently visible near infra-red (vis-NIR) spectra provide good estimates for carbon and clay content that are able to be supplied to farmers, but the National Spectral Library needs to be increased before a wider range of attributes can be reliably predicted. International research clearly shows this is possible, particularly recent results from the USA using mid-infra-red (MIR) spectral analysis.
- The S-map farm test helped to validate the existing soil maps on each farm. Three farms had existing S-map coverage; the observation points indicated that for two farms (Whatawhata and Sefton) the current S-map map units were a reasonable representation of the soil pattern. However, on Rakaia Island the S-map farm test observations indicate that the current S-map boundaries should be remapped. The

map units of the Electro-magnetic (EM) map at Rakaia Island and the farm soil map at Opiki both correlated well with the variability shown by the S-map farm test.

- The S-map farm test also helped to downscale regional estimates of key soil fact sheet attribute information by using on-farm data to produce customised S-map fact sheets. While the variation observed was in the range estimated by the regional S-map, the S-map farm test observations were able to refine this range to a specific farm. For the two farms that had farm-scale soil maps, there was no information available on the soil attributes needed for tools such as Overseer. In this case the S-map farm test was able to fill this data gap and greatly improve the utility of these farm-scale soil maps.

Conclusions

This pilot project has shown the following about the feasibility of the S-map farm test.

- Cost-effective quantification of key soil attributes at the farm scale is possible.
- It is possible for consultants with limited soil pedological expertise to complete the on-farm sampling efficiently.
- The workflow and methods were flexible enough to be adapted to the four case study farms, which had different levels of base soil map data (e.g. EM map vs farm soil map vs S-map Online).
- The S-map farm test and underlying workflow were shown to be adaptable to collect soil data to answer a range of questions and for a range of uses.

Recommendations

While the pilot project has demonstrated the feasibility of the S-map farm test, there are a number of key areas that will require more investment before an operational service can be offered to farmers, consultants and councils. We recommend a stage 2 project, which would include the following advances in the steps of the workflow outlined in Figure 1.

- The most significant level of investment will be required to complete the National Soil Spectral Library and the calibration equations for a wide range of soil attributes. International research (such as for the USA in Figure 6) shows that predicting a range of key soil physical, chemical and biological indicators is achievable, but this requires a spectral library with a large number of replicates across the range of soils in New Zealand. We are fortunate that the National Soil Data Repository and accompanying physical samples in the National Soil Archive enable the potential for significant progress in a short period of time. However, investment is required to scan all the National Soil Archive samples, and then from the resulting spectral library to develop the calibration equations for a range of soil attributes.
- As part of the spectral modelling project, consideration should be given to implementing spectral scanning in commercial laboratories, which could be calibrated using the reference data set from the National Spectral Library. Hill Laboratories have already approached Manaaki Whenua to express their interest in this, particularly in the vis-NIR calibration equations, as Hill currently use vis-NIR as part of their standard testing. Based on overseas research, Manaaki Whenua would recommend that MIR

seriously be considered as part of commercial lab services, because both the accuracy and breadth of attributes that can be predicted are much greater.

- The on-farm soil sampling will need standard guidelines developed to ensure samples can be collected in a consistent and auditable way by a range of consultants. This may include a tool to help identify the number and location of sampling points, as well as consistency in sampling increments, sample identification codes, GPS recording, etc. A certain level of sampling consistency is essential for the cost-effective analysis of samples in later steps of the workflow. Further work is also required to develop a time-efficient method of sampling stony soils.
- Experience from S-map has shown that the information delivery service / platform will be essential to the success of the S-map farm test: the right information needs to get to the right person at the right time. The stage 2 project would need to clarify how best to deliver the S-map farm test data to clients to ensure the results have the ease of use, and flexibility in format, for the information to be used in a range of tools and to address a range of issues. This could utilise some of the advances in the S-map NextGen research programme in developing a custom fact-sheet builder, or direct delivery via web services to tools such as Overseer. This could be through a central platform, or the project could work with different laboratories to enable implementation within their services.
- The S-map farm test has potential for a wide range of applications. A practical approach to achieving a high degree of uptake is to involve a range of consultants in a co-design approach. This has the benefit of road testing the science as it is developing, as well as upskilling the consultants through their direct involvement in the development pathway. Potential roadblocks to practical implementation can be identified early on and addressed through this collaborative approach.

1 Introduction

New Zealand has a widespread and ongoing demand for soil information, particularly as the National Policy Statement for Freshwater Management is implemented through regional council policies and plans. Most regions now require farm environment plans and nutrient budgets using Overseer. Soil information is also required for many farm decisions, for example, irrigation management, effluent application, crop production models. Increasingly, soil information is used in a regulatory or market access compliance context, where the need is for data based on quantitative and auditable methods.

The ongoing demand for good-quality soil information is reflected in over 33,000 soil factsheet downloads from S-map over the last year, together with over 100,000 data requests from Overseer model users. A survey of S-map online users in 2019 showed that 60% of these users were from private industry and were applying this soil knowledge to a wide range of issues (see Table 1), all of which required quantitative and auditable soil information.

S-map spatial data available online has a nominal scale of 1:50,000, which is district scale information. The associated sibling and base property data in the S-map database (that informs the factsheets) is scale-less. While S-map provides a step-change in the quality of soil information available, it is widely recognised that land managers are most interested in farm- or paddock-scale information. Two key components of soil information are required: (1) a map of the spatial variability in soil types, and (2) quantitative characterisation of the attributes of each soil type.

Regional councils recently commissioned a protocol for farm-scale soil mapping to ensure consistency and confidence in the increasing number of farm-scale soil maps being generated (Grealish 2017). A real limitation of these farm-scale soil maps is the absence of cost-effective, quantitative and auditable methods to characterise key soil physical and chemical attributes at the farm scale, which are needed for tools such as Overseer. While a soil map identifies the spatial variation in soil types, tools such as Overseer need the actual attributes of each soil type (e.g. percentage clay, anion storage capacity, water-holding capacity). The same attributes are also fundamental for a wide range of other applications, such as irrigation design and management, effluent application, crop production models, land suitability assessment, and soil health monitoring.

The data that underpin S-map modelling of soil attributes cost around $10,000 per site, with about 700 sites in the National Soils Data Repository, which S-map uses to predict soil information across New Zealand. While the S-map models are of good quality, they are limited by the scale of the inputs. Using farm-scale measurements together with S-map models has the potential to significantly improve soil information – and farmer confidence.

Research at both Manaaki Whenua and internationally has identified a potential solution that could be widely applied to improve farm-scale measurement of key soil attributes. This research has shown the potential of proximal soil sensing to provide good-quality and cost-effective quantitative predictions of a range of soil attributes, both in commercial laboratories and to assist research. The opportunity here is that a wide range of soil attributes could be measured from a single cost-effective spectral scan using soil samples that can be collected by non-specialist consultants.

The Fertiliser Association of New Zealand (FANZ) has funded this project to test, as a proof of concept, the ‘S-map farm test’, which involved developing a workflow to apply proximal soil-sensing technology to cost-effectively sample and quantify the soil attributes of key soil types at the farm scale.

Table 1. The wide range of issues that S-map online users require quantitative soil information for (Source: Richardson et al. 2020)

Answer choices	% respondents	No. of respondents
Crop/pasture production management decisions or planning (including modelling)	37.09%	369
Farm nutrient budget or management models – e.g. OVERSEER®, MitAgator	30.75%	306
Managing nutrient losses	30.35%	302
Fertiliser applications	28.44%	283
Land use capability mapping	28.24%	281
Assessing soil erosion risk	27.64%	275
Irrigation management	25.93%	258
Farm operational management and planning decisions	25.13%	250
Environmental modelling research and reporting	23.02%	229
Effluent or wastewater management	22.81%	227
Managing sediment erosion or sediment runoff	20.20%	201
Preparing, updating or auditing farm environment plans	20.20%	201
Resource consent applications (preparing, auditing etc)	18.49%	184
Assessing the suitability of land for urban or rural residential development	18.09%	180
Catchment hydrological modelling	17.19%	171
Land and property sales (e.g. pre-purchasing assessments)	17.09%	170
Informing land use change processes (e.g. irrigation)	16.38%	163
Research (experimental, fundamental or student level)	15.48%	154
Providing professional advice (excluding the models mentioned earlier)	14.17%	141
Training, teaching or educational purposes (academic and vocational)	10.15%	101
Informing planning processes (e.g. subdivisions)	9.85%	98
Flood protection or catchment works	9.75%	97
Informing regulatory work or policy development (e.g. national policies, regulations, district plans)	9.15%	91
Other (please specify)	8.94%	89
Infrastructure planning (e.g. transport, utility)	8.74%	87
Geotechnical surveys	8.54%	85
Data mining or deriving new information	8.34%	83
State of environment monitoring	7.14%	71
Economic modelling and studies	6.33%	63
Transport or utility infrastructure planning	3.22%	32
Official statistics (National Greenhouse Gas Inventory, National System of Environmental & Economic Accounts)	1.31%	13
	Answered	995
	Skipped	31

2 Objectives

1 Develop a proposed workflow of the steps involved in the S-map farm test.

2 Demonstrate the workflow on four farms as a proof of concept.

3 Recommend the key areas needed in a stage two scaled-up project.

4 Deliver a detailed assessment report to FANZ.

3 Vision of the S-map farm test

To develop a method by which a range of consultants, who may have limited soil expertise, can cost-effectively characterise a broad range of soil profile attributes at the farm or paddock scale, and which would support farm management decisions and planning.

4 Principles of the S-map farm test

To guide the development of the S-map farm test we propose applying the following principles.

1 The S-map farm test can be used by consultants for farm- and paddock-scale soil characterisation.

2 Consultants do not need to have specialised soil pedological skills.

3 Soil samples can be collected by a range of techniques, but a minimum standard would require consultants to follow a standard operating protocol enabling soil samples to be collected to at least 1 m depth using a rapid and safe method.

4 The soil spectral analysis is rapid and cost-effective, allowing a range of soil attributes to be estimated at an accepted accuracy from a single soil sample.

5 The soil spectral method is suitable for application in commercial soil-testing laboratories.

6 The soil attribute data can be supplied in customisable electronic (digital) form that enables farmers and consultants to use their farm-specific soil information for a wide range of models and tools.

7 The soil attribute data supplied are quantitative and auditable, allowing farmers and consultants to use the data for regulatory and planning purposes.

5 Review of methodology options for each workflow step

5.1 Overview of workflow

The concept of the S-map farm test is outlined in Figure 1. In this scoping study only those steps highlighted by a red star are being tested. The following sections review the options available for implementing each work step.

