



Manaaki Whenua  
Landcare Research

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Issue 2, March 1998

Printed on recycled paper



ISSN 1174-0922

# SOIL HORIZONS

## Gathering soil information

Landcare Research pedologists (or field-orientated soil scientists) specialise in collecting and interpreting soil data for soil maps and related databases.

General soil maps (scales 1 : 50 000 to 1 : 100 000) are available for many areas in New Zealand. Some detailed soil maps (scales 1 : 10 000 to 1 : 25 000) have also been published. The detailed maps cover areas of intensive land use. Soil maps accompany descriptions published in DSIR Bulletins, NZ Soil Bureau Soil Survey Reports and DSIR Land Resources Scientific Reports. These publications give information on soils and their spatial distribution, topography, geology, soil classification, soil texture, soil drainage, soil chemical, and sometimes physical characteristics of key soils and interpretative classifications for major land uses. The soil publications are available from

Manaaki Whenua Press,  
PO Box 40, Lincoln 8152.

In recent years, production forest owners have needed more detailed soil surveys of their existing forests. These surveys provided information on a wide variety of issues, including: better spatial expression of soil variability, rooting depth, and chemical characteristics; soil physical characterisation, wetness duration, risk of compaction and variation in soil trafficability from season to season; soil-site relationship as a basis for species planting programmes; and sites of importance to Māori. Equipped with such soil information, forestry owners have found they are better able to maintain site productivity and optimise wood volume production, as well as improve their environmental performance. They also found that soil knowledge is a very important consideration when evaluating land for purchase.

For further information contact  
Wim Rijkse, ph (07)838 4441,  
e-mail [rijksew@landcare.cri.nz](mailto:rijksew@landcare.cri.nz)



## Editorial

Welcome to Issue 2 of *Soil Horizons*. This issue is also available over the Internet from <http://www.landcare.cri.nz/newsletters/>

The feedback in response to Issue 1 of *Soil Horizons* was very encouraging and emphasised the importance of communicating our current soil-related research to our stakeholders and customers. Soil quality assessment was of interest to many readers, which is natural, as monitoring soil quality is comparatively new for New Zealand (and for the rest of the world).

Environmental reporting is required under a number of international environmental agreements to which New Zealand is a signatory. Under the Resource Management Act, regional councils are required to report on soil, air and water quality.

Monitoring soil quality differs greatly from monitoring air and water quality. The latter, in particular, has a long history, and national and international standards are reasonably well-defined. This

is not so for soil. There are no internationally accepted standards for sampling protocol, indices or methodologies, and no standard values to define whether a soil is of "good" or "bad" quality. Soils naturally differ from paddock to paddock, and from one end of the country to the other. Perceptions of soil quality also differ. A farmer may consider a good quality soil to be one with high levels of nutrient to maintain pasture production. But a hydrologist may consider a good quality soil to be one with very low nutrient levels to avoid nutrient enrichment of surface waters and contamination of ground water.

Our current research at Landcare Research tries to reconcile these different expectations of soil quality. We use a standard range of simple chemical, physical and biological indices to determine the impact of land use on different soil types. We then compare these indices with database information that defines the "normal baseline" index range for different soil types to see how soils have changed over the years. If a soil does fall below the

normal quality status for that soil type we also need to know if it can be restored, and how long this will take. Some of our research is aimed at providing answers to such issues. Maintaining soil quality makes sound ecological sense and ensures soils are used in a sustainable manner.

Dr Graham Sparling,  
ph (07) 838 4441, e-mail  
[sparlingg@landcare.cri.nz](mailto:sparlingg@landcare.cri.nz)

## Hieracium improves high country soils

Hieracium invasion can be positive, at least from an organic matter perspective. The invasion and continuing dominance of Hieracium in semi-arid tussock grasslands is considered a major threat to the ecological and economic sustainability of New Zealand high country pastoralism. A couple of years ago, Peter McIntosh and Ralph Allen (Landcare Research, Dunedin and Lincoln) established that soil total carbon and nitrogen increased and soils became more acid by up to 1 pH unit as Hieracium invaded depleted tussock grasslands. (see Figure 1).



It appeared Hieracium was removing nitrogen from the "halo" of surrounding bare ground, and accumulating it in the soil beneath the plant. Hieracium, as a perennial, was returning more carbon to the soil from dying leaves and roots than were the annual plants in surrounding tussock grasslands.

