Soil Horizons

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A newsletter communicating our work in soil-related research to end-users, customers and colleagues.

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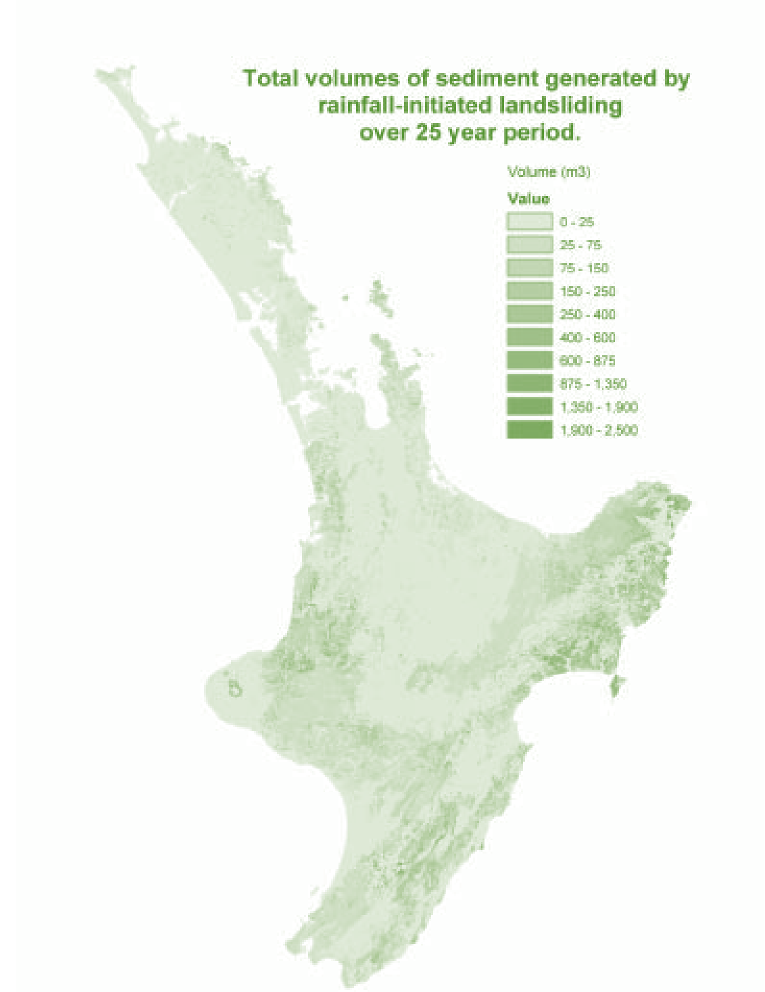
Manaaki Whenua
Landcare Research

How do landslides contribute to regional sediment and carbon fluxes?

Because it is a major sediment generating process in its own right, and because it has considerable influence on other geomorphic processes, landsliding contributes significantly to regional sediment fluxes in New Zealand. Further, the soil organic carbon mobilised by erosion and thus associated with regional sediment fluxes plays a small but potentially very significant part in the carbon cycle. Landcare Research scientists have estimated the contribution of erosion to the annual carbon flux by simple spatial extrapolation of estimated



The model being developed can be used to estimate volumes of sediment generated by landsliding at the national scale (N.B. scale is non-linear).

rates of individual processes, and the assumed rates of soil organic carbon mobilisation associated with them. This estimate was necessarily rather broad—3 to 11 Mt/a—and researchers in Landcare's current Erosion-Carbon Programme are developing a process-based modelling approach that aims to reduce its range by 50%.


Landsliding resulting from storm rainfall following forest harvest.

Landsliding is represented using a simple probabilistic model incorporating storm rainfall magnitude and slope angle. The relation between rainfall and landslide occurrence has been established using historical landsliding episodes and rainfall records, and the probability of slope failure associated with slope angle has been derived empirically from field studies throughout New Zealand. This approach permits estimation of long-term, spatially averaged generation of sediment from landsliding. Replication of the physical behaviour of the landsliding process at sub-regional scales will allow prediction of landslide occurrence and delivery of debris to channels on a spatially distributed basis and under a range of potential land use and/or climatic scenarios.