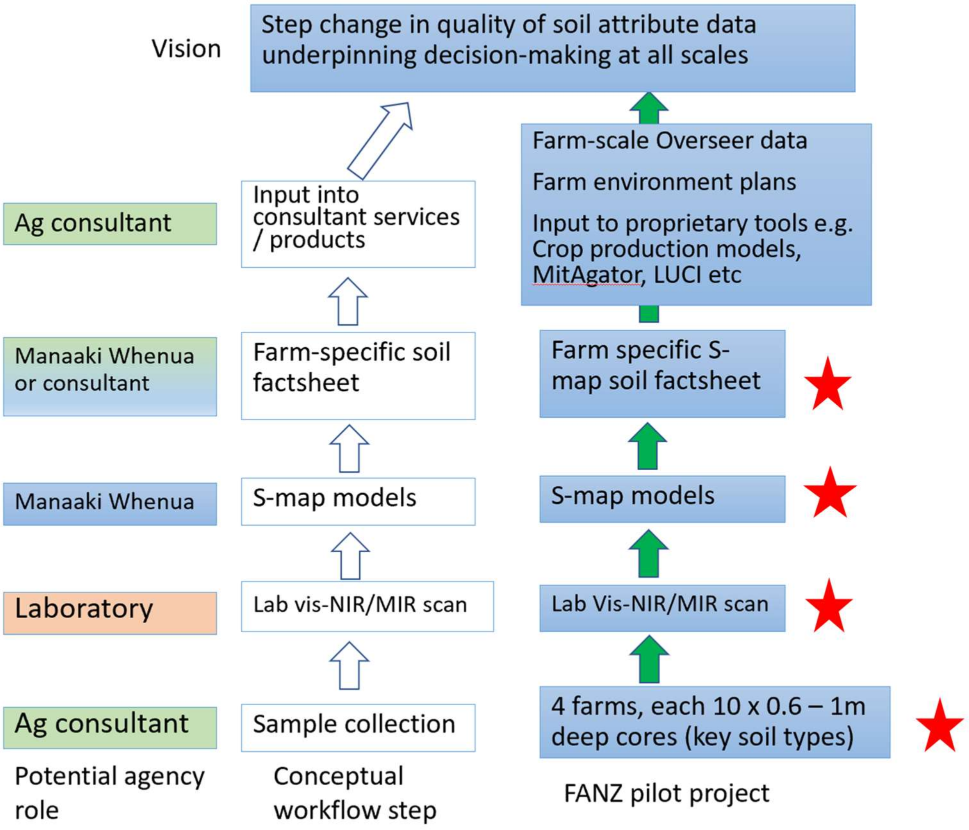


Figure 1. Overview of the conceptual workflow for the S-map farm test.

5.2 Sampling design options to select site locations

Sampling design is a key element of any field soil sampling activity. A number of national guidelines have already been established, including:

- national/regional soil quality monitoring
- farm/paddock fertility assessment
- national to farm-scale soil survey
- national soil carbon monitoring.

The most appropriate sampling design will be determined by the question that needs to be answered. In the case of this project, the S-map farm test was aimed at answering two main questions:

a Can I collect on-farm soil data on key soil types to give me greater confidence in my Overseer inputs?

b How good is my existing soil map?

To answer these questions, the following options were considered to determine the site locations for field sampling, as summarised in Table 2.

Table 2. Sampling design options considered for the S-map farm test pilot project

Sampling approach	Strengths	Limitations
Random sampling	• Statistically robust	• Will not give a spatially balanced sampling of soil landscape if the number of sites is limited • Minor, unimportant areas may be sampled • Can be costly to physically get to all the sites efficiently
Purposeful sampling	• Traditional soil survey approach – the experience of the surveyor means they can stratify sampling based on their understanding of the landscape • May be cost-efficient for experienced surveyors	• Not statistical: sampled locations are subjective, and lead to bias • Requires expert knowledge of soil landscape to strategically locate observation points • Level of expertise is not quantifiable, and approach is not reproducible
Grid sampling	• Statistically robust • Easy to implement (e.g. for non-technical person) • Does not rely on existing knowledge or data • Does not make assumption about what field variability looks like • Useful for validation (quality assurance) testing of existing maps	• Expensive because it typically requires more observation points • Minor, unimportant areas may be sampled
Stratified random sampling	• Statistically robust • Could align with using the existing fertility monitoring transects • Useful for validation (quality assurance) testing of existing maps • Is adaptable to ensuring sampling on key parts of the landscape	• Stratification requires prior data and/or knowledge relevant to the soil attribute variation that is to be characterised

5.3 Sample depth options

What depth to collect soil samples

The S-map farm test is aimed at quantifying soil attributes at the soil profile scale, which is taken as 1 m depth in S-map. However, for both irrigation management and nutrient management through Overseer a depth of 0.6 m is used. Deep-rooted crops, perennial vine and tree crops, and forestry all require characterisation to a greater depth. Internationally, the GlobalSoilMap project is recommending sampling to 2 m (or to the depth of bedrock if it occurs before 2 m).

What sample depth increment to use

The choice of depth increments over which to collect samples is also an important consideration. Traditional soil survey methods have characterised soils based on morphologically defined taxonomic soil horizons. To maintain consistency with the wealth of legacy soil survey information in New Zealand, S-map uses similar functional soil horizons. Increasingly, though, soil characterisation is being based on quantitative assessment, which is based on sampling at fixed depth intervals. In New Zealand, soil carbon assessments have been based on 10 cm depth increments, over either 0–0.3 m or 0–0.6 m depths.

The specifications of the GlobalSoilMap project, geared towards the production of soil attribute grids, define a suite of six standard depth increments, where thickness increases with depth: 0−5 cm, 5−15 cm, 15−30 cm, 30−60 cm, 60−100 cm, 100−200 cm. S-map is moving to supply soil attribute information according to both functional horizons and the standard depth increments from GlobalSoilMap.

Both approaches have advantages and limitations, with depth increments being the standard for soil chemistry characterisation, and morphological horizons the basis for soil physics measurements (primarily because soil structure is a major driver of soil water dynamics and is a key feature of defining soil horizons).

5.4 Field soil sampling technology options

The following options were considered for collecting field soil samples, with the strengths and limitations of each summarised in Table 3. A brief description and photos of each field sampling option are then provided.

Table 3. Strengths and limitations of field sampling technologies for use in the S-map farm test

Sampling method	Time to sample to 1 metre (minutes)[a]	Strengths	Limitations
Hand auger	15–30	• Easy to use • Low equipment cost • Highly portable equipment • Little training or H&S requirements • Capable of reaching to 1 m or deeper	• Volume of sample cannot be determined (therefore, for example, couldn't be used for carbon stock calculations) • Care needed not to cross-contaminate depth increments • Can't be used for stony soils (more than about 15% stones) • Care needs to be taken to collect sample from required depth increment
Mechanical corer	30	• Fast in good conditions (soil profile moist to sampling depth) • Collects continuous core of soil profile of relatively consistent volume • Accepted standard around the world • Vehicle-mounted corers have mechanical equipment to extract the core (not an option for hand-held equipment, which will require an extracting tool or person strength)	• H&S for corer use • Cost of corer • Weight (less portable) • Can't be used for stony soils (>~15% stones) • Occasionally soil will compress or drop from the bottom of the core when extracted (therefore, sometimes sample collected doesn't align with true sample depth) • Requires strong person or vehicle mounting • Most manual tools are set to core to about 60 cm, so to get to 100 cm may require a second push to obtain the lower soil • Hand-held corers can be difficult to extract manually (particularly at depths >1 m)
Soil pit	120	• Best way to see whole profile, photograph soil profile and collect accurate depth increment samples • Only way to characterise stony soils	• Requires considerably greater time • Greater land disturbance • Requires a strong person • Limited in sampling depth to c. 1 m

[a] Note: the time here assumes no soil description and no collection of cores for volumetric data – just extraction and bagging of samples, and recording of basic location information.

Hand auger

The hand auger is the standard tool used for observing the soil profile during soil survey, and it is widely used globally by both scientists and consultants. As the simplest technology available it was the method tested in this pilot project. The steps involved in sampling are summarised in Figure 2, with a full description of the sampling protocol in Appendix 1.

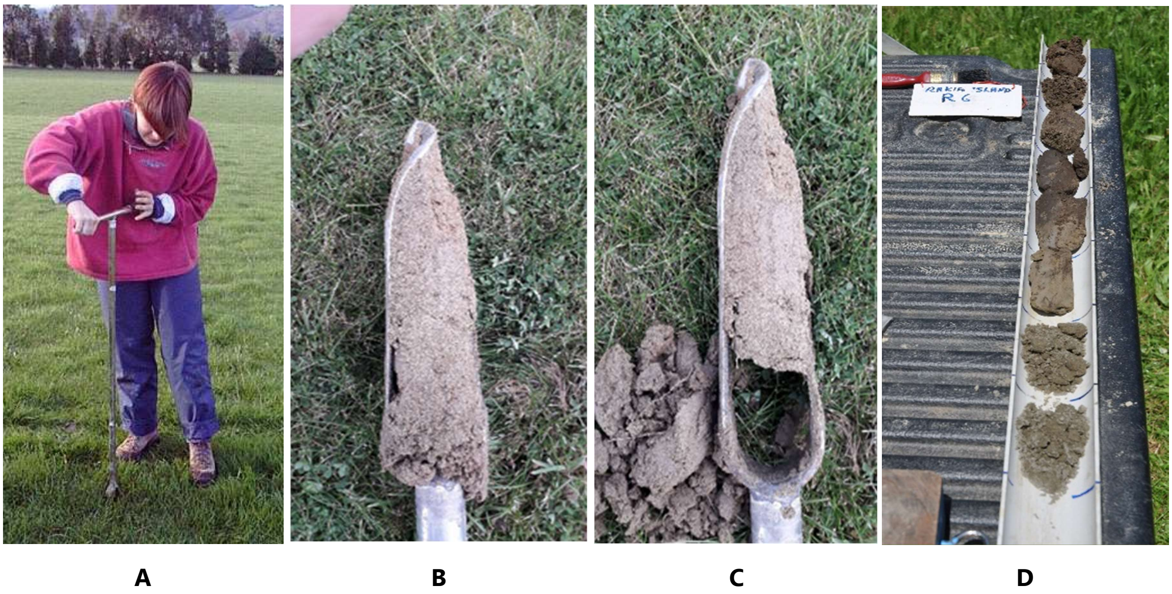


Figure 2. Steps involved in sampling a soil profile in 10 cm depth increments using a hand auger. A. The hand auger, with 10 cm depth increments marked up the auger shaft. B. Example of auger from one 10 cm depth increment. C. The top few centimetres of 'spoil' removed from the auger head before collecting the sample. D. Soil samples from each depth increment laid out on a half pipe, ready for placing in sample bags.

Mechanical corer

The next level of soil sampling involves using a mechanical corer, where either high-frequency vibration or hydraulic/mechanical pressure is used to push a soil-coring sleeve vertically down into the soil. In New Zealand this is the standard method now used for the National Soil Carbon Inventory, using 50 mm diameter sleeves, sampled down to 0.6 m depth. A large variety of mechanical corers are available, being widely used internationally for soil sampling. These corers can either be hand held (Figure 3A), mounted on an all-terrain vehicle (ATV) (Figure 4A), or on a work truck (Figure 4B). Examples of sample cores are shown in Figure 3B.

