FAQ: Soil Property Maps from Radiometrics

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CONTENT

This note addresses Frequently Asked Questions (FAQs) that have arisen with the SoilSelect methodology. These relate to:

- The gamma radiation measurement
- Analysis of the radiometric data
- Methods for soil description.
- Relationship of results to those provided by other methods.
- Reliability of results.
- Use in developing understanding of processes.
- Cost effectiveness.
- Communication and Application

SoilSelect Methodology Design and Development

The method was developed to address deficiencies in the information on soils provided by traditional methods. Scientific and utilitarian applications determined the requirements.

Applications addressed in the design were:

- Determination of factors controlling the distribution of native biota.
- Provision of soils information to support land management.
- The design requirements for the applications were:
- Provide site-specific information (not probabilistic).
- Derive mapped information independently of other factors used in biophysical analysis (eg. terrain).
- Map soil physical and chemical properties (not soil types defined by a prior classification).
- Provide tests of reliability.
- The development history has been:
- Development with radiometrics commenced in 1987.
- Commercial in 1992.
- Most recent significant change (consultation) around 1996.

Awards and Recognition

SoilSelect results were the key element in Environmental Research & Information Consortium Pth Ltd (ERIC) receiving the following.

- Finalist in the 1999 Australian Technology Awards
- Showcased by Business Australia and Environment Australia
- Member of the Australian Technology Showcase
- Support for commercialisation under the COMET scheme
- Nominated by Murdock University as a Sunrise Technology
- ACT Government Award for Research & Innovation 2001
- Application of the SoilSelect methodology led to the identification of the Salinity Class that identifies a distinct signature in the radiometrics associated with salinity.

RADIOMETRIC MEASUREMENT

The questions relate to the nature of the gamma radiation measurement, its relationship to soils, and its analysis.

The radiometric measurement only reflects the surface 30 cm

This question has the components of the source of the signal and what it represents.

Source of the signal

Radiation emissions from the soil represent the balance between the generation and absorption or radioactive particles by near surface material. Assuming radiation is uniformly generated throughout the soil the relative source of the signal measured at the soil surface decreases exponentially with depth due to absorption. Around 70% of the signal derives from the surface 30cm of soil but some of the signal can derive from below 1m.

What the signal represents

While most of the signal derives from the A horizon the nature of the signal depends on the underlying material. The signal from a 50cm deep sandy surface will differ depending on whether the underlying material is sand or clay as the underlying material affects leaching. ***Knowledge of the whole soil profile is required to interpret the radiation signal***.

The effect of underlying materials is reflected in the use of radiometrics to map underlying (surficial) geological structures such as fractures and dykes. The underlying structures affect the signal by altering the accumulation and leaching of clay and ions in the soil surface.

The spatial resolution is coarse

The complex spatial characteristics of the measurement produce uncertainty as to the spatial resolution but it is generally taken to be one quarter of the flight line spacing.

The SoilSelect procedures employed to address the spatial characteristics are:

- Use of spatial statistics in the classification.

- Obtaining field samples from the centres of radiometric classes.

Samples obtained on boundaries between radiometric classes have limited value.

The SoilSelect methodology has mapped linear features one pixel in width and provides a resolution 1/4ha across a large region with 200m line spacing data. The resolution required varies with application but is around 1ha for most land uses. This is much better than by any means other than implementing fine grid sampling.

Confounding by other factors

Confounding can arise for two main reasons:

- Radiometric emissions are moderated by factors such as soil moisture and vegetation density.
- The radiometric signal largely reflects two factors and the same signal can arise for different reasons.

Separation of factors

Soils basically represent the weathering of parent material hence the radiometric patterns should reflect patterns of soils. However, production of an unambiguous result depends on the separation of effects of weathering and parent material. This is seldom an issue with data having a high signal to noise ratio but it can be when the signal to noise ratio is poor.

Separation of the effects of parent material and weathering can usually be readily achieved by identifying areas of different materials by reference to the radiometric patterns, the geology map and field sampling. The initial field sampling in the with the SoilSelect methodology address this requirement.

Signal moderation

Radiometric signals can be altered by factors such as soil moisture and vegetative cover but their effects on the results depend on the survey specification by way flying height and line spacing, crystal volume, and the signal processing. The effects of moderating factors have to be assessed against the survey specification.

