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Visual soil examination techniques as part of a soil appraisal framework for farm evaluation in Australia

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ABSTRACT

Despite major advances in remote sensing and soil-landscape modelling, the use of visual soil examination and evaluation (VSEE) techniques in the field remains a crucial component of soil assessment and management packages for farmers in rural Australia. Of particular value are techniques for the rapid assessment of soil structural form and stability, which are fundamental issues affecting the ability of soil profiles to accept and store water in farming systems constrained by drought. An improved soil appraisal framework for farm evaluation, usable for all crops, derived from the successful VSEE-based 'Cotton SOILpak' system, is proposed. It has the potential to enhance the ability of farm businesses to deal with four soil-related issues; annual profitability, maximising land values, minimising the impact of increasing input costs, and negotiation of favourable outcomes for themselves and the local community when confronted by competing land uses. An overview is given of the proposed technical contents of the new scheme for 'whole-farm soil assessment and management planning', which is based on a blend of VSEE methods, modern soil databases, and extra laboratory testing where appropriate. Also outlined are the associated human resource requirements and organisational structures required to deliver practical and ethical soil management outcomes to farmers and the nation.

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1. Introduction

Visual soil examination and evaluation (VSEE) techniques (Boizard et al., 2005) are of immense value for soil management, particularly methods associated with the rapid assessment and optimisation of soil structural form (Kay, 1990). They complement newly developed techniques for soil assessment such as remote sensing and soil-landscape modelling, and well established procedures such as laboratory analysis of soil samples.

Unfortunately, the application of packages for soil assessment and management across the globe has been inadequate: land degradation issues are widespread and continue to become worse in many areas (Cribb, 2010). The soil science community must bear some of the responsibility for poor application of its knowledge to clients who require assistance. Bouma (2001) has noted that if soil scientists are to remain relevant in our modern network society, they must learn to listen to and to communicate with their stakeholders, learn to present their expertise in a flexible manner and, from the beginning, become thoroughly engaged in settings of joint learning and negotiation. This paper responds to Bouma's challenge by examining client requirements for information about soil assessment and management in rural Australia. A framework that builds on existing decision support systems is proposed for the integration of VSEE procedures with other types of soil related information so that land degradation problems can be addressed more effectively in conjunction with clients. Possible linkages with professional accreditation schemes and training providers also are explored.

2. Soil information deficiencies on Australian land used for farming and grazing

2.1. As experienced by individual farmers

Much of the farmland in Australia is owned by family farmers/graziers (referred to collectively in this paper as "farmers") who live on their properties and manage the farms as family-owned enterprises. Subsidies from government are minimal, relative to farmer support programs in USA and Europe. Involvement by the author with 67 VSEE training workshops (1998–2011; mainly government-funded via Catchment Management Authorities) for approximately 900 farmers and their advisers in New South Wales, Queensland and Western Australia allowed him to conclude that there are four major soil-related issues requiring attention by Australian farm businesses:

2.1.1. Annual profitability

Farm profitability is a key issue for landholders who aim to maximise the output of high quality produce, and to minimise

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costs by making efficient use of inputs such as water and fertilisers.

Climatic extremes – prolonged drought and high temperatures in the period 2001–2009, followed by unusually wet conditions in 2010–2012 – have severely impaired the magnitude and continuity of farm income in eastern Australia. The problems with hostile weather have been aggravated by soil limitations. For example, sodicity is a widespread subsoil constraint that can retard soil water intake and storage in dry years, when extra soil water means improved plant growth, but creates waterlogging and trafficability problems under wet conditions that also limit progress (So and Aylmore, 1995). Often there is a poor match between soil requirements of the crop being produced and subsoil characteristics such as salt concentrations and pH.

Many farmers have soil test information provided via agronomic advisers but it usually only applies to the topsoil (0–10 cm or 0–7.5 cm), with a focus on plant nutrition (Brown, 1999). The soil information tends to be stored by farmers in their offices in an ad hoc manner that is difficult to access and hard to interpret. Important soil physical factors such as compaction severity and water holding capacity generally are overlooked. This lack of a clear and comprehensive approach to soil constraint definition means that inappropriate fertiliser products often are selected by farmers. Soil survey databases are provided by Australian state governments – for example, Soil and Land Information System (SALIS) in NSW – to give soil data that extends deeper than 10 cm, but the sampling sites usually are too widely spaced to be of value for field-by-field decision making. Farmers who intend to stay on their properties and make the most of future production opportunities therefore need to assess their topsoil and subsoil much more thoroughly, and present the results more clearly, so that their soil management regimes can be optimised in conjunction with other professionals.

