Soil Horizons

Issue 7 March 2002

ISSN 1174-0922

Contents

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

Printed on recycled paper.

Manaaki Whenua
Landcare Research

Soil quality assessed at 500 sites nationwide

Over a 3-year period, the '500 Soils Project' collected data on soil quality from over 500 sites throughout New Zealand. The project was funded by the Ministry for the Environment's (MfE's) Sustainable Management Fund and participating regional councils, and was completed in July 2001. The final reports and data are available (free!) on the MfE website http://www.smf.govt.nz/search.php.

Ten Regional and District Councils took part in the project – Northland, Auckland, Waikato, Bay of Plenty, Hawke's Bay, Taranaki and Wellington in the North Island, and Marlborough, Tasman, and Canterbury in the South Island. The project resulted in a substantial database with 511 site and soil descriptions, and laboratory analyses on surface soil (0–10 cm depth). Analyses included organic matter characteristics (total C, total N), chemical characteristics (soil pH, Olsen P, exchangeable Ca, K, Mg), and a measure of biological activity (mineralisable N). Soil physical condition was measured by bulk density, total porosity and macroporosity, total and readily available water, and aggregate stability. Data were analysed and interpreted by Crop & Food Research in the South Island and by Landcare Research in the North Island.

Sites, selected by council land resource staff, generally reflected the predominant

Photo courtesy of Graham Shepherd, 2001

Land use	Allophanic	Annthropic	Brown	Gley	Granular	Melanic	Organic	Pallic	Podzol	Pumice	Raw	Recent	Ultic	Total
Arable cropping	8	1	2	11	2	2	1	8	0	1	0	7	1	44
Mixed cropping	0	0	0	1	0	4	0	10	0	0	0	2	0	17
Horticulture	6	0	6	5	1	0	2	4	0	2	0	11	2	39
Dairy	52	1	9	10	6	0	7	2	1	14	0	13	6	121
Drystock	28	2	22	7	9	3	0	11	2	19	0	27	6	136
Tussock	0	0	12	0	0	0	0	0	0	0	0	8	0	20
Forestry	13	0	19	0	1	1	0	1	2	15	2	9	4	67
Scrub	0	0	2	0	0	0	0	0	0	0	0	4	0	6
Indigenous	7	0	19	1	5	1	2	3	3	3	0	8	6	58
Urban	0	0	0	2	0	0	0	0	0	0	0	1	0	3
Total	114	4	91	37	24	11	12	39	8	54	22	90	25	511

Table: *Distribution of land use and soil orders in the 500 Soils data set*

land uses and soils of the region, and combinations of these that have adverse effects on soil quality and sustainability of land use (see Table above).

Land use had the greatest effect on soil quality, and despite regions having their different soil, some consistent patterns emerged. Sites under indigenous vegetation were generally acidic with low nutrient status, but had high organic matter content and good physical condition. Sites under forestry (mainly Radiata pine) were also acidic with low nutrient status, except where trees were newly planted into pasture. The long history of liming and topdressing has led to most pasture soils being much less acidic and having much higher Olsen P status. High levels of organic matter, in pastures have been maintained, and N fixation by clover has increased N content. More than half the pasture sites were compacted, with macroporosity below 10% (Figure), which is known to reduce pasture growth. The more intensively used arable cropping soils showed evidence of organic matter depletion and decreased aggregate stability, which has been compensated by high levels of fertiliser applications and corresponding fertility levels.

The 500 Soils Project has provided a national baseline against which environmental staff can measure future trends in soil quality.

It is anticipated the sites will be re-analysed after 5–10 years to assess the rates of change and to gauge longer term sustainability. Some regional councils are continuing to collect soil quality data, and the project is currently undergoing external review (by Environment Waikato, Environment BOP, and Lincoln University). The data collected by the 500 Soils Project have alerted some regions (Taranaki, Bay of Plenty, Waikato) to potential problems, allowing them to target monitoring strategy, and to prepare overviews of soil quality in their regions.