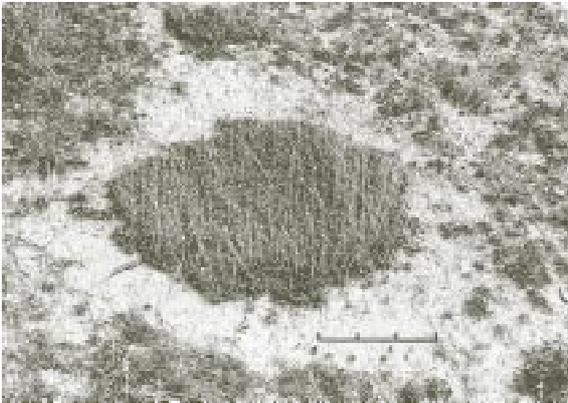


Fig 1: *Hieracium pilosella* L. invading tussock grassland, showing the characteristic patch form, halo with little or no vegetation, and surrounding depleted tussock grassland (mixed herbfield and annual grasses).

Surinder Saggar (Landcare Research, Palmerston North), a specialist in soil organic matter and nutrient cycling, has shown that soil processes under this plant are profoundly different from those in depleted soils of tussock grassland which may be only a metre away. Surinder determined the amount of microbial **biomass** (mostly bacteria and fungi, with some microfauna and algae) under and around Hieracium. He also found that

there was more microbial carbon, nitrogen and phosphorus in soils under Hieracium than in soils of the halo zone or soils under tussock grassland. Microbial **activity** was measured by trapping the carbon dioxide produced by soils under Hieracium, the halo zone, and tussock grassland over a six-month period. The results

(Figure 2) showed that there was a higher rate of microbial respiration under Hieracium, confirming the greater biomass under Hieracium and that the "soil bugs" were working harder (i.e. they had more food).

Measurements of mineral nitrogen (nitrogen in ionic form that is more readily available to plants) showed that there was about half as much in soils under Hieracium than in soils under tussock grassland. Soils of the halo zone had intermediate values. However, soils under Hieracium had more microbial N (in complex organic matter) and more total N. From this we now conclude that as Hieracium

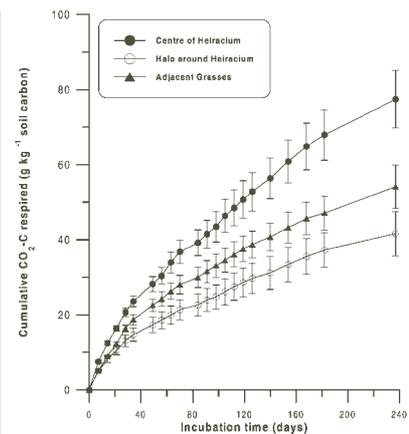


Fig 2: Influence of Hieracium infestation on carbon respiration.

invades tussock grasslands, it "mops up" mineral N, and transforms it into organic forms.

This work suggests that Hieracium is very efficient at transforming soil organic matter and forms of nitrogen, and this probably accounts for its outstanding success in invading nitrogen-deficient environments like the high country. A question remains: "What makes it so efficient?" It is possible that the high levels of acid polyphenolic compounds in Hieracium could provide the answer. We believe these compounds may reside in the sticky white sap in Hieracium roots, and may leak out of the roots providing the energy source for the microbial activity which transforms the organic matter. Breakdown of these compounds in the soil could also explain why soils under



Hieracium are more acid. Future research by Surinder will analyse the significance of polyphenolic compounds in determining vegetation dynamics and associated soil changes in the high country.

For further information contact Surinder Saggar, ph (06) 356 7154, e-mail saggars@landcare.cri.nz

## Do pine trees have an effect on the soil?

The conversion of hill country pasture to exotic forest plantations occurs at a rate of approximately 70 000 ha/yr in New Zealand. This has several benefits: wood production, erosion control, and the sequestration of carbon dioxide, which is a potent greenhouse gas. The carbon dioxide aspect links with other research being carried out by Landcare Research relating to greenhouse gas emissions. (See Soil Horizons Issue 1 April 1997).