2.1.2. Land values

Maximising farm value is a big motivator for Australian farmers. Some have large debts and want a dignified departure from farming through selling of their land. Farmers understand that soil is an extremely important part of their business venture. However, often there is anxiety about a thorough quantification of their soil condition because of fears about an embarrassing conclusion that may reduce the sale price for their farm.

Soil condition is recognised as a key factor in rural land valuation (Baxter and Cohen, 2009). Two distinct approaches are available: (1) comparisons with recent sales in a district, which tends to overvalue the worst land and undervalue the best land; and (2) an income based assessment that may overlook attractive cost–benefit ratios for repair strategies.

A fair sale is said to have occurred when an amiable negotiation has taken place between '*a willing but not anxious seller*' and '*a willing but not anxious purchaser*', both of whom are supposed to be well informed about the condition of the land under consideration (Baxter and Cohen, 2009).

A lack of objective data about soil condition in most sales transactions means that land with a severe productivity constraint that can be repaired in a cost-effective manner (for example, poor topsoil structure that is preventing a large percentage of the rainfall from entering a soil) tends to be undervalued because the potential for improvement usually is not factored into the valuation process. Farmers who have gone to the trouble of repairing degraded land often are not rewarded properly for their efforts when selling their land, despite improvements in short-term and long-term profitability. Sometimes agricultural land is overvalued; for example, where severe subsoil acidity remains undetected.

This data-poor transaction process contrasts strongly with the premium wine regions of France where 'per hectare' vineyard values can be as high as A$6-10 million. The soil characteristics of these sites – particularly geochemical composition and structure – and the associated wine quality are well understood, in conjunction with other environmental aspects of the 'terroir' of a site (Halliday, 2009).

At a minimum, Australian farm valuers – and the buyers and sellers of agricultural land – need a quick and inexpensive system of soil evaluation for both the topsoil and subsoil to provide outcomes that are more equitable than the current procedures. VSEE techniques can provide the foundation for such a scheme. Procedures that give a more accurate and comprehensive measurement of soil fertility and associated processes can then be applied at key sites identified by 'first approximation' VSEE methods.

2.1.3. Predicted increases in the cost of agricultural inputs

Australian agriculture is highly dependent on affordable supplies of fuel and nitrogen fertilisers derived from crude oil and natural gas. Expected shortages of liquid fossil fuels in the near future will force farmers to become even more efficient with their use of inputs that will become more expensive. Predicted 'peak phosphorus' constraints will provide similar challenges (Cribb, 2010). The threats associated with 'peak oil' and 'peak phosphorus' mean that farmers will have to focus on improvement and maintenance of good soil structure to allow maximisation of the efficiency of use of nitrogen and phosphorus fertilisers. Beneficial soil organisms such as nitrogen fixing bacteria and P-scavenging fungi require encouragement through provision of adequate habitat (favourable soil structure), suitable food (organic matter) and sufficient water.

2.1.4. Negotiations with mining and gas extraction companies

Mineral resources beneath Australian farms are the property of governments which grant exploration licences and land access rights to geological exploration companies. In the states of New South Wales and Queensland, the rapid expansion of coal and coal-seam-gas developments into agricultural land has created uncertainty for farmers. Regional planners within state government are developing procedures for the protection of 'prime agricultural land' from mining developments, with assessment based on schemes such as the NSW Agricultural Land Classification (Hulme et al., 2002) and the NSW 'Land and Soil Capability' scheme (Murphy and Taylor, 2008). Where land is to be developed for mining, farmers with high quality soil information are likely to be in a better position to negotiate a fair deal with 'Infrastructure Development Teams' from mining and gas extraction companies than farmers with poor information about the soil on their properties.

2.2. In relation to community expectations

Soil scientists in the Australian and global communities are expected to provide soil information for decision makers who have to deal with the following challenges:

- Assurance of national and global food security despite an expanding human population, finite production inputs and increasingly difficult climatic conditions (Cribb, 2010);
- Optimising the use of water resources; within Australia, attention has turned to the tropical north where there is a much greater amount of under-utilised water flow in rivers than in southern areas such as the Murray-Darling Basin, but soil information is sparse;
- The need to provide 'ecosystem services' such as soil carbon sequestration on a large scale, and minimisation of emissions from the soil of 'greenhouse gases' (carbon dioxide, nitrous oxide, methane), to reduce the rate of global warming;

