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Submission to Garnaut Report on Climate Change
Land use - Agriculture and Forestry

The Australian Commonwealth Government is to be congratulated on its participation in the Garnaut Climate Change Review. The Garnaut Review Team is also to be congratulated on its comprehensive summary of climate change issues relating to the agriculture and forestry sectors, raised at the August 17, 2007 public forum.

It may seem presumptive to be making a submission from New Zealand on these issues. However, in the last year there have been a number of relevant cross-Tasman initiatives. I submit that there is considerable value in looking at building on these initiatives, particularly in areas of mutual interest requiring a common research input. Such an area is in the fundamental research required to develop either a single market voluntary carbon market, or at least a common framework for managing soil carbon.

A good example of an area of mutual interest where there has already been considerable cross-Tasman exchange is the research on agricultural uses of biocarbon/biochar. The inaugural International Agrichar Initiative conference in Terrigal in May 2007 was followed in Perth in June by a workshop organized by Agricultural Research West Australia on the Potential of Biochar in Agriculture. As a result of discussions around research in progress, a review of the role of biocarbon/biochar in agriculture was published in the Australasian based Journal of Organic Systems in December 2007:
http://www.organic-systems.org/journal/Vol%202(2)/pdf/02-13%20HARRIS-HILL%202nd%20Hill%20edit%20accptd%2007b.pdf

The ARWA workshop highlighted some important research and practical initiatives of relevance to climate change mitigation in West Australia:

1. Research led by Dr Paul Blackwell on the use of biocarbon/biochar in field-scale wheat production is part of an agricultural systems research team at the Dept. of Agriculture and Food, West Australia, led by Dr David Bowron. This systems based research provides an invaluable base from which rapid progress could be made on establishing how the soil sequestration of carbon can be linked with improved profitability and environmental sustainability. Sadly, the market oriented reforms of Government research in New Zealand in the early 1990s fragmented the research effort, and in agriculture saw a significant loss of systems capability as the research effort was increasingly focused on the application of technology (generally understood as GM technology) to agriculture.

2. Research led by Professor Syd Shea of the University of Notre Dame, has made significant progress in the practical integration of elements of indigenous mallee

ecosystems into agricultural systems to the benefit of both. This research also provides important options for mitigating greenhouse gas loses from agriculture while increasing the environmental and economic resilience of agriculture. Of the additional biomass produced by mallee, much of the carbon is directly sequestered in the soil by the roots, while the above ground biomass gives additional options for the soil sequestration of carbon.

Recent EC concerns over biofuels highlight the need for lifecycle analyses to identify the most effect agricultural options for climate change mitigations. It is hard to avoid the conclusion that the most effective options will come from producing biofuels from agricultural and forestry wastes. This issue was explored for New Zealand agriculture in a discussion paper prepared for the Agricultural and Marketing Research and Development Trust (AgMardt) last year, and is attached in Appendix 1.

It is most encouraging to note that in the summary of issues raised at the public forum, consideration was given to the need for research and development to be undertaken in a participatory way. A Visual Assessment System method developed in NZ by Graham Shepherd and adopted internationally, e.g. by the FAO, allows farmers to make a rapid semi-quantitative assessment of soil health, as well as providing a quick and simple means of assessing trends in soil carbon levels under cropping (see p161 of the paper attached in Appendix 2)
http://crops.confex.com/crops/wc2006/techprogram/P18241.HTM
It also has the potential to be extended to include soil carbon under pastoral grazing.

The VSA has shown that it is possible to correlate a semi-quantitative visual assessment system for soil carbon by farmers with quantitative objective analytical measurements. This basic approach could be used and developed to produce a comprehensive system for assessing soil carbon and provide a framework for the further development of a voluntary carbon market for managing soil carbon in agriculture and forestry.

From a public policy point of view, the best tools for mitigating agricultural greenhouse gas emissions are those that increase profitability. While voluntary carbon markets are an important long-term component, shorter term options include:

- Effective quantitative farm management systems such as that developed by eGOGENT.biz in New Zealand (http://www.ecogent.biz/) supported by the Visual Soil Assessment method.

- Improved farm profitability through the development of international Eco-brands based on objective measurement of soil carbon sequestration. Research is already underway in NZ in this area and would benefit from trans-Tasman collaboration.

Participatory research and development could also include opportunities for indigenous people to participate in any new economic options arising out of changes in public policy or from the spending of public money on research and development. Exactly how this is worked out in practice will differ from country to country. In Aotearoa/New Zealand, in addition to the land returned to Maori a part of Treaty of Waitangi settlements, there is additional significant multiple owned Maori land classed as ‘undeveloped’. Opportunities exist for using capital from the carbon credit value of retaining scrub and bush on that land for sustainable development. Similar opportunities may exist for aboriginal people in Australia.

Finally, it is important for the scientific community to remind politicians that in the rush to take action on global climate change, it is vital to support research that advances our critical understanding of current climate change models. These include research on:

- The mitigating effect of soils with good structure and porosity on GHG emissions
- Politically and commercially independent research on the effect of nitrogen inhibitors on microbial biomass, activity, and species diversity
- The evidence that as much as 30% of the sea level rise may result from the combination of groundwater withdrawal, surface water diversion and land-use changes, rather than greenhouse gas emissions.
  http://www.nature.com/nature/journal/v367/n6458/abs/367054a0.html
- Whether water vapor or carbon dioxide are the primary drivers of global climate change. Valuable critical thinking on this issue has been initiated by the CSIRO, and was reported in "The biology of global warming and its profitable mitigation" http://www.bml.csiro.au/SusnetNL/Network%20Letter%2064E.pdf

Additional research in these areas will further improve predictive modeling and ensure that public money is spent on the most effective mitigation options in agriculture and forestry.

Alfred Harris
18 January, 2007

Appendix 1: Discussion paper submitted to AgMardt October 2007

The Role of Biocarbon In A Systems Approach to Carbon Neutral Agriculture

A life cycle approach to carbon neutral agriculture is likely to involve biocarbons in 3 key areas:

- Integrated solid waste/energy management
- Direct soil sequestration of carbon
- Management of microbial ecology in the soil and rumen

Farmers, processors, and exporters will derive the maximum benefit if the life cycle changes are captured in a branding system with an objectively based auditing system. Such objective production standards would ideally combine an accurate qualitative system for farmers that can be correlated with objectively verifiable analytical standards.