Landcare Research scientists, Roger Parfitt and Harry Percival, together with Randy Dahlgren from the University of California at Davis, have been looking at the

differences in nutrients in soil water under pasture and under radiata pine growing in former pasture. The soil water was extracted with lysimeters, and also by spinning the soil at high speeds in a centrifuge which literally squeezes the water out.

Under pasture, respiration by roots and soil microbes produces much higher soil carbon dioxide concentrations than under pine trees. These concentrations lead to a predominance of bicarbonate ions in the pasture soil solution. Under pine trees, however, chloride ions predominate, probably as a result of the tree canopy 'capturing' wind-blown sea salts.

**When the pine trees are harvested, oversowing with legumes may be required to maintain the nitrogen (N) status for a second crop of trees.**

Under pine trees both the soil and soil solution are more acidic. A combination of processes may be the cause: increased production of organic acids; tree uptake of more positive ions than negative ions; and enhanced nitrogen mineralization,

and leaching of nitrate. Higher concentrations of magnesium, potassium and sodium occur under pine trees because the trees catch sea salts and the tree roots absorb these minerals from deep in the soil profile. The nutrients are returned to the soil surface in rain water and in shed foliage.

When pine trees are planted in pasture, the soil organic matter decomposes. This loss of soil organic matter is partly balanced by the buildup of litter on the forest floor. However, as nitrogen-fixing pasture legumes are absent and since the growing trees take up nitrogen, there is a significant soil nitrogen loss. As the pine canopy intercepts rain, leaching beneath the pine trees is reduced and much less water leaches through the pine soil profile. Rain usually adds 1-2 kg N/ha/yr which is a small amount compared with the 450 kg N/ha over 25 years taken up by pines.

For further information contact Roger Parfitt, ph (06) 356 7154, e-mail parfitt@landcare.cri.nz.



## Soil carbon levels near natural CO<sub>2</sub> springs

Hakanoa Springs in Northland is a mineral springs area with natural vents of carbon dioxide (CO<sub>2</sub>). Des Ross and Kevin Tate, with Paul Newton from AgResearch, have been using the site as an outdoor laboratory to study whether the elevated atmospheric CO<sub>2</sub> levels there influence the levels of carbon stored in the surrounding soil. Knowledge of carbon stored in soil is important for calculating New Zealand's national carbon balance, for understanding the cycling of greenhouse gases, and for developing strategies for future land management in a CO<sub>2</sub>-enriched world.

Because some environmental factors cannot be controlled and because of variations in sampling, it is difficult to draw firm conclusions. However, results so far strongly suggest that soil carbon content can increase under elevated CO<sub>2</sub>, especially when available nitrogen levels are adequate. To test the generality of the Hakanoa results, further work at other naturally occurring CO<sub>2</sub> springs is needed.

For further information contact Des Ross ph (06) 356 7154, e-mail rossdj@landcare.cri.nz

## Soils and the national carbon budget

In 1993, New Zealand agreed to stabilise its national CO<sub>2</sub> levels by signing the (International) Framework Convention on Climate Change. To achieve this, the government adopted a net reductions policy, based on 20% reduction from lowering fossil fuel source emissions, and 80% from increased plantings of new (exotic) forest. As soils are the largest reservoir of carbon (C) in the terrestrial biosphere, small changes caused by changes in land use can have major effects on national (and global) C balances. The consequences of this major afforestation effort (and other changes in land use and management) on soil C storage for all New Zealand are poorly understood. A Ministry for the Environment project is developing a national framework for monitoring changes in soil C associated with changes in land use and management. This work is closely linked with another project to monitor C in the indigenous forests and scrublands of New Zealand

(see Issue 1, Soil Horizons).

The initial step has been to establish 1990-baseline soil carbon estimates for all New Zealand to three soil depths (0-0.1 m, 0.1-0.3 m, and 0.3-1.0 m), by updating an existing database comprising point data for soil C linked to spatial surfaces of climate, land use and soil. The provisional soil C estimate for the 0-0.1 m depth is 1144 ± 68 million tonnes.

The next step is to develop the link between the soil C information and the major drivers of change in soil C storage namely, climate, land use and soil type. This link will provide a system of spatially explicit "land-use coefficients" to predict future changes in soil C with land-use change.