A B

Figure 3. The hand-held mechanical corer method. A. Example of a hand-held ‘vibrating’ mechanical corer. At the left of the photo is the lever used to extract the core. B. Example of soil cores extracted from the sampling tube and placed into half pipes, ready for dissection into 10 cm increments.

A B

Figure 4. Vehicle-mounted mechanical corers. A. Hydraulic corer mounted on an ATV. B. Hydraulic corer that mounts on the deck and towbar of a 4WD ute.

Soil pit

The soil pit is the standard method for describing and classifying the soil profile. Pits vary in size and depth depending on their purpose. Figure 5 demonstrates some types of soil pits used in New Zealand. In this project, soil pits were used to sample stony soils with the method in Appendix 2.

Figure 5. Examples of different soil pits for different purposes. A. A small, quick soil pit to identify key soil features. B. A small soil pit to measure stone content. C. A large soil pit to 1 m depth for full reference pit characterisation and collection of soil cores.

5.5 Laboratory testing options

Numerous international studies have shown the value of proximal sensing as a rapid and low-cost method for soil characterisation. This is a highly active area of international soil research, which is increasingly showing that numerous soil properties can be predicted from visible near- and mid-infrared spectra (vis-NIR and MIR, respectively). Both vis-NIR and MIR record the spectral reflectance of soils across a range of wavelengths, and the resulting spectra are a response to the variation in soils' mineral and organic composition (Soriano-Disla et al. 2014; Wijewardane et al. 2018). The major advantage of these methods is that many soil attributes can potentially be predicted from a given spectrum recorded from a single soil sample.

Globally, these methods are becoming central to soil characterisation. Work is being done on developing a global soil spectral library, with the aim of using spectral soil attribute analysis as the basis for a global soil map (FAO 2020). However, a major constraint on the wider uptake of soil spectroscopy is the lack of spectral calibration libraries for different soil types. Building spectral calibrations requires a soil database with reference soil analytical data for a range of attributes, along with matching spectral data for the diversity of soils in a region of interest. Also, spectral calibration models are not easily transferred from one laboratory machine to another.

Solving this issue is the subject of a recent Global Soil Partnership proposal for an inter-governmental project to co-ordinate national soil spectral libraries, with the aim of developing a global soil spectral calibration service (FAO 2020). More generally, there is a need for a set of standards to be established so that this active field of research can be turned into a successful production tool.

Visible near-infrared spectroscopy

Worldwide there has been considerable investment in the development of visible near-infrared spectroscopy (vis-NIR) to predict soil attributes, with numerous comprehensive reviews published (Rossel et al. 2006; Stenberg et al. 2010; Hedley et al. 2015). Vis-NIR spectrometers typically record reflectance between 350 and 2,500 nm, and they have proven to be a cost-effective and versatile method of predicting a wide range of soil attributes. Government agencies in a number countries have invested in developing national suites of calibration equations, including national spectral libraries for China, Brazil, Portugal, and Australia.

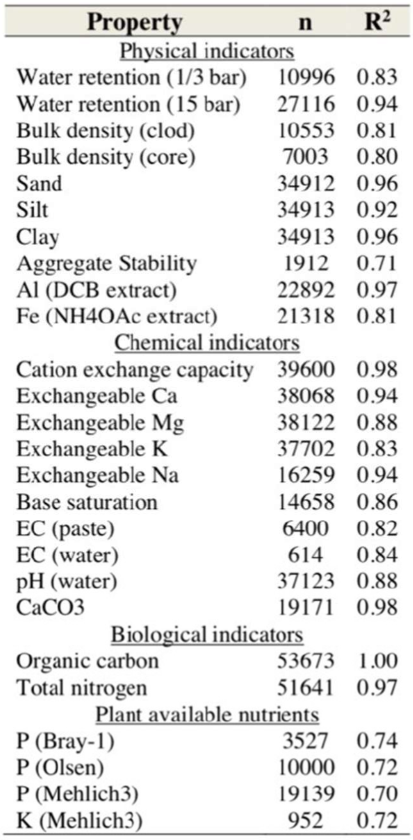
Rossel et al. (2012) scanned over 20,000 soil samples in the Australian National Soil Archive to develop calibration equations for 24 soil attributes. Good predictions were found for clay and total sand content, total organic carbon and total nitrogen, pH, cation exchange capacity, and exchangeable calcium, magnesium and sodium. Several other properties were moderately well predicted, including air-dry water content, volumetric water content at field capacity and wilting point, bulk density, the content of silt, fine sand and coarse sand, total and exchangeable potassium, total phosphorus, and extractable iron. Properties that were poorly predicted included the carbon:nitrogen ratio, available phosphorus, and exchangeable acidity.

Mid infra-red spectroscopy

Mid infra-red spectroscopy (MIR) is also a very active research area in international soil literature. MIR generally provides more accurate predictions than vis-NIR because the primary absorbance features due to the interaction between light and soil compounds mainly occur in the MIR range, while variations observed in the vis-NIR range are overtones of these primary features. As a result, the MIR spectrum often presents some sharper, better-defined absorbance features that can be better exploited by prediction models.

The USDA-NSSC National Kellogg Soil Survey Laboratory has demonstrated excellent MIR spectral calibrations for key soil properties for a very wide range of soil types across the continental USA (Figure 6). They note that the foundation for the high performance of the calibrations is both the excellence in reference analytical quality of the laboratory sustained over many years, and investment in a National Soil Archive (NSA) that retains the physical samples of the wide range of soil types that have been processed in the national laboratory over the years. Australia has also completed MIR analysis of samples in their NSA, which was used to help produce a quantitative digital soil grid map for a range of soil attributes across continental Australia.

MIR analysis does require an additional laboratory processing step compared to vis-NIR, because samples need to be finely ground before spectral scanning. This process can be automated, however. For example, in New Zealand Intellitech Automation has developed an automatic machine to grind and subsample soil samples for Analytical Research Laboratories (ARL). Hill Laboratories have developed an automatic soil-tapping robot to prepare samples for in-line vis-NIR scanning.



Property	n	R^2
Physical indicators		
Water retention (1/3 bar)	10996	0.83
Water retention (15 bar)	27116	0.94
Bulk density (clod)	10553	0.81
Bulk density (core)	7003	0.80
Sand	34912	0.96
Silt	34913	0.92
Clay	34913	0.96
Aggregate Stability	1912	0.71
Al (DCB extract)	22892	0.97
Fe (NH4OAc extract)	21318	0.81
Chemical indicators		
Cation exchange capacity	39600	0.98
Exchangeable Ca	38068	0.94
Exchangeable Mg	38122	0.88
Exchangeable K	37702	0.83
Exchangeable Na	16259	0.94
Base saturation	14658	0.86
EC (paste)	6400	0.82
EC (water)	614	0.84
pH (water)	37123	0.88
CaCO3	19171	0.98
Biological indicators		
Organic carbon	53673	1.00
Total nitrogen	51641	0.97
Plant available nutrients		
P (Bray-1)	3527	0.74
P (Olsen)	10000	0.72
P (Mehlich3)	19139	0.70
K (Mehlich3)	952	0.72

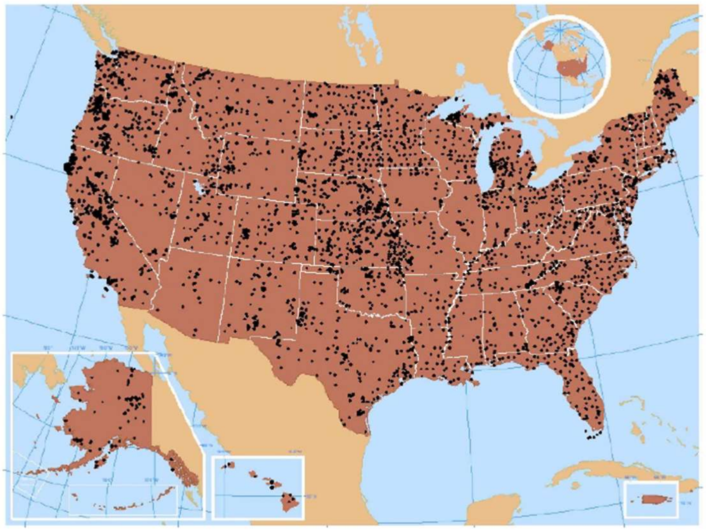


Figure 6. Example of the prediction accuracy of MIR spectra analysis for a range of soil attributes for a diverse range of soils in the USA. Map shows location of samples used for the spectra calibration. Sources: Dangel et al. 2019; Sanderman et al. 2020.

5.6 Soil spectral progress at Manaaki Whenua

Manaaki Whenua has a long history of developing and testing proximal sensing technologies to characterise the attributes of New Zealand soils. In recent years there has been a focus on vis-NIR as a tool to quantify soil carbon stocks, with several papers published (Kusumo et al. 2008; Hedley et al. 2015; Roudier et al. 2015). There was also a sustained effort to build a national vis-NIR soil spectral library through the systematic scanning of samples in the National Soil Archive (NSA). The NSA stores the physical samples for a wide range of New Zealand soils that have had traditional analytical laboratory measurements completed on them.

The analytical data and soil profile descriptions for a large number of the NSA samples are stored in the nationally significant National Soil Data Repository (NSDR). The NSDR holds data on c. 5000 soil profiles, equivalent to c. 15,000 individual soil horizons. The NSA holds physical samples for c. 25,000 soil horizons, many of which match the horizons with analytical laboratory data in the NSDR. It is important to note that the soil horizons in the NSDR vary in their range of soil analytical measurements. For example, there are c. 9,000 with soil carbon, but only c. 4,000 with soil water-holding measurements. Therefore, the number of NSA–NSDR pairs for any given soil attribute will vary when scanning and developing calibration equations for vis-NIR and MIR spectra analysis.

Many of the NSA samples have now been scanned with vis-NIR, allowing a strong calibration for soil carbon. Work is now underway to start using this spectral library to predict a range of other soil attributes, with progress on a shortlist of potential attributes summarised in Table 4. Progress on developing calibration for soil water storage attributes was published in Blaschek et al. 2019.

In 2017 Manaaki Whenua also purchased an MIR scanning spectrometer, and work has started on building up an MIR spectral library. This is only in the early development stage, but initial testing of calibration equations for some key soil attributes is shown in Table 4. Calibration models will improve with more data, as the number of samples and the range of soil samples increased.

Hill Laboratories routinely use vis-NIR for soil tests (total nitrogen and carbon, potentially mineralisable nitrogen, anion storage capacity, total sulphur) that are reported to customers, and they are in the process of building a calibration for hot-water-extractable carbon. Scion have this year invested in MIR and they are wanting to collaborate with Manaaki Whenua to develop calibration equations for forest soils.