Current work will contribute to a national sediment and carbon budget being constructed so New Zealand can have a better understanding of its annual carbon flux, and thus be in a position to address Kyoto Protocol obligations. In addition, with use of the more detailed local-scale models, landslide researchers will be able to investigate the effects—both on-site and downstream—of various land-use and management scenarios. Used in conjunction with increasingly sophisticated monitoring and remote sensing capabilities, such an approach will greatly enhance our ability to represent landslides as a process of sediment generation and redistribution in both time and space. This will facilitate the development of tools for land-use management (e.g., riparian buffer zones, harvest techniques), erosion mitigation, event forecasting, and hazard/risk preparedness and management, and contribute to policy formulation (e.g., development of rating schemes).

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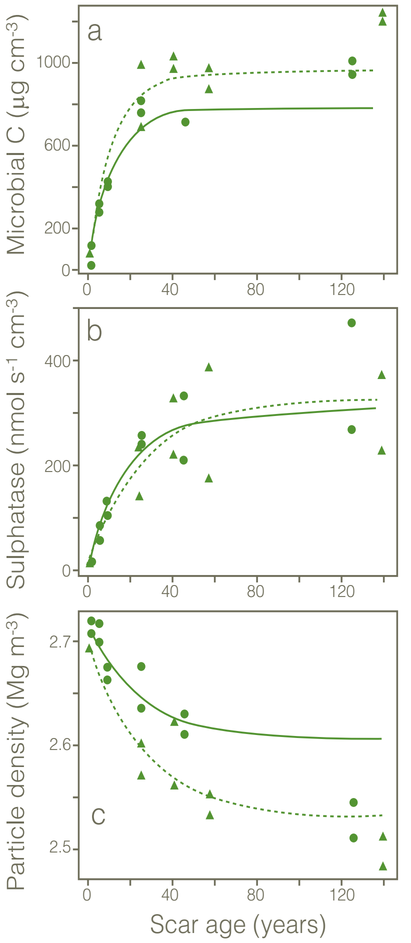
How well do soils bounce?

The ability to bounce back after adversity is a valued characteristic for soils as well as humans. Some short-term degradation might be tolerated if a soil is able to recover within an acceptable time. Our agricultural ancestors made use of this principle with "shifting agriculture", where a patch of land was cleared, used intensively and then left to recover before being used again. We no longer have the luxury of leaving land idle for even a few years, so information on recovery rates is useful for sustainable management.

Hill land in the Wairarapa was cleared for pastoral use around 1850. The cleared land on erodible siltstone is prone to slipping and slumping. When a slip occurs, all the topsoil in the scar area is lost down to about 50 cm depth. Do these scar areas recover? Will they bounce back? How long will that take?

A series of landslip scars from 1 to 60 years age was identified from archive aerial survey photographs. We sampled the scars to see how much topsoil had reformed, and compared them with unslipped areas. Characteristics measured were soil microbial biomass, soil respiration and soil enzymes, total C and N, mineralisable N, pH, exchangeable cations, Olsen P and total P, bulk density, aggregate stability, porosity and available water.

Topsoil started to reform in the scar area very quickly, with a steady improvement lasting many years. Examples for microbial C, suphatase activity and particle density are shown in Figures a, b, c. The two curves on each graph are from samples collected in 1986, and again in 2001. Most other soil characteristics followed those general patterns, but different properties recovered at different rates. Generally, the recovery phase lasted 18–50 years, but only reached about 80% of the levels on the unslipped sites. The shape of the curves suggests that there will be little further recovery. The incomplete recovery of topsoils on the slips is linked to the lower pasture production (also 80%) on slipped sites compared with non-slipped sites.



The changes over time in microbial C, sulphatase activity and particle density in a slip scar, (●———● 1986; ▲— — —▲ 2001)

We can't always expect soils to recover from degradation, not within our lifetimes. It's too late now to do much about the slipped areas; they will have changed characteristics and reduced productivity for many years to come. At least in the Wairarapa, there is still sufficient "bounce" remaining in the soil to grow some grass and trees. We need to protect what we have left. Erosion control and protection of susceptible slopes by planting with suitable trees needs to be ongoing.