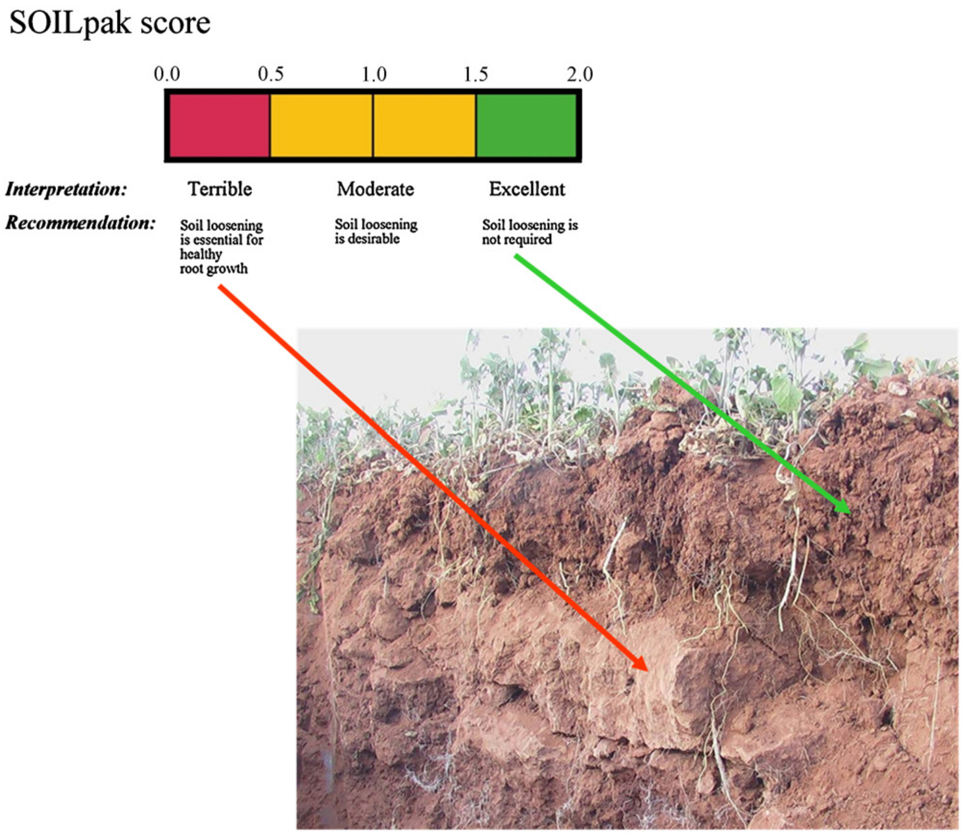

Fig. 1. The range of possible scores and interpretations for the SOILpak 'structural form' assessment.

- Achievement of a sensible balance between protection of high quality agricultural land and land allocation for competing land use activities such as urban development and mining.

3. Existing frameworks for delivery of soil information to farmers in Australia

3.1. 'Cotton SOILpak' initiative

VSEE techniques have been used successfully as part of a decision support system by farmers and their advisers in the Australian cotton industry since the 1980s to improve the physical fertility of both topsoil and subsoil and greatly boost productivity. This industry funded program, referred to as SOILpak (Daniells and Larsen, 1991; Daniells et al., 1996; McKenzie, 1998), was motivated initially by a series of wet cotton harvests, combined with uncontrolled farm traffic, which created serious soil degradation problems that were not being assessed effectively through the traditional agronomic approach to soil testing described in Section 2.1 of this paper. Most of the cotton grown in Australia is produced under irrigation on Vertisols.

Assessment and management of subsoil compaction was the main focus when the SOILpak decision support system was being developed and extended to growers. It was based on assessment techniques described by Batey (1988). On-farm measurements were compared with the specifications of an "ideal" soil profile for cotton farming, i.e. a soil that allows as full an expression as possible of the genetic potential of cotton plants (and associated rotation crops) under the prevailing climatic conditions.

Soil assessment is recommended within the following depth intervals in geo-referenced soil pits; topsoil (0–10 cm), sub-surface (10–30 cm), upper subsoil (30–60 cm), mid subsoil (60–90 cm) and lower subsoil (90–120 cm). To ensure consistency of measurement in relation to wheel compaction patterns, each soil profile description focuses on the root-zone directly beneath a planting line three plant rows beyond the edge of a main wheel track in a controlled traffic layout.

The SOILpak scoring procedure for assessment of soil structural form (Fig. 1), now extended to other crops, focuses on aggregate/clod morphology assessed from the faces exposed in soil pits, but over-riding factors are available to allow for continuous vertical macropores. McKenzie (2001a) describes how the SOILpak scoring terminology interlinks with aggregate description terms used by NCST (2009), i.e. grade, type and size of the peds, consistence and fabric.