Kiwifruit

With kiwigreen and organic certification systems, regional packhouses, and packhouse energy audits, the kiwifruit industry is well placed to make a rapid transition to and reap the maximum market benefit from carbon neutral production and branding.

Energy and waste management options include producing:

- Biocarbon and syngas from flash carbonized prunings
- Ethanol from fermenting waste fruit
- Biodiesel from algae using the solid wastes from fermentation and CO_2 from both biocarbon and fermentation.

Such integrated solid waste/energy management solutions have the potential to generate surplus energy in addition to entirely eliminating the emissions associated with fossil fuel used in transport and generating the power required to run chillers.

Perennial kiwifruit vines sequester considerable carbon for quantifiable periods of time in roots and stems. Biocarbons provide an additional, longer term option for soil sequestration of carbon. Improved mycorrhizal growth from adding biocarbon to the soil would provide an additional soil sequestered carbon pool with a shorter, but significant half-life.

Conversion to organic production is generally accompanied by a reduction in crop volume and fruit size. Analysis suggests that this is primarily due a drop in N availability due to the much higher cost of organic N compared to urea N. The GHG emission cost of both urea and compost production will need to be quantified and eliminated in carbon neutral production systems. A promising option in both systems is to change the composition and management of the groundcover in both systems to supply the total crop N requirements, and some if not all of the K requirements.

Dairying

The emissions of the GHCs methane and nitrous oxide put dairying in a different league to those of kiwifruit. Further emissions from the collection and processing of milk are likely to make the emissions on the transport and processing side of the equation an order of magnitude or two greater than kiwifruit transport and chilling! However, the basic principles of a systems solution to the reduction of GHG emissions are likely to involve many of the same components.

On the production side critical issues include:

- Volume and uneven distribution of urine and dung
- NO2 production
- Management of dairy shed effluent
- N enrichment of groundwater
- Reducing rumen methane production

Herd homes and standoff pads allow the collection of a substantial quantity of urine and dung. This provides an option for more even redistribution of animal derived nutrients and elimination of a substantial proportion of the GHG emissions resulting from fertiliser production. Herd homes and standoff pads also reduce pugging and reduce the anaerobic conditions associated with NO2 production.

Dewatered dairy shed effluent has potential to enhance algal growth for biodiesel production, and warrants further investigation.

Intensification of dairying is a particularly issue on the volcanic plateau where N enrichment of groundwater results in algal blooms, eutrophication, and potential deterioration of the recreational and economic return from tourism. Practical long term solutions will require increasing soil C to bind N and prevent it entering the groundwater. This is likely to include some combination of:

- Soil addition of chipped and/or carbonized biomass during forest to dairy conversions
- Soil addition of chipped and/or carbonized waste from forest harvest during pasture improvement or cropping
- Increasing pasture root volume
- Increasing root associated mycorrhizal fungi

Improving rumen efficiency improves productivity and reduces methane production. While the relative contribution of protein and fibre to rumen efficiency and methane production is known, the effects of biocarbon in the rumen have not been analysed. Biocarbons have proven methane and sporidesmin absorption capacity, and through their aerating capacity are likely to influence both rumen and dung microecology. Further research is required on the economic production of suitable biocarbons and their influence on methane production at the front end and nitrous oxide production at the back end where the dung meets the soil!

As with kiwifruit, integrated waste management/energy options from processing on both the milk and meat sides of the equation have potential to minimise GHG production, and to produce surplus energy. A systems approach is required to identify the range of options and economics of various combinations of carbonization, ethanol, and biodiesel production.

Integrated Production Systems

Further options for carbon sequestration and reductions in GHG emissions are provided by integrating trees into productive landscapes, and planting trees on less productive parts of the farm or for riparian protection/conservation value. End use options include harvest for timber, pollarding to supplement stock feed, and carbonization for energy and soil C sequestration. Economics and regional sensitivities in an emission responsive economy will determine the most viable options.

Broader scale redesign options for integrated changes in an emissions/C sequestration responsive economy could include:

- Changes from pasture to shrub based browsing systems and different ruminants (e.g. goats/alpacas) in some of the more fragile landscapes.
- Change from energy intensive monocultures to more labour intensive poly cultures such as share eeling on dairy farms.

These options provide a tighter biological integration with the wastes of one productive system more directly used to reduce the input costs in another system. The use of dairy shed solids for growing earthworms or similar high protein feed for eels is such an example. Reduction in transport costs and tighter energy transfers may also provide further worthwhile reductions in GHG emissions.
Previous research has proven that biocarbons can remove low levels of soluble N from waste water. New emission free and energy producing biocarbon technologies fundamentally change the economics of such uses. Further, N saturated biocarbons have potential for addition to the soil as slow release fertilisers, for the direct sequestration of carbon, and enhancing mycorrhizal fungal growth. Research and economics will determine the viability of these options.

Carbon Neutral Branding
The substantial pools of soil carbon and nitrogen fractions contained in mycorrhizal surface glycoproteins such as glomalin are likely to play a key role in carbon sequestration and nutrient cycling. Analytical measurements of these soil organic fractions may be robust enough to provide an objective basis for an internationally acceptable carbon neutral brand as well as providing farmers with a useful soil management tool. This management tool would be of even greater value if the objective analytical measurements of glycoprotein C and N correlate well with a NZ developed and internationally acknowledged visual assessment of soil structure and microbiological activity.

Essential Research Prerequisites

- Accurate quantitative life-cycle carbon maps for primary production
- Accurate quantitative life-cycle GHG emission figures
- Accurate data on what feedstock and pyrolysis parameters produce biocarbons suitable for soil and/or rumen use
- Accurate data on half-life of biocarbons produced from different feedstock and pyrolysis parameters
- Broad scale analysis of current land use patterns and changes in terms of impacts on carbon neutrality and potentially national level resource management responses
- Predictive models to provide estimates of the impact of land management and production and processing changes to provide hypotheses for objective testing and model refinement.

Alfred Harris (Current Carbon Consultants Ltd.)

Appendix 2:

Shepherd, T.G. 2003. Assessing soil quality using Visual Soil Assessment. In: Tools for nutrient and pollutant management: Applications to agriculture and environmental quality. (Eds L.D. Currie and J.A. Hanly). Occasional Report No. 17. Fertilizer and Lime Research Centre, Massey University, Palmerston North. pp. 153–166.