Climate surfaces (1 km<sup>2</sup> grid cells) of monthly temperature, rainfall and potential evapotranspiration have been generated using the BIOCLIM climate model. Soil moisture classes, created by combining precipitation and soil class information, have been combined with temperature to provide integrated temperature/moisture classes which



include boreal, humid boreal, very dry temperate, dry temperate, moist temperate, and humid temperate.

The major land uses being considered include indigenous forest, exotic forest, pasture, unimproved pasture, arable crop, wetland, and scrub. New Zealand soils have been reclassified to be compatible with the soil type categories outlined by the Intergovernmental Panel for Climate Change. These are: soils with high activity clay (2:1 clays), soils with low-activity clays (1:1 clays), sandy soils, Andisols (volcanic soils), Aquic (gley) soils, Histosols (organic soils), and Spodosols (podzols).

Overlaying of the climate, land use and soil data layers has revealed spatial gaps in the soil C inventory, principally from unimproved pasture on humid boreal high activity clay soils, and from mixed indigenous forest on humid temperate high activity clay soils. Once these gaps are filled, we will assess the effects of land use on soil C across different soils and climate regimes. The resulting initial set of

“land-use coefficients” can then be used for (a) improving the accuracy of the 1990 baseline, (b) predicting changes in soil C as a function of land use and climate, (c) resampling sites for which archived soil samples are available, and (d) resampling critical land-use types. A combination of regular updating of land cover databases and remote sensing techniques will provide a framework to assess current and future land-use change effects on soil C and CO<sub>2</sub> emissions.

This work is being undertaken for the Ministry for the Environment jointly by Landcare Research and the Forest Research Institute, and was described at the 5<sup>th</sup> International CO<sub>2</sub> Conference, Cairns, Australia, 8-12 September 1997.

For more information contact Kevin Tate, ph (06) 356 7154, e-mail tatek@landcare.cri.nz

## International Conference on the Biogeochemistry of Trace Elements

Harry Percival presented a poster paper (“Soil solution chemistry of contrasting New Zealand soils amended with heavy metals”, Harry Percival and Tom Speir) at the 4th International Conference on the Biogeochemistry of Trace Elements held at the Clark-Kerr campus, University of California at Berkeley, USA. This conference attracted about 400 registrants. The programme comprised six symposia and 14 general sessions, which ranged from ‘cadmium in soils’ to ‘risk relationships in ecosystems’. The next conference in this series will be held in Vienna, Austria, in 1999.

## International Clay Conference

Harry Percival and Benny Theng, soil scientists based in Palmerston North, were invited to chair sessions on Soil mineralogy and Clay-organic interactions respectively at the 11th



International Clay Conference held at Carleton University in Ottawa, Canada. Benny presented two oral papers: "Surface analysis of silica springs allophane by X-ray photoelectron spectroscopy", Benny Theng, M.Soma, Cyril Childs, K.Inoue, H.Seyama, & Guodong Yuan; and "Possible discrimination between D- and L-alanine dimers by allophane", H.Hashizume and Benny Theng. Harry and Benny gave a poster paper "Specific surface area measurements of topsoils differing in organic matter content and clay mineralogy", Harry Percival, Benny Theng, G.G.Ristori & C.Santi. Harry and Benny were the only New Zealand representatives, although the conference attracted about 550 registrants from 40 countries. The programme was wide-ranging with nine symposia and 11 general sessions offered. The symposia and sessions ranged from 'isotope geochemistry' to 'agriculture and the environment'. The next conference will be held in Bahia Bianca, Argentina, in 2001.

## The Effect of management on soil and vegetation in high country

In the high country, soil and vegetation changes often take place so slowly that the relationship between cause and effect is not immediately obvious. However, where neighbouring farms or paddocks have been managed very differently, changes in soil and vegetation condition may be marked and measurable across fencelines, allowing desirable and less-desirable trends in soil properties and vegetation to be identified. Results from two soil and vegetation fenceline studies have implications for land management. These studies were undertaken as part of three Landcare Research public good science research programmes, with additional support from Ravensdown Fertiliser Cooperative. The studies looked at the effects of differing management on soils of both the dry (<600 mm rainfall) and moister (c. 1000 mm rainfall) Mackenzie Basin hill country.