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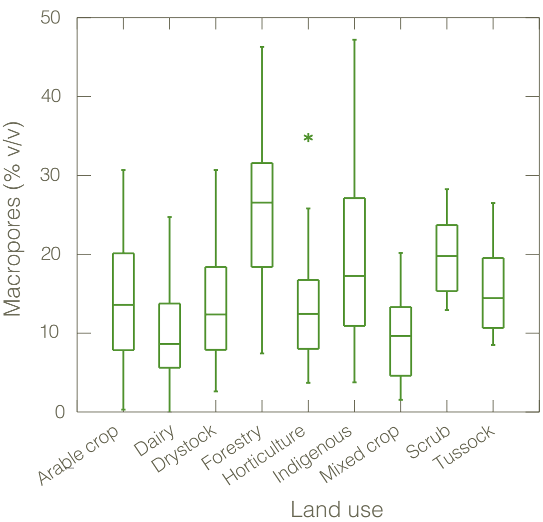

Figure: *Macroporosity of soils under different land uses in the 500 Soils dataset. The recommended range for macroporosity is 10–30 %. Pasture and cropping soils were frequently outside that range.*

Measuring land-management pressures

Human activities exert pressures on the environment, changing its quality and the quantity of natural resources. Soil compaction is an insidious, invisible pressure caused by heavy machinery driving over soils during forest harvesting, urban subdivision or agricultural cropping. The vulnerability of a soil to compaction can be predicted using a combination of laboratory tests, data on the 'natural' soil state, and pressure distribution at sites of interest.

To improve both the prediction of field measures of excessive compaction, and the potential to decrease damage by altering site management, Landcare Research staff selected 12 soils from throughout New Zealand, covering a wide range of texture and mineralogy. The compaction sensitivity of these soils was rated by

- change in density with increasing soil moisture under a constant pressure. If the soil is resistant to compaction when dry, damage can be minimised by avoiding traffic during wet weather, e.g., solid lines for Type 1 soils in Figure below.
- soil strength and its response to increasing soil moisture. Soil resistance greater than 2 to 3 MPa can prevent root growth, e.g., dotted lines for Type 1 and 2 soils in Figure.
- site and environment information – field measurements of relatively undisturbed sites to assess initial 'natural' or baseline large-pore volume and soil strength. These indicate the extent to which topsoil can be degraded without impacting plant growth. Root distribution and type of root barriers indicate the potential for roots to compensate for degraded topsoil. Moisture budget and water table data indicate when sites are likely to be dry enough to resist compaction. Topography and soil heterogeneity indicate the potential to restrict traffic to the most resistant soils.

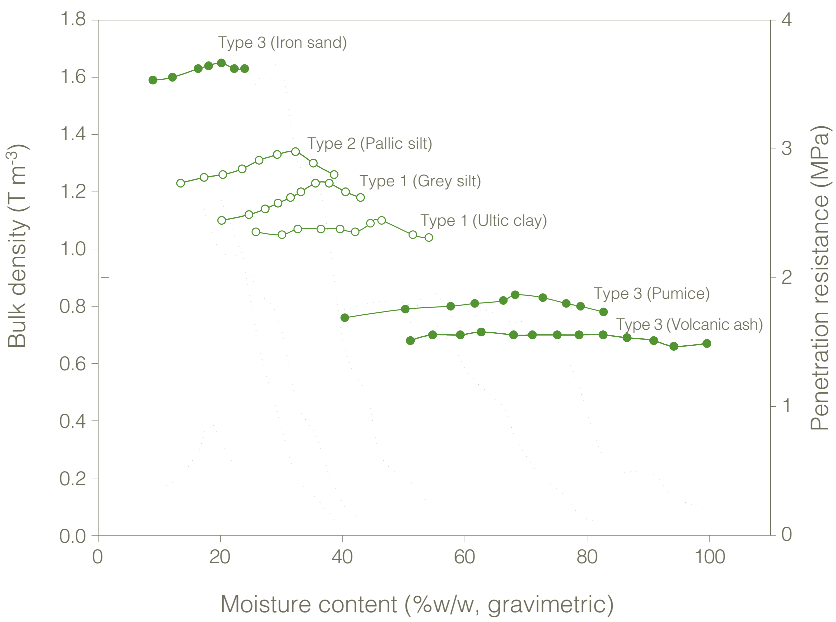

Figure: *Sensitivity of 6 soils measured by their response to change in density (——) and strength (….) with increasing soil moisture after applying a standard level of compaction. There are 3 typical responses: type 1 – sensitive to compaction; type 2 – moderately resistant; type 3 – resistant to compaction.*

Type 1. The soils most sensitive to compaction have high penetration resistance when dry (>2 MPa), low 'natural' air-filled pore volume (<15%), and subsoils unfavourable for root growth, i.e. most **Ultic** and **Gley** soils, **Recent** silts and clays. Compaction risk is reduced either by restricting traffic to dry periods and reducing the number of passes or by identifying 'sacrifice lanes' that are subsequently ripped.

