DEPARTMENT OF
PRIMARY INDUSTRIES

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Soil Health for Victoria's Agriculture
Appendices to final report

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Victoria
The Place To Be

Appendices

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Introduction

The North East Soil Health Action Plan (NESHAP)(DNRE 2001) was developed in response to growing community interest in soil health and research work that was being conducted locally and regionally on the impact of acid soils. A component of the plan was the identification of the region's soil resources and soil health issues which were presented in the document, Soil Health in North East Victoria (DNRE 1999). Both documents are components of the North East Regional Catchment Strategy (NECMA 1997). The North East was the first region in Victoria to produce a strategy for soil health, and the plan outlines 11 key action programs that work towards addressing the key soil health issues in the North East. NESHAP was not formally endorsed by the government and remained relatively static primarily due to a lack of funding for its implementation.

A regional funding proposal was submitted to the Regional Catchment Investment Plan (RCIP) for a regional soil health implementation strategy, which was approved for a two year period until May 2007. A full time Soil Health Project Officer (SHPO) was employed in May 2005 as part of the implementation project.

Key soil health partnerships in North East Victoria

1. **North East Catchment Management Authority (NECMA) and Landcare networks** – NECMA have been proactive in their support to the implementation of the soil health project in the region. The Landcare network co-ordinators in particular have been crucial in supporting the delivery of soil health information through the organisation of meeting events, locations, and audiences.
2. **PIRVic / Rutherglen Research Institute** - The lack of an exisiting formal soil health extension network has meant that the extension program has been highly dependent on input and guidance from soil health researchers within PIRVic.
3. **Other agency staff – salinity & soil conservation group project officers and managers** - A number of the objectives of NESHAP are co-objectives of the North East Salinity strategy and soil conservation program. Many of the issues regarding soil health require a holistic approach to practice change requiring inputs from a range of agency staff and programs.
4. **Goulburn Broken Soil health stakeholder group -** A strong relationship has been established between agency staff developing a soil health strategy in the Goulburn Broken and the soil health group in North East Victoria. This has involved some job sharing and joint tool and resource development.
5. **Biological farming groups** - The Ovens Landcare Network (OLN) in NE has been particularly active in a soil health program and has enlisted the services of a private biological farming consultant. Workshops, trials and annual events have attracted large numbers of participants. A strong relationship has been developed between the OLN project personnel and agency staff to provide a more unified message to land users on soil health issues in North East Victoria. This has resulted in a range of benefits to both parties including assistance in the establishment and awareness of the DPI Soil health strategy and extension program in the region.

However it is important that the message land users receive is both balanced and quantified. Currently there is a bias toward supporters of soil health biological farming methodology in the delivery of soil health messages in the community leading to variety of unproven and largely unchallenged claims being made on the merits of alternative soil heath practices.

Soil health strengths in North East Victoria

- **North East Soil Health Action Plan (NESHAP 2001)** - The plan provides a valuable framework and direction for the long term improvement of soil health in North East Victoria. Most of the National Landcare Projects (NLP) with a soil health component in the region have aligned their project proposals with the aims of the strategy. NESHAP has been used extensively in the design, development and implementation of an extension strategy for NE Victoria. The SHPO position and the level of interest and degree of soil health activity in the region are largely outcomes of this document.
- **Land Resource Assessment of North East Victoria (LRANE)** – Is a land capability analysis of freehold land within the North East Catchment Management Authority boundaries. This soil-landform model has been produced at a 1:100,000 scale and is a valuable resource for soil and landform identification, definition and distribution in North East Victoria. Training in the use of the LRANE has been included in all land user workshops, and staff training events conducted by the SHPO. The Tallangatta Valley Landcare Group project is using the model extensively in the design of a paddock scale soil health and management plans.
- **Interest and impetus in soil health in NE Victoria** - There is significant interest in soil health throughout the North East region now. The introduction of a soil health extension strategy has occurred during this period of high community interest and this has facilitated implementation of extension work.
- **Rutherglen Research Institute** - The quantity and quality of research that has been conducted in the NE through the Research Institute is respected throughout the community. Rutherglen staff have at all times provided valued assistance and guidance to extension staff.
- **Victorian Resources Online** - This resource is not limited to the North East or soil health. As a readily accessible database of information on soil health for the region it is an invaluable primary resource. Its use is encouraged within the soil health extension program.

Soil health extension activity in North East Victoria

During the period May 16 2005 and May 16 2006 the SHPO has been involved in the following activities;

- Preparation and delivery of 52 soil health related presentations to a range of Landcare, industry (BeefCheque and whole farm planning), community and agency groups. Media releases, radio interviews and articles for regional newsletters have also been produced during this time.
- Four agency (DPI, DSE & CMA) soil health training days have been delivered both in the North East and Goulburn Broken.
- Much of the extension activity in the region has been in response to community demand. There are 12 NLP funded projects operating within the NE totalling approximately $928,000 of NLP investment, all of which have some component of soil health in their focus. The SHPO has been involved in the design and support of 5 of these project proposals. Two projects in particular have considerable input from the SHPO, being based around increased landholder awareness of soil variation within the landscape, improved understanding of observed soil properties and use of this information to implement management strategies based around soil capability.
- Much of the initial focus has been in relationship building and liaison with the range of groups interested in a variety of soil health topics in the community. Technical support has been provided where and when required, and co-ordination within and between groups through the provision of tools and resources has been a key role of the SHPO.
- There has been a strong emphasis in working positively with other regional and statewide soil health projects and staff and complementary natural resource projects.

During the year to May 2006 a number of DPI programs and projects within the North East also contribute with a soil health component. These include;–

- Whole farm planning and Environmental Management Systems programs.
- BeefCheque and Target 10 contain a significant soil health component.
- The Salinity group and soil conservation (Catchment project officers) group work towards addressing the salinity and erosion programs within NESHAP.

Issues relating to soil health extension in North East Victoria

Soil health project timeframes and focus

The improvement of soil health takes many years, and yet most projects and employment contracts are targeted at short (2-3 year) time frames. Reinforcement of messages and follow through on project outcomes outside of these time frames is required if practice change is to be achieved.

The improvement of soil health in the region is highly dependent on the success of other agency and industry projects. The adoption and implementation of holistic Best Management Practices (BMP), including farming to land capability, establishing deep rooted perennials and maintaining a vegetative cover should be the focus of a soil health extension program for the region and not soil health per se.

Incorporating land holders in the design, implementation and evaluation of BMP programs is essential, as land holder ownership and understanding of the components of BMP implementation appear to be weak in the community. There is an opportunity for a combined multi agency and community demonstration farm type model where wide ranging natural resource BMPs are adopted and examined. A similar model was used in the Meat Research and Development Council (MRDC) Sustainability Monitor Farms in New Zealand. (http://www.maf.govt.nz/mafnet/publications/rmupdate/rm4/rm4001.html). Under this scenario if personnel or projects change an established resource that can be used to benchmark, monitor and follow through on practice change is maintained in the community.

The use of Landcare groups for soil health extension work

The use of the Landcare network for the delivery of soil health programs and workshops developed by the Soil Health Project Officer has merit however it limits the potential audience to active Landcare participants. Logistically, given the current high demand for soil health extension services in NE Victoria and the relative limits of staff resources appealing to a wider audience is difficult.

The focus within projects is on numbers of events or products produced with very little qualitative analysis of the effectiveness of these events or products. Short project and contract time frames further reinforce the need for utilising Landcare networks that enable you to meet your project deliverables.

The alignment of project priority areas and soil health interest

The guiding document for the implementation of soil health extension in the North East indicates 8 priority areas where soil health extension should initially be focussed. These priority areas have been identified because of the risk of salinity and water quality issues and do not necessarily reflect where the majority of interest in soil health lies within the community and balancing the demands of the community and the objectives of the project can at times be difficult.

Demand for soil health work is occurring primarily in the sheep and beef hill country grazing environments where the range of soil health issues impacting on production, the physical and financial limitations in addressing soil health issues, and limited number of soil health programs previously targeted at this sector has contributed to the keen interest in soil health projects and workshops.

Agency resources are already being invested into the priority areas of water quality and salinity and a slight re-alignment of roles within DPI (particularly the sharing of acidification extension with the salinity group) would enable more flexibility in the location of soil health extension in the North East. It also highlights the importance of establishing catchment condition indicators for other soil health criteria, for example organic matter, subsoil pH, soil structure degradation and soil loss, that may help direct soil health activity to areas where it is most required.