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STOP PRESS! – World experts to unravel climate, erosion and sedimentation

World climate and geomorphology experts recently visited New Zealand to study the Gisborne area's unusual geology and erosion.

Scientists funded by the United States National Science Foundation have chosen the Waipaoa River (Gisborne) as one of the two top sites in the world in which to study past climate change and the impact such change has had on erosion and sedimentation in rivers, lakes and oceans. The other site is in Papua New Guinea.

The visit was coordinated by Noel Trustrum (Landcare Research) and Lionel Carter (NIWA). Both scientists lead research programmes that have been unravelling pieces of the Waipaoa climate change and sedimentation puzzle. Nick Preston's article in this issue of *Soil Horizons* describes some of the activities being undertaken by Landcare Research.

Analysis of past storm events preserved in lake and ocean deposits allows improved prediction of storms in a world dominated by marked changes in climate. More than 90 per cent of Waipaoa river sediment is trapped on the riverbed and in a basin off the Gisborne coast, a much more complete geological record than in most on-shore rocks and sediments. Noel said "The layers of sediments act as a tape recorder of the Earth's history … that tell scientists of the relative effects of floods, cyclones, earthquakes, and volcanic eruptions over thousands of years".

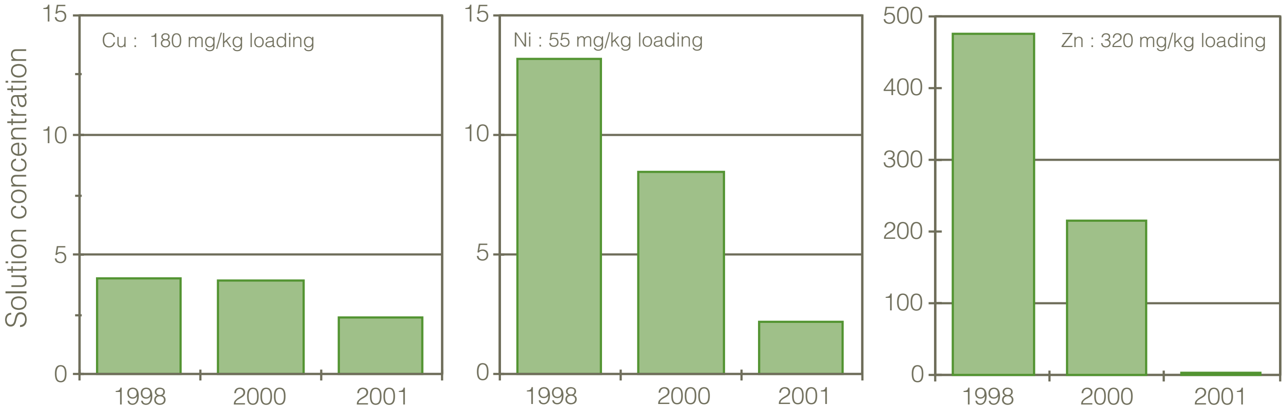
– *Peter Stephens*

Liming reduces bioavailability of heavy metals in sewage sludge-amended soils

In an earlier edition of *Soil Horizons* (Issue 5, February 2001) we reported initial results from a programme on sludge application to land being researched jointly by Environmental Science Research, Landcare Research and Lincoln University to establish meaningful guidelines for heavy metal contents in New Zealand soils. A field trial on a pasture soil near Lincoln was established in1997 with application of sludge completed in early 1998. A number of soil plots were treated with both sewage sludge supplied by the Christchurch City Council and the same sludge spiked with copper (Cu), nickel (Ni) and zinc (Zn) to raise total soil metal concentrations, both above and below the current New Zealand guideline values of 140 mg/kg for Cu, 35 mg/kg for Ni, and 300 mg/kg for Zn.

