

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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EDITORIAL—Controlling the nitrogen cascade

During the last century, anthropogenic nitrogen inputs into the environment increased massively – from 15 million tonnes to 165 million tonnes per year. These inputs will continue to increase as developing countries increase production through application of cheap manufactured fertiliser. While millions of people are alive today because of food grown by artificial fertilisers, nitrogen also causes many adverse impacts on the environment, and these need to be addressed.

There are vast amounts of unreactive nitrogen gas in the atmosphere but there are also multiple reactive forms (e.g., gaseous nitrous oxides, nitrate, nitrite, ammonium, and organic nitrogen). These reactive forms move rapidly

through different ecosystems before finally being transformed back to the atmosphere. A single molecule of this reactive nitrogen in the atmosphere can contribute to global warming and ozone depletion before deposition onto land. There, the same molecule can change terrestrial biodiversity through acidification and eutrophication of soils (this has occurred in large areas of forest and wetlands in Europe and North America). Moving on, this same molecule can pollute drinking water and degrade surface water. Large “dead zones” in the world’s oceans are now regularly documented due to nitrogen excess (e.g., in the Gulf of Mexico the dead zone has grown to 20 000 km²) (see Figure 1).

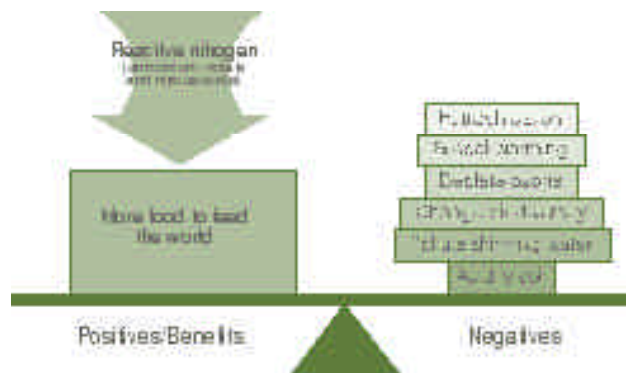


Figure 1: Multiple effects of the nitrogen cascade - positive and negative.

New Zealand could be adversely impacted in a number of ways. N-fertiliser use in New Zealand has risen 10-fold in the last 20 years. Nitrogen pollution is degrading our ecosystems (Taupo and Rotorua lakes) – which has the potential to impact on the tourism industry. Further, as pollution becomes more evident, other countries will impose restrictions on nitrogen use and expect us to do the same.

It is critical for us to develop mitigation strategies and new ways of producing food with less N fertiliser or indeed less nitrogen fixation from clover. Alternatively, crops and management practices with greater nitrogen capture could reduce nitrogen impact on the environment. Central to this effort is a need to develop large-scale budgets of nitrogen pools and flows. Once we have a better idea of where the problems are spatially and of the holes in our knowledge, we can develop sensible mitigation strategies. We know surprisingly little about the fate of nitrogen at regional scales.

Budgets need to be developed at regional scales with catchments acting as elements. How much of the

nitrogen being added to the land can we find in the river? As the global increase in nitrogen inputs has been relatively recent, are there buffers in the system that mask the increased load into the environment? Examples would include the length of time groundwater takes to reach surface water (about 50 years at Lake Taupo), and nitrogen accumulation into soil organic matter. Both have a finite capacity for buffering impacts and at some point will be overwhelmed.

Despite decades of research there are large uncertainties about these processes at paddock scale. While spatially explicit nitrogen budgets are being constructed and refined we need to develop improved ways of managing nitrogen for food and fibre production. Development of these new practices and budgets will need to be supported by basic studies into the cycling of nitrogen.

A useful reference summarising international thinking is:

Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW, Cowling EB, Cosby BJ. 2003: The Nitrogen Cascade. *BioScience* 53(4): 341–356.