Soil health extension network & succession planning

There are only three full time Soil Health Project Officers or managers in DPI Victoria – one in North East Victoria and two in South West Victoria / Corangamite, this limits the opportunity for shared activity, resource development and training for staff. Training is limited towards more generalised groups who have only a partial interest in soil health in their roles.

There is currently no succession planning for soil health extension in North East Victoria. The limitation of a two year employment contract for the Soil Health Project Officer and lack of certainty about the position in the future is already impacting on the ability to commit to longer term project proposals. This is an important consideration for groups planning soil health projects in the region.

There are few opportunities for continuing on a career pathway in extension within DPI. It appears that senior extension officer roles do not exist and remuneration is limited to a grade 3 scale. Similar job positions within NSW are attracting DPI Victoria staff from the NE region, with 15-30% increases in salary typically quoted.

Soil health extension versus soil health research on a statewide basis

One of the roles of an extension practitioner is to feed back key information from field observations concerning perceptions towards and uptake of practice change information or new technology, to the researchers involved. Extension personnel are also crucial in helping shape the output of research data into forms that are tangible and relevant to the target audience. Within the organisation little opportunity exists for this process to work effectively. The large discrepancy between the number of staff involved in soil health research and those involved in extension within DPI is problematic. Soil health has a range of definitions within the community which often differ to those of researchers. An extension officer’s role is to be the link between these definitions.

In the North East region an example of the mutual benefits of developing strong linkages between extension and research is beginning to emerge between the SHPO and Soil Biology Platform at Rutherglen Research Institute. The SHPO has been included in the Soil Biology Platform meetings providing input on both extension and community activity and needs. The Soil Biology group has also used the extension network for input into possible training programs and projects both in-house and with other agency and industry groups. The advantages for the extension personnel is a clearer understanding of the research being carried out by the Soil Biology Group, enabling more authoritative communication within the community, and an increased understanding of the technical aspects of soil biology. A plan is currently underway to conduct a more formal soil biology training event in the near future and to provide assistance in the development of tools and resources.

Other opportunities for improving the linkages between research (PIRVic) and extension (CAS) include;

- CAS involvement at the initiation of PIRVic research projects.
- A workshop between PIRVic and CAS staff involving staff from both the soil health and practice change groups to clarify respective needs and establish a formal process to improving linkages.
- The establishment of a formal committee or co-ordination position within the organisation as a liaison point between research and extension activity.
- Look at the possibility of more collaborative PIRVic & CAS projects and funding proposals.
- Making allowances in PIRVic work commitments and funding proposals for more engagement with CAS staff.

Tools & Resources required for soil health extension in North East Victoria

1. **Collation and collection of regional soil health data** - There is a significant quantity of historical data relating to soil in NE Victoria which needs to be collected and collated. Accessible information to historical trial data would be beneficial to the soil health extension program. Clarification and quantification of what new data needs to be collected (eg. Land holder soil test results) and how it is to be used or presented is also required.
2. **Specific and targeted soil health monitoring tools** - Significant time has been invested in developing new or existing tools and resources for extension activity in the North East. There are a range of resources available, but these are now becoming outdated and do not reflect where the community interest in soil health lies. They also make little use of current practice change, or adult learning theory. A number of 'best guess' estimates for a variety of risk assessment monitoring tools is required. For example, a suitable drainage classification system, soil compaction risk index, soil phosphate loss risk and a simple soil health assessment.
3. **Larger scale support on soil acidification issues** - A priority issue in NE Victoria is soil acidification. Awareness is widespread within the farming community however the ability to address acidification is limited largely by the prohibitive cost of carting lime in to the region. The implementation of BMP's to reduce acidification often requires large-scale changes to current management which many landholders are reluctant or financially unable to implement. A larger, more concerted effort is required to address this issue. For example investigation into lime cartage alternatives, soil testing subsidies, targeted publicity campaigns and potentially soil acidification BMP monitor farms as significant practice change will be difficult solely through the action of extension staff.
4. **Specific training in soil biology** - There is particular interest in soil biology within the NE community and this is reflected in the range of soil health projects and requests for information relating to soil biology. There is significant community interest in biological farming practice programs in North East Victoria and an increase in the range of soil biological amendments and products available to land holders. Much of this operates within knowledge gaps of agency staff. Training in specific soil biology topics would be highly beneficial.
5. **Evaluation and monitoring program** - Surveys relating largely to water quality have been carried out in the region but are limited in their soil health scope. Gathering information on the uptake of BMP's and the issues and resources impacting on their adoption is a key requirement of the extension program. We need Information on the range of soil health practices currently being employed in the region, as well as how extensively the soil health message is permeating within various community and industry sector groups.

Summary

The North East region has benefited from the identification and prioritisation of soil health issues through NESHAP and much of the current soil health momentum in the region could be attributed to the work done in the production of this action plan. There is considerable interest and action taking place in soil health now in the region and from an extension perspective this makes implementing programs and projects comparatively easy. The following recommendations would assist to further improve the quality and effectiveness of the implementation of NESHAP:

- Succession planning on the future of the soil health program in the North East is required now to ensure that the current interest and momentum in soil health activity is carried on not only into next year but also well into the future. A mechanism needs to be in place to reinforce the importance of soil health and soil health best management practice implementation in the community. The focus should be on long term community based activities such as localised soil health monitoring programs and multiple NRM best management practice monitor or demonstration sites, rather than revising the tools or resources in soil health which traditionally have quickly become outdated.

- Much of the current soil health implementation focus has been on the activity of the SHPO, and it is important that other programs and priorities articulated in NESHAP are also targeted. Revision of NESHAP is required to review priority areas in soil health and to design strategies that ensure soil health is adequately addressed in all our NRM programs.
- Co-ordination of soil health programs, tools and resources at a state level is required given the limited resources currently available for soil health extension activity and the demands being placed on staff by the community. A workshop between PIRVic and CAS to promote better co-ordination between staff and to clarify the needs of each group would be of benefit.
- There is opportunity for closer and more collaborative programs with biological and organic farming systems programs. Fundamentally there is often very little separating the concepts and methods used between a number of the approaches towards soil health improvement being suggested currently. Articulation of where views may differ on BMP is important for the community.
- A measured response is required from PIRVic with regard to some of the claims being made by the biological farming sector. A reminder to land holders of the importance in substantiating claims with data and the analysis of the costs and benefits to any practice change exercise. It is necessary to reinforce the message that soils vary widely and a one shoe fits all approach to soil health is potentially costly and or damaging.
- A better understanding of the state of the soil resource in the North East is required. This could be achieved through benchmarking parameters such as organic carbon, macro-porosity and subsoil aluminium.
- A regional survey of soil health practices is required to indicate how the understanding and implementation of best management practices within the community is progressing. What the perceptions on soil health are, and what alternative practices being used in addressing soil health issues is essential in measuring the success of the extension program and also to better plan strategies for the future.

Appendix B: Application of satellite remote sensing to soil quality assessment - James Nuttall

Introduction

Plant growth and water use provide an integrated measure of soil quality, taking into account soil physical, chemical and biological factors over the entire soil profile. Measuring plant growth, using biomass estimates and water use is relatively inexpensive compared with edaphic characterisation. From a grower perspective, crop yield and input costs are prime indicators for sustainability, where production is likely to influence management decision made by growers.

Plant Biomass is potentially a robust indicator of soil quality for the following reasons:

1. it integrates soil physical, chemical, and biological condition,
2. it encompasses the soil profile within the effective rooting zone
3. it is linked closely to gross margin thus has grower incentive to measure, and
4. it is readily measurable. For agricultural production systems the challenge exists in relating point source quantitative analyses of soil quality to broader scale ecosystem process of sustained crop growth and production.

Measurement of biomass can be made over a range of scales from point source to regional level using sensors mounted on vehicles, airborne and satellite platforms. Vehicle and airborne mounted sensors serve intra-, inter-paddock purpose of crop assessment such as canopy management in precision agriculture. In contrast satellite platforms tend towards large-scale appraisal of landscape systems, thus suitable for assessment of spatial and temporal variation of vegetation across a broad area. As this review focuses on soil quality and capacity to support production systems at an ecosystem scale then discussion will focus on satellite derived vegetation indices.