When developing the 'soil structural form' component of the SOILpak system, research was carried out to establish the degree of correlation between visual-tactile examination and time-consuming physical measurements such as bulk density, soil strength and image analysis parameters that have been related experimentally to the growth and function of plant roots. The strength of these relationships was shown to be significant for Vertisols (McKenzie, 2001a,b). The r^2 values, respectively, for the correlations with the 'SOILpak score' were 0.64 (bulk density), 0.58 (air filled porosity) and 0.59 (soil shear strength). The association of these data with 'limiting water ranges' and cotton root growth thresholds has been discussed by McKenzie and McBratney (2001).

The developers of SOILpak recognised that diagnosis and management of soil structural form could not be considered in isolation. Soil structural stability in water, and structural resilience (Kay, 1990), also had to be part of the measurement package.

The 'aggregate stability in water' (ASWAT) dispersion test (Field et al., 1997) was developed to complement the SOILpak structural form procedures. The ASWAT procedure (Fig. 2) is derived from the slaking and dispersion test of Emerson (1983) and the dispersion assessment of Loveday and Pyle (1973). Dispersion is the separation of soil micro-aggregates into sand, silt and clay particles, which tend

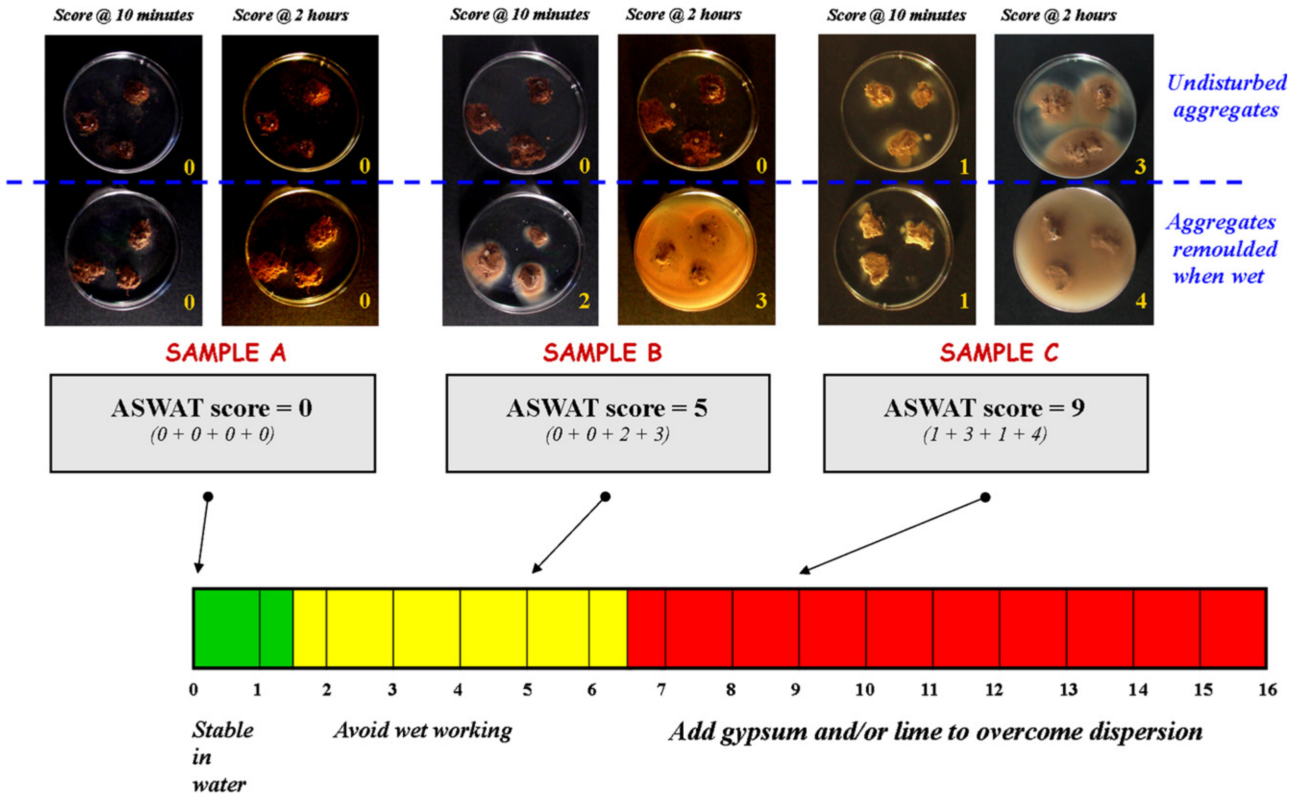

Fig. 2. The range of possible scores and interpretations of the ASWAT 'structural stability' assessment. The Petri dishes contain aggregates in deionised water, and the scoring on a scale of 0–4 refers to the degree of dispersion of clay from the undisturbed and remoulded aggregates (diagram prepared in conjunction with the 'Central West Catchment Management Authority NSW' 2007).