ASSESSING SOIL QUALITY USING VISUAL SOIL ASSESSMENT

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Abstract

Visual assessments of soil properties provide a semi-quantitative and cost-effective method to assess and monitor soil properties and soil quality compared with field and laboratory-based measurements. The Visual Soil Assessment (VSA) method was developed to provide farmers, land managers and regulatory authorities with a simple tool that would enable them to assess and monitor the condition of their soil quickly, cheaply and effectively. To justify the use of VSA as a tool for assessing soil properties at farm and regional scales in New Zealand, we compared VSA scores against conventional, laboratory-based, measures of soil properties. This was done on a wide range of soil types of varying ages, parent materials, climate, topography, and under different land uses and management practices.

All VSA scores were significantly related to corresponding laboratory-based measures of soil properties. The VSA soil structure score was strongly related to dry aggregate-size distribution (r^2=0.91; $P<0.001$), saturated hydraulic conductivity (r^2=0.86; $P<0.001$) and air permeability (r^2=0.80, $P<0.001$), moderately related to macroporosity (r^2=0.69; $P<0.001$) and dry bulk density (r^2=0.64, $P<0.001$), and weakly related to aggregate stability (r^2=0.58; $P<0.01$). The soil porosity assessment was strongly related to dry aggregate-size distribution (r^2=0.83; $P<0.001$) and macroporosity (r^2=0.78; $P<0.001$), and weakly related to bulk density (r^2=0.51; $P<0.001$). The VSA colour score was strongly related to total carbon (r^2=0.80; $P<0.001$) and moderately related to anaerobic mineralisable N (r^2=0.64; $P<0.001$) of conventionally cultivated mineral soils that do not have strongly bound and/or high amounts of organic matter, and that do not show visual evidence of anaerobicity. The VSA mottle score was weakly related to macroporosity (r^2=0.47; $P<0.001$).

These relationships indicate the VSA can provide a reliable and defensible tool to assess key soil properties semi-quantitatively, and can be used in conjunction with, and complement, quantitative procedures at a farm and regional scale. Farmers and regulatory authorities can use the VSA to assess the condition of their underground economy, and evaluate the effectiveness of their management practices and on-farm quality assurance programmes.

Introduction

The environmental and economic performances of land uses are significantly affected by inherent soil characteristics and the condition of the soil. It is in the interest of farmers/land managers, therefore, to know something about the quality of their soil and how to assess it.

Farmers are also increasingly required to meet industry standards for certification, and need a simple means to demonstrate compliance. At the national and international level, New Zealand is required to promote the sustainable management of its natural and physical resources both through its Resource Management Act (RMA) (1991), and as a signatory to international conventions on environmental performance. Consumers and governments also often require confirmation of environmentally friendly and sustainable farming practices for New Zealand to acquire and maintain access to international markets. Environmental indicators and assessment procedures are therefore needed for state of the environment reporting, to help formulate environmental policies, to evaluate the effectiveness of these policies, and to provide improved advice and education for good soil management. While quantitative measurements are essential, they are often poorly understood by end-users. Furthermore, because farmers/land managers are not usually involved in the assessment process, 'ownership' and subsequent use of the information are generally poor. Laboratory measures can also be costly (Shepherd & Dando 1997), limiting their spatial application and the number of sites selected for monitoring. There is a need therefore for simple, quick and easily understood methods to assess and monitor soil properties. The recognition of this need is widespread (Peerlkamp 1959; Boekel 1963; Batey 1988; Romig et al. 1996; King et al. 2000; Lobry de Bruyn & Abbey 2003; Ditzler & Tugel 2002). Simple methods of soil assessment must also be reliable, accurate, economical, able to give rapid results, and meaningful to farmers and landowners with minimum training (Sarrantonio et al. 1996).

The Visual Soil Assessment (VSA) method was developed to allow people to convert visual messages of soil properties into a meaningful assessment of soil characteristics, providing a simple, inexpensive method to assess soil quality semi-quantitatively, quickly and effectively (Shepherd 2000; Shepherd & Janssen 2000). The VSA is based on a weighted additive model of key soil 'state' indicators of soil properties (both inherent and dynamic), and presented as a scorecard. Each indicator is a subset of the attributes used to assess aspects of soil quality. Key indicators include soil morphology and genesis criteria (e.g., structure, porosity, colour and mottling). The soil indicators are complemented by plant 'performance' indicators that link soil characteristics to plant response, farm productivity and farm-management practices. VSA scores are closely related to crop yield, pasture dry matter production, biomass cover and utilisation (Shepherd 2000; Shepherd & Park 2003). The VSA kit includes Soil Management Guidelines for the prevention and amelioration of soil degradation and the sustainable management of farms (Shepherd et al. 2000a, b).

While the VSA is based on pedology and underpinned by extensive laboratory and field-based research, its reliability as an effective, defensible method of assessing soil properties needed to be established. We assessed the relationship between the VSA indicators and their equivalent laboratory-based measures by comparing VSA indices on a wide range of soils of different parent materials, under different climatic regimes, topography, land uses and management practices, that had also been characterised using laboratory procedures.

Materials and Methods

Soils, location and land use

VSAs were carried out at 91 sites on 40 soil types under dairying, dry stock farming, cropping, indigenous and exotic forestry in 10 regions of the North Island of New Zealand: Auckland, Waikato, Rotorua, Bay of Plenty, Taranaki, South Taranaki, Hawke's Bay, Wairarapa, Manawatu and Horowhenua. The soil series, soil classification, land use and location for each site are given in Table 1. Eleven of the 15 Soil Orders in the New Zealand Soil Classification were represented in the study, accounting for 97% of New Zealand.

500 Soils sites
VSAs were made at 64 sites along the same transects previously sampled for the 500 Soils Project (Sparling et al. 2001). That project measured total C, total N, anaerobic mineralisable N, soil pH, Olsen P, exchangeable cations, bulk density, total and macro-porosity, readily and total available water, and aggregate stability at 0−10 cm depth (Schipper & Sparling 2000). The individual VSA scores for soil structure, porosity, colour and mottles at the 0–10 cm depth were regressed against macroporosity, bulk density, aggregate stability, total C, and anaerobic mineralisable N. VSA normally assesses the condition of the whole topsoil, or to a maximum depth of 20 cm if the depth of topsoil is greater than 20 cm. To match the sampling depth of soils analysed for 500 Soils, two 20×20×10 cm samples were combined for the VSA test, and replicated at four sites along a 50-m transect.