The main factor causing erroneous signals is high soil moisture associated with irrigation as this greatly reduces the signal level. Soils cannot be mapped using radiometrics where the soils are artificially flooded. Trees can theoretically reduce signals by up to 20% and they decrease the size of the sample area by collimating the signal.

Effects of signal moderation are most significant when the requirement is for absolute emissions in counts per second (cps). The SoilSelect methodology does not rely on absolute calibration and uses field sampling and consultation to identify and correct erroneous results. The SoilSelect methodology is designed to produce reliable results given the potential occurrence of artifacts.

RADIOMETRIC ANALYSIS

Visual vs Numerical Analysis

The disadvantages of visual analysis relate to subjectivity, the low level of discrimination, and the difficulty of using more than three radiometric bands. The potential benefits relate to the incorporation of spatial context in the analysis.

The SoilSelect methodology includes a spatial statistic and so incorporates information on spatial context. The numerical analysis maximises the resolution and reliability of results and provides much more information than can be extracted by visual analysis alone. Numerical analysis is most cost efficient.

Why use Total Count?

Maximum discrimination is achieved by using all of the available information hence all bands should logically be used. The only issues relate to independence of observations and the signal to noise ratio.

Independence of observations

Independence of observations is a basic element of the scientific method that prevents circularity of argument and allows separation of cause and effect. The measurement of total count incorporates information for the uranium, thorium and potassium bands hence its derivation is not fully independent from the other bands.

Statistical analysis of covariance identifies that Total Count contains considerable information that is not in the other bands. The level of additional information ranges from around 60% for coarse reconnaissance grade data to 90% for very high-resolution data. There is statistical justification for concurrently analysing all bands and failure to use Total Count means that most of the information in the radiometric signal is not used, particularly with high-resolution data.

Signal to noise ratio

The signal to noise ratio generally ultimately limits all analyses regardless of the data type. It will therefore generally be limiting with radiometrics but recently acquired data are much improved over historic data even when acquired to the same survey specification due to improvements in data processing. Good results can be obtained with existing data but better results will be achieved in future.

The uranium band typically has a very poor signal to noise ratio and usually provides only one level of discrimination, high and low. While this can potentially double the number of soil classes discriminated it is common that uranium provides no useful information. However, uranium in a very high quality survey provided five levels of discrimination and these mapped fine patterns of erosion and deposition within landscapes.

Factors that improve the signal to noise ratio are the flying height, the crystal volume and the processing used to reduce diurnal variations in atmospheric effects. Total Count always has a high signal to noise ratio.

The SalinityMap results illustrate that signals can be discriminated when they occur at below the signal to noise ratio provided they have a distinct signature.

SOIL DESCRIPTION

Soils have traditionally been described by way of soil types identified by a prior classification. The main classifications used in Australia have been Great Soil Groups and Northcote's Factual Key. The current 'standard' is The Australian Soil Classification.

Most soil classifications have been developed to reflect the genesis or development of the soil profile (pedogenesis). They incorporate an interpretation of how the profile developed as well as information on what is there. This interpretation means that the identification of soil type need not define the soil properties important for agricultural or engineering applications. The description of soil type addresses the requirements of soil taxonomists but not necessarily the users of soil information.

The SoilSelect methodology directly addresses soil physical and chemical properties as these determine the suitability of soils for different applications. For example, information on soil properties is required when modeling drainage and calculating water holding capacity.

RELATIONSHIPS TO OTHER METHODS

The main comparison is with Soil Landscape mapping as this is the standard method that has been applied in essentially its current form over the last 60 years. EM has recently been advocated as a means of mapping soils.

Soil Landscape Mapping

The usual expectation is that results from SoilSelect should be compared with those from Soil Landscape mapping. This has been done by way of detailed statistics and general comparisons and the results are always unfavourable to Landscape mapping. The response to such comparisons has been that they are unfair and invalid because of differences in scale.

The comments on scale are erroneous as evaluations should be based on the purpose or use of the results. Soil Landscape mapping was developed for planning but is now promoted as being applicable to management. The SoilSelect methodology was developed to address management thus the results should be comparable regardless of scale.

Soil Landscape results are deficient for management if only because of the inability to map distributions of discrete soil types. The implementation of Soil Landscape mapping also embodies scientific limitations such as the focus on terrain and limited attention to parent material. Results for SoilSelect typically demonstrate that parent material is around five times more important in determining soil properties than landscape position.