Satellite-derived information for estimating crop production has been well established. In particular the Advanced Very High Resolution Radiometer (AVHRR) installed on the National Oceanic and Atmospheric Administration (NOAA) suite of satellites has been used to analyse agricultural systems. Applications include crop forecasting (Maselli, 1992; Quarmby, 1993; Benedetti, 1993; Smith, 1995), crop water dynamics studies (Veron, 2002) assessing ecosystem service (Prince, 1986; Konarska, 2002; Lu, 2003) soil mapping (Dobos, 2000) and climate (Kerr, 1989). For NOAA-AVHRR the limited spatial resolution of the sensors means these data are best suited to large-scale appraisal of landscape systems however, paddock scale assessment is not practical (possible). Alternatively, sensors on Landsat and SPOT provide higher resolution information making them well suited to assessing impact of human activity to agricultural production from paddock to regional scale. These remote sensing techniques can potentially detect where agricultural activity has caused a shift in production potential due to changing soil quality. Alternatively in regions where open cut mining has occurred on agricultural land, satellite derived information may offer a way of determining the effectiveness of mine rehabilitation, where historical and post-mining biomass production information is compared. This would provide assessment of the long-term impact of mining on soil quality.

Satellite and sensor capability

Satellite base spectrometers measure reflectance from terrestrial features where the sensors collect information cumulated from an instantaneous field of view (IFOV) snap shots, where IFOV differs depending on sensor capability. Consecutive IFOV are taken as the satellite traverses it orbit typically ca 98.9 degrees, 8.9 degrees offset from N-S. Each snap shot represent a scene, which constitutes layers of simultaneous matrices made up of elements (pixels) each recording a reflectance values. Reflectance values are recorded using digital numbers (DN). Each simultaneous matrix represents different wavelength interval collected by the sensor. The DN's are transformed to range from 0 to 255 where increasing number represent higher reflectance (Frank, 1985)

Reflectance data recorded from satellites range widely, depending on age and capability of sensors and orbit path (Lillesand, 1994). There are three main satellite programs, NOAA (National Oceanic and Atmospheric Administration), Landsat (formally ERTS (Earth Resources Technology Satellites)) and SPOT (Systeme Pour l'Observation de la Terre) which all have a sun-synchronous orbit (Figure 1). These satellites track westward with successive north-south orbits thus maintaining the equivalent sun angle incidence on each pass of the equator and so comparable surface illumination. Irrespective, time of year and global position impact on the suns angle of incidence and so reflectance characteristics of terrestrial features. Satellite pass frequency, off-nadar angle and cloud cover also impede comprehensive data collection.

Figure 1. Sun-synchronous orbit of Landsat-4 and –5 after (Lillesand, 1994)

For the satellites, NOAA, Landsat and SPOT, their orbit characteristics are similar, however, difference in on-board sensor design control characteristics such as orbit repeat period and resolution and so variation in monitoring capability. NOAA AVHRR has a wide scan angle compared with Landsat TM and SPOT HRV consequently coverage repetition is shorter (8-9 days) thus providing high temporal resolution. This high temporal resolution allows correction for cloud cover where successive overpasses for a discrete period are combined and the maximum reflectance taken for each grid point (Holben 1986; Smith 1995; Benedetti 1993). Conversely, AVHRR low spatial resolution (1100 × 1100 m) limits it application to paddock scale studies.

For Landsat TM (30 × 30 m) and SPOT (20 × 20 m) their sensitivity is suited to monitoring paddock scale processes, although their lower temporal resolution gives less control over noise filtering due to factors such as cloud cover. For example, data estimating wheat crop distribution and yields in NSW, from Landsat was 57% cloud affected for paddock assessed around anthesis (Dawbin, 1980). Assessment of vegetation cover in south central Utah was also complicated by reduced temporal resolution of data due to cloud (Ramsey, 2004) and again estimation of wheat cover in Kansas and Indiana was hindered by cloud cover (Bauer, 1977). Despite these potential draw backs, data from Landsat based sensors appear the best option for assessing temporal/spatial change in soil quality, through remotely derived vegetation indices.

Table 1. Comparison of current satellites and sensors. TM*, spatial resolution for the thermal-IR band is 120m. ETM+ spatial resolution is 60 m in thermal band and a 15 m panchromatic band.

	Satellites		
Parameter	Landsat -5, -7	SPOT-1,-2, -3 (4&5)	NOAA-7, -9, -11
Altitude (m)	900	832	833
Orbit time (min)	103		102
Orbit inclination (degrees)	98.2	98.7	98.9
Orbits per day	14.5		14.1
Orbit repeat period (days)	16/18 (offset 8)	26	8-9
	Sensors		
	MSS, TM & ETM+	HRV × 2	AVHRR
Scan angle from nadir (degrees)	7.7 - TM	variable up to 27	55.4
Swath width (km)	185	80 to 117	2400
Scene (IFOV) (ha)			
Resolution (m)	30 – TM* 80 – MSS	10 – panchromatic 20 - multispectral	1100
Cost (scene)	$600 (US)		

HRV, high resolution visible; TM, thematic mapper; ETM+, enhanced thematic mapper plus; NOAA, National Oceanic and Atmospheric Administration; SPOT, Systeme Pour l'Observation de la Terre; AVHRR, Advanced Very High Resolution Radiometer; RBV, return beam videocom; MSS, multispectral scanner

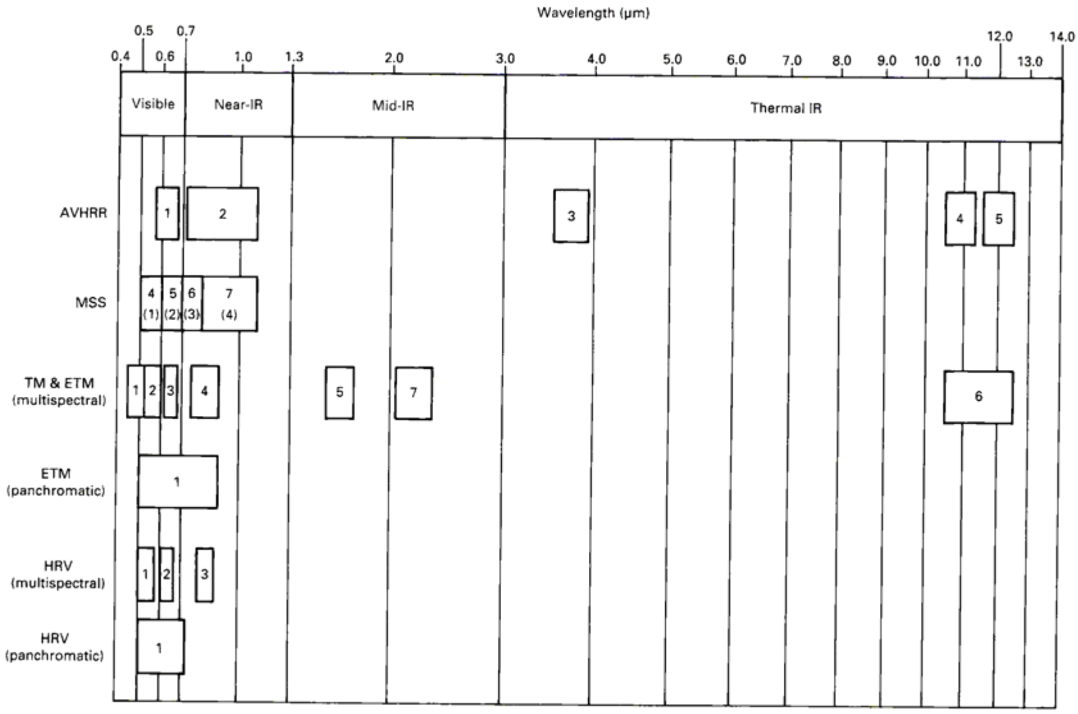

Figure 2. Spectral sensitivity of AVHRR, MSS, TM&ETM and HRV (Lillesand, 1994)

Landsat coverage

The coverage of Landsat is defined by the world reference system (WRS). The WRS is a grid overlaid on the earth surface made up of 233 near vertical paths, numbered consecutively from east to west, which relate to the ground track of the satellite. Path 001 intersects the equator at 64.60° west longitude and consecutive swaths overlap. The horizontal (latitudinal) portion of the grid is defined by rows (1 to 122), which provide the interval at which scenes are captured. Scenes are identified by the nomenclature 195/028, where path number is listed first, and the intersection of the path and row define the centre point of a single scene (Figure 3) (Anon, 2006b).