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Animal wastes as a source of endocrine disrupting chemicals (EDCs) – a New Zealand perspective

Some natural and synthetic chemicals can interfere with the normal working of hormones that control reproduction and development (the endocrine system) in many aquatic and terrestrial animals, including humans. Such chemicals are called endocrine disruptors or endocrine disrupting chemicals (EDCs). Livestock wastes are potential sources of EDCs in the environment and include the hormones estradiol, estrone, and estriol. These hormones are of particular concern because even minute concentrations in water (nanogram per litre) can adversely affect the reproductive biology of fish and other aquatic vertebrates. Animal wastes also contain estrogen and the male hormone, testosterone, which may be even more potent EDCs than the estradiol group. They all have the potential to migrate into soil, ground- and surface-water when wastes containing them are applied to land.



New Zealand has a large and expanding dairy industry and established beef, sheep, pig and poultry production, coupled with numerous lakes, rivers and streams.

Agriculture is a major source of water pollution, largely because of the widespread occurrence of pastoral farming, which comprises more than half the land cover, and affects nearly all catchments. For many years, wastes from dairy farms in New Zealand were treated in oxidation ponds before being discharged into nearby waterways. More recently, there has been a shift to the direct application of effluent and wastes to land. Within the Waikato region of New Zealand alone, effluent is now applied to pasture by 70% of farm dairies, 70% of piggeries, some municipal sewage treatment plants (e.g., Taupo), and through wash water and litter from poultry farms.

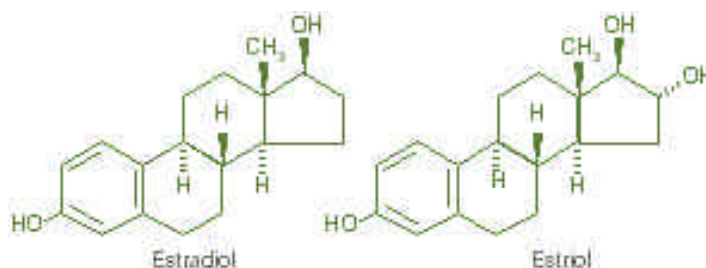


Figure 2: Molecular structures of estradiol and its daughter product, estriol.

Recent overseas reports on the sources of EDC in the environment, coupled with the widespread occurrence of animal-based industries in New Zealand, suggested EDC could also be present in New Zealand animal wastes. We undertook a survey to measure the occurrence of some natural estrogens in waste samples collected from 5 dairy farms, 1 piggery and 1 goat farm in the Waikato region.

Our survey showed that significant quantities of estrogens are excreted into the environment in the urine and faeces of all species, sexes, and class of farm animals, with concentrations from dairy cattle being

generally higher than from pigs and goats. Different estrogens were associated with different livestock species. Estriol, a daughter product of 17 β -estradiol, was not found in any of the samples.

In the United States, 45, 0.8, and 2.7 Mg estrogens enter the environment every year from cattle, pigs, and chickens, respectively. Our survey showed EDCs are present in the excreted wastes from New Zealand dairy cattle, pigs and goats, and that given the extensive nature of pastoral farming, it is very likely EDCs loadings to the environment and receiving waters are increasing. We will check whether that is the case by a survey of EDCs in rivers and streams in the Waikato Region. We also plan to carry out laboratory studies to check which factors hasten the breakdown of EDCs in soil-water systems.

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Table 1: GC-MS analysis of EDCs in effluent samples (ng/L) collected from farms within the Waikato region.

Compound	Dairy					Piggery	Goat
	1	2	3	4	5		
17 α -estradiol	40.0	592	458	1028	18.8	10.9	172
17 β -estradiol	28.8	289	147	331	ND	8.0	47.1
Estriol	ND	ND	ND	ND	ND	ND	ND
Estrone	66.9	3123	696	3057	40.9	27.3	157
Total	136.7	4004	1301	4416	59.7	46.2	376.1

ND: not detected



Underground diversity

A huge number and range of organisms live in soil, but because they are microscopic in size their presence goes largely unnoticed. But it is the invisible soil microbes that are responsible for forming organic matter and humus, decomposing contaminants to harmless products, treating our wastes, and releasing plant nutrients. A soil without living organisms is dead – like moon dust.

Not only are soil microbes very numerous in soil (a teaspoon of pasture soil has a greater number of bacteria than there are people in the world, and about 10 km of fungal hyphae) but they probably have more diversity than all other plants and animals. There are potentially one and a half million species of fungi (not all have yet been discovered), one million species of nematode worms, and a million species of bacteria. Only the beetles come anywhere near this diversity, with about one million species: larger plants and animals comprise just over half a million species.