Type 2. Moderately sensitive soils are vulnerable when moist, with marginal subsoils and higher natural large pore volume and/or distinct summer-dry periods (**Pallic** soils) or are imperfectly drained (some **Brown** soils). Compaction is minimised by restricting traffic to dry periods and distributing machine passes across the site.

Type 3. These soils have moderate to high allophane contents (P retention >50%) and are difficult to degrade to a condition that restricts plant growth. These soils typically have high organic carbon levels, high large-pore volume (>25%), low penetration resistance, and moderate to excessive drainage. Some finer textured **Pumice** soils in this group can be vulnerable to compaction if their subsoils are unfavourable, as compaction can cause bridging of pumice grains and prevent root penetration. Minimising machine ground pressures and dispersing traffic reduce compaction risk. This group also includes some **Recent sands** and gravels resistant to compaction due to their well-sorted, unstructured, coarse particles that behave like ball-bearings. These soils have high natural bulk densities.

A more extensive dataset is being developed for a) spatially modelling land management compaction pressures, and b) providing a guide to land managers to minimise and ameliorate soil degradation through compaction.

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SINDI has been improved!

SINDI is a web-based software tool designed to allow users to compare and assess the quality of their soil sample (see *Soil Horizons* Issue 4, 2000). It graphically interprets a user's sample data in terms of different aspects of soil quality. Over the last year improvements have been made to SINDI that include incorporating recent science developments, updating information derived from the soils database, and implementing changes to the user-interface.

Recent research shows that the original set of 10 key soil properties can be reduced to seven properties, grouped into acidity, fertility, organic, and physical aspects of soil quality. Interpretation of each of the seven indicators is now based on knowledge from soil experts throughout New Zealand. This knowledge was gathered in two MfE-funded workshops, where response curves for each of the seven soil quality indicators were established for both production and environmental

Environmental & production Response Curve for Total N Indicator on all soils for pasture land use

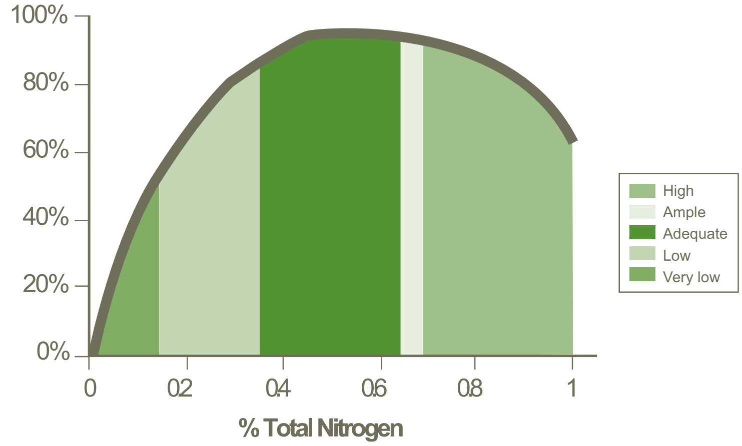

Figure: *Example of the new response curves that drive the assessment of a soil sample in SINDI.*

responses and/or impacts; soil quality ranges were also defined (Figure). These response curves, which vary according to the selected soil order, land use, and textual descriptions, are included in the latest version of SINDI.

Users can compare their soil sample with similar soils from Landcare Research's soil database, which includes recently acquired samples from the 500 Soils project. SINDI box plots have been extended to cover five soil properties – total carbon, total nitrogen, bulk density, macroporosity, and pH.

Improvements to the interface include the facility to switch between mean and minimum indicator values. As an example, physical quality is made up of three indicators, and now both the mean and the minimum of these three indicators can be seen. At users' requests, some indicator units have been changed to the more familiar percent values. Users are also provided with more information to help them identify the Soil Order to which their sample belongs.

The updated website (SINDI v3.0) is available now on http://sindi.LandcareResearch.co.nz

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Soil mapping made easy!