**Fenceline effects in dry hill country areas:** In 1994, we were able to assess the effect of fencing, oversowing and fertilising on soil and vegetation on the Benmore Range using sheep and rabbit-proof trial areas established in 1979.

Removing grazing animals for 15 years resulted in a doubling of both vegetation biomass and root mass. It appears that grazing puts stress on root systems, as plants cannot allocate resources to roots when they are constantly replacing above-ground herbage.

On grazed land soil pH levels fell, relative to 1979 values. However, over the fence, on ungrazed treatments that had not received fertiliser, not only did oversowing establish a 100% ground cover, but topsoil nutrients and pH in 1994 were the same as 1979 values. [Oversowing and removing grazing could therefore be an effective low-cost solution for rehabilitating soils at risk of degradation.] However, soil pH levels fell on ungrazed treatments when fertilisers were applied. The most positive effect of fertilising was the effect on soil organic



matter: fertilising without grazing increased soil carbon by 9 tonnes/ha relative to the grazed areas over the fence. Fertilising also greatly increased standing biomass, litter and root biomass.

**Fenceline effects in moist high country areas:**

In the moister land there were no established trial areas from which to judge the effect of enclosure on soil and vegetation condition. However, some farmers have been actively applying fertiliser for many years, while others have continued grazing but left some areas in a so-called "native" and unfertilised state. To assess the influence of different management techniques on soil and vegetation condition, we used ten pairs of sites, with each site pair spanning a farm boundary. Site pairs were matched for altitude, aspect, rock type and soil depth. At each site measurements were made of topsoil chemistry, organic matter, soil fauna and vegetation species and vegetation cover.

Fertilising and oversowing doubled the level of vegetative cover. However, on the fertilised farm it is difficult to maintain high-

quality pastures even though over 1 tonne/ha of fertiliser had been applied. The presence of Hieracium in the fertilised areas indicates potential vegetation if grazing continues at the present fertilizer input levels.

As in the dry areas, fertilising increased the amount of carbon and nitrogen in topsoils, by 7 tonnes/ha and 0.8 tonnes/ha respectively, compared with the farm in the "native" state. Total phosphorus increased by 47 kg/ha in the fertilised soils. Organic phosphorus was higher in the fertilised areas, suggesting that some applied phosphorus ends up in the more stable organic form. Other nutrients, exchangeable calcium, magnesium, potassium and sodium, were all higher in the fertilised areas.

Soil microbial biomass and soil microfauna were investigated at four paired sites. Measurements of microbial biomass activity showed that not only do fertilised soils contain more carbon and nitrogen, but that more of this carbon and nitrogen is contained in the microbial biomass. This means that the fertilised soils are more "alive", are in better

condition, and contain more microorganisms. Fertilised soils also contained more grass grubs, worms and nematodes than unfertilised soils. The significantly greater populations of worms and nematodes indicate increased cycling (turnover of nutrients) in the more productive and fertilised soils. The increased number of grass grubs in these soils was supported by the greater plant root biomass. In general, the greater biological activity in the fertilised soils can be regarded as a positive development.

In summary, accepting that biological activity of the soil is a measure of soil health, or good soil condition, these studies show that soil health is stimulated by both retiring from grazing (which increases vegetation biomass both below- and above-ground) and by fertilising (which increases plant cover, microbial activity, and numbers of soil animals). These biological measures of soil health increase at the same time as favourable changes in other soil properties, such as soil carbon and nitrogen.

Further information contact Peter McIntosh, ph (03) 477 4050, e-mail mcintoshp@landcare.cri.nz



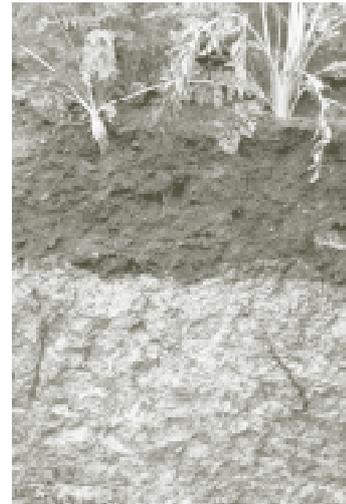
## New Zealand soils: structural vulnerability to management impacts

Some New Zealand soils appear capable of withstanding intensive cultivation. They can support continued high levels of production while retaining the essential features of sustainable soil physical health. These soils may show some deterioration of water infiltration, aggregation and aeration over extended periods or under particularly heavy cultivation, yet they have the ability either to resist impacts or to recover rapidly when fallowed. In other soils, however, soil physical health deteriorates rapidly under even moderately intensive management practices. These soils are particularly vulnerable to management impacts.