It's been estimated that only 4–6% of soil microbes have been discovered and described. This is because

they are so small and need specialised methods to detect them: many also refuse to grow in the laboratory. However, we know they are

there in soil because we can see them using powerful microscopes, and we can detect their metabolic activity such as respiration. The modern technique of DNA analysis has shown that a

vast number and range of organisms are present in soil, although most can't be cultured. Some 95% of the DNA extracted could not be matched to the DNA of any known microorganisms, and



Figure 3: A mycorrhizal fungus (the dark-stained threads) attached to a grass root. Mycorrhizal fungi can assist the plant roots to take up phosphorus from soil at very low concentrations.

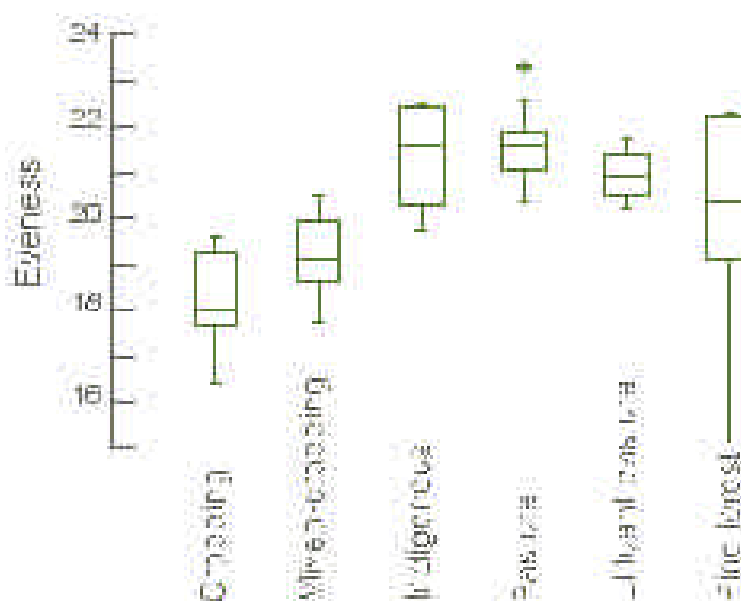


Figure 4: Microbial diversity (measured as functional evenness, max = 25) of cropping, pasture and forest soils. The box encloses 50% of the samples; the horizontal line shows the median value. "Whiskers" show the spread of 95% of the data, and the asterisk shows outlier points. Cropping soils have lower evenness than pastures and indigenous sites.



the researchers estimated there were over 5000 (largely unknown) different microbial species in one gram of soil.

An active and diverse microbial population is necessary for a healthy and functioning soil ecosystem. We have found that soils from natural ecosystems have high microbial diversity (measured as evenness), whereas cropping soils were of much lower diversity (Figure 4). Pastures and plantation forests were intermediate, with a more variable evenness. Natural ecosystems are typically very efficient in conserving nutrients and preventing pollution. For example, mycorrhizal fungi can assist plant roots to absorb nutrients from soil, and other specialist organisms help to break down pesticides. If we can understand the factors that control the diversity of soil organisms then we may be able to manipulate biological diversity. This could aid nutrient retention in the soil and decrease contamination, thereby protecting and improving water quality.

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What about the heavy metals in sewage effluent?

A major focus of new guidelines for sewage sludge (biosolids) application to land (Guidelines for the Safe Application of Biosolids to Land in New Zealand, NZWERF 2003) is prevention of soil contamination by heavy metals. Could the liquid sewage effluent also be a source of heavy metals?

Between 20 and 30% of most of the metals of concern in sewage (arsenic, cadmium, chromium, copper, lead, mercury and zinc) may pass unscathed through the treatment process and emerge in the effluent from the wastewater treatment plant (WWTP); for nickel, up to 60% remains in the effluent. It is not normal practice for WWTP operators to monitor heavy metals in effluent, primarily because the concentrations are very low compared with those in sludge. For at least some of the metals, concentration would be below detection limits of most methods of analysis. However, from our understanding of heavy metal behaviour in soil, we know that low concentrations do not necessarily equate to low risk. Metals are strongly bound to soil mineral and

organic components and, in a well-managed irrigation scheme where bypass flow is minimised, we would expect them to be stripped out of the effluent at or near the soil surface. Where effluents are applied in large volumes, heavy metals could accumulate in topsoil.