Harry Percival (Landcare Research), Tom Speir (ESR) and colleagues, have since been studying the bioavailabilities of Cu, Ni and Zn and their influence on sensitive biological and biochemical soil properties. The most bioavailable fraction of heavy metal is held in soil solution between the soil particles and is potentially toxic to plants and soil organisms. Examination of the chemistry of soil solutions extracted by centrifugation from the sludge-amended soils was therefore an important part of the overall study of sludge effects on the soil.

Initially, the mean soil pH at the trial site before sludge amendement was 5.6, but without management of the soil pH some plots, after sludge amendment, were declining towards pH 5 by



Soil solution Cu, Ni, Zn concentrations (μM) after amendment, at the highest metal loadings (averages) in 1998 and 2000, and after liming, in 2001. Note change in scale for Zn.

the time of the year-2000 sampling. To reverse the decline, which was affecting pasture growth, lime was applied later in 2000, raising soil pH to around 7. This change produced some quite dramatic effects on the soil solution chemistry in the 2001 sampling.

Both before and after liming, soil solution concentrations of individual “target” metals (Cu, Ni, Zn) were always higher with higher levels of metal-spiking in the applied sludge. However, before liming (1998–2000), Cu concentrations changed little with time, and those of Ni and Zn tended to decrease slowly, whereas, after liming in 2001, there were substantial decreases in all metal concentrations, particularly with Zn (see the dramatic change in the Figure above). This change is mainly due to increased adsorption of the metals (particularly Zn) on to the soil particles at the higher soil pH.

The substantial change in pH also strongly influenced the proportions of the various heavy metal species in soil solution. Before liming, the free metal ions, Cu^{2+}, Ni^{2+}, and Zn^{2+}, were the dominant species (>70%) for each metal in the soil solutions. After liming there were substantial decreases in free-metal-ion percentages: Ni^{2+} and Zn^{2+} were still dominant (>60%) but Cu^{2+} was <1% because of metal complexation with the substantially increased level of dissolved organic matter produced in soil solution at the higher soil pH.

The free metal ions are the most toxic soluble forms of the metals. Before liming, the highest Cu and Ni free-metal-ion concentrations reached in soil solution were possibly high enough to cause some toxicity problems to soil biological systems. However, sensitive biochemical properties of the sludge-amended soils showed no adverse effects in the short term that could be attributed to Cu or Ni. After liming, their concentrations were too low to be a problem. The highest Zn concentration before liming was very much higher than for Cu and Ni, and likely to affect sensitive biochemical properties. Indications of heavy metal stress were found in this case. However, after liming, the highest Zn concentration was well below that likely to cause toxicity and had no effect on biochemical properties.

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Maps of potential leaching of microbes following effluent irrigation to soil

Land treatment of animal or human waste can result in microbial contamination of shallow groundwater or waterways. In some New Zealand regions the increase in dairying is associated with an increasing microbial load in streams and groundwater. In Issue 4 of *Soil Horizons* we reported on our experiments into the fate of a microbial tracer applied to effluent-irrigated soil cores. We are now begining to understand the soil conditions that lead to the rapid leaching of microbes through the upper soil layers.

We have subsequently made a generalised map of all flat to rolling land in New Zealand, ranking the potential for leaching of microbes through soil. The rules for ranking the rate of microbial transport are based on the fact that microbes, although very small, tend to move predominantly through larger soil cracks and pores where transport velocity is faster, because we think they are often attached to larger particles or colloids in the effluent. Consequently, soils with relatively large cracks between the individual soil structural units are rated as having a high potential for the rapid transport of microbes. Microbial transport appears to be slowed down in soils developed in volcanic tephra because of its lack of large soil cracks and its good filtering and binding characteristics. In waterlogged soils we think there is less chance for microbes to attach to soil as they remain in suspension within water-filled cracks and pores, hence are not retained within the soil. Following these rules, we classified the potential for rapid microbial transport through the soils into three classes—high, medium, low—based on their soil structure, waterlogging and the amount of volcanic tephra in the soil.