Table 4. Progress at Manaaki Whenua to develop calibration equations for vis-NIR and MIR soil spectra of New Zealand soils

	Soil attribute	**N**	**R^2**	**RMSE**
Vis-NIR	Total carbon	7,953	0.90	0.7%
	Total nitrogen	7,946	0.89	0.06%
	pH	2,484	0.57	0.39
	Clay	1,260	0.90	4.06%
	Silt	1,260	In development	
	Sand	1,260	In development	
	Available water-holding capacity	970	0.58	4.86%
	Field capacity	970	0.70	6.68 %
	Wilting point	970	0.78	4.41%
MIR	Carbon	840	0.94	0.68%
	Clay	400	0.92	2.22%
	Sand	394	0.93	4.58%
	Total nitrogen	840	0.90	0.04%
	Silt	400	0.92	3.78%
	pH	88	0.65	0.19
	CEC	280	0.89	1.85 cmol/kg

N: number of spectra-measurement pairs in the spectral library. R^2: coefficient of determination, between 0 and 1 (1 being the best). RMSE: root mean squared error, which quantifies the average error of the spectral model.

5.7 Options to deliver results to clients

Experience from S-map has shown that the information delivery service / platform will be essential to the success of the S-map farm test: the right information needs to get to the right person at the right time. Table 5 summarises the strengths and limitations of some different options to deliver the S-map farm test results.

Table 5. Options to deliver S-map farm test results to clients

Delivery option	Strengths	Limitations
Email soil attribute data straight to the client as a standard table	• Simple • Minimal formatting • Most have email and can open an attachment	• Requires client to have systems to ingest the tabular data • Limited context for the data provided to inform client • Can require expertise to re-interpret in a form required for different applications
Consultants use the existing S-map information system to create factsheets	• Familiar soil data output • Matches existing S-map data delivery • Factsheet system and workflow are operational and proven	• Data not in a flexible format for other uses or tools • Fixed description of the data • Requires some degree of pedological expertise to classify soils
Tool developed to automatically generate customisable factsheets from the soil data	• Provides flexibility • Accommodates varying client needs to view results • Immediately responsive to client questions about the data • Requires little pedological expertise by the client / consultant	• In development stage; requires testing • Technological infrastructure and ongoing maintenance required; unknown cost
Direct feed via API web data service of soil data into tools such as Overseer	• The existing S-map API could be adapted to allow direct import of lab data into the client's Overseer account. • Provides the most up-to-date information	• Overseer is the only tool set up to utilise API data feed at this stage (although it is the most widely used tool)

6 Methods tested in the pilot study

Sampling design

For this proof of concept project the S-map farm test was aimed at answering two related questions:

a Can I collect on-farm soil data on key soil types to give me greater confidence in my Overseer inputs?

b How good is my existing soil map?

A random stratified sampling design method was chosen, because this allowed the sampling to be stratified by the existing soil map units that contain the different soil types on each farm. Within each soil map unit the target was to sample a minimum of three randomly selected sites.

Each case study farm had a slightly different approach, as the questions they required soil information for differed. These are set out in Table 6 below.

Table 6. Details of the farm-specific research questions and approach to sampling design to select site locations

Farm	Questions asked of study	Sampling design
Rakaia Island, Canterbury	• Is S-map an accurate representation of soils on my farm? • Can I collect on-farm soil data on key soil types to give me greater confidence in my Overseer inputs? • What does my electro-magnetic (EM) map mean?	• Stratified random • Stratified by EM map zone • Random selection of paddocks, with sampling locations manually selected to coincide with different EM readings
Sefton, Canterbury	• Is S-map an accurate representation of soils on my farm? • Can I collect on-farm soil data to give me greater confidence in my Overseer inputs?	• Stratified random • Stratified by S-map soil boundaries • Random selection of paddocks within an S-map soil map unit, with one sample randomly selected per paddock (avoiding gateways, fences, etc.)
Opiki, Manawatu	• Is my consultant farm-map an accurate representation of soils on my farm? • What are the soil properties of the different soils the consultant identified? • Can I collect on-farm soil data to give me greater confidence in my Overseer inputs?	• Stratified random • Stratified by farm map soil boundaries • Random selection of paddocks within an S-map soil map unit, with one sample randomly selected per paddock (avoiding gateways, fences, trough areas, etc.)
Hamilton, Waikato	• Is S-map an accurate representation of soils on my farm? • Can I collect on-farm soil data to give greater confidence in Overseer inputs?	• Stratified random • Stratified by S-map soil boundaries • Random selection of locations within an S-map soil map unit.

Sampling technology, depth and numbers

The hand auger option was used, primarily because this is the most cost-effective and portable technique that can be used by a wide range of consultants. Samples were collected in 10 cm depth increments to 1 m depth for stone-free soils and 0.6 m depth for stony soils. The depth increment method was chosen because this is the simplest method that a wide range of consultants can use without the need for specialist soil observation and taxonomic knowledge (just requires measuring depth from soil surface).

At the Rakaia Island farm, stony soils were encountered, which are not possible to sample with a hand auger. In this case a 'quick' soil pit method was used (see Appendix 2), but it is important to recognise that sampling of stony soils will take longer than for deep soils.

The number of sites to be sampled was limited to what could be achieved during 1 day on the farm. This turned out to be about 10 sites per farm, including farmer contact/communications, travel to and within the farm, as well as equipment and sample organisation at the start and end of the day. Also, for this study the surveyor completed an in-field soil description to allow an S-map sibling classification of each soil profile. This is not envisioned in the future application by consultants, which means it is possible more sites could be sampled in a day.

Laboratory analysis

For this proof-of-concept project, samples were air-dried, sieved to 2 mm, and analysed using Manaaki Whenua's vis-NIR spectrometer. Calibration equations developed from the National Soil Archive were applied to predict pH, and the percentage of carbon, sand, silt and clay. It is important to note that these calibration equations are only preliminary as this is an area of research in the early stages of development for New Zealand soils. The current prediction accuracy for these soil attributes is shown in Table 4.

Soil information delivery

The primary delivery pathway used for this proof of concept was the existing S-map data entry tool to produce custom soil factsheets for each soil observation point, based on the on-farm sibling description and the laboratory-measured sand, silt and clay. This was chosen because the modelling engine infrastructure already exists, which means it could be applied straightaway. In the future it would be possible to adapt the data entry tool so that consultants can use it.

A prototype automatic factsheet generator was also developed through co-funding from the S-map NextGen MBIE Endeavour research programme. The aim of this prototype is to demonstrate how customisable soil factsheets could be delivered directly from the laboratory, without the need for data entry from the consultant. Screen shots of some features of the prototype automatic fact sheet generator are shown in Appendix 3.

7 Results for case study farms

7.1 Rakaia Island, Canterbury

Questions the S-map farm test aimed to help answer

- Is S-map an accurate representation of the soils on my farm?
- Can I collect on-farm soil data on key soil types to give me greater confidence in my Overseer inputs?
- What does my EM map mean?

Summary of findings

The location of the observation points in relation to the S-map soil map units is shown in Figure 7, and the comparison of the S-map soil map siblings with those identified in the farm test is summarised in Table 7.

S-map has estimated a complex soil pattern for this area of the farm, with five different map units and 10 different siblings (Table 7). The S-map farm test observation points do correlate with this range of soils, but the current S-map soil map unit boundaries look as if they could be improved to better map the soil pattern in this location.

The S-map farm test observations indicate that AWC_{60cm} varies in the range of 50 to 110 mm in this area, which is a similar range estimated by the current S-map. All soils were well drained and classify to the Recent soil order. The S-map farm test observations do classify to different siblings, which reflects the variation of texture in each soil profile.

The S-map farm test observation points do seem to correlate well with the EM map, indicating that this could be a good basis on which to adjust the S-map soil boundaries in this area. In Figure 7 the soils with low AWC_{60cm} seem to occur in EM zones with low EM (redder colours), while higher AWC_{60cm} points appear to align with higher EM values (yellow to green). However, the strength of this apparent correlation is not possible to accurately assess without the GIS layer of the EM map. The consultancy (Agri-optics) should be able to do this correlation now that they have the measured soil attribute data from the S-map farm test.

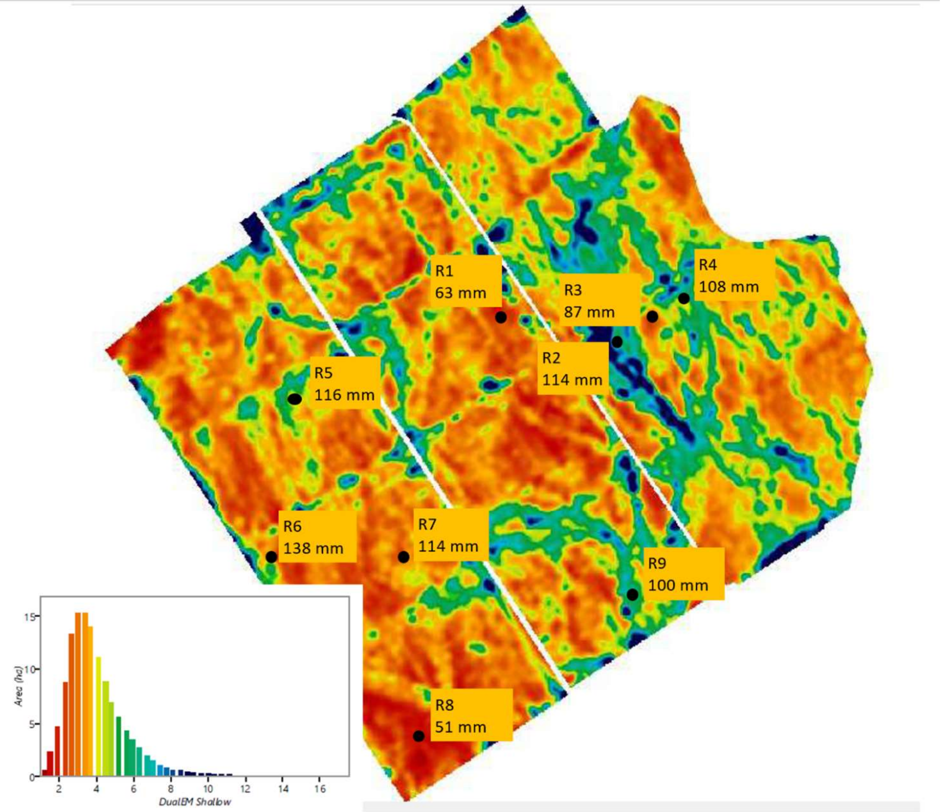


Figure 7. Observation sites (black dots) on the Rakaia Island farm in relation to the EM map, labelled by the site number and the AWC to 60 cm depth. Yellow boxes indicate all sites were well drained. The graph shows the relationship between EM map colour and the relative EM signal, in relation to the proportion of the spatial area.