Additional sites
The individual VSA scores for soil structure, porosity, colour and mottles were also regressed against published and unpublished analytical data from a further 27 sites (Shepherd & Dando 1997; Shepherd et al. 2001b; Shepherd et al. 2004), incorporating five soil types under pasture and cropping (Table 1). The data included the five 500 Soils parameters as well three key soil physical properties: dry aggregate-size distribution, saturated hydraulic conductivity (Ksat) and air permeability.

Visual Soil Assessment
VSAs were carried out and scorecards completed according to the methodology of Shepherd (2000) for cropping and lowland pastoral sites, and according to Shepherd & Janssen (2000) for hill-country pastoral sites. Four replicate sites were selected along representative transects within a paddock, and their position recorded with a Garmin eTrex Global Positioning System so they can be revisited for future monitoring. A spade slice of topsoil was taken from under the nearest fence line or similar undisturbed area for comparison with the sample sites. At the sampling sites, a 20-cm cube of topsoil was removed with a spade and dropped a maximum of three times from a height of 1 m onto a firm base in a plastic basin. The material was transferred to the surface of a large (50×75 cm) plastic bag and graded, the coarsest aggregates/clods graded to one end, and the finest to the other. The resulting sample provided the material for the assessment of most of the indicators. Each indicator was given a visual score (VS) of 0 (poor), 1 (moderate) or 2 (good), based on the soil condition observed when comparing the site sample with three photographs provided in the Field Guide. Scoring is flexible, so should a sample not align clearly with any one of the photographs, but sit between two, a score in between is given, for example 0.5 or 1.5. An explanation of the scoring criteria and the importance of each indicator, accompanies each set of photographs. Because some indicators are relatively more important for soil quality than others, the visual scores are multiplied by a weighting factor of 1, 2 or 3 to give VS rankings. The VS ranking of each indicator is summed to give a ranking score (a visual soil quality index), the value of which determines whether the soil has a good, moderate, or poor soil quality.

The visual soil quality index is sufficiently sensitive to provide an early warning indication of any change or decline in soil quality from a baseline reference point, or from a point in time. The condition of the soil can be assessed in 15 minutes using the VSA, while the plant indicators are assessed in 5–10 minutes.

A soil quality index is gained through assessment of the soil indicators alone, as this does not need prior knowledge of the paddock history. The plant indicators require knowledge of the immediate paddock history and because of this, only those with the necessary information, or those with farming experience, will be able to complete the plant indicator scorecard accurately. The ranking scores for soil and plant indicators are compared to provide an indication of plant performance relative to a soil quality rating. Soil scores significantly higher than the plant score suggest the full productive potential of the soil resource is not being realised. Plant scores significantly higher than the soil score can indicate high fertiliser inputs to counter the detrimental effects of poor soil quality on production. Comparing the

Table 1 Soil series, land use, location, and soil classification

Soil series	**New Zealand Soil Classification** [3]	**USDA Soil Taxonomy** [4]	**No. of sites**	**Land use** [5]	**Location**
Ardmore [1]	Mellow Humic Organic	Typic Medisaprist	1	D	Auckland
Te Rapa [1]	Mellow Humic Organic	Typic Medisaprist	1	D	Waikato
Ahikouka [1]	Typic Recent Gley	Typic Fluvaquent	4	C, D, DS, I	Wairarapa
Kaikarangi [1]	Mottled Immature Pallic	Aeric Endoaquept	1	DS	Taranaki
Mercer [1]	Typic Recent Gley	Mollic Endoaquent	1	D	Waikato
Pongakawa [1]	Peaty Orthic Gley	TypicEndoaquoll	1	C	Hawke's Bay
Moutoa [2]	Melanic Orthic Gley	Typic Endoaquoll	4	C, DS	Manawatu
Awamate [1]	Typic Orthic Gley	Humic Endoaquept	3	D, DS, O	Wairoa
Hastings [1]	Typic Orthic Gley	Mollic Endoaquept	1	C	Hawke's Bay
Kaiapo [1]	Typic Orthic Gley	Mollic Endoaquept	2	C, DS	Hawke's Bay
Kaipara [1]	Typic Orthic Gley	Typic Endoaquept	1	D	Auckland
Kairanga[2]	Typic Orthic Gley	Typic Endoaquept	10	C, D, DS	Manawatu
Mangateretere [1]	Typic Orthic Gley	Mollic Endoaquept	1	C	Hawke's Bay
Te Awa [1]	Typic Orthic Gley	Aeric Endoaquept	2	C, DS	Hawke's Bay
Waitemata [1]	Typic Orthic Gley	Typic Humaquept	1	C	Auckland
Waikare [1]	Mottled Yellow Ultic	Aquic Hapludult	1	DS	Waikato
Warkworth [1]	Typic Yellow Ultic	Typic Hapludult	2	C, DS	Auckland
Mamaku [1]	Humic Orthic Podzol	Andic Haplohumod	1	E	Waikato
Hangatahua [1]	Vitric Orthic Allophanic	Thaptic Udivitrand	1	E	Taranaki
Egmont [1, 2]	Typic Orthic Allophanic	Typic Hapludand	2	C. DS	South Taranaki
New Plymouth [1]	Typic Orthic Allophanic	Typic Hapludand	6	C, DS; I, E	Taranaki