In the North Island, rapid microbial transport is associated with the old, clayey soils of Northland, young, water-repellent, coastal sand dunes, low-lying ground in the Hauraki Plains, and seasonally dry soils of the Manawatu and east coast. Volcanic soils of the central and Taranaki regions generally allow minimal microbial transport. In the South Island, rapid microbial transport is generally associated with poorly drained soils on the west coast and in Southland, while the alluvial soils of the Canterbury Plains generally have medium rates of microbial transport.

While the present New Zealand-wide map is generalised, for a specific application the same rules can, in many instances, be applied locally to more detailed areas. Matching irrigation strategies to the potential of soils to leach microbes rapidly will decrease pollution of shallow ground and surface water.

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Check Soil Horizons on the web

http://www.landcareresearch.co.nz/information_services/publications/newsletters/soilhorizons

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Raingardens for the urban landscape

Selected stormwater pollutants removed by two "raingarden" lysimeters. Influent bars represent pollutant load applied as stormwater (total volume 1200 L); effluent bars represent loads in effluent draining from the base of the lysimeters.

Soil-plant systems are increasingly used for the disposal and treatment of waste water (*Soil Horizons*, Issue 4). These systems buffer water flows, store and recycle nutrients, degrade organic compounds, and filter out many pollutants. The same soil-plant processes are now being called on for the disposal and treatment of stormwater in urban areas. With the exception of some sediment removal via gully pots, stormwater has historically been discharged without treatment to local waterways and estuaries. However, flash flooding during moderate rains, and the polluted nature of urban stormwater, has seen a growing interest in the use of soil-plant systems for stormwater disposal and treatment.

As land-based treatment systems in urban areas are hampered by limited available land, often coupled with soil in poor physical condition (*Soil Horizons*, Issue 6), engineered soil-plant systems are being developed to overcome these limitations. A recent concept to emerge is the "raingarden". These are terrestrial gardens engineered to infiltrate stormwater to reduce volumes, remove pollutants, and, in some cases, enhance groundwater recharge. Raingardens are constructed to a specified depth and filled with layers of gravel, sand, soil material and bark mulch. Their size is determined by the volume of stormwater they must receive and infiltrate. The soil material has specified characteristics for optimum infiltration and pollutant sorption capacity, and suitable native vegetation for both functional and aesthetic value.

Julie Zanders, Robyn Simcock and colleagues are developing the raingarden

concept for New Zealand conditions, and are investigating the ability of soils to remove pollutants from stormwater and attenuate the flows. Lysimeters (1 m diameter by 1.3 m high) have been repacked with two contrasting soils (Allophanic and Ultic) and planted with *Muehlenbeckia complexa*, a shrubby, low-growing native species. Simulated stormwater (200 L) is applied to these lysimeters once a week, and the leachate monitored for metals, nutrients and suspended solids.

Results to date confirm the value of soils for removing metals and phosphorus (Figure). However, nitrogen loads in the effluent currently exceed those in the applied stormwater due to the nitrogen released from the raingarden soils. Suspended solids are also elevated in the Ultic soil. The clay material found in this soil is easily washed out by the infiltrating stormwater, leading to coloured, turbid effluent. In contrast, clay in the Allophanic soil is stable in water and does not readily disperse. This soil has consistently produced clear effluent with a low suspended sediment load. The soils have also shown differences in their ability to attenuate the stormwater flows: the Ultic lysimeter produces effluent in 20 minutes; the Allophanic soil takes 60 minutes. This difference is attributed to soil types and their different characteristics. These results show clearly that soil type will have an important influence on the success of raingardens as stormwater treatment systems.

The study is ongoing. Results for re-engineering soil for raingardens will be collated in draft guidelines to be made available to regional and city councils and land developers.