to block soil pores and create problems with poor aeration and inadequate water intake. It is a process with the potential to reduce root growth and adversely affect profitability of most cropping enterprises. Dispersion may be associated with slaking, which is the collapse of soil aggregates to form micro-aggregates under moist conditions (So and Aylmore, 1995). Slaking is associated with a lack of organic matter, which is important for the binding of soil micro-aggregates. Dispersion of the micro-aggregates is related to excessive exchangeable sodium percentages; the sodicity problems are aggravated by low electrolyte concentrations and elevated exchangeable magnesium, and are most evident after mechanical disturbance of the soil when it is moist.

'SOILpak for Cotton Growers, third edition' (McKenzie, 1998) is available on the Web and its soil structure management practices are built into 'Best Management Practice' program for the Australian cotton industry. The uptake of controlled traffic technologies and reduced tillage techniques (Hulme et al., 1996) has been widespread (Shaw, 2005) and very high lint yields and water use efficiencies are obtained. Geophysics methods sometimes are used by cotton growers as a supplement to the SOILpak procedures, for example electromagnetic induction (EM) surveys to assess subsoil salinity and rates of deep drainage. SOILpak is used in conjunction with companion manuals such as NUTRIpak (Rochester, 2001) and WATERpak (Dugdale et al., 2004).

The SOILpak approach has also been applied to the vegetable industry (McMullen, 2000; Anderson et al., 2007) for a broad range of soil types, but the other agricultural sectors that dominate rural landscapes in Australia (dryland grain and pasture systems) have not embraced the concept in a systematic fashion.

3.2. Soil survey databases

Apart from presenting soil information from state agencies in a national context, the Australian Soil Resource Information System (ASRIS) web site (www.asris.csiro.au) provides national grids of soil properties created from the best available soil data; for example, grids (250 m) of 0–30 cm clay content, 0–30 cm bulk density and 0–1 m plant available water capacity. This initiative is linked with the Global Soil Map project (www.GlobalSoilMap.net) that aims to provide users with the best available estimates of soil attributes – such as depth, density, moisture and nutrient capacity, salinity, level of acidity or alkalinity, and proportions of clay, sand and silt – worldwide at depths of up to two metres in areas of 90 m by 90 m (Harris, 2011).

The information from these sources will be very valuable for rural land managers. However, the managers of individual fields within Australian farms are likely to find that the confidence intervals of some of the estimated soil factors will be too broad and inaccurate for the management decisions under consideration. Also, anthropogenic impacts on soil fertility, for example compaction patterns created by farm machinery or livestock, are unlikely to ever be included with sufficient accuracy in the modelling process. Therefore, visual soil assessment carried out by teams of soil management professionals (including farmers) will continue to be a vital component of soil assessment and management on rural land in Australia.

4. An improved framework for soil assessment and management

4.1. Technical aspects

The 'Cotton SOILpak' decision support system has been successful (Shaw, 2005) but its focus on a single cropping system located mainly on clay-rich soil under irrigation limits its appeal to potential users. The SOILpak scheme needs to be upgraded to provide a framework that is more comprehensive and universal, and to include a clearly defined human resources framework that maximises benefits from the technical information. Much of the soil used for cropping and grazing in Australia has multiple problems in addition to structural issues such as compaction, sodicity and a poor ability to regain favourable soil structural form through shrink–swell processes; these spatially variable constraints include acidity, salinity and nutrient deficiencies. The poor match that occurs on many farms between crop/variety requirements and subsoil conditions is highlighted when deep reserves of moisture have to be exploited by rain-fed crops and pastures during droughts.

'Whole-farm soil assessment and management plans' – built upon a combination of modern soil databases, field-based VSEE techniques, and extra laboratory analysis where appropriate – are recommended for all Australian farms. This information can then be interlinked with the operations sections of farm business plans. A comprehensive approach is required that takes into account all of the points in Table 1. An important priority is to avoid excessive expenditure of measurement resources at a single point. It is recommended instead that a 'first approximation' of the main patterns of variation be prepared using VSEE techniques, followed if appropriate by detailed assessment at a small number of key locations (Table 1). Yield mapping procedures are available to highlight the least-productive and best zones within a farm that can be targeted for soil sampling (McKenzie et al., 2008). Existing soil information should be incorporated into such an assessment if it has adequate quality and is readily accessible.