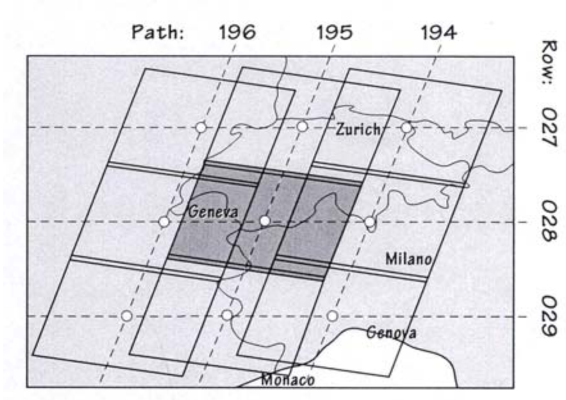

Figure 3. (Anon, 2006b).

Although a standard full scene (170 × 185 km) covers a prescribed portion of ground, several options exist in the acquisition of Landsat data. Within Australia, the Australian Centre for Remote Sensing (ACRES) - http://www.ga.gov.au/acres/ supply these data. Apart from purchasing a full standard scene, floating full scenes and portions of single scenes are available, where floating scenes constitute portions of several scenes. Portions of single scenes (eg quarter scene) are also based on the standard and floating options (Anon, 2006b). These variations relate to geometric manipulation of data, see 'data processing'.

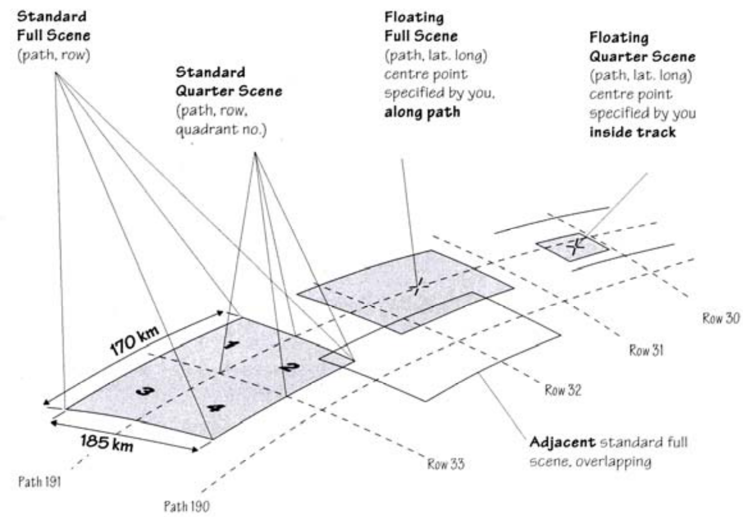

Figure 4. (Anon, 2006b).

Data Processing

Information from satellite sensors is received as a sequential stream of pixel data, which requires reconfiguring into a useable format. The degree of processing varies depending on what the end user requires. Typically processing level falls into two categories, level 0 and 1. Level 0 (0R) constitutes raw data that has not had radiometric noise removed and are not geometrically corrected. Data in this format requires substantial manipulation by the end user. In contrast level 1 data has correction applied for either radiometric (1R) or radiometric/geometric factors (1G). Raw data supplied by ACRES is equivalent to the United States Geological Survey (USGS) 1R level, which has radiometric correction.

Radiometric calibration

Radiometric correction removes/minimises effects due to impulse noise, and recalculates band reflectance as integer values. Within this manipulation there is the standardization of radiances across detectors. This is required as satellites carry multiple detectors within each band that vary in their compliance. As these detectors operate simultaneously to produce scenes where scan lines are compiled from multiple sensors, brightness values of adjacent scan lines vary, producing images that are stripped in the across track direction (Anon 2006a). Relative radiometric correction removes this effect by correcting brightness values using a reference standard. This standard is either taken from a nominated single reference detector, or by taking the mean brightness values across all detectors and correcting to this. Alternatively the multiple detectors within each band are individually corrected using time-dependent calibration algorithms (look up tables (LUT)). ACRES (Geoscience Australia) provide data that has been radiometrically corrected. For Landsat 5 TM data this is corrected in bands 1, 2, 3, 4, 5 and 7 using LUT and band 6 (thermal) using across detector averages. (Anon 2006a).

Geometric correction

Geometric correction realigns pixel data into a spatial context. Within this conversion, several factors have to be accounted for which include sensor operation, satellite orbit and terrestrial characteristics. Terrestrial variables are earths rotation and curvature. Spatially the data can be reconstructed as path or map orientated product. For path orientated data, the map grid is aligned with the satellite path (ca. 10^{o} east of north) and is not compatible to GIS applications. Alternatively, the data can be manipulated to align with map-grid north. A relic of the re-sampling process is a reduction in pixel size from 30 × 30 metres to 25 × 25 metres. ACRES supply both path and map orientated data where projection format is the Australian Geodetic datum of 1966 (AGD 66). These data are not corrected for atmospheric effects such as cloud cover (Anon, 2006b).

Registering the map grid to actual terrestrial position involves either a systematic or precision correction (Anon 2006a). The systematic correction relies on theoretical calculation of position using satellite trajectory information. In contrast, the precision correction (ortho-corrected) uses ground control points (GCP) for more accurate grid to terrestrial registration. Historically ACRES, Australia assigned GCP using topographic maps, however, more recently GCP have been redefined using geo-coded image chips, calibrated from controlled passes of Landsat ETM+ (Wang). Assessment of these orthocorrected products indicates that absolute positional accuracy is between 7 and 13 metres (< 0.5 pixel). This infers that multi-temporal, sub-pixel registration is possible, which potentially provides the capacity to make temporal assessment of land systems on a paddock scale. Ortho-corrected products are routinely available form ACRES for Australian coverage. Table 2 gives costs of sourcing Landsat data for Australia coverage which depends on scene size and degree of data manipulation required.

Table 2. Cost and scene size for satellite data.

Satellite/Sensor	Scene size	Cost (A$)
Landsat7/ETM+ Landsat5/TM	25 × 25 km	450-550
	60 × 60 km	670-770
	90 × 90 km (quarter scene)	860-960
	130 × 130 km (half scene)	1100-1200
	185 × 170 km (full scene)	1500-1800
	Double scene	2000-2200
	Triple scene	2600-2800
Landsat5/MSS	185 × 170 km (full scene)	595

Vegetation Indices

Remote sensing techniques can be used for monitoring vegetation (Lillesand, 1994). Numerous satellite systems measure reflectance in the optical spectrum, which includes the ultraviolet, visible, near-, mid-, and thermal infrared wavelengths (0.3-14 μm). Specifically bands in the visible and near infrared region can be used to derive various vegetation indices. The link between radiation reflectance from transpiring leaves and growth occurs due to the surface structure of leaves attenuating radiation in the red visible and near infrared bands. When solar radiation incorporating the visible and near infrared range (0.4 – 1.5 μm) hit transpiring leaves internal scattering of frequencies occurs. Radiation in the 0.4 –0.7 μm (red) range is heavily absorbed by the leaf chlorophyll whereas little absorption occurs in the 0.7 –1.3 μm near infrared range (Tucker, 1986). A common index used to define plant growth and biomass production, based on this principal, is the normalized difference vegetation index (NDVI). This is a ratio of the difference between the red (0.63-0.69 μm) and near infrared (0.76-0.90 μm) and their sum i.e.

$$NDVI = (NIR\text{-}red)/NIR\text{+}red)$$

Where, the index relates to the plants photosynthetic efficiency (Tucker, 1986). Alternative indices are also simple ratios (SR) of NIR and red bands (Lobell, 2001) or their difference (difference vegetative index (DVI)) (Anderson, 1993).

1. Differentiating ground cover

Early example using Landsat MSS was identifying and making area estimation of winter wheat in Kansas (Bauer, 1977), found good agreement between Landsat and United States Department of Agriculture statistics. Other applications of reflectance data from Landsat MSS were differentiating between degree and type of ground cover in semi-arid regions. (Frank, 1985) showed that reflectance band ratios could differentiate between halophytic shrubs, perennial grasses, shrubs and forest stands in Utah, USA using growth rate, where successive images were compared over a 2-month period. Similarly (Dawbin, 1980) showed that temporal comparison of radiance, from Landsat MSS, over a 3-month period during the wheat-growing season could discriminate between wheat, pasture and fallow paddocks in agricultural regions of New South Wales, Australia. In contrast assessing area of corn and soybean crops in Indiana using MSS was less successful due to crops being spectrally similar to other cover types (trees) and the smaller paddock size being beyond the spatial resolution of these sensors. Alternative cover indexes have also been used to monitor change in vegetation cover over time (Pickup et al. 1993). These workers used Landsat MSS scenes from over arid rangeland in Alice Springs, where the index was designed to differentiate between bare earth and vegetation cover. They used Band-4/band-5 data space to define an upper soil line (limit) and calculated the relative perpendicular position (PD54) of individual pixels to this line. This index showed better agreement with percent vegetation cover under dry and wet conditions than NDVI. For monocultures, however, it is likely that the NDVI will be a superior index as it has high greenness sensitivity implied better predictor of variation in crop biomass within paddock.