An additional consideration relates to the independence of observations. Soil Landscape mapping is based on an interpretation of terrain, vegetation and any other factor thought useful in mapping the distribution of soils. Relationships between patterns of soils and vegetation and terrain therefore arise by definition. The results cannot reliably be used to develop an understanding of system function and should not be analysed in GIS with information on terrain and vegetation. This greatly limits their value in application and in developing understanding.

The features of the Soil Property Maps from the radiometrics that benefit application are:

- The mapping of discrete soil units at high spatial resolution and accuracy.
- Description and mapping of soil properties rather than soil types.
- Derivation of mapped results independently of other information used in environmental management.
- The routine testing of reliability.

EM

EM provides a measure of the inductive capacity of the soil by subjecting it to an electromagnetic field. The measured signal depends on factors such as clay, water content, salinity, and inductive materials such as iron oxides.

The EM measurement provides a spatial average and the measurement depth depends on the signal frequency and the antenna configuration. The two ground systems most used for soil provide an average measure for the surface 6 and 2 m.

Soil applications of EM were initially restricted to mapping salinity and this is applicable provided the contribution by clay, water and other inductive materials is known. As this interpretation involves at least three factors it is more difficult than with radiometrics where there are basically two. Reliable identification of salinity hazard or risk using EM requires extensive field work.

Use of EM in mapping soils is limited by:

- The measurement depth.
- The dimensionality (single band).

Soils typically show marked vertical differentiation within the surface metre and are largely defined by this vertical stratification. The EM measurement does not contain information on this vertical stratification and the signal cannot be interpreted to reliably identify associated soil properties. Its use in soil mapping is therefore based on identifying structural boundaries and this makes impractical its applications across large areas due to the very high field sampling requirement.

Comparison of EM and radiometric measurements is only warranted for use in mapping surficial structure and salinity. The higher spatial resolution of ground EM can then provide benefits compared with airborne but not ground based radiometrics.

Ground EM is only practical for small areas and airborne EM would be required to address regions. The best airborne EM data currently available do not provide information on the surface 5m and hence cannot be used to address soils.

RELIABILITY OF RESULTS

It has been suggested that the SoilSelect methodology is unproven, with the inference that the Soil Landscape mapping method has been. The situation is the reverse. The SoilSelect methodology routinely tests the reliability of the mapped results. Soil Landscape mapping does not and essentially cannot for discrete soil types. Results obtained using SoilSelect identify the unreliability of the Soil Landscape approach.

The SoilSelect methodology incorporates tests of reliability at two separate stages and also uses consultation to identify potential errors. The level of testing is the maximum that is scientifically justifiable.

Number of Field Samples

It is often suggested that the number of field samples routinely used to test the reliability of SoilSelect results is inadequate. These perceptions derive from experience with other mapping methods such as visual analysis of aerial photography or ground EM where the reference spatial information used for mapping contains very little information on soils.

An inordinate amount of field information can be required to make any sense of the 'soil' patterns mapped from aerial photography or EM. Even with intensive field sampling the limited relevance of the reference information means that statistical significance can rarely be provided for Soil Landscape mapping.

The radiometric data contain considerable information relevant to soils hence the radiometric patterns provide a highly efficient means of stratifying field soil sampling. Few field samples are required to obtain statistical significance for mapped soil patterns. However, the statistics also demonstrate that there is considerable room for improvement.

Robustness of the Method

The SoilSelect methodology involves a number of discrete activities conducted sequentially. Each activity must be implemented according to the specification to produce a good result.

The implementation of SoilSelect involves different personnel undertaking different stages of the method. It has also involved separate teams undertaking the same activity in the same and different surveys. Personnel with limited technical knowledge of soils (eg, farmers) have been trained to collect field samples. Repeatable, quality results are produced despite the involvement of multiple and often relatively unskilled personnel in its implementation. The method is robust if implemented according to the specification.

USE IN DEVELOPING UNDERSTANDING

Most benefit from the provision of information ultimately derives from improvements in understanding. The use of objective measures and the derivation of mapped information independently from other environmental information allows reliable analysis of relationships between soils and other factors using SoilSelect. This aids application and promotes understanding of system function.

The development of understanding is greatly restricted when soils are described according to a prior classification due to the assumptions inherent in the identification of soil type. It is also greatly restricted when applying Soil Landscape mapping because of the assumptions inherent in the mapping methods.

Use of SoilSelect results in developing understanding is illustrated by the ability to determine the relative significance of terrain and parent material in determining patterns of soils and the effect of soil properties in determining the distribution of plant species. It is also illustrated by the identification of surficial pathways associated with the accumulation and movement of salt.