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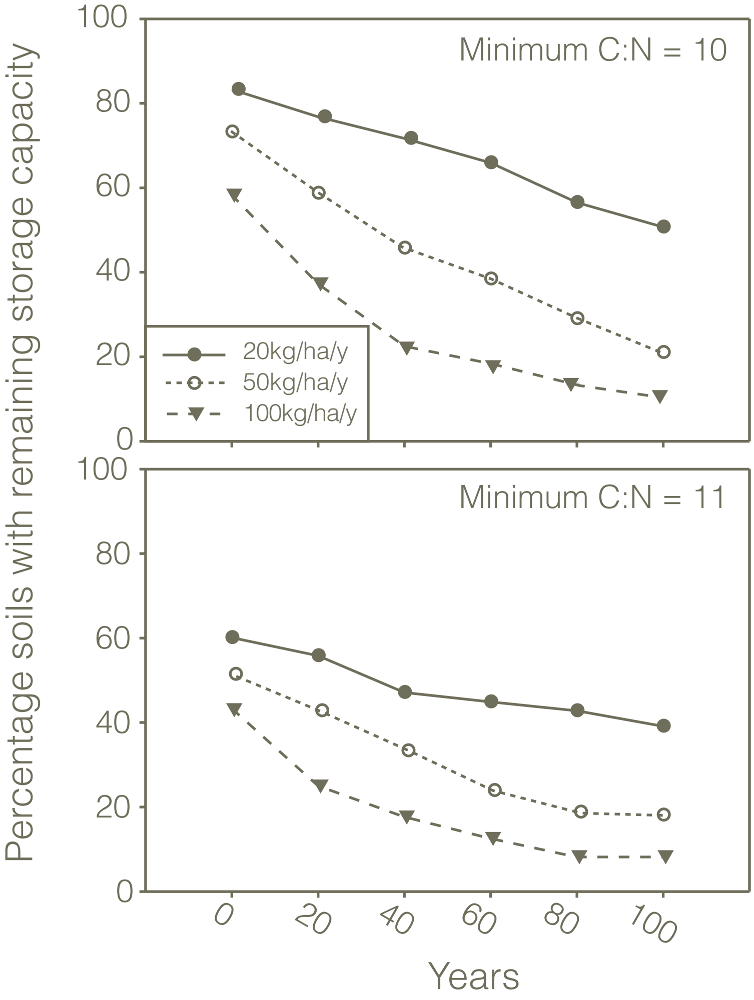
Nitrogen saturation an emerging issue?

In an earlier edition of *Soil Horizons* (Issue 6) we reported that New Zealand soils appear to be reaching saturation with nitrogen. As a soil's capacity to store nitrogen approaches saturation it is likely nitrate leaching will increase. Our initial study looked at the potential for nitrogen saturation for 53 soil profiles from the Waikato region. Here we describe results from across New Zealand.

We used data from the National Soils Database (NSD) to identify 138 soil profiles under pasture that had data for total carbon, nitrogen and bulk density. Carbon in pasture soils is generally considered to be in a steady state (i.e. not increasing or decreasing), and the carbon to nitrogen ratio (C:N – weight:weight) in soils rarely falls below 10. Hence, we calculated the total amount of carbon (kg ha^{-1}) in the top metre of soil, and then divided this by 10 to get the *maximum nitrogen storage potential* (kg ha^{-1}) of each soil. Finally, the amount of nitrogen in the soil profile was subtracted from the maximum potential nitrogen storage to determine the remaining nitrogen storage capacity of the soil.



Declines in the percentage of New Zealand soils with nitrogen storage capacity remaining for three storage rates (20, 50 and 100 kgN/ha/yr) and two minimum C:N ratios.

How quickly this capacity is used up depends on how much nitrogen soils store each year. We assumed an annual nitrogen storage rate of 20, 50 and 100 kg N ha^{-1}, then calculated the number of years before storage capacity would be reached or exceeded at C:N ratios of 10 and 11 (see Figure).

While it is clear that the capacity of our soils to store nitrogen is declining, the rate at which this occurs is highly dependent on the starting assumptions. One scenario might assume a minimum C:N ratio of 10 and a storage rate of 20 kg/ha/y. Under this scenario, 49% of the pasture soils in our data set in the next 100 years will have no further capacity to store nitrogen. Under the scenario of 50 kgN/ha stored each year, 79% of the soils became saturated within 100 years.