Liebig's 'Law of the Minimum' (Wallace and Terry, 1998) is applicable. It reminds land managers that all soil limitations at a particular site must be addressed if productivity is to be improved. For example, if soil pH, nutrient status and dispersibility are corrected through a soil amelioration program but a soil

Table 1
A checklist of soil physical, chemical and biological factors that should be considered for soil assessments on Australian farm land, and associated soil amelioration strategies that may be appropriate.

Soil factor to be tested	Associated processes that have practical importance for farmers (Kay, 1990; White, 2006)	'First-approximation' VSEE testing (rapid and inexpensive tests for use in the field or at home)	Detailed testing, if required, at selected sites (uses relatively complicated testing equipment) (McKenzie et al., 2002; Rayment and Lyons, 2011)	Amelioration strategies to consider, if economically feasible for the land use under consideration (McKenzie et al., 2008)
Structural form (compaction severity)	Water intake Water storage Rate of drainage of excess water and pollutants Erosion losses Root growth and function Emissions of nitrous oxide and methane (see waterlogging section below)	SOILpak score (McKenzie, 2001a) VESS (Ball et al., 2007) VSA (Shepherd, 2009)	Bulk density measurement Penetrometer/shear vane Image analysis/clod shrinkage parameters Moisture status; content, potential and rate of flow	Mechanical loosening "Biological tillage" (loosening via shrink–swell processes; bioturbation)
Structural stability in water	Ability of soil to maintain vital functions associated with its soil structural form after water has been applied	Emerson slaking/dispersion assessment (Emerson, 1983), ASWAT dispersion test (Field et al., 1997)	Exchangeable sodium percentage (ESP) Electrochemical stability index (ESI) (Blackwell et al., 1991) Ca/Mg ratio Organic carbon Loveday and Pyle (1973) dispersion test	Gypsum Gypsum-lime blends Organic matter
Structural resilience	Ability of a soil to regain a desirable soil structural form via natural processes, for example shrinkage/swelling associated with wetting and drying cycles	Slurry dried in a Petri dish in the oven (linear shrinkage)	Cation exchange capacity, COLE testing	Clay addition to sandy soil Deep mouldboard ploughing of duplex soil
Texture	Water storage capacity Nutrient retention	Hand texturing (NCST, 2009)	Particle size analysis	Clay addition to sandy soil Deep mouldboard ploughing of duplex soil
Stoniness	Water storage capacity Reduction in erodibility	Visual estimation of coarse fragment content (NCST, 2009)	Particle size analysis	
Depth to hard rock	Water storage	Direct measurement in soil pit	–	Soil importation
Water repellence	Water intake	Time taken for a drop of water to be absorbed by the soil (Hall et al., 2009)	'Molarity of ethanol drop' (MED) test	Clay addition to sandy soil
Waterlogging severity associated with impermeable bedrock and shallow watertables	Root growth and function Emissions of nitrous oxide and methane	Redoximorphic features in the deep subsoil (Batey, 1988) Depth to slowly permeable layer	Eh assessment (James and Bartlett, 2000) Soil gas movement (Scanlon et al., 2000)	Install drains
pH	Nutrient availability and the possibility of aluminium toxicity	Indicator solution sprayed onto the soil profile (Hall et al., 2009) Carbonate patterning in alkaline soil (NCST, 2009)	Laboratory testing of pH ($CaCl_2$), aluminium availability, 'acid sulphate soil' status	Lime application
Salinity	Water uptake restriction, toxicities	Hand-held electrical conductivity meter with approximate 1:5 soil:water suspension (Lanyon, 2011)	Laboratory testing of ECe, boron concentrations EM surveys	Profile leaching
Nutrients	Deficiency avoidance	Visual plant deficiency symptoms (Grundon, 1987)	Soil and plant tissue analysis by laboratories	Fertilisers
Soil biological status	Soil structure improvement, improved nutrient availability	Soil fauna observations, soil aroma, soil darkness, stubble cover	Organic carbon status Micro-organism assessments	Biological additives

compaction problem remains untreated, productivity will continue to be limited by the compaction issue.

In drought years, the ability to maximise the storage of plant available water in soil is a crucially important objective. Moore et al. (1998) have shown that soil water holding capacity can be doubled over a broad range of texture groupings by improving soil structural form. Therefore, the VSEE soil structure assessments are of critical importance in moisture constrained agricultural environments.

Clarity of presentation of the soil information and management recommendations is very important for clients unfamiliar with soil science jargon. The use of a 'red–amber–green' colour coding scheme on maps of key soil factors for each depth interval (for example, SOILpak structural form scores, ASWAT scores, pH, salinity) to signify, respectively, 'soil problem requiring attention', 'possible soil constraints' and 'keep up the good work' helps to achieve this aim. Where interpolation of colour-coded data is presented on soil maps, it is vital that the accuracy of prediction is presented to the clients. 'Key soil factor maps' can be accompanied by 'variable rate soil amelioration maps' that contain, for example, details about gypsum and lime application.