2. Assessing crop production

Reflectance measurements can be used to estimate crop yield by linking amount of photo-synthetically active radiation absorbed by the crop canopy to biomass production. Prediction of wheat yields in north-western NSW was made using Landsat MSS where temporal difference in reflectance data was calculated between early emergence and maturity. For two combinations of bands, a log transformed ($\log_{10}$) ratio of bands 7 and 5 (near-infrared/red) best fit observed wheat yield. Landsat 7 (ETM+) imagery could also accurately predict wheat yield at both the regional and local scale in Sonara, Mexico (Lobell, 2001) using a light-use efficiency estimated by the simple ratio (SR) and NDVI. This methodology overcomes atmospheric effects and the need for extensive ground truthing compared with models that rely on leaf area indices (Lobell, 2001). In shrub-steppe environments in south-central Utah, vegetation cover was also estimated using Landsat ETM where the NDVI had superior agreement with vegetation abundance compared with single band reflectance data (Ramsey, 2004). For growth of short grass prairie in central plains of north-east Colerado three vegetation indices were tested against three methods of combining spectral data from Landsat TM and biomass production. For univariate models, best agreement existed between green biomass and NDVI, when biomass data was combined into greenness strata prior to registration with reflectance data (Anderson, 1993). Reflectance information was also used in phenological studies of crop (Boissard, 1993), where NDVI was strongly linked to ear water concentration in wheat after anthesis and crop developmental stage, allowing for forecasting of crop maturity times. Overall, of the various possible reflectance channels and indices, the NDVI appears the most robust in estimating photo-synthetically active vegetation within a growing season.

3. Assessing change in soil quality

Using Landsat MSS, Frank (1985) (Frank, 1985) demonstrated that registration of pixels across successive images using simple regression could identify change in land quality (deviation from x=y) in a semi-arid environment after thunderstorm events. In this case reflectance information was sensitive to vegetation productivity and erosion process over a 2-month period in Utah, USA, where the region was uniformly exposed to thunder storm events. This approach demonstrates the capacity to monitor small-scale change in land quality, however, varying seasonal condition across the landscape may complicate its application to large regions (Frank, 1985). In contrast (Anderson, 1993), who was using Landsat TM data to monitor short prairie grass on semi arid central plains in east Colerado, found a poor correlation with vegetation indices when direct sample point to pixel (or aggregated pixels) were used. These workers contributed this to inability to accurately register pixels to sample points.

The other difficulty is deciding if the change is due to management factors, natural variability of physical processes or both.

Proposed methodology for assessing change in soil quality

When assessing soil quality in agricultural zones, it is assumed that the main ecosystem service associated with the soil resource is the potential to support biomass production. Logically if, the capacity of soil to sustain production changes then this implies a change in soil quality.

The challenge is to use crop biomass estimates to identify those parts of the landscape that are fluxing in production stability. Although numerous applications of satellite derived data attempts to make quantitative measurement for crop yield forecasting purposes etc, estimating change in soil quality is more one of assessing temporal change in production for any one point (pixel) within the landscape. For example within a single paddock regions may be consistently low or high yielding (stable) or alternatively show temporal switching tendencies where yield from year to year is variable, all of which would not suggest any fundamental change in soil quality but relate more to intrinsic/static soil quality. To demonstrate a shift in soil quality there needs to be a change in stability. If parts of the paddock/landscape become more/less stable this may infer there has been a shift in capacity of the soil to support growth of vegetation and so change in soil quality. Ideally at an intra-paddock level if the paddock could be divided up into a grid based on sensor resolution and registration accuracy, then temporal change of these individual blocks could be tracked.

For Landsat sensors with 30 × 30 metres resolution and ortho-corrected data being sub-pixel in absolute position accuracy, then it is possible to have accurate multi-temporal registration of pixels on a 30 metres grid. Alternatively, to decrease overlap error, pixels could be grouped eg 2 × 2 or 3 × 3, where the average radiance values of these is used. Once multi-temporal data, spanning 5 to 10 years is acquired and grid points are registered then each layer will require standardisation to allow for difference in range of absolute radiance data for each year, associated with different biomass potential across crops. This standardized data could be used to infer stability of biomass production relative to the paddock mean at any point within the paddock.

The output is likely to fall into one of three categories, which include, a). areas that are consistently high or low yielding, this would relate to potential inferred by intrinsic soil quality, b). portions of the paddock which are show temporal switching (unstable) which relates to interaction of intrinsic soil quality, season climatic conditions and crop type and c). parts of the paddock which have a negative trend, which implies a shift in soil capability to support plant growth and thus a potential shift in soil quality. A simplistic example could be the gradual expansion of saline land in a discharge zone, which is expressed as a gradual reduction in plant growth, radiating out form the saline source.

The information could be expressed either spatially in a map format where the various zones are identified. Alternatively, the multi-temporal reflectance data, after standardisation, could be divided into percentiles for each year. The distribution of these percentiles could then be compared across years. A shift in distribution of biomass with time would indicate changing status of soil quality.

Indices used

1. (Bauer, 1977) Landsat MSS

- - Green = Band4
- - Red = Band5
- - NIR1 = Band6
- - NIR2 = Band7

2. (Dawbin, 1980) Landsat MSS

- - Green = Band4
- - Red = Band5
- - NIR1 = Band6
- - NIR2 = Band7
- - $10\log_{10}(100 \times NIR2/Red) = 10\log_{10}(100 \times Band7/Band5)$

3. (Frank, 1985) Landsat MSS

- - Green = Band4
- - Red = Band5
- - NIR1 = Band6
- - NIR2 = Band7

4. (Anderson, 1993) Landsat TM

- - DVI (difference vegetative index) = NIR – Red = Band4-Band3
- - RVI (ratio vegetative index) = NIR/Red = Band4/Band3
- - NDVI = (NIR – Red)/(NIR + Red) = (Band4 – Band3)/(Band4 + Band3)

5. (Pickup, 1993) Landsat MSS where band 4 = green, band 5 = red, band 6 = near IR and band 7 =near/mid IR

- - Red = Band5
- - NDVI = (NIR2 – Red)/(NIR2 + Red) = (Band7 – Band5)/(Band7 + Band5)
- - SSI (soil stability index) = perpendicular distance of each pixel from the soil line in band4/band7 and band 5/band 7 data space

- PD54 = perpendicular distance of each pixel from the upper soil line (upper soil band limit) in the band 4 and band 5 data space.

6. (Boissard, 1993) SPOT HRV

- - NDVI = (NIR – Red)/(NIR + Red) = (Band4 – Band3)/(Band4 + Band3)

7. (Lobell, 2001) Landsat ETM+

- - SR (simple ratio) = NIR/Red = Band4/Band3
- - NDVI = (NIR – Red)/(NIR + Red) = (Band4 – Band3)/(Band4 + Band3)

8. (Ramsey, 2004) Landsat ETM

- - Blue = Band1
- - Green = Band2
- - Red = Band3
- - NIR = Band4
- - MIR1 = Band5
- - MIR2 = Band7
- - NDVI = (NIR – Red)/(NIR + Red) = (Band4 – Band3)/(Band4 + Band3)

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Appendix C: A Soil Biological Perspective on Soil Health – Pauline Mele

Background

The current renaissance of soil health as a key issue for regional and rural communities has been driven by a number of key socio-political and environmental factors that have simultaneously aligned. These factors include a market driven demand for clean and green produce, a growing land stewardship ethos driven in part by generational succession and demographic transition, the State Government response to the Environment and Natural Resources Committee Inquiry on the Impact and Trends in Soil Acidity (ENRC 2004) that highlighted the broader problems associated with soil health decline and in turn provided the impetus for the development of a DPI Soil Health Policy framework for Victoria (2006) and individual CMA soil health strategies. Most recently the release of the 'Action Agenda on Climate Change and Greenhouse' (DPI Science Policy Unit 2006) and specifically the abatement strategy related to 'extra carbon sequestration via agricultural soils' has further added impetus for soil health BMP.