Table 7. Rakaia Island case study farm: comparison of the S-map soil map unit siblings with those identified in the farm test

S-map map unit	S-map siblings	% area	order	drainage	depth	AWC (60 cm)	AWC (1m)	Texture group	FANZ sites	FANZ sibling	order	drainage	depth	AWC (60 cm)	AWC (1 m)	Texture group
1	Raka_2	50	Recent	well	shallow	55	63	Loamy	R1	Rivd_15a.1	Recent	well	shallow	63 mm	77 mm	Sandy
	Raka_1	30	Recent	well	shallow	79	89	Loamy								
	Raka_10	20	Recent	well	very shallow	46	55	Loamy								
2	Rang_21	50	Recent	well	shallow	67	76	Sandy	R2	Waiti_3a.1	Recent	well	deep	114 mm	178 mm	Sandy
	Rang_23	25	Recent	well	shallow	52	57	Sandy	R3	Waiti_7a.1	Recent	well	mod deep	87 mm	103 mm	Sandy
	Selw_25	25	Recent	well	deep	115	132	Loamy	R4	Waim_88a.1	Recent	well	mod deep	108 mm	140 mm	Silty
									R9	Waiti_6a.1	Recent	well	mod deep	100 mm	115 mm	Sandy
3	Waim_40	60	Recent	well	mod deep	116	134	Silty	R5	Waim_88a.2	Recent	well	mod deep	116 mm	138 mm	Silty
	Raka_1	30	Recent	well	shallow	79	89	Loamy	R6	Waim_89a.1	Recent	well	mod deep	138 mm	172 mm	Silty
	Raka_2	10	Recent	well	shallow	55	63	Loamy								
4	Fere_1	60	Recent	well	deep	75	85	Sandy	R7	Waiti_5a.1	Recent	well	mod deep	114 mm	142 mm	Sandy
	Rang_32	40	Recent	well	shallow	52	59	Sandy								
5	Raka_1	60	Recent	well	shallow	79	89	Loamy	R8	Raka_47a.1	Recent	well	shallow	51 mm	66 mm	Silty
	Waim_4	30	Recent	well	deep	128	157	Loamy								
	Raka_2	10	Recent	well	shallow	55	63	Loamy								

7.2 Sefton, Canterbury

Questions the S-map farm test aimed to help answer

- Is S-map an accurate representation of the soils on my farm?
- Can I collect on-farm soil data to give me greater confidence in my Overseer inputs?

Summary of findings

The location of the observation points in relation to the S-map soil map units is shown in Figure 8, and the comparison of the S-map soil map siblings with those identified in the farm test is summarised in Table 8.

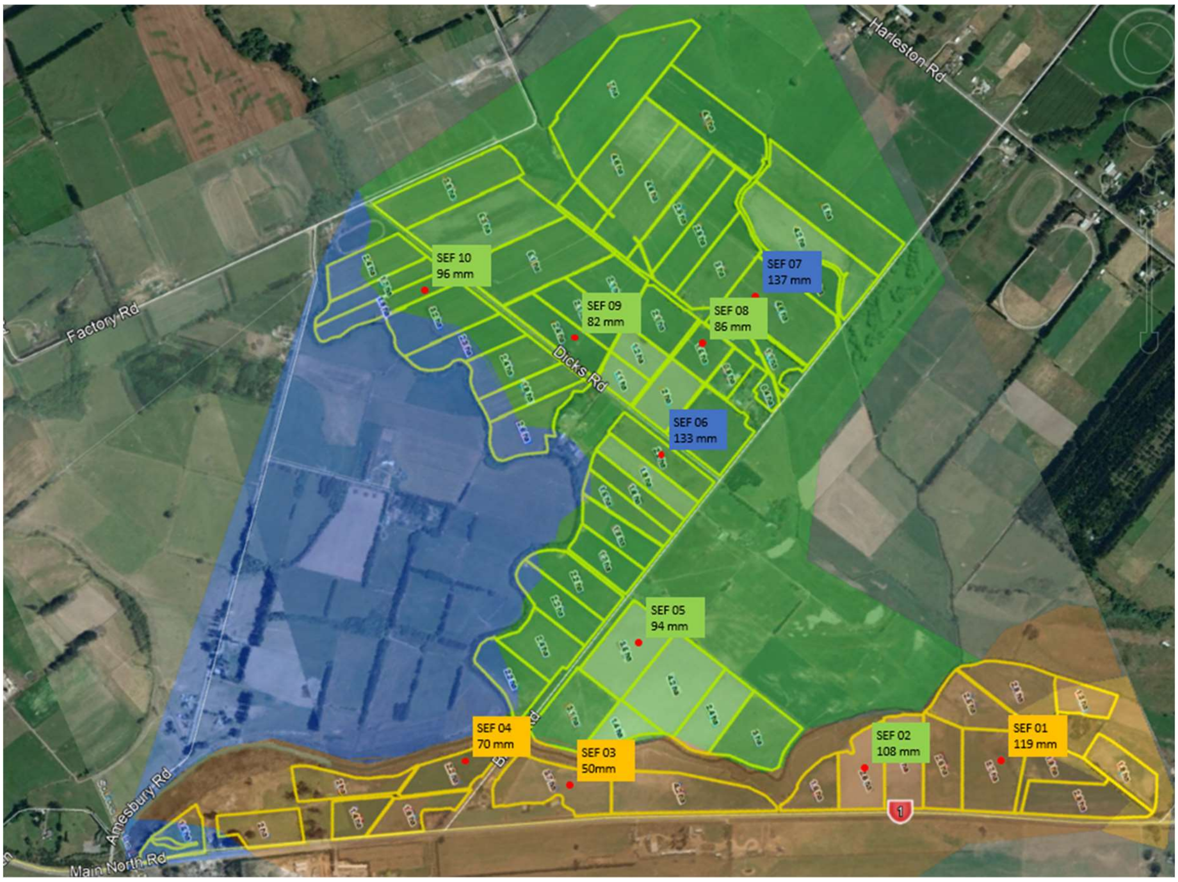


Figure 8. Observation sites on the Sefton farm in relation to the S-map soil map units, labelled by the site number and the AWC to 60 cm depth. Blue boxes indicate poorly drained soil, green indicate imperfect drainage, and yellow indicate well drained.

The S-map map units are a reasonable representation of the soil variability observed with the S-map farm test observation points. The most dissimilar soils were SEF 03 and 04, which were shallow to gravel, whereas S-map has mapped this area as deep sandy soils.

For both map units the S-map farm test observations estimate a higher water-holding capacity (AWC_{60cm}), averaged across the map unit. This reflects the fact that the soil texture measured on the farm overall had a higher silt and clay content than the regional S-map siblings, which are estimating across a much wider spatial area.

For map unit 1 (adjacent to State Highway 1) the area was mapped as sand plain, but the farm test measurements showed that a layer of silty textured river alluvium has been deposited over the sand plain. For map unit 2, which occupies the main farm area, the soils were similar to S-map, but two of the observations were Gley soils with a higher AWC.

7.3 Opiki, Manawatu

Questions the S-map farm test aimed to help answer

- Is my consultant farm-map an accurate representation of the soils on my farm?
- What are the soil properties of the different soils the consultant identified?
- Can I collect on-farm soil data to give me greater confidence in my Overseer inputs?

Summary of findings

The location of the observation points in relation to the farm map is shown in Figure 9, and the comparison of the S-map soil map siblings with those identified in the farm test is summarised in Table 9.

The farm map units are a reasonable representation of the soil variability observed with the S-map farm test observation points. The most dissimilar soil was OPI 05, which was a Kairanga soil, but mapped in the Manawatu map unit (indicating this area may need more observation points to see if it should be merged with the adjacent Kairanga map unit).

The farm map provided only qualitative soil descriptions, so the quantitative measurements of the S-map test had made this information much more usable for tools such as Overseer. The farm test results indicate that the Manawatu soil has a moderate AWC_{60cm} of 75 to 90 mm, and the Kairanga soils have high AWC_{60cm}, typically between 120 and 140 mm, reflecting the higher clay and silt content.

In terms of the phases of the Kairanga soil that were identified in the farm soil map, no major differences were observed in the S-map farm test observations: all points were classified as Gley soils with poor drainage, and there was no clear pattern in the variation of clay content and AWC_{60cm}. However, this does not reflect the fact that Kairanga wet and peaty silt loam phases may be lower lying and risk more frequent ponding, which is important for farm management. There is no evidence from the carbon results that the peaty phase has peaty soil characteristics, so it is possibly misclassified.

The farm map had described the Kairanga silt loam as imperfect drained, but the S-map farm test points indicate the soil classifies as poorly drained. While this aligns with the definition of these soils in the nearby Kairanga County soil survey, it is important to note that the classification of drainage class is subjective and therefore can vary between soil surveyors. The farm map had also indicated that soils on the farm were predominantly silt loam textures in the topsoil, but the S-map farm test showed that these soils are more clayey, with clay content typically 40−50% in the topsoil.

Figure 9. Observation sites on the Opiki farm in relation to the S-map soil map units, labelled by the site number and the AWC to 60 cm depth. Blue boxes indicate poorly drained soil, while green indicate imperfect drainage.

Table 8. Sefton case study farm: comparison of the S-map soil map unit siblings with those identified in the farm test

S-map map unit	S-map siblings	% area	order	drainage	depth	AWC (60 cm)	AWC (1 m)	Texture group	FANZ sites	FANZ sibling	order	drainage	depth	AWC (60 cm)	AWC (1 m)	Texture group
1	Wiku_1	70	Brown	well	deep	62 mm	100 mm	Sandy	1	Waim_90a	Recent	well	deep	119 mm	180 mm	Silty
	Burw_1a.1	20	Recent	Imperfect	deep	108 mm	167 mm	Sandy	2	Barp_2a	Recent	imperfect	deep	108 mm	183 mm	Sandy
	Wiku_20b.1	10	Brown	well	deep	61 mm	98 mm	Sandy	3	Raka_48.1	Recent	well	very shallow	50 mm	68 mm	Silty
									4	Raka_50a.1	Recent	well	shallow	70 mm	86 mm	Silty
2	Paha_3a.1	50	Pallic	Imperfect	deep	81 mm	127 mm	Silty	5	Paha_78a.1	Pallic	imperfect	deep	94 mm	151 mm	Silty
	Salix_4a.1	30	Pallic	Imperfect	deep	73 mm	116 mm	Clayey	6	Ayre_24a.1	Gley	poor	deep	133 mm	215 mm	Clayey
	Paha_16a.1	20	Pallic	imperfect	deep	88 mm	145 mm	Silty	7	Flax_150a.1	Gley	poor	deep	137 mm	233 mm	Silty
									8	Paha_79a.1	Pallic	imperfect	deep	86 mm	145 mm	Silty
									9	Paha_80a.1	Pallic	imperfect	deep	82 mm	133 mm	Silty
									10	Paha_16b.2	Pallic	imperfect	deep	96 mm	152 mm	Silty

Table 9. Opiki case study farm: comparison of the soil types mapped in the farm soil map units, with those identified in the S-map farm test

Farm map soil type	drainage	depth	Texture	Sites	FANZ S-map sibling	order	drainage	depth	AWC (60 cm)	AWC (1 m)	Texture group
Kairanga silt loam	imperfect	deep	z/cl	1	Temu_92a.1	Gley	Poor	Deep	133 mm	215 mm	Clayey
				12	Temu_96a.1	Gley	Poor	Deep	121 mm	228 mm	Clayey
				4	Payn_13b.1	Gley	Poor	Deep	176 mm	364 mm	Clayey
Kairanga silt loam, wet phase	poor−very poor	deep	z/cl	9	Flax_151a.1	Gley	Poor	Deep	137 mm	230 mm	Silty
				11	Temu_95a.1	Gley	Poor	Deep	126 mm	220 mm	Clayey
Kairanga peaty silt loam	imp − poor	deep	zc	6	Temu_93b.1	Gley	Poor	Deep	118 mm	199 mm	Clayey
				8	Temu_94a.1	Gley	Poor	Deep	135 mm	229 mm	Clayey
Manawatu mottled silt loam	mod well	deep	z/zc	2	Bobb_5a.1	Recent	Imperfect	Deep	89 mm	150 mm	Clayey
				3	Bobb_6a.1	Recent	Imperfect	Deep	75 mm	135 mm	Clayey
				5	Invr_20a.1	Gley	Poor	Deep	140 mm	221 mm	Clayey

7.4 Hamilton, Waikato

Questions the S-map farm test aimed to help answer

- Is S-map an accurate representation of the soils on my farm?
- Can I collect on-farm soil data to give me greater confidence in my Overseer inputs?