As a perennial crop (or a series of annual crops) grows over time, the soil itself is being continuously modified (Rasic, 2005). Therefore, consistently good production can be achieved only if ongoing attention is given to soil maintenance with adjustment of management practices to match the patterns of soil variability over time and space. The adoption of a soil management program that includes regular monitoring is as important as the amelioration process itself for the long-term success and sustainability of the farm.

In the operations section of the business plan for each farm, all of the following soil related issues must therefore be addressed to provide a successful customised outcome:

- Change the soil via amelioration to suit the needs of the crop(s) under consideration, where favourable cost–benefit ratios exist;
- Improve the matching between plant requirements and subsoil condition, where amelioration is unlikely to be cost-effective, through a more appropriate selection of crop types and varieties – some native plants have a natural tolerance of very poor soil conditions;
- Introduce management systems that minimise the risk of a soil problem recurring; for example, controlled traffic farming using GPS guidance, avoiding the working of wet soil;
- Assess soil conditions regularly and monitor progress via the use of yield maps – converted where possible to profitability maps – and productivity measures per unit of rainfall/irrigation and nutrient inputs. Yield maps can be produced either via monitoring equipment on modern harvesters or through the use of 'low-technology' hand drawn maps prepared by farmers and their advisers. Most farmers know how to use inexpensive hand-held GPS units to geo-reference their soil sampling sites.

Apart from being invaluable for day-to-day farm management, the soil information for an individual farm can be combined with similar data sets held by neighbours to give detailed information about broader issues such as the land degradation status of entire catchments, if business confidentiality concerns can be overcome. Government-funded organisations such as Catchment Management Authorities and Landcare Groups would be able to assist with this process.

4.2. Human resource planning

A possible set of responsibilities for soil science professionals (including farmers) associated with farm land management in Australia is presented in Table 2. A human resources framework for the provision of soil-related services needs to be defined to ensure that key technical components such as VSEE procedures are actually delivered in a consistent and professional manner.

Soil scientist accreditation systems already exist, for example the Soil Science Australia 'Certified Professional Soil Scientist' (CPSS) scheme (Soil Science Australia, 2012a,b). A similar scheme exists in UK (BSSS–IPSS accreditation). A reference to 'structure descriptions using a visual-tactile scheme' has been included in the CPSS competency document (Soil Science Australia, 2012b).

Table 2
Suggested allocation of responsibilities with the proposed 'Community of Soil Management Professionals'.

Professionals in the community of soil management	Professional responsibilities			
	First-approximation VSEE procedures (rapid and inexpensive test for use in the field or at home)	Detailed testing (uses relatively complicated testing equipment)	Amelioration and maintenance strategies to optimise soil related processes (physical, chemical, biological)	Research to overcome knowledge gaps, including publication in scientific journals
Farmers	Overview of topics	Overview of topics	Overview of topics Implementation skills	Available to assist research scientists and soil management specialists with studies of soil-crop interactions; for example, provision of yield maps and testing the value of ameliorants
General Practitioner ("GP") advisers (some farmers may choose to work at this level)	Overview of topics Accredited to carry out tasks	Overview of topics Accredited to carry out tasks	Overview of topics Accredited to supervise farmers implementing the amelioration strategies	
Soil management specialists	Overview of topics Accredited to carry out tasks Expert soil knowledge; able to provide training & accreditation for farmers and GPs	Overview of topics Accredited to carry out tasks Expert soil knowledge; able to provide training and accreditation for farmers and GPs	Overview of topics Accredited to supervise tasks Expert soil knowledge; able to provide training and accreditation for farmers and GPs	Able to assist research scientists with problem definition, experimental design and paper writing
Soil research scientists (improvers of soil assessment techniques and soil management strategies)	Overview of topics Expert knowledge in at least one of the above disciplines			A leader in experimental design, statistical analysis and publication of the results