It has been claimed by consultants, extension specialists and landcare coordinators that 'soil biology is fuelling the interest in soil health'. This specific interest in soil biology as an important component of soil health can be attributed to many factors including the increased influx of 'alternative' products such as soil conditioners and biofertilisers, the 20-30% growth in organic certification since 2003, a general heightened awareness of soil biology in farming systems driven by a Grains Research and Development Corporation (GRDC)- led soil biology initiative (AJSR special edition volume 44, 2006), land-holder driven demand for regionally relevant information and monitoring tools and the rapid expansion in new detection, data integration and visualization technologies. The focus provided by the alignment of these factors has also exposed the limitations in soil health databases in terms of accessibility and quality of data and in the case of soil biology the general paucity of data.

Victoria's Soil Infrastructure.

The concept of soil as infrastructure is based on the principle that soil represents the natural capital that underpins all terrestrial ecosystems by providing 'essential' ecosystem services such as water quality, nutrient supply and storage and plant and ecosystem health. These services have both amenity and production value. An inventory of the soil infrastructure is therefore critical in order to:

1. assess the quality and sustainability of existing services and therefore the extent and scope of land management impacts, and
2. to extend the knowledge of 'new' or 'yet to be defined' services. Collectively this knowledge will provide science based evidence for agri-environmental policy development and for practice change.

The Soil Health Trilogy.

Soil health assessment and monitoring requires collection of physical, chemical *and* biological data. The geomorphology and spatial extent of the major Victorian soils have been relatively well classified (**www.dpi.vic.gov.au/vro**) and supplemented with physico-chemical data collected at GPS referenced sites throughout the state. The physico-chemical datasets are being further augmented with Mid-infrared spectral (MIRS) analyses of archived Victorian soils to develop predictive calibration set for a number of soil parameters as part of a State Government and industry investment (ORL initiative and GRDC funded project work). The GRDC rapid soil testing project incorporating MIRS work is being undertaken by the State Chemistry Laboratory (SCL-DPI) with a timeline for completion of 2007.

In relative terms, soil biology databases are far more rudimentary. An international review of soil monitoring programs or environmental monitoring systems highlighted that only 29% of the 52 programs surveyed collected biological data (Winder, 2003).

More locally, a survey of the soil biological data collected in Victoria over the last 26 years has highlighted the relative paucity of data and the fragmented, localized and the point-in-time or 'snap-shot' nature of collection activities. Furthermore, the data generated is limited in its utility to comparing long-established treatments (at least 5 years) and for comparing broad land-use categories within soil type and climatic boundaries, the latter of which has not been attempted.

Improvements in soil health monitoring will require consideration of the trilogy of components that constitutes soil health. The dynamic nature of these elements and ecological concepts such as 'soil resilience' and 'soil resistance' must be incorporated into tool design.

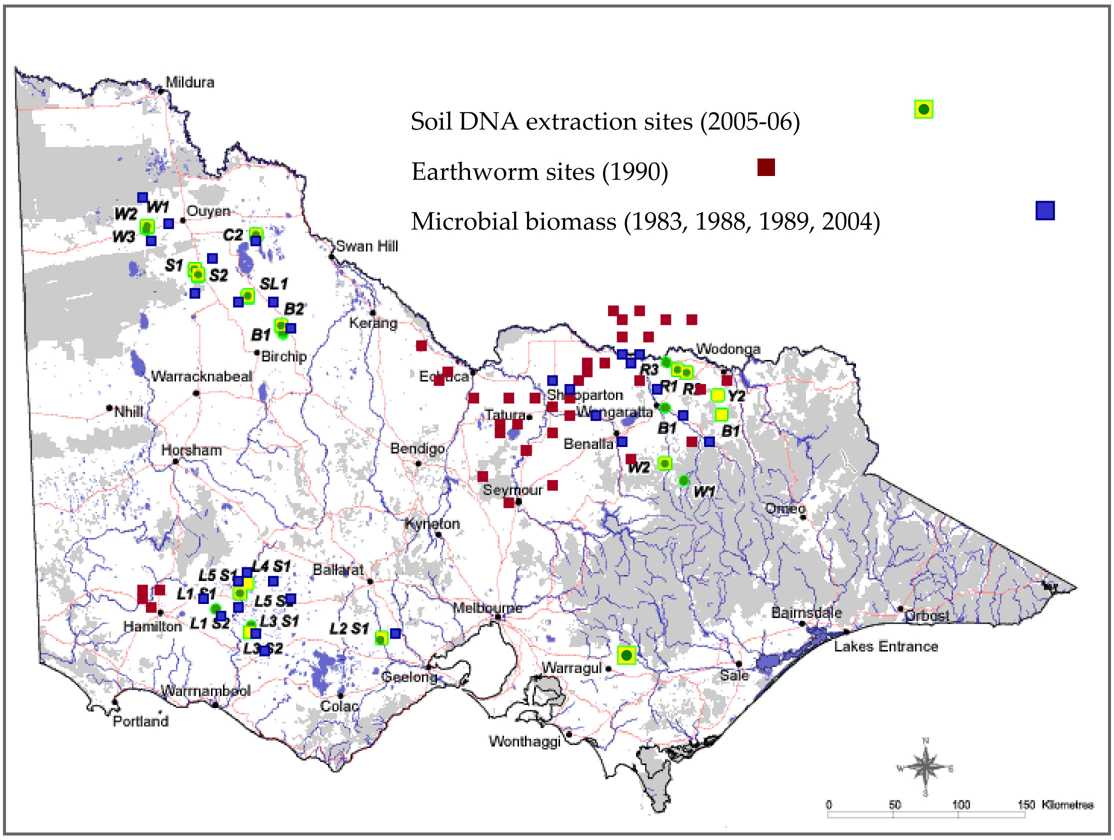

Figure 5. Location of sites where soil biological data has been collected (1980-present).

Soil Health. The function algorithm.

The consensus definition for soil health is provided by Doran et al 1996 (refer to Introduction by Richard MacEwan), and this together with many variants of this definition feature a recurrent theme 'the capacity of soil to function'. Soil functions relate closely and indeed may be interchangeable with the concept of 'ecosystem services'. A high proportion of the significant functions that underpin soil health are directly attributable to the living entity of soil, or the 'soil biota' (Table 3).

Table 3. Specific soil biological functions and ecosystem service provided

Biota	Function	Ecosystem service
Ants	Infiltration, OM mixing	Increased plant nutrients, seed dispersal
Earthworms	Infiltration, Plant residue breakdown and redistribution	Increased plant nutrients, reduced surface runoff
Dungbeetles	Organic matter burial	Increased plant available nutrients
Bacteria	Nitrogen fixation	Increased plant available N
	Nitrogen mineralisation	Increased plant available mineral N (NH_4^+ and NO_3^- forms)
	Phosphorus (P), Sulphur (S) mineralisation	Improved plant P and S availability
	Communication system (Quorum sensing molecules eg Homoserolactone)	Regulates numbers of disease organisms
	Antibiotic or probiotic production	Disease protection by suppression of soil-borne root diseases
	Plant hormone production	Improved root growth (for water and nutrient uptake)
	Pesticide degradation	Reduced accumulation in ecosystem (plant & animal toxicities)
	Fe and Zn chelation	Enhanced plant Fe and Zn nutrition
	Polysaccharide production	Improved structure + moisture retention (reduced erosion)
Fungi	Hyphal (filamentous) growth form	Improved structure + aeration (reduced erosion)
	Glomalin protein production (mycorrhizal fungi)	Improved structure + moisture retention (reduced erosion)
Bacteria and Fungi	Cellulose and lignin decomposition	Decomposition and C transfer

The soil biota are represented by a vast array of organisms that collectively constitute the most diverse ecosystem on the planet. These organisms range from simple, single-celled organisms to more complex, multicellular forms and from the microscopic (µm) eg bacteria, viruses, protozoa, fungi, algae and microfauna through to the macroscopic (mm) fauna eg springtails, mites, ants, earthworms.

Functional attributes have been assigned with a high degree of accuracy for the macro-meso and microfauna but with more limited precision to the microflora. In fact, attributing function to soil biota becomes exponentially more difficult as organisms within a soil community decrease in size and increase in abundance and diversity. For example, at the macroscopic scale, it is well accepted that earthworms mix plant residues in the profile thereby accelerating decomposition and nutrient transfer and improving water infiltration through burrow formation (Carter et al 1994).