Tom Speir (ESR), working in Landcare Research programme Soil Processes and Groundwater Protection, carried out a small pilot survey of the soils at three sewage effluent irrigation schemes, Levin, Waitarere Beach and Taupo. Tom was interested in determining whether heavy metals had accumulated appreciably in the irrigated topsoils. Some characteristics of the effluent applied to the irrigation area are given in Table 2 (over).

Heavy metal concentrations in the effluents were measured on three occasions at the Levin WWTP, and cadmium and mercury were always below detection limit. Concentrations of chromium, lead and nickel ranged from below detection to 0.006, 0.008 and 0.004 mg m⁻³, respectively, those of copper from 0.017 to 0.023, and zinc from 0.003 to 0.130 mg m⁻³.



Table 2: Some effluent characteristics (mean and range, mg m⁻³).

Location and commencement year	Levin ¹ 1985	Waitarere ² 1986	Taupo ³ 1996
Soil Type	Waitarere Sand	Waitarere Sand	Atiamuri Loamy Sand
BOD	22 (8–69)	48 (17–126)	30 (21–65)
Ammonium-N	29 (10–44)	41 (23–59)	34 (27–44)
Nitrate-N	2.2 (0.4–4.8)	6.3 (1.4–11.1)	0.7 (0.01–2.1)
Phosphate-P	Not measured	15.8 (15.3–16.2)	9.2 (7.8–12.3)

¹BOD, 188 analyses since Oct 1999; other properties, 19 analyses since Nov 2001.

²BOD, 46 analyses since Nov 199; other properties, two analyses only.

³All properties, weekly analyses through 2002.

Soil samples, 0–10 cm depth, were taken from irrigated and non-irrigated (control) locations at each of the land application areas, and analysed for heavy metals by x-ray fluorescence spectrometry (XRF). At Waitarere, irrigation ceased in 2001 on the original irrigation site, and the trees (*P. radiata*) were harvested. Irrigation was started on a new site at that time. Results are shown in Table 3.

The results suggest a possible slight build-up of copper and zinc at the Levin

and Waitarere sites as a result of effluent irrigation, but no change at the Taupo site. It is interesting that zinc appears to be elevated to almost the same extent after 2 years' irrigation at Waitarere as occurred after 15 years at the old site. The high, aberrant, lead concentration at the old irrigation area at Waitarere is unexplained. However, it could not be a result of effluent irrigation because effluent lead concentrations were too low to allow such a high soil level to be reached in only 15 years. It is likely to

result from soil contamination during tree harvesting and site preparation for replanting.

The results of this preliminary investigation suggest that, even if metal concentrations do increase under effluent irrigation, the build-up is gradual. Further work is needed to verify these trends and to assess whether there are likely to be any long-term environmental consequences.

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STOP PRESS

We have a new Chief Editor for *Soil Horizons*. With Peter Stephens' departure, Graham Sparling has taken on this role. Peter left Landcare Research in November 2003 to take up a position with the New Zealand Climate Change Office. In his new role, he is responsible for developing a national integrated carbon accounting system.

Graham Sparling is one of our leading soils research scientists, and has recently developed criteria to assess soil quality that have been adopted nationally. Graham has a genuine interest in communicating science to the wider community, and sees *Soil Horizons* as an ideal medium for that. Welcome, Graham.

Table 3: Heavy metal concentrations (mg kg⁻¹ soil) in topsoils (0–10 cm) from effluent-irrigated and non-irrigated areas.

	Arsenic	Chromium	Copper	Nickel	Lead	Zinc
Levin irrigated	4	37	17	9	21	56
Levin control	3	37	11	10	14	42
Waitarere irrigated, 1986–2001	2	40	24	11	115	69
Waitarere irrigated, 2001–2003	3	41	18	10	15	67
Waitarere control	4	41	10	10	11	44
Taupo irrigated	5	19	20	8	15	78
Taupo control	5	17	25	8	18	84



Where and when is land fallow?