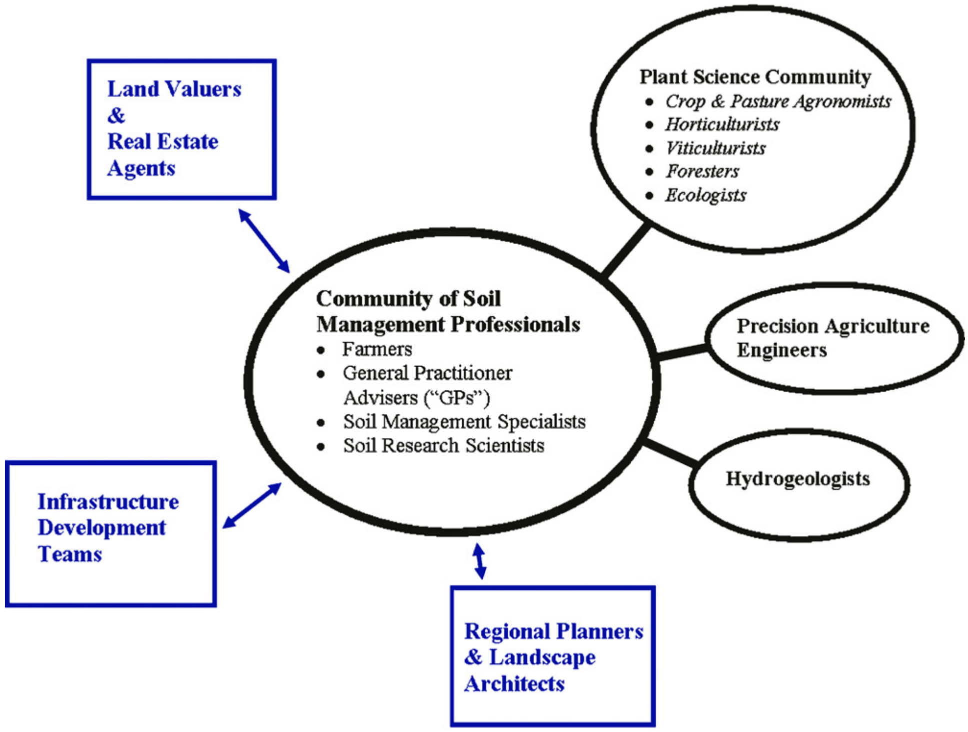

Fig. 3. A proposed community of networked professionals for managing the soil resources in rural Australia.

Although codes of ethics and lists of recommended competencies are essential, Maister (2000) has noted that professionalism is predominantly an attitude, not a series of competencies. He defines a real professional as a technician who genuinely cares about the wellbeing of their clients.

It is proposed that a 'Community of Soil Management Professionals' (Fig. 3) be established, interlinked closely with the 'Plant Science Community', Precision Agriculture Engineers and Hydrogeologists, and communicating with associated professional groups involved with rural land management (Land Valuers and Real Estate Agents; Infrastructure Development Teams; Regional Planners and Landscape Architects). The professional associations that represent the proposed groups need to negotiate a way for these mutually beneficial interactions to take place. Farmers and the groups that work closely with them, including farmer associations and Catchment Management Authorities, almost certainly will be better off with such an arrangement.

Associated with this proposal is a need to provide suitable educational programs in soil science for the respective professional groups. The paper entitled '*Producing the thinking soil scientist*' by Field et al. (2010) discusses a national 'Teaching–Research–Industry–Learning' framework that is being used to build on current teaching and learning practices already utilised by soil science academics, and to develop and map a new client-focused soil science curriculum.

5. Future directions and requirements

Bouma (2001) and Cribb (2010) have made it clear that soil scientists need to do better in the future when helping a broad range of clients to deal more effectively with soil-related problems such as land degradation. This paper presents a possible framework for responding to the challenge within an Australian context, with emphasis on VSEE techniques as a crucial component of future schemes for soil assessment and management, in conjunction with modern soil databases.

Improved information about the condition of agricultural land from accredited professional soil scientists will allow farmers to operate more profitably and sustainably via the use of 'whole farm soil assessment and management plans', and developers of new agricultural enterprises will reduce their risk of failure when searching for suitable land. Valuers of farming land will be able to do their work more accurately. An improvement in the quality of soil data across farms also will benefit other professionals – plant scientists, hydrogeologists, engineers associated with the development of new rural infrastructure (for example, mines, gas pipelines, roads), Regional Planners and Landscape Architects – who work in conjunction with farmers, both directly and indirectly. Governments can promote this cooperation by enshrining, in legislation, the need for inputs from accredited soil science professionals associated with the wise management of rural land. The education system for soil management professionals will have to take into account the contrasting responsibilities and knowledge requirements of farmers, 'general practitioner' advisers and soil science specialists when developing curriculums for the assessment and management of rural land.

Numerous technical challenges remain. Optimal depths and intensities of sampling for visual-tactile procedures, and associated soil chemical tests, need to be refined for application under different land uses and contrasting landscapes. Guidelines are required to improve the integration of VSEE and associated techniques with modelled soil data, and with new crop monitoring technologies such as yield/profitability maps. Much remains to be learnt about soil amelioration requirements of land with various degrees of soil physical, chemical and biological constraints under a broad range of rural land uses and for contrasting climatic conditions.

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