At the microscopic scale, estimates of bacterial abundance range from 10^3 to 10^9 colony forming units per gram of soil, or in terms of biomass from 225 to 2625 kg ha^{-1} (0-10 cm depth) with most communities comprising hundreds to thousands of species in a gram of soil with more than 16,000 species now listed (National Centre for Biotechnology Information 2005). Functional attributes have been ascribed with confidence to only a relatively minute subset of microbes such as the N-fixing root nodule bacteria (presence of nodules on leguminous plants), the P-scavenging mycorrhizal fungi (presence on and inside plants) and pathogens (presence of disease on plants) with the vast majority of knowledge related to how microorganisms contribute to ecosystem function being based on whether those organisms can be cultured on artificial media. Whilst improvements have been made in media development (Davis et al 2004) it is still estimated that between 1 and 10% of soil bacteria are cultivable, indicating, as a worst case scenario, that up to 99% are, as yet uncultivated and therefore largely uncharacterized.

With the advent of approaches that involve direct extraction of DNA from soil, the 'need to cultivate' microbes will be largely circumvented and will result in a significant knowledge generation-phase related to the nature and extent of existing and novel soil microbial functions. In fact, it is estimated that there are more than 1.5 M novel genes that may contribute to functions that are as yet undescribed (Daniel 2005, Tringe 2005, Tyson 2004, Venter 2004). Metagenomic approaches that rely on DNA sequencing of a whole range of microbial genomes in soil (the metagenome) will therefore offer enormous scope for developing monitoring tools for existing functions and for uncovering novel agroecosystem functions. Building a comprehensive 'catalogue' of soil microbial functions will enable refinement of soil health tools for regional applications.

Soil Health. The 'resilience' algorithm.

Quantitative measures of both biological structure and function that reflect basic ecological concepts are becoming increasingly important in describing soil biological quality. Some attempts have been made to develop indices that combine microbial parameters to account for the 'dynamic' component that is soil health (Table 4). These attempts however do not come close to describing terms such as community stability, species richness, biodiversity (structural and functional) and functional redundancy.

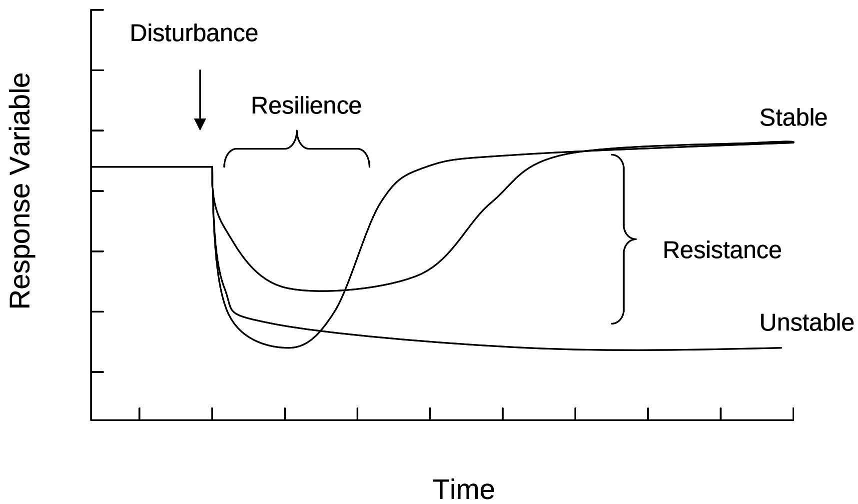

Figure 6. Response patterns and parameters used to describe dynamics in soil biological properties following disturbance

Microbial community stability is comprised of two components; resistance or the relative amount of change in a community structure, and resilience, the amount of time required for recovery to predisturbance levels (Figure 6). While a simple stability algorithm has great utility in quantifying the capacity of soil to recover after perturbation, only a limited number of microbial parameters have been tested.

Biological diversity and species richness are important indicators of stability and resilience of soils. Methods that allow detection and measurement of different taxa and species will provide valuable data on the capacity of soils to resist and recover from disturbance. Generally, the higher the species richness and diversity, the more stable and resilient and community is. Furthermore many notable overseas studies have demonstrated a positive relationship between above and below ground biodiversity in that the more diverse the plant species, the more diverse the soil microbial communities. Indeed our knowledge of the importance of symbiotic associations between microbes and plants (eg root nodule bacteria and legumes and orchids and mycorrhizal fungi) and the connection with dietary requirements of certain Australian marsupials (Claridge 2002) illustrates the important connection between above and below ground communities.

Table 4 Soil quality indices that reflect, to varying degrees of complexity, the dynamics of the soil ecosystem.

Soil Quality Index	Index formula	Index Method
Stability		Uses formulas yielding values between -1 and +1 that can be applied to any particular measure of a microbial community function or characteristic.
Resistance	$\mathrm{RS}\ (t_0) = 1 - \frac{2\lvert D_0 \rvert}{(C_0 + \lvert D_0 \rvert)}$	
Resilience	$\mathrm{RL\ at}\ t_x = \frac{2\lvert D_0 \rvert}{(\lvert D_0 \rvert + \lvert D_x \rvert)} - 1$	
Sensitivity – resistance	Ratio of metal tolerant to metal sensitive bacteria	Enumeration of sensitive and resistant bacteria, fungi, and actinomycetes capable of growth in media containing Cd, Zn, and other metals
Nematode feeding groups and biodiversity	Ratio of bacteriovores to fungivores	Requires species level identification of nematodes for assignment to functional groups
Nematode maturity index	$\mathrm{MI} = \sum_{i=1}^{n} v(i) \cdot f(i)$	Proportion of persistent (K strategists) and colonizers (r strategists) in nematode populations
Earthworm abundance	Species abundance per m^2, % maturity stage / total population	Earthworm abundance and biomass at temporal and spatial scales to determine dominance hierarchies.
Ecophysiological index	Ratio of r and K bacteria	Population size of r and K organisms by plate count methods.
Biovolumes ratio	TA/AFB	Ratio of total to active (TA) fungal plus bacterial biovolumes, divided by the ratio of the active fungal to bacterial biovolume (AFB): yields total/active/active fungal/bacterial (TA/AFB) biovolumes ratio.
Metabolic quotient	qCO_2	Respiration per unit of microbial biomass
Microbial biomass	◎g biomass C, N, P, S / total organic pools	Ecological marker for carbon, nitrogen, phosphorus and sulfur use efficiency. Estimates proportion of total organic pools contained in biomass.
Heterotrophic evenness	Substrate evenness by Simpson-Yule index	Catabolic substrate diversity utilization using CO2 efflux
Catabolic diversity	Shannon diversity index	Catabolic diversity based utilization BIOLOG®Microtiter ecoplates

Knowledge of the inherent capacity of soils to resist and recover based on the soil microbial diversity will be a major advancement in soil , plant and animal health monitoring. The most successful example of species data collection and application in assessment of resilience has been in the Natural Environment Research Council (NERC) Soil Biodiversity program at Sourhope in the UK (Irvine *et al.* 2006).

Soil Health Monitoring.

The paradigm shift that has occurred in the last decade related to soil health monitoring approaches and particularly biological monitoring can be ascribed to a shift from a 'one size fits all' to a 'purpose and place' approach. In general, soil health monitoring is becoming more sophisticated with the application of both ecological and integrative approaches in tool design.

These factors together with the rapid advancement in biotechnologies for discovery and measurement of the microflora will herald in a new era in tool development.

There are two categories of soil bioindicator. Those that can be used in a practical field based monitoring program and those that require passage through a laboratory due to the reliance on complex analytical equipment. A summary of tests currently utilised are provided in Table 5 with a more comprehensive review of microbial indicators of soil health provided by Nielson and Winding 2002. In the new paradigm, there is likely to be a convergence in these bioindicators as infrastructure becomes more portable and knowledge acquisition more instantaneous.

Table 5. Summary of some key soil bioindicators currently available or under development.

Test	Soil Health Information
Cotton strip assay	Decomposer potential
Fungi/bacterial ratio	Ecosystem health (overall)
Microbial biomass C,N &P	C,N&P turnover
CO_2 respiration	Soil microbial activity (aerobic)
Earthworms (abundance and species richness)	C availability and soil structure (pore continuity)
Dung beetles	C availability, topsoil depth, structure
Functional groups (eg cellulose degraders)	Specific microbial processes
Microbial enzymes	Specific microbial processes
BIOLOG™	Microbial diversity and richness
Molecular profiles (eg DGGE, T-RFLP, PFLA)	Microbial community structure and function
Bacterial genes	Specific microbial functions and structures
Microarrays	Multiple microbial functions and community structures

Tool design principles.