Paengaroa [1]	Buried-allophanic Orthic Pumice	Typic Udivitrand	1	DS	Bay of Plenty
Ohinepanea [1]	Typic Orthic Pumice	Typic Udivitrand	1	DS	Bay of Plenty
Waiwhero [1]	Typic Orthic Pumice	Typic Udivitrand	1	DS	Rotorua
Naike [1]	Typic Oxidic Granular	Typic Haplohumult	2	D, DS	Waikato
Patumahoe [1, 2]	Typic Orthic Granular	Typic Haplohumult	3	C, DS	Auckland
Kokotau [1]	Acidic Perch-gley Pallic	Aeric Endoaquept	4	C, D, DS, I	Wairarapa
Levin [2]	Pedal Allophanic Brown	Andic Dystrochrept	3	C	Horowhenua
Te Horo [1]	Mottled Orthic Brown	Typic Dystrochrept	4	C, DS; I	Horowhenua
Whangamomona [1]	Acidic Orthic Brown	Typic Dystrochrept	3	DS, E	Taranaki
Tirangi [1]	Acidic Orthic Brown	Typic Dystrochrept	2	DS, E	Taranaki
Aroha [1]	Typic Orthic Brown	Andic Dystrochrept	1	DS	Waikato
Farndon [1]	Mottled-saline Fluvial Recent	Typic Endoaquent	2	C, DS	Hawke's Bay
Otara [1]	Mottled Fluvial Recent	Typic Hapludoll	2	C,D	Bay of Plenty
Manawatu [1]	Acid-weathered Fluvial Recent	Dystric Fluventic Eutrochrept	2	C, D	Horowhenua
Manawatu [2]	Weathered Fluvial Recent	Dystric Fluventic Eutrochrept	6	C, DS	Manawatu
Opouriao [1]	Weathered Fluvial Recent	Dystric Fluventic Eutrochrept	1	C	Bay of Plenty
Karapoto [1]	Weathered Fluvial Recent	UmbricDystrochrept	1	DS	Taranaki
Rotomahana	Typic Tephric Recent	Typic Udorthent	1	DS	Rotorua
Pinaki [1]	Sandy Raw	Typic Udipsamment	1	E	Auckland

[1] VSA indices regressed against 500 Soils measurements
[2] VSA indices regressed against saturated hydraulic conductivity, air permeability and dry aggregate-size distribution
[3] Hewitt (1998); [4] Soil Survey Staff (1998)
[5] C = cropping; D = dairying; DS = dry stock; O = Orchard, I = indigenous forest; E = exotic forest

soil score to the plant score encourages farmers to address why differences, if any, occur; what effect management can have on the two scores; and how the two scores could be improved.

Soil Physical Properties

Seventeen lubricated cylindrical cores (100 mm diameter × 77 mm long) were sampled from each site in the 0–10 cm depth zone using a hydraulic ram. Cores were sampled at random intervals along three transect lines over a 30 × 20 m area for the pasture sites, and at random intervals along wheel traffic rows on cropping sites. All replicate cores were brought to saturation with reverse osmotic water in a water tray. Nine cores were used for measuring saturated hydraulic conductivity by the method of Clothier and White (1981). The cores were then oven dried at 107°C to obtain the dry bulk density (p_b). Total porosity (S_t) was calculated from the formula: $S_t = 100[1-(p_b/p_p)]$, where p_p is the particle density. p_p was determined in triplicate from field samples by the pycnometer method of Gradwell and Birrell (1979). Air permeability and macroporosity were measured on the remaining eight cores equilibrated at a matric potential (P_s) of –10 kPa by placing them on a 0.5 bar ceramic moisture release plate attached to a hanging water column adjusted to a height of 1.0 m. Air permeability was measured using a flow-rate air permeameter (Corey 1986). The weight of the core was measured to derive its volumetric water content (θ), from which the macroporosity was calculated: where macroporosity = total porosity (θ/water density). Dry aggregate-size distribution was measured using a drop-shatter procedure (Shepherd et al. 2001b). Four large replicate cores (20 cm diameter by 20 cm deep) were taken with a hydraulic ram, extruded, and dropped (up to a maximum of three times) from a height of 1.0 m onto a firm surface to break the soil into its primary structural units. If large clods broke away after the first or second drop, they were individually dropped once or twice again. If the clods shattered into primary structural units after the first or second drop, it was not necessary to drop them again. No part of the soil sample, or clods breaking away from the sample, was dropped more than three times. The soil was dry sieved through a stack of sieves with mesh openings of 2, 5, 10, 20, 50, 100 and 150 mm. The weight percent of soil retained on each sieve was calculated, and the overall aggregate mean weight diameter (MWD) calculated using the formula: MWD = Σ(Wt% sample on sieve × mean inter-sieve size/100). All soils were sampled and 'dry' sieved in the field when the soil-water matric potential was approximately –100 kPa.

Analysis of data

All quantitative laboratory measurements were regressed against VSA measurements using an exponential non-linear regression curve, fitted by least squares. The results are shown as scatter plots, along with their regression curves and coefficients of determination.

Results and Discussion

All VSA indices are related to laboratory-based soil characteristics (Table 2; Figs 1–6). The VSA soil structure score was strongly related to the dry aggregate-size distribution, saturated hydraulic conductivity (Ksat) and air permeability, moderately related to macroporosity and bulk density, and weakly related to aggregate stability (Table 2; Figs 1–3). The VSA soil porosity assessment was strongly related to dry aggregate-size distribution and macroporosity, and weakly related to dry bulk density (Table 2; Fig. 4). The colour score was strongly related to total carbon and moderately related to anaerobic mineralisable N of conventionally cultivated mineral soils (Table 2; Figs 5–6). The soil colour relationship holds only for those conventionally cultivated soils that do not have strongly bound and/or high amounts of organic matter, and do not show visual evidence of anaerobicity. The VSA mottles score was weakly related to macroporosity (Table 2).

Soil structure, bulk density, organic C, hydraulic conductivity and soil aeration (as indicated by air permeability and soil porosity) are important characteristics to assess the condition of the soil and whether a soil provides a favourable environment for plant roots. The results (Table 2; Figs 1–6) indicate these key characteristics are, in most cases, closely related to the visually-assessed soil properties.

Table 2 Relationship between VSA indices and measured soil properties

VSA indices	Measured soil properties	Coefficient of determination (r^2)	*P*-value (Probability)	Relationship	Figure
Structure	Dry aggregate-size distribution	0.91	<0.001	Strong	1
Structure	Ksat	0.86	<0.001	Strong	2
Structure	Air permeability	0.80	<0.001	Strong	3
Structure	Macroporosity	0.69	<0.001	Moderate	NS[1]
Structure	Bulk density	0.64	<0.001	Moderate	NS[1]
Structure	Aggregate stability	0.58	<0.01	Weak	NS[1]
Porosity	Dry aggregate-size distribution	0.83	<0.001	Strong	NS[1]
Porosity	Macroporosity	0.78	<0.001	Strong	4
Porosity	Bulk density	0.51	<0.001	Weak	NS[1]
Colour	Total carbon	0.80	<0.001	Strong	5
Colour	Anaerobic mineralisable N	0.64	<0.001	Moderate	6
Mottles	Macroporosity	0.47	<0.001	Weak	NS[1]