It is likely the rate of nitrogen storage and minimum C:N ratio will depend on soil type and land use, particularly nitrogen inputs either through fertilisers, dung and urine, or nitrogen fixation. We have some evidence of the importance of land use. The '500 Soils' project (see *Soil Horizons* Issue 7) found that dairy farms have an average C:N ratio of 11.3, while drystock (sheep, beef and deer) farms have a higher C:N ratios of 12.1, and indigenous vegetation averaged 16.7.

Our future work will focus on defining the minimum C:N ratios and storage rates for different soils and land uses, and finding out what happens when soils reach their minimum C:N ratio. Presumably, the main consequence will be increased nitrate leaching. To minimise nitrate pollution of ground and surface waters, N loadings may need to be decreased through restrictions on the amounts of N applied in effluent and fertiliser.

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Nitrogen supply in organically farmed soils

Organic farms rely particularly heavily on soil biological activity to provide nutrients for plants. Nitrogen (N) is the major nutrient stored in soil, and is released from soil organic matter by the action of enzymes produced by soil bacteria and fungi. Given the limited options for adding N (mainly by use of legumes), organic growers seek to maintain or enhance soil organic matter to provide an N supply to plants. If we measure the amount of soil organic matter (approximately 58% carbon (C)) we can then make simple estimates of the amount of N supplied by the soil under New Zealand conditions. For example, the Ashhurst soil at Massey University has a soil C content of 5.9%, and the N released each year is 290 kg/ha for the top 10 cm of soil. A further 80 kg/ha is released in the 10–20 cm layer. The 370 kg/ha released closely matches the amount of N taken up by the pasture herbage in a year.

	N released mg/kg	Soil C:N	Soil C %	Nematodes number/g	Microbial Biomass C mg/kg
Farmlet 1	204	11.1	5.5	50	1670
Farmlet 2	211	11.4	5.2	36	1670
Farmlet 3	104	13.1	4.9	39	1400
Farmlet 4	109	13.3	4.9	25	1990
Farmlet 5	24	14.5	5.1	23	1860

Table 1 *N released (mg/kg) in a laboratory incubation of Ballantrae topsoils with different organic matter quality (C:N), quantity (%C), number of nematodes and microbial biomass carbon.*

Soil C	C:N=11	C:N=12	C:N=13	C:N=14
3.0%	70	45		
4.0%	90	50	**35**	10
5.0%	**120**	**90**	**60**	**15**
6.0%	**160**	120	80	20

Table 2 *N released in the field (kg/ha) for 2 months in spring for soils at Ballantrae with different organic matter quantity (C%) and quality (C:N)*

The N release, however, depends on the quality of soil organic matter as well as the quantity. The soil C:N ratio can give an indication of the quality. A high ratio (14:1) shows low N quality and a low ratio (11:1) shows high N quality (Table 1). The N release for 5 farmlet soils at Ballantrae (near Woodville) is strongly controlled by the C:N ratio. Preliminary results suggest nematodes may also be involved, but not amount of microbial biomass carbon or enchytraeids. Earthworm numbers will be measured at the end of the trial.

N taken up by herbage gives a measure of N released by soil. Table 2 shows our results for spring 2002 (in bold) for the different farmlets, and the other numbers have been interpolated. This Table can be used as a guide for N released by hill country pastures, and may be useful for predicting N release by micro-organisms on organic farms. You will see N release differs enormously depending on the C:N ratio and the amount of organic matter, ranging from 160 kg/ha in the best case down to only 10 kg/ha in the worst.

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Minimising nitrate leaching under Canterbury wheat crops

The concentration of nitrate in groundwater is affected by many factors—climate, land-use, soil type and farm management. In any region and at any time, each factor will vary considerably, and each interacts to produce an overall effect on nitrate leaching. For example, the effect of applying 100 kg/ha of nitrogen fertiliser depends on soil water content at time of application, the timing and amount of rainfall that follows, and the age of the crop and its subsequent growth. Consequently, land managers and local authorities face considerable uncertainty about the effectiveness of particular management practices in reducing nitrate leaching. In many cases, changing the land use is the only viable option to improve groundwater quality significantly.