Many regional and district councils are interested in the potential risk of groundwater contamination by the leaching of nitrate from agricultural sources. To predict contamination risk at a regional scale, knowledge of key management practices is needed.

One approach is to use agricultural statistics and questionnaires to collect the information, but this is time-consuming, so does not lend itself to regular updates. An alternative approach is to use remote sensing to map those relevant management practices that can be visually detected. One key cropping management practice is the sowing date of a crop and the duration over which the land is fallow in the critical winter period with higher risk of nitrate leaching. So a team of Landcare Research scientists led by Heather North is using satellite imagery to identify land that is bare for significant periods in the winter.

A sequence of Landsat and SPOT images has been acquired over the last 2 years along with coincident fieldwork. A ratio of the red and infrared bands (Normalised Difference Vegetation Index (NDVI)) is

used as a proxy for percent live vegetation cover. Expert knowledge of agricultural practices and risk factors was used to derive two rules:

- **Rule 1:** A field is fallow throughout the winter if percent vegetation cover is <50% in late autumn (May/June) and it is still in the same low or sparsely vegetated state in July/August.
- **Rule 2:** A field is fallow for a shorter but still risky period if it is fully vegetated in late autumn (percent vegetation cover >50%) but only has low vegetation in July/August (percent vegetation cover <15%). Satisfaction of this rule usually indicates a cultivation or herbicide application event.

These rules were applied to the images at a pixel level (25 m). Figure 5 shows the results of both rules combined into one map. All areas bounded by a heavy line were recognised as being in a near fallow state over most of the critical winter period. This equates to approximately 20% of agricultural land on the Canterbury Plains between the Ashburton and Waimakariri rivers.

Analysis comparing image timing with seasonal rainfall

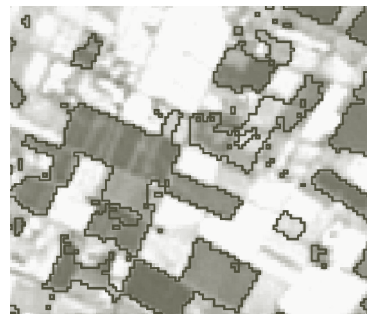


Figure 5: Polygons showing land that is fallow for either a long or shorter period in the winter of 2002, overlaying the August image.

and soil moisture conditions showed there was a possibility of missing significant leaching events in the autumn or early spring, so this year it is planned to modify the rules to use a third image to provide a better estimate of land that is fallow over the critical leaching period. The disadvantages of using satellite data include cost and the potential for image acquisition to be delayed due to cloudy weather. However, mapping is automated, allowing for trends over time to be easily estimated in comparison with more manual techniques such as questionnaires.

The maps of winter fallow ground in Canterbury can now be used for the assessment of nitrate leaching risk.

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How much have our farming practices changed soils?

The 500 Soils Project, supported by the MfE Sustainable Management Fund and participating Regional Councils, collected data on soil quality on nearly 600 sites from all around New Zealand between 1995 and 2002. We used these data to find out how much farming practices have changed the soil quality characteristics of the soils. Soil quality characteristics (0–10 cm depth) were: organic matter status (total carbon, total nitrogen and mineralisable N), acidity (soil pH), level of fertility (Olsen phosphate), and soil compaction (bulk density and macroporosity).

We calculated the average values under different land uses and compared them

against the soil condition under indigenous forest. This is an over-simplification of the actual differences because some land uses tend to be concentrated on particular soil orders, such as forestry on Pumice Soils, and dairying on volcanic ash Allophanic soils, which differ in their basic characteristics irrespective of land use. However, we knew from earlier work that land use was more important than soil order in explaining differences in soil pH, Olsen phosphate, total nitrogen, mineralisable nitrogen, and macroporosity. For this study we took the simple strategy of combining all the soil orders under a single land use, and

applied the approach to all 7 soil quality characteristics including total C and bulk density.

Soils under indigenous forest were used as the “baseline” to show the extent of change. We emphasise the characteristics of indigenous forest soils are not desirable soil quality “targets” for other land uses and in many cases would be highly unsuitable for productive agriculture. This is the reason our farmers and foresters have worked long and hard to raise the fertility levels by adding phosphates, raising the pH by adding lime, and increasing the nitrogen status by introducing legumes.