[1] NS Not shown

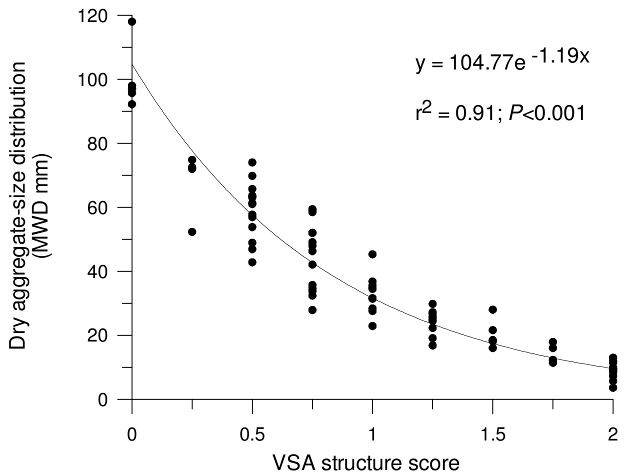

Fig. 1. Relationship between the VSA structure score and the mean weight diameter of the dry aggregate-size distribution

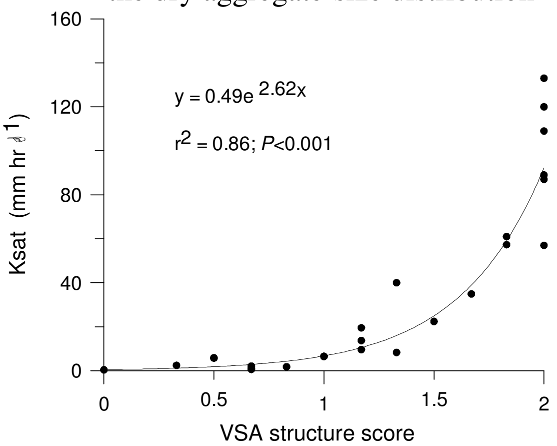

Fig. 2. Relationship between the VSA structure score and saturated hydraulic conductivity

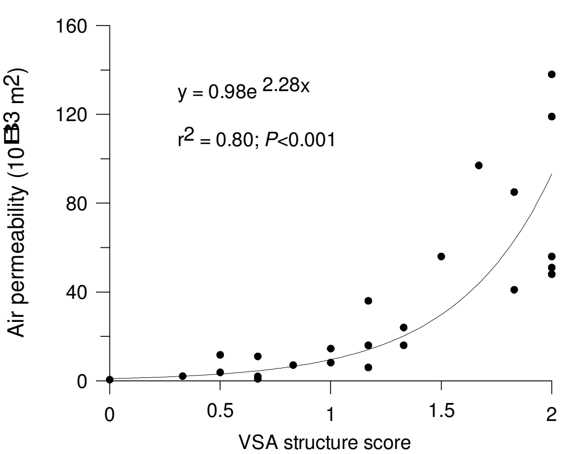

Fig. 3. Relationship between the VSA structure score and air permeability

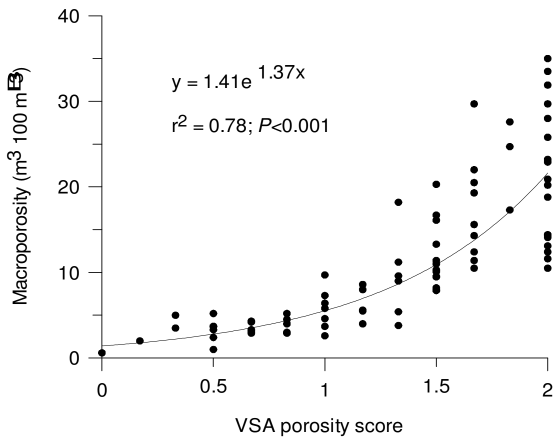

Fig. 4. Relationship between the VSA porosity score and macroporosity

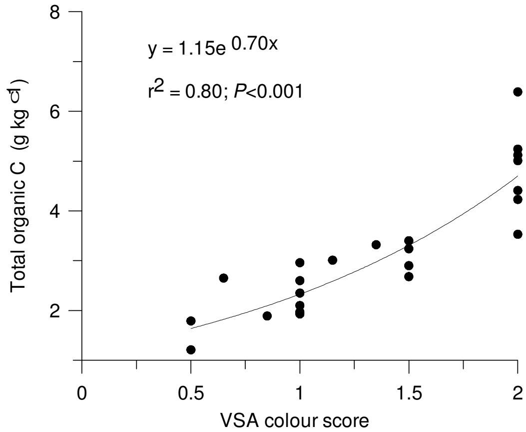

Fig. 5. Relationship between VSA colour score and total organic carbon

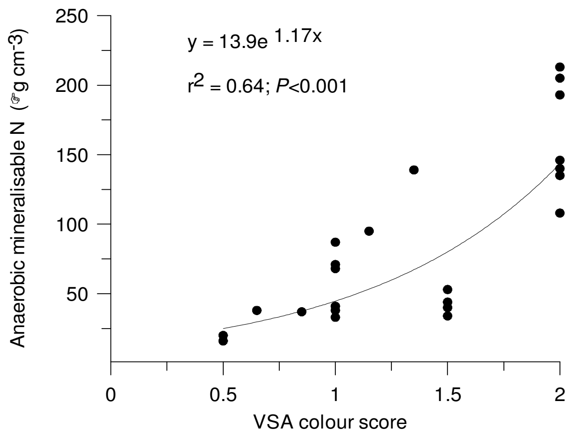

Fig. 6. Relationship between VSA colour score and anaerobic mineralisable N

Soil physical properties are emphasised in the VSA for several reasons: 1) they are easily seen; 2) they have a profound influence on soil biological and chemical characteristics; 3) they have a significant impact on the productivity and input costs of a farming enterprise; 4) it can take decades to recover from their loss; 5) they are costly to remedy; 6) they regulate those primary functions of the soil that provide plants with air, water, nutrients, and physical support.