Innovative technologies are becoming increasingly accessible to land users. Remote sensors, when combined with technologies that store, handle and apply spatial data about crop and soil resources can be used to produce maps for a range of purposes. For example, yield sensors installed on conventional harvesting machinery can output instantaneous crop yield data. When used with a Global Positioning System (GPS), a map can be produced showing the spatial variability of crop yield. However, causes of this variability are unknown. Electro-magnetic induction sensors that measure the apparent electrical conductivity (EC_a) of the soil profile are becoming increasingly attractive for accurate field-scale mapping with identification of contrasting soil zones. Clays

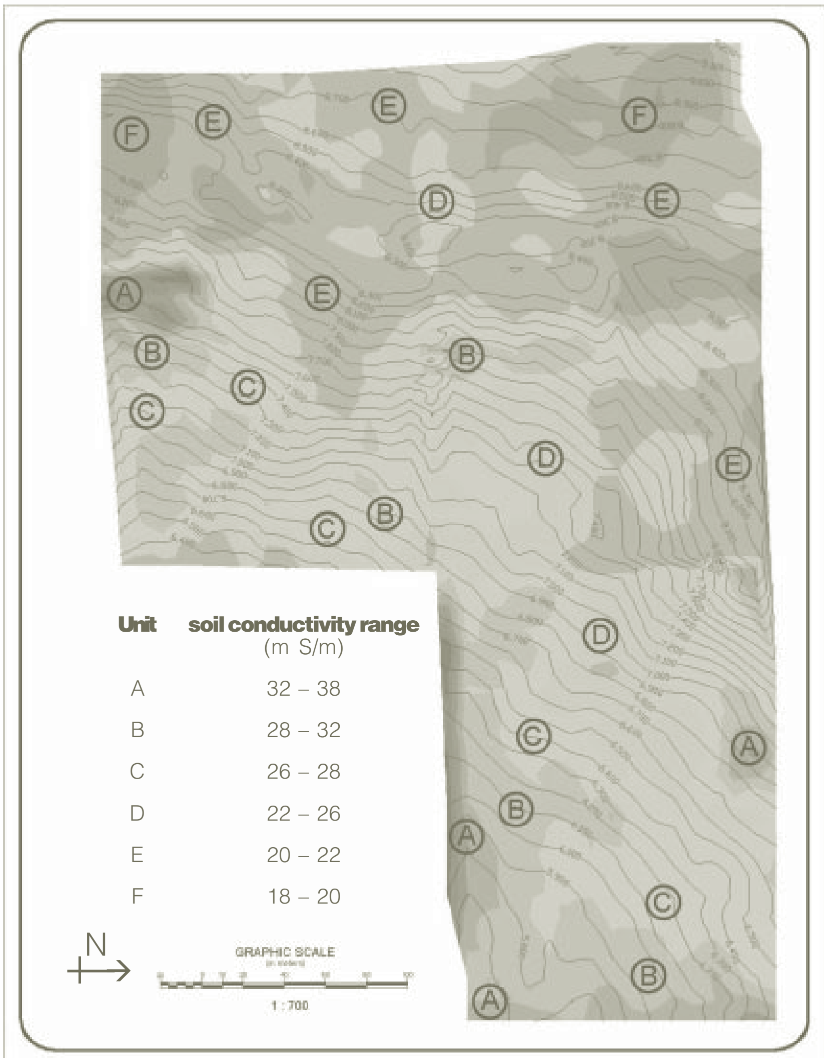

Figure 1: *Soil conductivity map of a pasture-cropping systems unit, Aorangi Research Station, Manawatu.*

have a high conductivity, silts an intermediate conductivity, and sands a low conductivity, so that contrasting textural areas within a paddock can be identified.

Landcare Research is currently evaluating the usefulness of soil conductivity surveys on a 12-hectare study area at Aorangi AgResearch Station, Manawatu; about 100 m due east of the Oroua River. This study is in collaboration with the NZ Centre for Precision Agriculture, who conducted the survey and produced the map. A detailed soil map of the area was produced in 1992 and the EC map (Figure 1) was produced in November, 2001, using a soil conductivity sensor (Figure 2). Input from the sensor is collected by an on-board field computer that also receives real-time GPS positioning data. The map produced shows a similar overall pattern to the soil map with coarser soils closer to the river and finer soils furthest away. Soil particle size and EC_a data for 106 sampling points were compared. A site with the lowest weighted average % clay (13%), gave the second lowest EC_a value (20.19 mS/m). The sampling site furthest from the river had the highest weighted average % clay (32%), and had one of the highest EC_a values (29.40 mS/m). Overall, however, EC_a has only a weak relationship with percent soil clay, silt or sand for the 106 sampling sites. The management effects, compaction and different fertilizer application rates, have affected conductivity levels. Compaction will cause a decreased soil porosity that provides a medium with increased conductance. Higher solute concentration in the soil solution, from increased fertilizer application, will also increase EC_a values. Non-uniform moisture distribution would also influence apparent electrical conductivity values. It is likely that this non-uniform distribution of water is present in these layered alluvial soils, which are imperfectly to poorly drained, with the presence of an intermittently occurring, slowly permeable, clayey horizon.