Summary of findings

The location of the observation points in relation to the farm map is shown in Figure 10, and the comparison of the S-map soil map siblings with those identified in the farm test is summarised in Table 10.

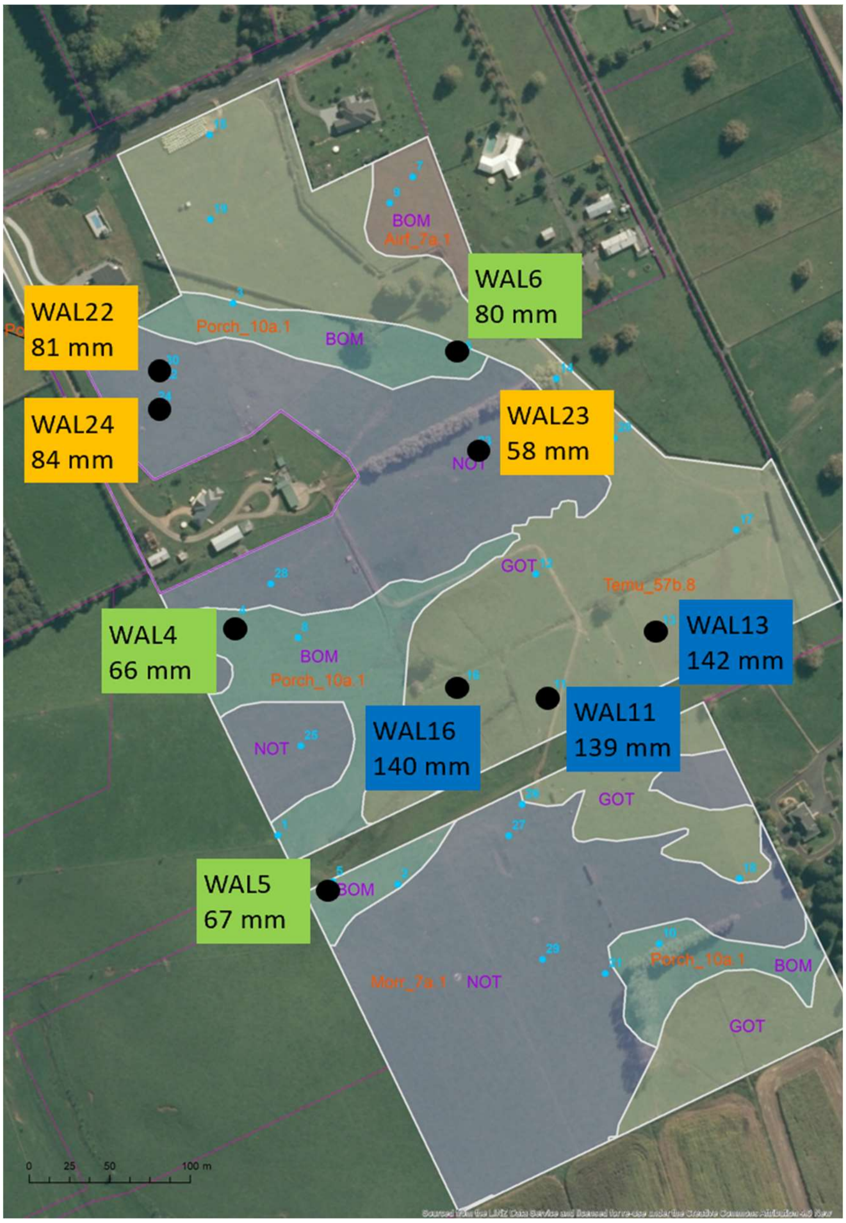


Figure 10. Observation sites on the Whatawhata farm in relation to the S-map soil map units, labelled by the site number and the AWC to 60 cm depth. Blue boxes indicate poorly drained soil, green indicate imperfect drainage, and yellow indicate well drained. Light blue points are the randomly generated potential sampling locations that actual sites were chosen from.

The existing S-map map units are a reasonable representation of the soil variability observed with the S-map farm test observation points. The S-map map units do estimate a higher variability in soil orders within a map unit than was observed on-farm. This is largely because the S-map map units are covering a much wider geographical area, where variation in soils within map units is likely to occur.

Functionally the most important distinction is between the poorly drained Gley soils in the low-lying areas (WAL 11, 13, and 16) and the imperfectly to moderately well-drained Granular soils observed on the higher land. The existing S-map boundaries appear to reflect this distinction. While the siblings identified from the S-map farm test observations are different, this largely reflects the lower variability in soil orders; for example, a minor proportion of the Brown soil order is estimated in the regional S-map, and that was not observed on-farm.

The differences in siblings also reflect the farm-specific measurement of soil texture compared to the regional S-map siblings that are estimating across a much wider spatial area. The Gley soils, in particular (WAL 11, 13 and 16), had loamy rather than clayey texture, reflecting a lower on-farm measured clay content. The differences in texture are also reflected in the estimates of water-holding capacity (AWC_{60cm}) from the on-farm data, which are different but within the range estimated by the regional S-map.

Table 10. Whatawhata case study farm: comparison of the soil types mapped in the farm soil map units, with those identified in the S-map farm test

S-map map unit	Smap siblings	% area	order	drainage	depth	AWC (60cm)	AWC (1m)	Texture group	FANZ Sites	FANZ sibling	order	drainage	depth	AWC (60cm)	AWC (1m)	Texture group
1	Porch_10a.1	50	Brown	imperfect	deep	74	119	clayey	WAL04	Puni_5	Granular	imperfect	deep	66	100	clayey
	Morr_7a.1	30	Granular	mod well	deep	67	111	clayey	WAL05	Puni_4	Granular	imperfect	deep	67	98	clayey
	Temu_76a.1	20	Gley	poor	deep	123	204	clayey	WAL06	Whatw_1	Granular	imperfect	deep	80	124	clayey
2	Temu_57b.8	70	Gley	poor	deep	109	182	clayey	WAL11	Hast_66	Gley	poor	deep	139	229	loamy
	Airf_7a.1	30	Brown	imperfect	deep	80	119	clayey	WAL13	Hast_64	Gley	poor	deep	142	230	loamy
									WAL16	Hast_65	Gley	poor	deep	140	228	loamy
3	Morr_7a.1	70	Granular	mod well	deep	67	111	clayey	WAL22	Morr_10	Granular	mod well	deep	81	125	clayey
	TeRah_1a.1	30	Brown	mod well	deep	62	96	clayey	WAL23	Morr_11	Granular	mod well	deep	58	94	clayey
									WAL24	Morr_9	Granular	mod well	deep	84	128	clayey

8 Conclusions

This pilot project has made the following findings about the feasibility of the S-map farm test.

- Cost-effective quantification of key soil attributes at the farm scale is possible.
- It is possible for consultants with limited soil pedological expertise to complete the on-farm sampling in a time efficient way.
- The workflow and methods were flexible enough to be adapted to the four case study farms, which all had different levels of base soil map data (e.g. EM map, vs farm soil map, vs S-map online).
- The S-map farm test and underlying workflow were shown to be adaptable to collecting soil data to answer a range of questions and uses.

9 Recommendations for stage 2 development of the S-map Farm Test

While the pilot project has demonstrated the feasibility of the S-map farm test, there are a number key areas that will require more investment before an operational service can be offered to farmers, consultants and councils. We recommend a stage 2 project, which would include the following advances in the steps of the proposed workflow (Figure 1).

- **Spectral library enhancement and improved calibrations for soil attribute prediction.** The most significant level of investment will be required to complete the National Soil Spectral Library and the calibration equations for a wide range of soil attributes. International research (such as for the USA in Figure 6) shows that predicting a range of key soil physical, chemical and biological indicators is achievable, but this requires a spectral library with a large number of replicates across the range of soils in New Zealand. We are fortunate that the National Soil Data Repository and accompanying physical samples in the National Soil Archive enable the potential for significant progress in a short period of time. However, investment is required to scan all the National Soil Archive samples, and then from the resulting spectral library to develop the calibration equations for a range of soil attributes.

- **Increasing capacity and production to meet commercial demands.** One component of the spectral modelling project could look at implementing spectral scanning in commercial laboratories, which could then be calibrated using the reference data set from the National Spectral Library. Hill Laboratories have already approached Manaaki Whenua to express their interest in this, particularly in the vis-NIR calibration equations, as Hill currently use vis-NIR as part of their standard testing. Based on overseas research, Manaaki Whenua would recommend that MIR seriously be considered as part of commercial lab services, because both the accuracy and breadth of attributes that can be predicted are much greater.
- **Standardisation and operational protocols.** The on-farm soil sampling will need standard guidelines developed to ensure samples can be collected in a consistent and

auditable way by a range of consultants. This may include a tool to help identify the number and location of sampling points, as well as consistency in sampling increments, sample identification codes, GPS recording, etc. A certain level of sampling consistency is essential for the cost-effective analysis of samples in later steps of the workflow. Further work is also required to develop a time-efficient method of sampling stony soils.

- **Responsive information delivery – timely and in useable format.** Experience from S-map has shown that the information delivery service / platform will be essential to the success of the S-map farm test: the right information needs to get to the right person at the right time. The stage 2 project would need to clarify how best to deliver the S-map farm test data to clients to ensure the results have the ease of use, and flexibility in format, for the information to be used in a range of tools and to address a range of issues. This could utilise some of the advances in the S-map NextGen research programme in developing a custom fact-sheet builder, or direct delivery via web services to tools such as Overseer. This could be through a central platform, or the project could work with different laboratories to enable implementation within their services.
- **Use cases.** The S-map farm test has potential for a wide range of applications. A practical approach to achieving a high degree of uptake is to involve a range of consultants in a co-design approach. This has the benefit of road testing the science as it is developing, as well as upskilling the consultants through their direct involvement in the development pathway. Potential roadblocks to practical implementation can be identified early on and addressed through this collaborative approach.