Landcare Research soil scientists Allan Hewitt (Dunedin) and Graham Shepherd (Palmerston North) have determined the essential differences between soils of low and high structural vulnerability. To do this they reviewed the

available information on the structural stability and physical degradation of New Zealand soils and identified the four soil attributes most likely to control structural vulnerability: phosphate retention, total organic carbon content, clay content and wetness (estimated from drainage class). These four attributes were standardised and transformed, and a simple structural vulnerability (SV) index for mineral soils was devised. The SV was determined for all mineral soils in the National Soils Database (see Issue 1, Soil Horizons). This provides a ranking of soil groups according to their structural vulnerability. Allan and Graham consider that the SV index may be used as a first approximation rating of the structural vulnerability of New Zealand mineral soils.

The SV index ranges from zero (0), for soils of lowest structural vulnerability, to 1, for soils of highest structural vulnerability. Applying the SV index to New Zealand soil groups represented in the National Soils Database showed that the well-drained Oxidic Soils of Northland have the lowest structural vulnerability with an average index of 0.23. The Perch-gley



**Waiareka soil** - very low structural vulnerability. This soil is intensively used for cropping. It shows some structural deterioration, but is capable of long term arable use and has the ability to recover. It has a high clay content and naturally high organic carbon content. The SV index is 0.34.



**Molyneux soil** - very high structural vulnerability. This soil is used for orchard crops and irrigated pastoral agriculture. Soil structure is vulnerable to management impacts. It has a very low clay content and low natural organic carbon content. Iron oxide content is also very low. The SV index is 0.79.



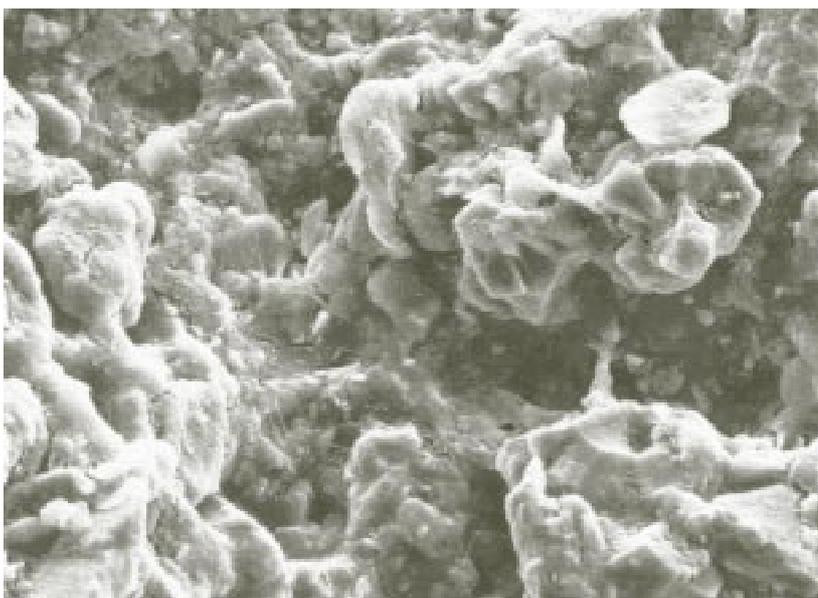
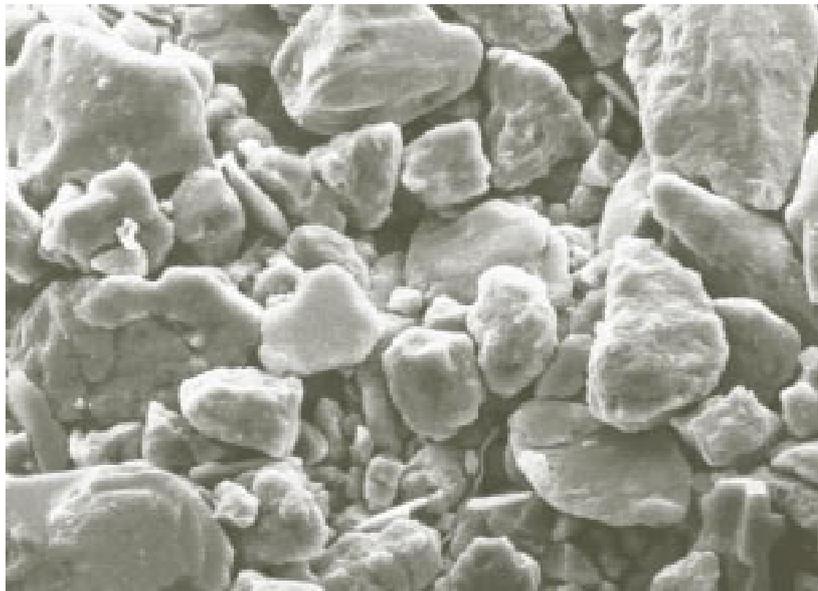
Podzols of Westland have the highest structural vulnerability with an average index of 8.4.