Table 4: Soil quality characteristics (mean and standard deviation) of key soil quality characteristics, averaged across all soil orders, and arranged by increasing intensity of land use. Figures in parenthesis show the number of sites in the land-use category.

Land use	Soil quality characteristic						
	pH 2:1 in water	Total Cmg/cm ³	Total Nmg/cm ³	Min-N µg/cm ³	Olsen P µg/cm ³	Bulk density Mg/m ³	Macro- pores (%)
Indigenous forest (62)	5.4±0.6	57±20	3.5±1.2	102±42	12±14	0.77±0.23	19±10
Plantation forests (69)	5.4±0.4	46±18	3.0±1.5	63±34	10±12	0.78±0.81	27±13
Sheep–beef pasture (154)	5.8±0.5	52±18	4.4±1.7	131±62	21±19	0.91±0.23	15±12
Dairy pasture (139)	5.7±0.4	67±20	5.9±1.4	159±49	46±32	0.83±0.24	11±9
Horticulture (48)	6.3±0.4	53±21	4.2±1.2	107±40	57±42	1.00±0.23	14±10
Mixed cropping (25)	6.1±0.5	41±11	3.4±0.7	68±31	54±44	1.16±0.21	20±22
Arable cropping (54)	6.2±0.6	44±24	3.5±1.5	54±31	53±47	1.04±0.22	19±16



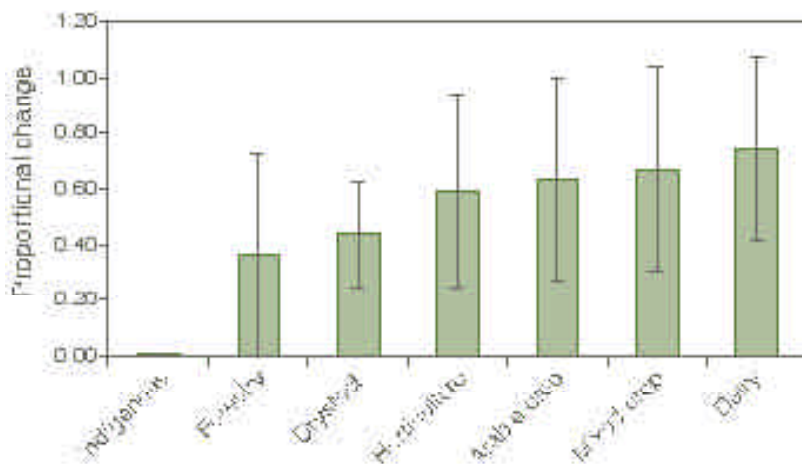


Figure 6: Proportional change in soil characteristics averaged across 7 key soil quality properties, combined across all soil orders and expressed relative to soils under indigenous forests. Histograms show the means and bars show the standard deviation.

Table 4 shows how soil characteristics differed with increasing intensity of use, moving along the series: indigenous forest, plantation forest, sheep-beef (drystock) pasture, dairy pasture, horticulture, mixed cropping, arable cropping. Soils under pastures, horticulture and cropping had more phosphorus and a more neutral pH. While pastures also had higher organic matter and nitrogen status compared with other land uses, they also had lower macroporosity than other land uses, indicating compaction had occurred. We assessed the overall effect of different land uses on soils by taking the absolute differences for

each soil characteristic under each land use compared with the indigenous sites, calculating the proportional change relative to the indigenous sites, and then averaging across all 7 characteristics. This approach showed dairy pasture was the land use that differed most from indigenous forests (Figure 6). Overall, the order was: indigenous forest < plantation forest < drystock pasture < horticulture < arable cropping < mixed cropping < dairy pastures. The characteristics of dairy pastures, with their high fertility levels (N and P), and lower macroporosity indicating compaction, raise concerns about potential

effects from leaching and nutrient run-off causing eutrophication of lakes and streams. Collaborative work with AgResearch suggests around 20% of dairy farms have Olsen P levels well in excess of the optimum for pasture growth. Cropping soils have traditionally been the target of concern for soil degradation and risk to the environment. These findings suggest intensive pasture use may be of equal or greater concern for the environment, especially as dairy pastures are much more common than cropping soils.