10 Acknowledgements

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Veronica Penny, Nadia Laubscher, John Payne and Sam Carrick completed the field sampling; Kishor Kumar and Thilak Palmada the laboratory soil spectral scanning; and Yuxin Ma and Pierre Roudier the modelling of soil attributes from the spectral scans.

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Appendix 1 – Auger sampling method used in S-map farm test pilot project

1 Record the GPS site location.

2 Set out either the half pipe sample collection tray (if the soil is moist) or the numbered collection containers (if the soil is dry).

3 Preferably use a spade to dig a small pit (one spade width) to 0–10, then 10–20 cm depth, collecting soil samples for each increment as you go. Place the samples in the appropriate depth increment in the collection tray. Alternatively, if the soil is moist, you could start using the auger straight from the surface.

4 Use the auger to sample down the rest of the profile in c. 10 cm depth increments (using the marks on the auger stem as a guide). In moist soils, about three to four auger turns should be about 10 cm depth. Each time a further 10 cm has been augered, make sure to place the sample in an appropriate depth increment in the collection tray. Remember to discard the top couple of centimetres of soil from the auger head (as per steps A and B, Figure A1).

5 Once augering is complete, take a photo of the soil (Figure A1, C), with each sample laid out in sequential order (0–10 cm sample at top of photo, 1 m sample at bottom).

6 Transfer the sample from each depth increment into the correctly labelled sample bag. This is best achieved by starting with the bottom increment, and sliding the increment soil sample down the pipe into the sample bag. Roll the bag up to remove air, and make sure the top is sealed (zip lock bags are best).

7 Record in a notebook which sample depths ended up being sampled at that particular site, along with other relevant details (date, etc.).

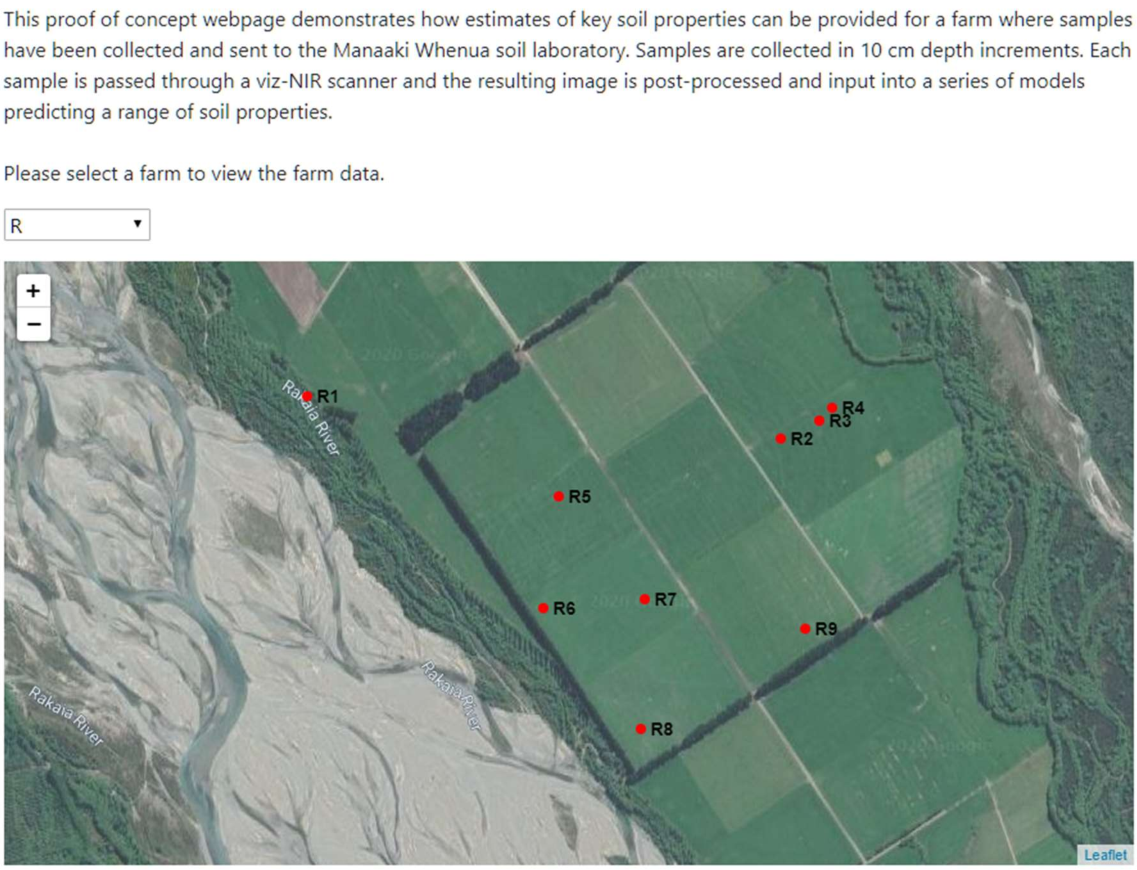
A **B** **C**

Figure A1. A. Example of auger from one 10 cm depth increment. B. The top few centimetres of 'spoil' are removed from the auger head before collecting the sample. C. Soil samples from each depth increment laid out in a half pipe.

Appendix 2 – Soil pit method to sample stony soils at Rakaia Island case study site

1. Set out the numbered collection containers.
2. Dig a small pit (15−20 × 15−20 cm is fine) using the trenching spade and/or the large screwdriver. Excavate to 10 cm depth and collect *all the sample* (stones plus fine earth) in the appropriate sample container. The easiest way is to excavate by scooping the soils out of the hole by hand (using a gardening glove).
3. Weigh all the sample excavated and record the weight.
4. Sieve all the sample through a 2 mm sieve (or, if the sample is too large, mix evenly and sieve a subsample). Record the weight of the soil (<2 mm) and the weight of the stones (<2 mm).
5. Collect two samples of the sieved soil. Sample A is for the lab spectral scanning, and sample B will be needed to calculate the moisture content of the soil.
6. Transfer the two samples from each depth increment into the correctly labelled sample bag. Roll the bag up to remove air, and make sure the top is sealed. Use the larger sample bags, but you may still have to use more than one bag to collect all the soil for each increment.
7. Repeat steps 2 to 6 to excavate in 10 cm increments down to 50−60cm depth.
8. Record in a notebook which sample depths ended up being sampled at that particular site, along with other relevant details (date, etc.).

Appendix 3 – Screen shots of some features of the prototype dynamic factsheet

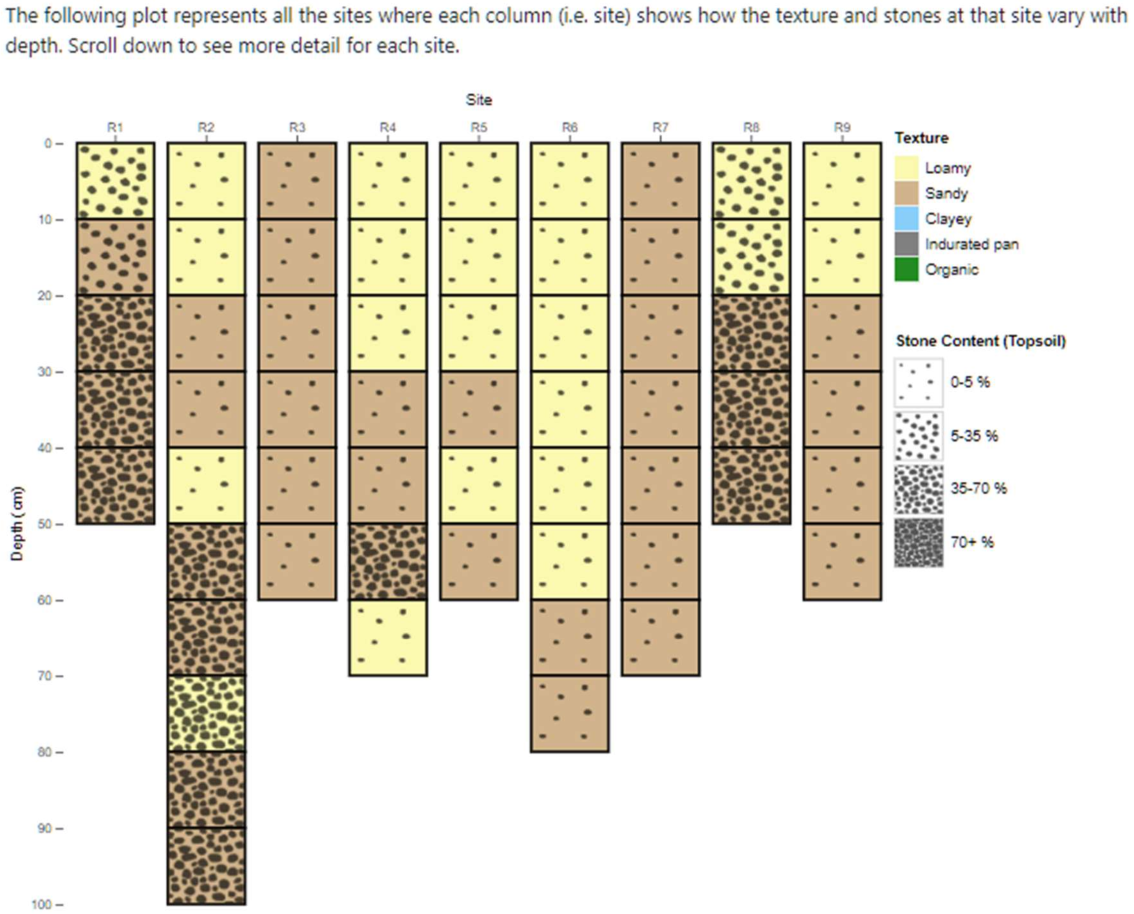


This proof of concept webpage demonstrates how estimates of key soil properties can be provided for a farm where samples have been collected and sent to the Manaaki Whenua soil laboratory. Samples are collected in 10 cm depth increments. Each sample is passed through a viz-NIR scanner and the resulting image is post-processed and input into a series of models predicting a range of soil properties.

Please select a farm to view the farm data.