Landcare Research scientists have been using the GLEAMS simulation model to determine the relative effects of climate, soil type and farm management on nitrate leaching under wheat in Canterbury. All combinations of 19 years of climatic data, four soil types, six sowing dates and five application rates of N fertiliser were assessed. Climate, soil type, and sowing date were found to be equally important, whereas fertiliser application rate had a lesser impact on nitrate leaching (see Figure).

Two significant results were:

- importance of maintaining autumn and winter crop cover to utilize soil N before the winter leaching period
- realization that nitrate leaching becomes increasingly sensitive to farm management practices with decreasing soil depth.

Project findings are that risk of nitrate leaching is very low on deep soils when the crop is sown in autumn or winter. Contrastingly, shallow soils (<45 cm to gravel) left fallow over winter have a high leaching risk. It is recommended that winter crop cover with judicious use of fertiliser will minimize nitrate leaching on cropped shallow soils.

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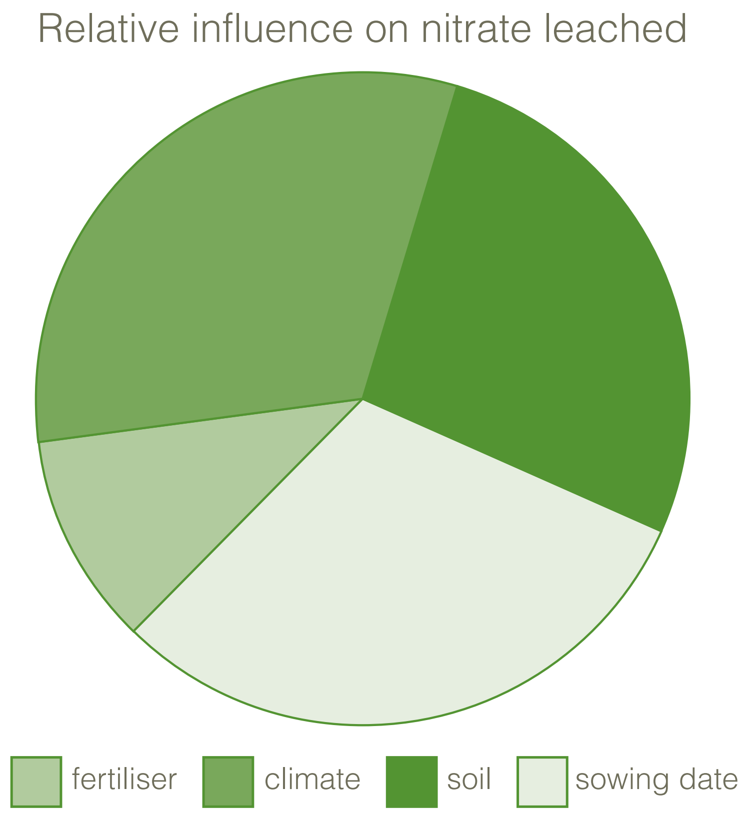

Pie chart showing percentage influence of climate, soil variablility, fertiliser rate and sowing date on annual leached nitrate

Just published: Land Environments of New Zealand Nga Taiao o Aotearoa (“the LENZ book”)

A joint effort by Landcare Research and the Ministry for the Environment, *Land Environments of New Zealand* presents a classification of NZ’s landscapes using a comprehensive set of climate, landform and soil variables chosen for their roles in driving geographic variation in biological patterns.

Building on the results of 20 years research, Landcare Research scientists have used powerful spatial analysis tools in conjunction with extensive databases describing our climate and soils to develop a profoundly different approach to the classification of our landscapes. The results clearly portray the rich diversity of our natural environments, providing new insight into the major factors that make New Zealand different.

The LENZ classification units (the *environments*) identify areas of land having similar environmental conditions, no matter where they occur, thus providing a framework that allows prediction of a range of biological and environmental attributes. *Land Environments of New Zealand* represents a major step towards the goal of sustainable management of our environment.

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