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Sensing soils

Large-scale maps showing within-field soil variability provide invaluable information to the farmer, but are very costly to produce. Such maps can now be generated in a few hours using a ground-based sensor. This article shows how well the map reflects mapped soil units, soil texture and soil fertility.

A 12-ha property was surveyed using an electromagnetic Geonics EM38 sensor attached to an all-terrain vehicle with GPS system, which maps soil zones of different apparent bulk electrical conductivity (EC_a). (For more information see *Soil Horizons Issue 7*.) Following that initial survey, a larger study area was mapped and at the same time

soil coring was carried out to 1 m at selected sites.

Study area soils are 6 textural phases of the Kairanga silt loam, a gleyed fluvial recent soil. The soil texture varies from clayey to coarse loamy. The Geonics sensor was able to detect this, and EC_a decreased as the soil became coarser (Figure 7). It is useful to be able to map the finer textured soils as they have a slowly draining clayey layer at depth and require careful management to avoid drainage problems, which can reduce crop yields.

About 72% of the variation in clay content was detected by the sensor. The sensor was also sensitive to cation exchange capacity (CEC) and Olsen P, and there were

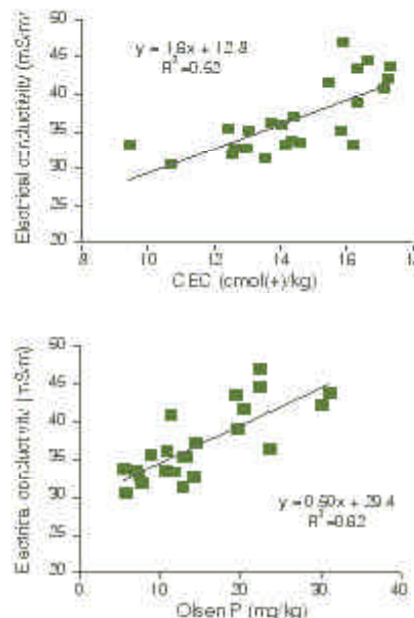


Figure 8

linear relationships between EC_a and both these characteristics (Figure 8).

The clay content, CEC, and Olsen P contents are all useful soil attributes to be able to map, as they reflect the likely drainage characteristics, the ability of a soil to retain nutrients, and provide a measure of plant-available phosphate.

The speed and accuracy of the EM method provides a rapid means of mapping soils at paddock scale. These soil maps can then be used to identify variability across paddocks, which improves farm management.

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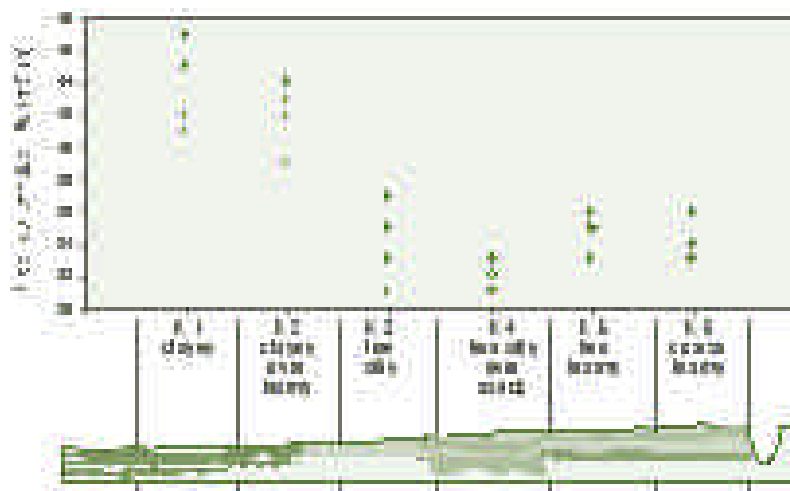


Figure 7: Idealised cross section of soils on the fluvial floodplain and EC_a of sampled sites .





LENZ – A new view of New Zealand

Land has multiple uses – economic, ecological and cultural. To help manage land most effectively we need flexible tools that allow us to depict information about land in many ways.