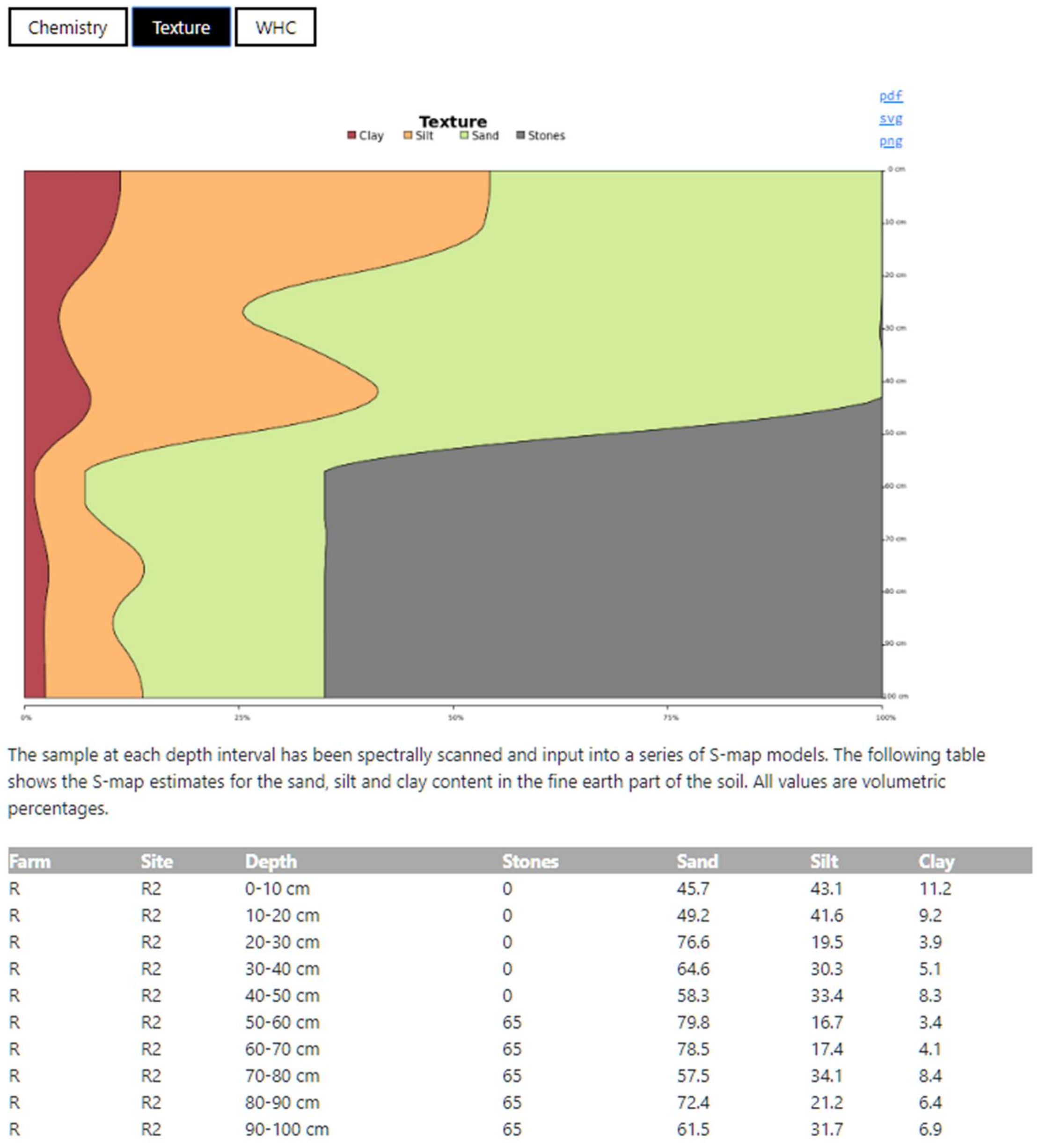
R

Figure A2. Map of sample locations



The following plot represents all the sites where each column (i.e. site) shows how the texture and stones at that site vary with depth. Scroll down to see more detail for each site.

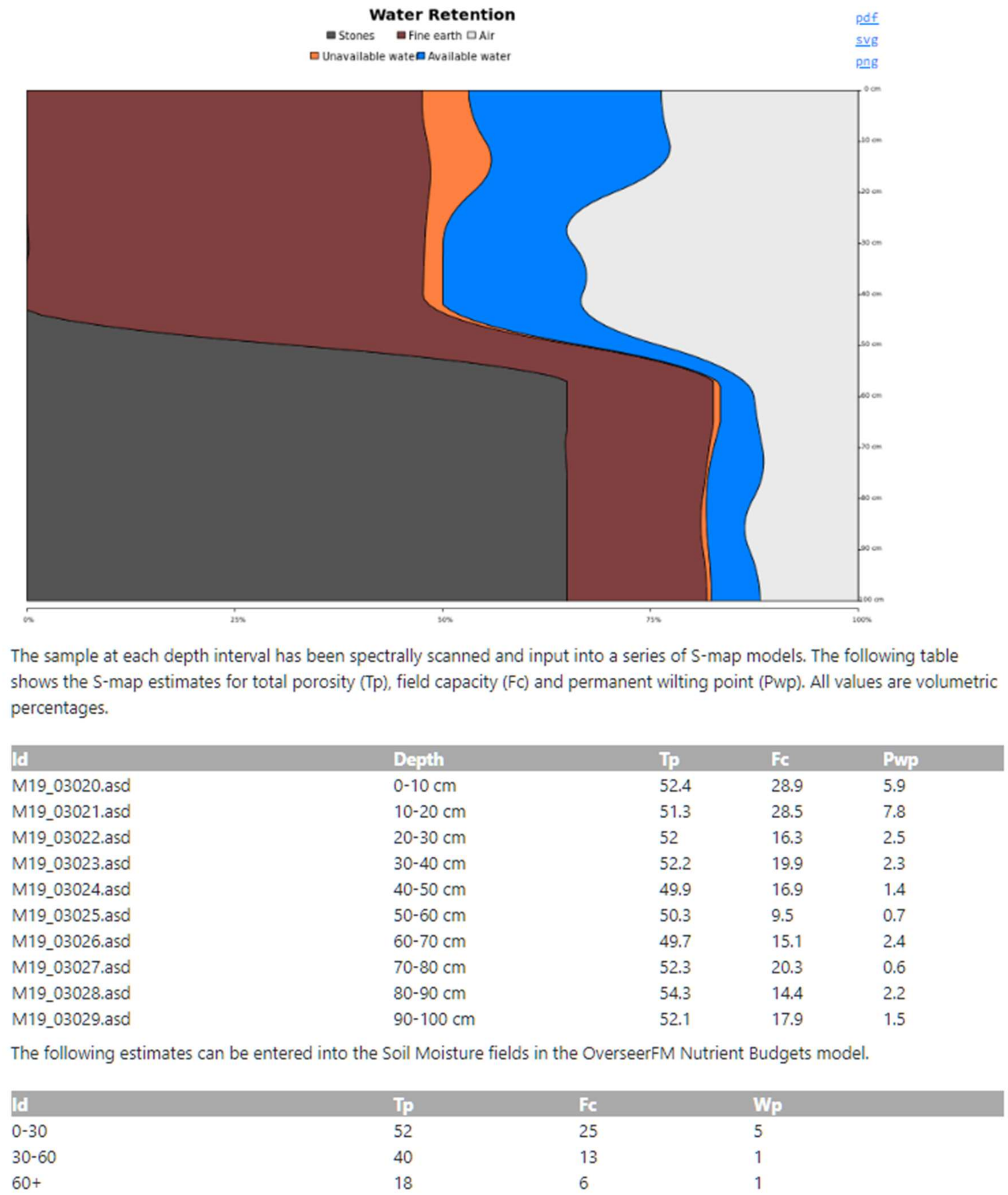
Figure A3. Plots can be generated to compare key attributes at depth increments within and between soils.



The sample at each depth interval has been spectrally scanned and input into a series of S-map models. The following table shows the S-map estimates for the sand, silt and clay content in the fine earth part of the soil. All values are volumetric percentages.

Farm	Site	Depth	Stones	Sand	Silt	Clay
R	R2	0-10 cm	0	45.7	43.1	11.2
R	R2	10-20 cm	0	49.2	41.6	9.2
R	R2	20-30 cm	0	76.6	19.5	3.9
R	R2	30-40 cm	0	64.6	30.3	5.1
R	R2	40-50 cm	0	58.3	33.4	8.3
R	R2	50-60 cm	65	79.8	16.7	3.4
R	R2	60-70 cm	65	78.5	17.4	4.1
R	R2	70-80 cm	65	57.5	34.1	8.4
R	R2	80-90 cm	65	72.4	21.2	6.4
R	R2	90-100 cm	65	61.5	31.7	6.9

Figure A4. The texture plot for site R2 on the Rakaia farm.



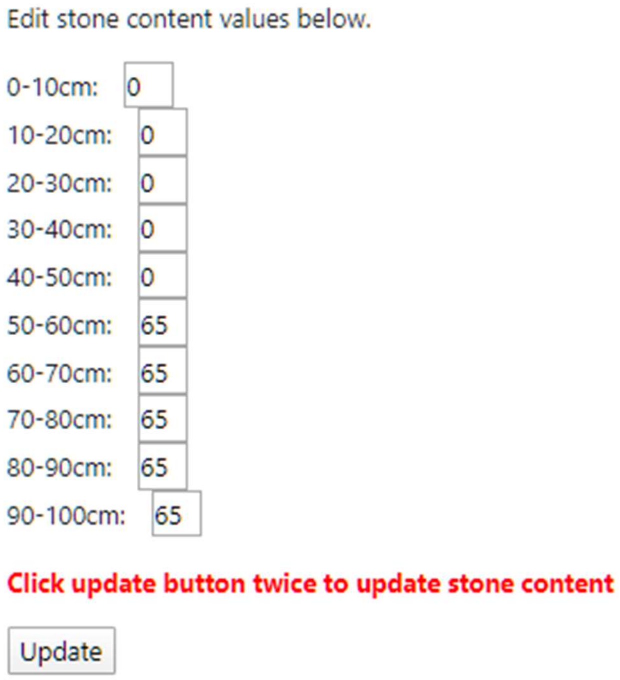
The sample at each depth interval has been spectrally scanned and input into a series of S-map models. The following table shows the S-map estimates for total porosity (Tp), field capacity (Fc) and permanent wilting point (Pwp). All values are volumetric percentages.

Id	Depth	Tp	Fc	Pwp
M19_03020.asd	0-10 cm	52.4	28.9	5.9
M19_03021.asd	10-20 cm	51.3	28.5	7.8
M19_03022.asd	20-30 cm	52	16.3	2.5
M19_03023.asd	30-40 cm	52.2	19.9	2.3
M19_03024.asd	40-50 cm	49.9	16.9	1.4
M19_03025.asd	50-60 cm	50.3	9.5	0.7
M19_03026.asd	60-70 cm	49.7	15.1	2.4
M19_03027.asd	70-80 cm	52.3	20.3	0.6
M19_03028.asd	80-90 cm	54.3	14.4	2.2
M19_03029.asd	90-100 cm	52.1	17.9	1.5

The following estimates can be entered into the Soil Moisture fields in the OverseerFM Nutrient Budgets model.

Id	Tp	Fc	Wp
0-30	52	25	5
30-60	40	13	1
60+	18	6	1

Figure A5. The water retention plot for site R2 on the Rakaia farm.



Edit stone content values below.

0-10cm: 0
10-20cm: 0
20-30cm: 0
30-40cm: 0
40-50cm: 0
50-60cm: 65
60-70cm: 65
70-80cm: 65
80-90cm: 65
90-100cm: 65

Click update button twice to update stone content

Figure A6. Users can enter their own observations for stone content