Figure 2: *Electromagnetic induction sensor displayed in its protective case on rubber mat pulled behind an all-terrain vehicle, with GPS antenna attached.*

The EC map produced provides a valuable insight into the variability of the soils of this study area. It indicates the overall pattern of textural classes, as well as areas where there are management effects that influence soil behaviour and potential use.

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Assessing capacity of soils to adsorb heavy metals

Heavy metals refer to elements with an atomic density greater than 6 g/cm^3. While some elements such as cobalt (Co), copper (Cu), zinc (Zn), and molybdenum (Mo) are essential in small concentrations for the normal growth of plants and animals, they are toxic at high concentrations. On the other hand, arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), and uranium (U) are of concern as they constitute significant potential threats to human health: Exposure to Pb can result in chronic toxicity manifestations, such as hypertension, kidney impairment, and cognitive disturbances; Hg is toxic to the nervous system and is carcinogenic; and Cd is a contributor to osteoporosis.

Some heavy metals in soils are derived from the parent rock. Heavy metals can also be introduced unintentionally into soils through use of agricultural chemicals, through sewage sludge and through mining and industrial activities. The affinity and capacity of a soil to adsorb introduced heavy metals are important characteristics: They affect metal availability to plants and metal leachability to water bodies. This affinity varies. For example, Cu is often strongly adsorbed by soils because it can form strong chemical associations with soil components (namely soil organic matter and clays). However, Zn is not.

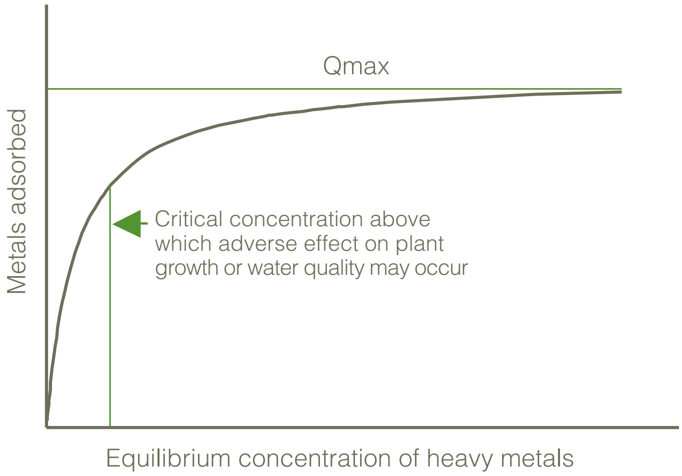

Figure: *Maximum adsorption capacity (Q_{max}) is not an environmental indicator of a soil's ability to retain heavy metals. Instead, the adsorption capacity at a user-defined (critical) concentration would be a useful indicator.*

The commonly reported maximum adsorption capacity (Q_{max}) is a chemical parameter without any biological and environmental consideration. For soils, this adsorption capacity is not very useful for environmental and health protection purposes. Below the Q_{max} level in soils, the high concentrations of metal in the soil solution would adversely affect water quality, microbial activity, or plant growth.

To overcome this problem, Landcare Research scientists are working on a new, more meaningful approach to estimate the adsorption capacity of a soil for heavy metals at concentrations acceptable to the environment and to human health. For example, if the maximum permitted Cd load in water bodies is 5 parts per billion (ppb) (i.e. 5×10^{-6} grams per litre), then this is the concentration that would be useful to determine the adsorption capacity of soils, and whether they can adsorb more extraneous Cd from anthropogenic sources without compromising water quality. The difference between this adsorption capacity and the natively adsorbed Cd (i.e. the Cd already in the soil) is the maximum amount of Cd the soil may receive before it affects water quality. As an example, an allophanic subsoil from New Plymouth can only adsorb 2 mg Cd/kg at the concentration of 5 ppb Cd, despite the fact that it has a Q_{max} of 1200 mg Cd/kg.

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Compost containing sewage biosolids beneficial to pasture soil

'Living Earth' compost produced at Wellington's waste management plant includes biosolids from Moa Point wastewater plant.