The use of the SV index by resource managers would allow them to identify vulnerable land and to develop performance standards for land-use activities. The SV index would allow refinement of land-evaluation assessments by using the index to specify appropriate land management intensity and land management practices, for example, crop rotation periods. It can also be used to design strategies for monitoring soil health, where soils identified as being highly vulnerable can be targeted for more intensive monitoring and appropriate management practices implemented.

For details on the SV index see: Hewitt, A.E. and Shepherd, T.G. 1997: Structural vulnerability of New Zealand soils. *Australian journal of soil research* 35(3): 451-74.

Further information contact Allan Hewitt, ph (03) 477 4050, e-mail [hewitta@landcare.cri.nz](mailto:hewitta@landcare.cri.nz)

## Organic matter and soil structure



Electron microscopic images (at 1000X magnification) of soil silt particles (2-60 microns in diameter) with different levels of organic matter binding. The upper micrograph shows little organic binding in a soil with weak structure that is easily compacted and eroded. By contrast, in the lower micrograph the soil particles are "glued" with organic matter, giving rise to high structural stability and the natural development of small aggregates. The distance across each micrograph is approximately 160 microns (the size of a single fine sand grain).

For further information contact Craig Ross, ph (06) 356 7154, e-mail [rossc@landcare.cri.nz](mailto:rossc@landcare.cri.nz)



## Getting to know soil microbes

One of the fundamental dilemmas of microbiology is that no more than 10 per cent of bacteria known to occur in natural habitats can be cultured in the laboratory. With almost all our knowledge about microbial physiology and genetics coming from pure culture studies, we do not know the significance of these organisms in their natural environment. Reliable estimates of microbial numbers, biomass, and activity are needed to understand (and quantify) the effect of land management and pollution on soil ecosystems.

Landcare Research has a new project that is applying molecular ecology to soil ecosystems. It is the first systematic study of this nature to be applied to a range of New Zealand soils. Molecular ecology of soil microbes can provide "indicators" of environmental contamination, and a means of monitoring environmental clean-ups. It can also provide a means of

describing the immense microbial diversity of soil ecosystems.