COST EFFECTIVENESS

Cost

Costs vary with the size of the study area and whether they are based on marginal or commercial rates. Soil Landscape mapping costs are typically identified without regard to overheads and assume that all data required for implementation of the method are free.

The high cost of acquiring gamma radiation data has been cited as a disadvantage of the SoilSelect methodology. This comparison apportions the full cost of the radiometric data to soil mapping but no cost to data used in Soil Landscape mapping.

The cost of acquiring radiometrics for a 1:100,000 map sheet is around $90,000. The cost of acquiring aerial photography and providing it in a form that can be incorporated in a GIS is around $60,000. The radiometric survey additionally provides information on elevation (a high resolution DEM) and magnetics.

The cost difference diminishes and can reverse when the cost of data duplication and manipulation are considered. Purchasing duplicates of aerial photographs could cost over $30,000 whereas the cost of distributing digital geophysical data is less than $100. Where geophysical data exist they are much cheaper to distribute and use than photography.

The cost difference dramatically reverses when the requirements for field sampling and soil analysis are included. The radiometric patterns provide a reliable basis for field sampling and this greatly reduces the number of field samples required to produce a reliable result. The time spent in obtaining and analysing samples represents over 50% of the cost when applying SoilSelect. It is a much higher percentage with Soil Landscape mapping due to the number of samples required to makes sense of patterns that do not map discrete soil types, lithology or any other tangible entity.

Costs for field sampling with EM are high due to its effective mapping of boundaries rather than soils. Ground EM is cost prohibitive except for small areas and is only acquired to address specific applications on a needs basis.

This cost comparison does not address the great difference in the detail provided by the different methods. Taking this into account the soil property mapping using radiometrics provides an improvement of 1 to 2 orders of magnitude (10 to 100 times improvement) over traditional methods. To date such comparisons have only been possible for one mineral exploration and one soil landscape mapping example because very few implementations of traditional methods provide a comparative level of detail.

Effectiveness

Effectiveness largely depends on the relevance of the information in addressing land use and management issues. Traditional soil type descriptions have particular meaning to pedologists but require interpretation for application in management. Soil landscape maps similarly require interpretation for application as they map mixtures of soils rather than discrete soil types. Application of traditional soil survey information in land use planning and management requires specialist expertise.

Soil properties can be inferred from traditional soil type descriptions provided some soil property measurements are available. However, the estimation of soil properties from soil types introduces uncertainty and the results can never be as reliable as with direct measurement.

The soil property information provided with SoilSelect is measured and has direct relevance to land use and management. Variables such as soil depth, texture, pH and salinity are readily understood by land managers. The detailed mapped information can be directly applied in management. Also, the measurements can be used to model additional variables such as water holding capacity.

As with radiometrics the effectiveness of EM depends on the soil variables that are determined through field observation. However, the sampling stratification provided by EM is much less relevant to soil properties than provided by the radiometrics. The single band of EM contains very little information on soils and a very large number of field samples is required to provide a high level of map detail on soil properties.

Cost-effectiveness

The cost-effectiveness of the SoilSelect methodology is around one to two orders of magnitude greater than the Soil Landscape approach (1,000 to 10,000% gain). This takes account of the higher detail provided by SoilSelect as well as the reduced costs.

The realised cost difference between different methods depends on the size of the area and the level of mapping detail. The cost of mapping a 1:100,000 map sheet using SoilSelect is around 30 to 50% of that identified for Soil Landscape mapping by government departments. Costs for SoilSelect represent full commercial rates with no hidden costs while the government rates are based on marginal costs, thus the costs of using the SoilSelect methodology are around 10 to 20% of the traditional methods for regional studies. Comparison with commercial soil mapping for individual landholdings indicates that SoilSelect costs are around 50% lower.

The cost savings with SoilSelect are large but the main benefit derives from the high level of detail provided on the patterns of soils and their properties. Such detail cannot currently be provided with Soil Landscape or any other form of soil mapping.

EM would not be considered for soil mapping across the 3,600 km^2 area covered by a 1:100,000 map sheet as it is cost prohibitive.