Land Environments of New Zealand – or LENZ – is one such tool. It groups together different areas of New Zealand with similar environments based on a set of 15 climate, landform, and soils attributes. Similar to New Zealand's Ecological Regions & Districts, LENZ identifies areas with similar ecosystem character (Figure 9). Unlike Regions & Districts, however,



Figure 9: Map showing areas with similar ecosystem characteristics.

LENZ is quantitative, scalable, repeatable, and can group together areas that are separated geographically.

LENZ is based on the consistent patterns observed between the environment and New Zealand's flora. For example, most New Zealand tree species reach their maximum abundance at particular combinations of environmental conditions. LENZ uses a set of 15 climate, landform, and soils variables that show the strongest correlations with native tree distributions and have strong links with tree physiological growth processes.

LENZ Underlying Variables

Climate influences plant growth, survival, primary productivity, and water balance, including drought and air dryness (Figure 10). Local climate conditions were estimated using mathematical techniques called thin-plate splines. Splines generate values for all points on a map by finding the best fit with

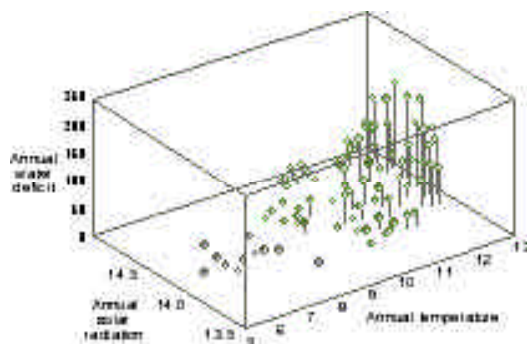


Figure 10

values at known points. For LENZ, known values came from long-term (1930s–1980s) New Zealand Meteorological Service weather station data.

Slope (landform) affects plant distribution by influencing factors such as soil formation and rejuvenation, water drainage, and cold air drainage. Slope values were derived from a 25-m digital elevation model (DEM) generated from 1:50 000 topographic data sources.

Soils influence plant distributions in a number of ways. They contain and can store varying amounts of nutrients needed for plant growth, they affect water availability through drainage and retention, and they can have unusual conditions that limit the types of plants that can grow. LENZ uses soil information derived from the New Zealand Land Resource



Inventory (LRI). Soils were grouped by parent material – the original surface rock or other material from which the soils formed – to estimate their fertility and weatherability.

LENZ Classification

LENZ classifies New Zealand into environments with varying degrees of similarity (Figure 11). First, all areas in New Zealand were placed into groups based on their environmental distance, which measures how “close” or similar two areas are in environmental space. For LENZ, environmental distance was measured in a 15-dimensional environmental space defined

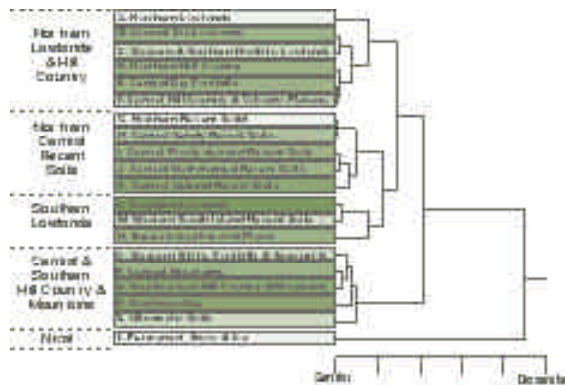


Figure 11

by the 15 underlying climate, landform, and soils variables.

Second, the similarity among groups was measured to create a hierarchical classification of New Zealand at 20, 100, 200, and 500 environments (Levels I–IV). Lastly, a map was created for each level that shows areas having the most similar environmental conditions.

Uses of LENZ

The same environmental variables that influence the distribution of native flora and fauna also influence human uses of the landscape. Therefore LENZ has applications for a broad range of issues including biodiversity conservation, ecological restoration, biosecurity, public health, and sustainable land management. LENZ Classification and Underlying Data Layers are available for purchase and use on projects. Visit the LENZ website (<http://lenz.landcareresearch.co.nz/>) for more information.

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