Given that the VSA is based on fundamental pedological principles and processes, as described by Buol et al. (1980), it was not surprising that strong relationships were found between VSA scores and key quantitative measurements of soil characteristics. Visually assessed soil characteristics can, in a number of instances, provide a more reliable indication of soil conditions that predominate throughout the year than measured values. For example, regardless of whether water and air permeability and oxygen diffusion rates are low or high at the particular time of measurement, a soil that has strongly developed grey mottles or gley features with blue/grey matrix soil colours, demonstrates it is by and large a poorly aerated soil with very low redox potentials for a significant part of the year. In contrast, many soil measurements are dependent on the time of year the sample was taken for analysis, the nature of the season, the soil water content, the sampling depth, and the instrumentation and laboratory methodology used. In an attempt to address a number of the above factors, most soil quality sampling schemes advocate sampling to a consistent depth, and at specific times of the year (Schipper & Sparling 2000; Sparling & Schipper 2002). Hydraulic conductivity, air permeability, macroporosity and bulk density, for example, can show high temporal dependency under a given land use. Observed morphological characteristics are, however, more stable and can therefore provide an accurate, reliable representation of the predominant long-term soil characteristics.

The results also demonstrate the generic nature of the VSA appraisal, making it independent of soil type (Table 1; Figs 1–6). While soil type can significantly influence the VSA score, the interpretation of each visual indicator (except for soil colour) is not soil-type dependent. For example, the development of massive large clods with grey mottles or grey matrix colours in a topsoil that is normally dark brown, friable, and mottle-free with a well-developed structure, demonstrates the soil has become degraded and poorly aerated owing to water logging and oxygen depletion (Fig. 7). This interpretation holds regardless of soil type. This generic relationship does not hold for many soil characteristics not related directly to VSA scores.

Fig. 7. Transition of a dark, friable, porous, well-structured and well-aerated soil to a pale, extremely firm, poorly aerated, structureless soil under poor management.

In contrast to the VSA, the interpretation of many analytically based measurements is dependent on soil type. For example, a topsoil bulk density of 1.0 Mg m^{-3} is low for a gleyed silty clay loam with an illitic mineralogy formed within quartzo-feldspathic alluvium, but is high for an allophane-rich silt loam formed within volcanic ash. Bulk density is therefore soil type dependent and, as such, the soil type must be taken into account to interpret its value correctly. Visual indicators of soil properties that are independent of soil type, such as soil structure, porosity and mottles, have the advantage of simplicity and ease of use for assessing soil physical condition. These features make it possible for farmers and lay people generally to assess the condition of soils correctly, regardless of soil type, geographical location, topography, climate or parent material (Shepherd et al. 2001a).

Conversely, our understanding of many of the properties we measure is by no means complete and we need to be careful how we measure soil properties and how we interpret the analytical data. For example, debate continues among universities, research institutes, analytical laboratories and fertilizer companies as to how best to measure plant available P. The collective 'wisdom' of soil scientists in New Zealand also suggested that the maximum environmental and production response curve for Olsen P occurred when the Olsen P was between 20 and 100 µgP/cm^3 for most pastoral soils (Sparling et al. 2003).

Tests have shown, however, that paddocks on dry-stock farms (on Typic Orthic Brown Soils) with Olsen Ps of 12 and 28 can have similar dry matter production (unpublished data). Those paddocks with Olsen Ps of 28 $\mu gP/cm^3$ had 0.47% P in the herbage, while those with Olsen Ps of 12 $\mu gP/cm^3$ had similar P levels (0.43%) in the herbage. While the production response curve suggests the soil with an Olsen P of 12 is deficient in P, the plant is clearly accessing sufficient P from the soil. This would suggest the Olsen P test is not recognising the organically bound P and the P being supplied by such soil microorganisms as mycorrhizal fungi. Similarly, the environmental and production response curve for macroporosity suggested a maximum response occurred with a macroporosity between 10 and 30 m^3 100 m^{-3} for all soils. Moutoa soils in the Manawatu region typically have a macroporosity of 12–16 m^3 100 m^{-3}; however, maize growers consider these soils to be too loose and 'open' for good production, and deliberately compact them to increase the root/soil contact area. Conventional 'wisdom' would also suggest soils with higher microbial biomass C have a better soil quality than those with lower amounts. The microbial biomass C of well aerated, unpuggd Kairanga soils under pastoral grazing varies between 1197 and 1557 $\mu g\ g^{-1}$ (Sparling et al. 1992), whereas values of 2029 $\mu g\ g^{-1}$ have been measured in very poorly aerated, severely pugged dairy pastures. While quantitative measurements of soil are essential, we need to be careful how we interpret the data. In the course of time, the provisional environmental and production response curves can be refined as more data become available. In contrast, the soil shown in Fig. 7 is severely degraded due to the visual loss of structure, porosity, colour, and to the presence of grey mottles. There can be no debate about the interpretation of the visual properties displayed by the soils in this figure. Such is the value and effectiveness of the visual messages provided.

While visual assessment of soil characteristics cannot replace quantitative measurements, the close relationships between visual scores and laboratory-based measures of soil properties show that VSA provides a reliable and defensible semi-quantitative method to assess some key soil characteristics. As such, it can play a complementary role to measurement-based approaches in regional land-monitoring programmes, and in the compilation of 'State of the Environment' reports required by the OECD. In addition to being able to identify the degree and extent of recognised soil constraints, farmers can use the VSA to monitor the effect of existing and new farming practices on soil condition, help establish and evaluate the effectiveness of best management practices, and provide information for quality assurance programmes. A simple and quick tool such as the VSA can also be used by farmers to demonstrate sustainable land-management practices and acceptable environmental performance levels for farm audits to gain certification by industry and environmental agencies. Developing a better knowledge and awareness of how soils function and respond under land-use pressures as a result of using the VSA will further improve current land uses and management practices, and help achieve the most profitable and environmentally sound long-term management systems.

Conclusions

The close relationship between VSA scores and measured soil properties demonstrates we can see what we measure. This relationship indicates the VSA can provide a valid semi-quantitative assessment of soil quality, in terms of the criteria defined. Being quick and economical, the VSA allows large areas of the landscape to be covered rapidly, and identifies areas that should be characterised quantitatively. It can therefore be used in conjunction with, and complement, quantitative laboratory measurements to characterise and monitor soil properties and soil quality at a farm and regional scale.

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References

Batey, T. 1988: Soil husbandry. (Soil and Land Use Consultants Limited. Aberdeen). Aberdeen University Press. 157 p.

Boekel, P. 1963: Soil structure and plant growth. *Netherlands Journal of Agricultural Science* 11:120–127.

Buol, S.W.; Hole, S.D.; McCracken, R.J. 1980: Soil genesis and classification. Iowa State University Press, Ames, Iowa. 406 p.