Composting pasteurises the waste, and quality controls are in place to ensure it does not contain significant levels of toxic heavy metals (se *Soil Horizons* Issue 6, 2001). Given such safeguards, biosolids amended with other organic wastes are useful as potential soil conditioners. This was demonstrated last year in a plot trial on Foxton sandy loam.

Each year since 1999, 'Living Earth' compost has been cultivated into a series of trial plots on dairy pasture at Otaki, an area with a long history of dairy farming. Some plots receive a 10 mm depth of compost, some receive 56 mm, and the control plots get zero compost. All are cultivated, resown and then grazed normally.

Soil property		Annual application of compost (mm)		
		0	10	56
Soil chemistry	Soil carbon (%)	4.0	4.7	10.2
	Soil nitrogen (%)	0.35	0.43	0.93
	Soil phosphorus (mg/kg)	1079	1404	3433
Soil biology	Topsoil-mixing earthworms (individuals / m^2)	238	398	604
	Dung worms as % worms	14	20	40
Soil physics	Soil bulk density (Mg / m^3)	1.14	1.09	0.79
	Total soil porosity (%)	55	57	66
	Soil macroporosity (%)	6.5	8.2	12.4
	Soil field capacity (%)	44.4	44.5	49.9

Table: *Soil properties under dairy pasture into which compost was cultivated annually.*

In January and October 2001, as part of a joint study with ESR, Landcare Research staff compared properties of topsoil in the various plots. The Table gives values for some of the properties. Despite the soil structure being disturbed by annual cultivation, the plots receiving compost clearly benefitted in terms of soil conditions for improved pasture production.

Incorporation of biosolids compost at pasture renewal could be a cost-effective way of utilizing sewage biosolids and improving soil conditions. There will clearly be regional differences in not only the practicality of such incorporation but also application rates.

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Growing Ohakune carrots affects soil physical properties

Around Ohakune, soils and climate have combined to make the area one of the prime carrot-producing regions in New Zealand. Carrot production is an intensive land use involving frequent cultivation. However, because the local soils are formed from young volcanic ash with a very fine structure, there is potential for physical degradation of these soils. Landcare Research is investigating soil degradation and its relationship to surface erosion at two sites with different management histories (16 and 6 years of continuous carrot cropping). These two cropping sites are being compared with long-term pasture.

Compared with pasture, soils under carrot cropping have less organic matter, higher bulk density in the lower part of the topsoil and subsoil, a soil structure comprising coarser soil aggregates, and poorer stability of soil aggregates. Organic carbon content under pasture is 14–15% compared with 10–11% after 6 years cropping, and

7–9% after 16 years cropping. The mean size of soil aggregates increases with increasing length of time under cropping, and the proportion of stable aggregates decreases, indicating soil structure is becoming coarser and less stable (Figure 1). Accordingly, there is an increased potential for soil erosion with increasing length of time under carrot cropping.

Cropping also alters the rate at which water is transmitted through the soil (Figure 2). Under pasture, saturated hydraulic conductivity (K_{sat}) is 300–900 mm/hr throughout the profile. Under cropping, cultivation results in higher hydraulic conductivity in the topsoil (often more than 1000 mm/hr), but reduced conductivity in the subsoil (as low as 20 mm/hr). These results suggest that while hydraulic conductivity has been altered by cropping, it will not generally limit the percolation of water as the soil's ability to store water is higher than typical rainfall intensities.

Like many vegetable crops, carrots are planted in beds. Recent research suggests that it is the wheel tracks between the beds that may be the surface runoff sites and source of eroded sediment. Infiltration rates were measured in wheel tracks used for crop spraying that were heavily compacted, wheel tracks that had been scarified (i.e. cultivated to a shallow depth), and in carrot beds. There were order of magnitude differences with infiltration rates with average rates of 4 mm/hr in the compacted tracks, 83 mm/hr in the scarified wheel tracks, and 850 mm/hr in the carrot beds.

Rain cannot soak away quickly enough on the compacted tracks. This generates surface runoff that may cause erosion of the edge of the carrot beds. When the infiltration rate measurements were made (January 2002), there was also considerable evidence of runoff and sediment being generated from the scarified wheel tracks. Bed preparation at Ohakune creates very fine soil aggregates, and shallow scarification may exacerbate erosion by loosening the soil surface and making it more susceptible to erosion. Further work is needed to determine the appropriate management techniques for wheel tracks formed in these light volcanic ash soils.