A review by Herrick et al (2002) outlined four guidelines for applying soil quality in a range of ecosystems, including agro-ecosystems. The guidelines include:

1. identifying a suite of indicators that are consistently correlated with the functional status of one or more critical ecosystem processes, including those related to soil stability, soil water infiltration, and the capacity of the ecosystem to recover following disturbance;
2. basing indicator selection on inherent soil and site characteristics, and on site or project-specific resource concerns such as erosion or species invasion;
3. using spatial variability in developing and interpreting indicators to make them more representative of ecological processes; and
4. interpreting indicators in the context of an understanding of dynamic, non-linear ecological processes defined by thresholds.

Integrative approaches.

Despite the vast and growing range of parameters that are promoted for soil health assessment, soil scientists have not been able to reach a consensus on which of these parameters best reflect the health status of soils. This difficulty not only reflects the great challenge in transcending a hierarchy of scales that for example, links genetic diversity to organismal diversity and soil ecosystem properties but also the need to consider soil physico-chemical indices. Attempts to solve this problem and understand these linkages has led to the emerging discipline of ecoinformatics, which is the application of computer modelling and statistical approaches to examine relationships between disparate types of environmental data at different scales that can be used to describe and manage ecosystems. One approach that is being pioneered for this purpose is distance based redundancy analysis (Legendre, 1999). Another powerful approach is the application of artificial neural networks (ANN) that are being used for integrated environmental assessment and visualization of complex multidimensional environmental data at multiple scales (Tran, 2003; Schultz, 1997; De la Rosa, 2004). With ANN, multidimensional data can be reduced in dimensionality by a combination of self-organizing maps (SOM) which are a type of neural network, and principle components analysis. Results generated from this approach provide a 2 or 3-dimensional map of clusters that reflect relationships between variables and site locations. The maps can be used to explore the influence of environmental variables on biological parameters (Lentzsh, 2005; Kampichler, 2000; Noble, 2000). This information can be used to identify key variables and can be used for forecasting changes in response variables over time. Most importantly the data generated can be presented visually in a way that provides for easy interpretation of complicated datasets.

Self organizing maps employ an unsupervised artificial neural network program to recognize patterns and associations at all levels of complexity within ecosystems from genes to ecological networks (Recknagel, 2003). Figure 7 illustrates conceptually how neural networks generate self-organising maps using computational methods. The model consists of two layers comprising an input layer that has nodes representing each input variable, and an output layer (Kohonen map) that is a 2-dimensional array of nodes. The input and output layers are linked by mathematical functions between every node in each layer. The computational model uses randomly selected input data (sample units) and calculates the distance between the input data and every node in the output layer. The program uses an ordering phase and a tuning phase to group all the input variables that vary similarly. The resulting Kohonen map contains color coded or shaded hexagons that summarize all of the component planes that represent individual abiotic and biotic variables, site locations, and other input information. The summary diagram is displayed as a "U-matrix" or unified matrix. Each of the component planes can be displayed separately and compared visually to examine their clustering relationships with all of the other variables.

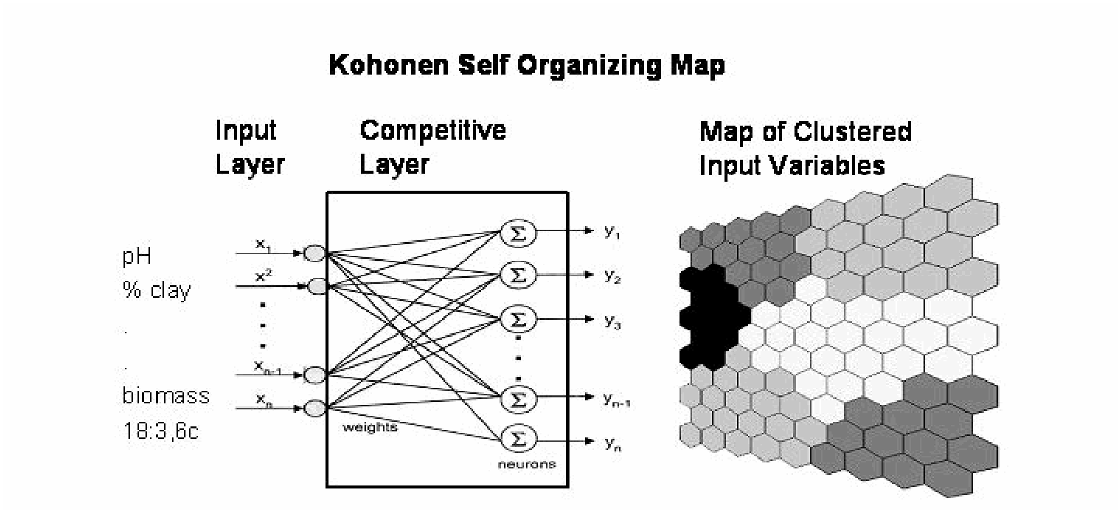

Figure 7. A Kohonen Self-Organizing Map illustrating the 3 key components; an input layer where the inputs refer to the soil quality variables, a competitive layer that weights and matches similar variables, and a map of clustered variables (Figure adapted from the 2004 ISIE workshop lecture by Recknagel).

Adoption of tools.

The first wave of interest in tools to assess soil health in the 90's in Australia gave rise to general consensus for single parameters or at least a 'minimum dataset'. A major failing of 90's efforts was the lack of attention to the interpretation of data that was generated from the tests which lead to poor uptake of these tools. Since then, we have seen the emergence of Environmental Management Systems (EMS) which engenders a whole new approach to implementation of monitoring tools based on the need for regionally relevant tools and for information, to flow back to the land manager to assist management choices (Carruthers and Tinning, 2003).

Land-holders will continue to demand simple tools for monitoring soil health, including biological health (Lobry-de Bruyn 1993). The growing acceptance that soil health is complex by virtue of its soil biological community, will justify investment in developing more sophisticated tools to satisfy more complex questions associated with land-use management and climate impacts. Despite the enormous interest in soil health in Victoria, there are no tools available that provide robust information to support practice change.

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Recommendations for Investment (soil biology and soil health)

1. Develop a centralized soil biology database for major regional Victorian soils. Features must be consistent with National Soils database.

This will require consensus on:

- *currently available* biological methods and sampling protocols. The criteria for selection of methodology should be based agreed by a range of soil practitioners and should cover specific and non-specific tests.
- biological methodologies to be used to establish monitoring tools.
- a network of benchmark sites (criteria for selection cross aligned with international protocols). The location of sites should conform to sites previously sampled for physico-chemical characteristics.
- development of reference or control sites to provide data upon which comparisons can be made. For example, a 'healthy' site and an 'unhealthy site.

2. Identify and prioritize applications for soil biology to assist in land-use management and transition.

These will encompass passive applications (eg monitoring change and impacts) and interventionary applications (eg microbial inoculant technologies vital for recovery of plant and animal based systems).

3. Centralize Activities in Soil Genomics*[1] with 2 output areas:

- Soil Functional Genomics: to identify new gene-based functions and structural signatures. New knowledge generated will be highly valued in environmental initiatives (Climate Change) and in pharmaceutical and bioenergy industries.
- Rapid through-put diagnostics (microarray) for assessing soil health and the impacts of a range of factors including climate change variables.

4. Build capacity in ecoinformatics to integrate multiparametric soils databases.

The outputs would be:

- Decision support tools based on visualisation tools designed by using multiparametric, regionally relevant soils data (physical, chemical *and* biological data) eg ANN or artificial neural networks that integrate disparate types of qualitative and quantitative data.
- Predictive models of soil health based on a range of soil class x land-use x management scenarios.

5. Efficient transfer of regionally relevant information on soil biology targeting 2 user groups:

- Soil health educators. This would involve a 'Train the Trainer' approach based on the direct interaction of research scientists with extension scientists, consultants, agribusiness personnel on an ongoing basis. Tools developed would be validated in a range of user groups.
- Soil health practitioners: This would involve practical instruction on tool applications and interpretation within a regional framework.

[1] This centre could align with the current infrastructure of the Victorian Agri Biosciences Centre.