Clothier, B.E.; White, I.. 1981: Measurement of sorbtivity and water diffusivity in the field. *Soil Science Society America Journal* 45:241–245.

Corey, A.T. 1986: Air permeability. p. 1121–1136. *In* . A. Klute (ed.) Methods of Soil Analysis, Part 1. 2nd edition. American Society of Agronomy, Madison, Wisconsin, USA.

Ditzler, C.A.; Tugel, A.J. 2002: Soil quality field tools: Experiences of USDA–NRCS Soil Quality Institute. *Agronomy Journal* 94:33–38.

Gradwell, M.W.; Birrell, K. 1979: Methods for physical analysis of soils. New Zealand Soil Bureau Scientific Report 10C.

Hewitt, A.E. 1998: New Zealand Soil Classification. 2nd edition *Landcare ResearchScience Series No. 1.* (Lincoln, NZ: Manaaki Whenua B Landcare Research New Zealand.)

King, C.; Gunton, J.; Freebairn, D.; Coutts, J.; Webb, I. 2000: The sustainability indicator industry: where to from here? A focus group study to explore the potential of farmer participation in the development of indicators. *Australian Journal of Experimental Agriculture* 40:631–642.

Lobry de Bruyn, L.A.; Abbey, J.A. 2003: Characterisation of farmers' soil sense and the implications for on-farm monitoring of soil health. *Australian Journal of Experimental Agriculture* 43:285–305

Peerlkamp, P.K. 1959: A visual method of soil structure evaluation. Proc. Intern. Symp. on Soil Structure. Meded. Landbouwhogeschool en Opzoekingsstations van de Staat te Gent. *Deel XXIV,* No. 1:216–221.

Resource Management Act 1991 and regulations: Hon. Justice Peter Salmon (ed.). Data Services Limited, PO Box 33, Takapuna, Auckland.

Romig, D.E.; Garlynd, M.J.; Harris, R.F. 1996: Farmer based assessment of soil quality: A soil health scorecard. p. 39–60. *In* J.W. Doran and A.J. Jones (ed.) Methods for assessing soil quality'. *Soil Science Society of America Special Publication* 49, *M*adison,Wisconsin, USA.

Sarrantonio, M.; Doran, J.W.; Liebig, M.A.; Halvorson, J.J. 1996: On-farm assessment of soil quality and health. p. 83–105. *In* J.W. Doran and A.J. Jones (ed.) Methods for assessing soil quality'. *Soil Science Society of America Special Publication* 49, Madison,Wisconsin, USA.

Schipper, L.A.; Sparling, G.P. 2000: Performance of soil condition indicators across taxonomic groups and land uses. *Soil Science Society of America Journal* 64:300–311.

Shepherd, T.G. 2000: Visual soil ssessment. Volume 1. Field guide for cropping and pastoral grazing on flat to rolling country. horizons.mw/Landcare Research, Palmerston North. 84 p.

Shepherd, T.G.; Bird, L.J.; Jessen, M.R.; Bloomer, D.J.; Cameron, D.J.; Park, S.C.; Stephens, P.R. 2001a: Visual soil assessment of soil quality – Trial by workshops. p. 119–126. *In* L.D. Currie and P. Loganathan. (ed.) Precision Tools for Improving Land Management. Occasional Report No. 14. Fertilizer and Lime Research Centre, Massey University, Palmerston North.

Shepherd, T.G.; Dando, J.L. 1997: Physical indicators of soil quality for environmental monitoring. Proceedings of Soil and Land Indicators: A Specialist Workshop Publication. Hawke's Bay Regional Council Technical Report EMT 96/3. Pp. 33–42.

Shepherd, T.G.; Janssen, H.J. 2000: Visual soil assessment. Volume 3. Field guide for hill country land uses. horizons.mw/Landcare Research, Palmerston North. 48 p.

Shepherd, T.G.; Janssen, H.J.; Bird, L.J. 2000a: Visual soil assessment. Volume 4. Soil management guidelines for hill country land uses. horizons.mw/Landcare Research, Palmerston North. 24 p.

Shepherd, T.G.; Ross, C.W.; Basher, L.R.; Saggar, S. 2000b: Visual soil assessment. Volume 2. Soil management guidelines for cropping and pastoral grazing on flat to rolling country. horizons.mw/Landcare Research, Palmerston North. 41 p.

Shepherd, T.G.; Park, S.C. 2003: Visual soil assessment: A Management Tool For Dairy Farmers. p 111–123. *In*: I.M. Brookes (*ed.)* Proceedings of the 1st Dairy[3] Conference. Continuing Massey University Dairyfarming Annual (Volume 55) Dexcel's Ruakura Dairy farmers' Conference, April 7–9, 2003, Rotorua.

Shepherd, T.G.; Saggar, S.; Newman, R.H.; Ross, C.W.; Dando, J.L. 2001b: Tillage induced changes to soil organic matter fractions and soil structure in New Zealand soils. *Australian Journal of Soil Research* 39:465–489.

Shepherd, T.G.; Parshotam, A.; Newman, R.H. 2004: Dynamics of organic carbon fractions and physical properties of a clayey soil continuously cropped and then returned to pasture. *European Journal of Soil Science*. Submitted.

Soil Survey Staff. 1998: Keys to Soil Taxonomy. 8th ed. United States Department of Agriculture. (Natural Resources Conservation Service. Washington D.C.), 326 p.

Sparling, G.P.; Lilburne, L.; Vojvodić–Vuković, M. 2003: Provisional targets for soil quality indicators in New Zealand. Palmerston North, NZ. :Landcare Research New Zealand, 2003.

Sparling, G.P.; Rijkse, W.; Wilde, R.H.; van der Weerden, T.; Beare, M.H.; Francis, G.S. 2001: Implementing soil quality indicators for land. Research Report for 2000–2001 and Final Report for MfE Project Number 5089. Landcare Research Contract Report LC0102/015.

Sparling, G.P.; Schipper, L.A. 2002: Soil quality at a national scale in New Zealand. *Journal of Environmental Quality* 31:1848–1857.

Sparling, G.P.; Shepherd, T.G.; Kettles, H.A. 1992: Changes in soil organic carbon, microbial C, and aggregate stability under maize and cereal cropping, and after restoration to pasture in soils from the Manawatu Region, New Zealand. *Soil and Tillage Research* 24:225–241.