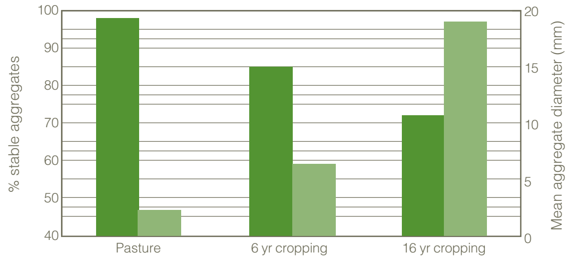

Figure 1: *Aggregate stability (dark) and mean aggregate size (light) in soils under pasture and cropping.*

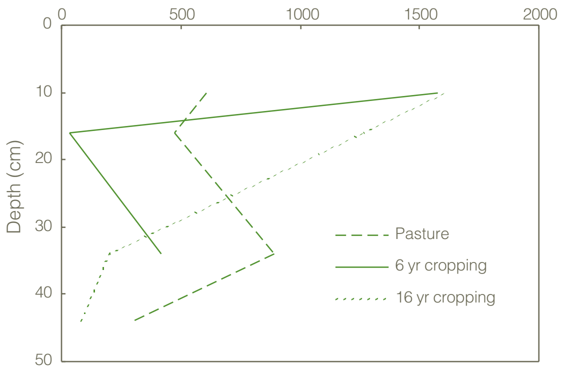

Figure 2: *Hydraulic conductivity in soils under pasture and cropping.*

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Soil water properties and soil organic carbon

Soil organic carbon (OC) is important for sustaining agricultural production and is a key indicator of soil quality. A previous issue of *Soil Horizons* (Issue 4, January 2000), described how the National Soils Database (NSD) was used to determine factors controlling OC accumulation in pasture soils. In that study, we found clay concentration related poorly to long-term OC accumulation when it had previously been thought to be a significant factor. We had also thought OC concentrations had a strong influence on soil water properties such as readily available water (RAW, v/v%) and total available water (TAW, v/v%).

We have investigated OC–soil water property relationships using the NSD. Our task was to find the largest sets of NSD soils that were similar in physical and mineralogical character within each set, and with OC concentrations that varied sufficiently for useful correlations with water properties. To do this, the contributing soils in each set were constrained to have similar texture, drainage profile, and mineralogy. Data were limited to topsoils, and soil-water relations with OC were tested by linear regression.

The soil series, the lowest category of soil classification, provided too few data points in any set of soils available. A higher category, the subgroup, provided several datasets with more data points (up to 21). However, the analysis outcome was disappointing, with most regression R^2 values being 0.10 or less for RAW and TAW. Finally, it was decided to try for a better estimate of a soil water relation by accessing a much larger set of soils with a common texture – the silt loams. The silt loam set was selected to exclude soils that would introduce variability from significant concentrations of short-range order minerals or unusually high concentrations of OC. The silt loam set contained 165 data points and the regression analysis examined RAW, TAW, plus water contents (v/v%) at 0.4 bar, 1 bar, and 15 bar tensions.

All the water properties were still weakly correlated with carbon (R^2 values from 0.00 to 0.12). However, when the dataset was split into two subsets based on drainage profile, viz., into broadly "well-drained" and "poorly drained" subsets, there were improvements in the R^2 values for the "poorly drained" subset (now from 0.04 to 0.38) but decreases in the R^2 values for the "well-drained" subset (now from 0.00 to 0.04). TAW showed the most improvement (R^2 value up from 0.12 to 0.38). The Figure illustrates the best TAW correlation found to date.

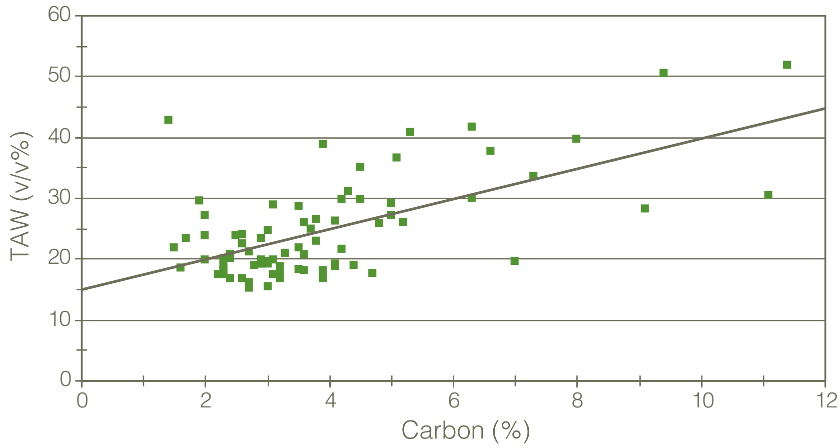

Figure: *Relationship between total available water (TAW) and total soil carbon concentration in the subset of "poorly drained" silt loams drawn from various Soil Orders in the NSD. Line through the data is the best-fit line for the regression.*