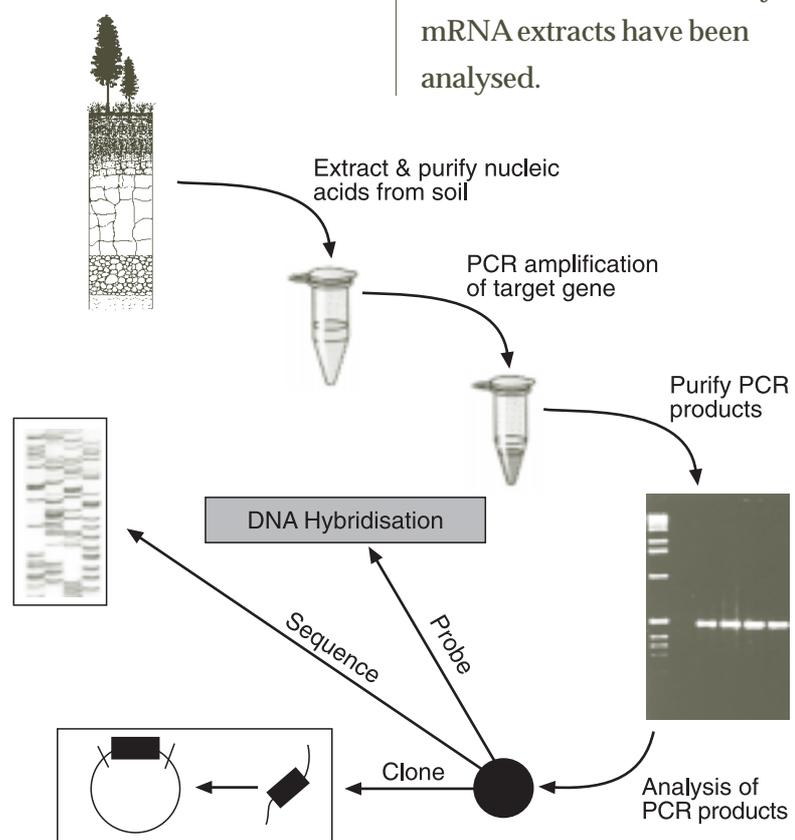
**DNA Deoxyribonucleic acid is the chemical blueprint of life**

**RNA Ribonucleic acid**

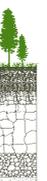
**mRNA conveys from DNA the information that is translated to produce polypeptides**

**rRNA is a component of the ribosome which is the site of polypeptide synthesis**

Molecular ecology is a relatively recent field of research which recognizes microbes and their function at the DNA or RNA level without the need for unrepresentative and unreliable classical laboratory cultures. Microbial communities, specific microorganisms or specific genes can be studied by analysing nucleic acids extracted directly from a natural environment. These nucleic acids are a mixture of molecules that should represent the biota present. Most research has focussed on DNA, but more recently mRNA extracts have been analysed.



Steps involved with molecular ecology study of soil ecosystems.



**PCR Polymerase Chain Reaction amplification is a procedure for making multiple copies of a specific segment of DNA**

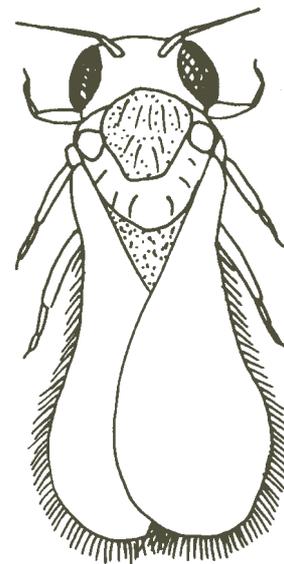
PCR amplification is a laboratory technique that allows the detection of specific gene sequences directly from DNA. The method will be applied to nucleic acids isolated directly from soil. Efficient extraction is often difficult to achieve, and many compounds that inhibit

subsequent analyses (such as humic acids) are extracted along with nucleic acids.

PCR has been used to amplify rRNA encoding genes and so obtain estimates of soil microbial diversity, an indication of soil ecosystem health.

Amplification strategies can also be used to evaluate the expression of single genes in soils. By targeting the genes involved in degradation or detoxification reactions, these strategies could be used to monitor the response of soil bacteria to pollutants.

For further information contact Gareth Lloyd-Jones, ph (07)838 4441, e-mail [lloyd-jonesg@landcare.cri.nz](mailto:lloyd-jonesg@landcare.cri.nz)



**Published by**

Landcare Research  
Private Bag 11052  
Palmerston North  
New Zealand

Also published electronically on the World Wide Web, at  
<http://www.landcare.cri.nz/newsletters/>

Telephone: (06) 356 7154  
Facsimile: (06) 355 9230

Editors: Peter Stephens, Linda Hill  
Anne Austin

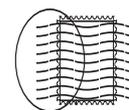
Layout: Elaine Hagenaars

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Unless otherwise stated, funds for the research described in this newsletter were provided by the Foundation for Research, Science and Technology.

***Manaaki Whenua: To cherish, conserve and sustain land — a place to stand, the source of life, food and wealth.***

For general inquiries and for inclusion in the mailing list, please contact:



Peter Stephens  
ph. (06) 356 7154  
e-mail [stephensp@landcare.cri.nz](mailto:stephensp@landcare.cri.nz)