COMMUNICATION AND APPLICATION

This addresses comments that SoilSelect results are as difficult to communicate and apply as traditional Soil Landscape Maps

Development of Soil Mapping Methods

Soil landscape mapping has been around for over 40 years. The soil information was used to promote regional development, and funding came initially from the Commonwealth and then the States. The requirement was to produce information for use in planning rather than management, and was addressed using the best technology then available (visual analysis of aerial photography).

SoilSelect was developed to provide information for analysing the significance of factors controlling the distribution of native biota, and to aid the management of military training areas. Development incorporated stringent scientific requirements for reliability testing and independence in the derivation of the mapped information. It also drew on the best technology available at the time and centers on numerical processing of digital imagery.

Basics of the techniques

Soils have traditionally been mapped by way of Soil Landscapes, with soils described by way of soil types. The soil type descriptions are based on an interpretation of the genesis of the soil profile as well as the material present. Each soil landscape contains a number of soil types such that the map units represent mixtures of soil types rather than discrete entities. A soil landscape typically describes the patterns of soils in the landscape but does not map them. Given the complexity and subjectivity of landscape assessment and description of soil type, Soil Landscape maps can usually only be produced and applied by trained soil scientists.

SoilSelect maps areas having uniform soils (discrete entities), and describes soils by way of their properties. The soil properties are standard physical and chemical measures, such as depth and pH, that are used in land management and modeling. The mapping usually identifies the geology / parent material, but does not invoke an interpretation of soil genesis.

The benefits of mapping discrete entities described by way of properties are:

- Some information can be directly applied by land managers without further interpretation (eg, soil salinity).
- Maps can readily be produced that address particular requirements, such as suitability for viticulture. This requires expert knowledge for derivation, but the derived maps can be applied by anyone.
- The reliability of mapping can be evaluated.
- The spatial relationships between soils can be numerically analysed.

- The relationships between soils and other attributes, such as terrain and vegetation, can be reliably evaluated.

The last point identifies a significant feature of SoilSelect that the information is derived independently of other information used in natural resource management. This does not apply with soil landscape maps as they draw on information on terrain and vegetation for their development. Soil Landscape maps cannot sensibly or reliably be used to analyse factors generating patterns of vegetation because they are usually based in part on vegetation patterns.

Institutional Responsibilities

State departments do not have a responsibility to produce soil information for use in land management by farmers. This position has been stated by the Murray Darling Basin Committee (MDBC) as their responsibility stops at the farm gate. Governments develop the information to address regional planning and policy development. Despite this focus on planning most agencies suggest that the information they collect is applicable to management. As their responsibilities stop where land management starts, at the farm gate, any relevance to management derives by accident rather than design.

The experience over 40 years is that soil landscape information has little relevance to management. Developers must expend considerable amounts of money to obtain necessary soils information and costs are high because of the low technological base of the methods. Farmers, the main land managers, generally cannot afford the funds needed to obtain the level of information that should be used when managing their basic resource.

The consequence of this information deficiency is land degradation. The response by the agencies has been to produce more information of the form used by them but which has little relevance to land management. This allows agencies to conduct further planning, and justify further restrictions, but does little to halt degradation or promote productivity and the sustainability of land management.

The requirement is to provide information that will aid land management and can be applied by all land users. There is a need to empower those who have the direct responsibility for land management and whose livelihood depends upon it. As there is strong motivation for land managers to improve their sustainability, the requirement is to provide the necessary information and to ensure transfer of the knowledge needed for its application.

Information Transfer / Education

Soil landscape maps are designed for production and application by specially trained soil scientists. As the methods are largely (almost completely) subjective, considerable experience is required and the interpretation often reflects tradition rather than rigorous analysis. Given this, there is virtually no scope for educating farmers in the use of soil landscape maps if only because of the difficulties in interpreting the relevance of soil type descriptions derived according to classifications such as Great Soil Groups or the Australian Soil Classification.

The SoilSelect methodology was designed to allow application of results by all land users, and to facilitate education in application. However, such detailed information has not been previously available hence there is a need for education as to its form and application. This need for education applies as much if not more to scientists and extension officers as well as farmers because the form of results differs from those previously available.

The use of soil properties addresses the requirement for general application while the mode of generating the information addresses education. Workshops are held with full implementation of the SoilSelect procedure and discussion allows stakeholders to identify their requirements and apparent deficiencies in the information. However, the method also allows for involvement by the stakeholders in the collection of the information where this greatly improves the transfer of knowledge. The SoilSelect method is based on the participation of stakeholders and empowers them through the provision of information and knowledge. Such participation is not possible with traditional methods.