The regression equation for this correlation implies that, for each decline of 1% carbon in a soil in the "poorly drained" silt loam set, there could potentially be a decline in TAW of 2.5 v/v %. However, the potential error in this estimate (because of the rather low R^2 value) is probably too large to allow practical use of this OC–soil-water relationship. Overall, soil water properties do not, unfortunately, relate well to soil organic carbon concentrations.

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Native forests rely on natural soil nutrients

Indigenous forests in New Zealand rely on the soil to provide nearly all their nutrient needs. The most important nutrients are nitrogen (N) and phosphorus (P), and forest soils can store several tonnes of N per hectare and several hundred kg of P in the top 20 cm of the soil. Even though New Zealand forests do not suffer from atmospheric pollution, most of the N has probably come from the air or from rain. The N from the air is taken up, in small amounts each year, by lichens, microbes, and legumes if they are present. Little is lost from the forest, and N accumulates in the soil over hundreds of years until the soil settles into a steady state, or until there is a major disturbance. Young pumice soils near volcanoes have a considerable store of N because thermal areas emit ammonium-N. The forests on pumice soils may have benefited from this natural fertiliser. The P, however, is mainly supplied by the geological materials in which the soil has developed.

Although forest soils have considerable stores of N and P, only a small part of these nutrients is available to the trees each year. Landcare Research has been assessing the availability of N and P to some indigenous forests to understand species distribution and mechanisms of forest succession. We have developed protocols for sampling soils, analysing N and P, and measuring N and P cycling. Generally, the results suggest that forest and scrub is under P stress. This is confirmed by the N and P concentrations in leaves from trees. The optimum ratio of N:P in leaves should be close to 10. Our results, however, ranged from 14 for Kamahi on Pumice soils to 28 for Rata on a West Coast Organic soil. An exception is forest on Recent soils (on flood plains and sand dunes) where the ratio is 9, signifying an apparently good supply of P.

New Zealand soils generally have much lower levels of available P than soils in the Northern Hemisphere. This is because our soils are not formed in glaciated limestone but are formed in siliceous loess, volcanic ash and pumice, or old weathered and leached geological materials. The P in these materials slowly dissolves and then, over hundreds of years, is either leached from the soil or is locked up in soil organic matter, in iron oxides or in allophane (the clay in many high country soils and wetter volcanic ash soils). In Recent soils the P is still mobile, and is readily available to the trees.

It is envisaged that this research will provide a better understanding of the function and performance of indigenous forests and scrub ecosystems, and as a result show us how better to manage and monitor these resources.

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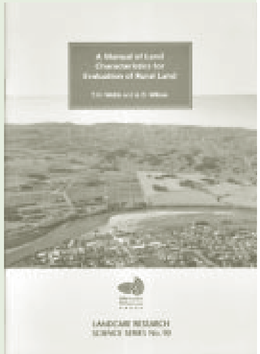
Buried Treasure

When the New Zealand Soil Bureau was closed in 1993, where did all the soil maps and publications go? Such gems seem to be regarded as buried treasure by many people, who breathe a sigh of exhausted relief when they finally reach Manaaki Whenua Press.

Manaaki Whenua Press started business in 1993 as part of Landcare Research. They produce and distribute New Zealand natural history and science publications, and soil science and soil management publications are an important part of the business.

Not only do Manaaki Whenua Press stock the bulletins, reports and maps inherited from the New Zealand Soil Bureau (and some revisions of these maps using the new NZ Soil Classification system), they also offer a range of titles on soil science and soil management. Many recent soil publications have been released in the Landcare Research Science Series, available from Manaaki Whenua Press. As New Zealand agents for CSIRO publishing, they have many CSIRO soil titles in stock and can order others in as necessary.



Those involved in land management, monitoring of land-use impacts, and land resource assessment will find essential reference material on the shelves at Manaaki Whenua Press. Pay them a virtual visit at their website www.mwpress.co.nz or phone 03 325 2127 for a list of available maps and publications.

Website

Soil Horizons is on the web

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

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Published by: Landcare Research New Zealand Ltd
Private Bag 11052
Palmerston North

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