GATHERING STORM CLOUDS:
CARBON AND NUTRIENT MANAGEMENT FOR A WARMER WORLD

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The year 2007 has been a watershed for warnings of global environmental change that, if unheeded, will imperil all life on earth by the end of this century. Publication of the four IPCC Fourth Assessment Reports on the state of the world's climate, together with the OECD Report 4, provide consistent and clear messages that urgent action on a global scale is vital to address current rates of environmental degradation and climate change.

Storm clouds are also evident for New Zealand's economy and environment, the result of our burgeoning greenhouse gas emissions and deteriorating water and soil resources. However, the encouraging facts for the globe, and for New Zealand, are that we already possess much of the knowledge and technologies we need to reverse these worrying trends. Examples include strategic reforestation to recover stored carbon on eroding hill land, some biofuel crops, nitrogen management strategies to curb N loss to waterways and the atmosphere, and emerging new technologies with the potential to store C in soil (biochar) and capture enteric methane emissions. The efficacy of most of these technologies relies on continuing supplies of affordable oil. The warning signs from imminent peak oil production suggest major changes in carbon and nutrient management will be necessary, possibly in the next 2–3 decades, if we are to continue to produce the food and fibre we need.

Later this century our soils will be increasingly vulnerable to the effects of global warming, but we may be able to adapt better than many other parts of the world. Some of these current and future challenges and their possible solutions will be discussed. However, do we have the resolve to act, starting with reducing the impacts of agriculture on our environment, and substantially reducing our greenhouse gas emissions by 2020?

BIOFUELS, FOOD SECURITY AND NATURAL RESOURCES

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Agriculture is undergoing a biofuel revolution that no one predicted even two years ago. Rapid economic growth in the world's most populous countries, political instability in regions with greatest petroleum reserves, and massive hurricane damage to much of the USA petroleum production and refining infrastructure combined to cause an abrupt rise in fossil fuel energy prices. In response, the USA Congress recently passed the 2007 Energy Independence and Security Act that mandates annual production of up to 57 billion L ethanol from grain by 2015, and another 61 billion L from ligno-cellulosic biomass by 2022. Generous federal tax incentives are provided to ensure these goals are met—especially for cellulosic ethanol. States and rural communities are also providing incentives to attract investment in new biofuel plants. In addition to these incentives, high gasoline prices make ethanol production from maize grain highly profitable, which has attracted investment capital to support a rapid growth of biofuel production capacity. As a result, USA maize-ethanol production capacity is projected to reach more than 46 billion L per year by early 2009 and 57 billion by 2012. The recent run-up in maize prices, however, may slow this expansion because current ethanol prices do not justify grain prices above US$180/t.

High petroleum prices and favorable government policies are also encouraging the expansion of biofuel in other countries with adequate land and water resources to support this growth. Significant examples are ethanol from sugarcane in Brazil and biodiesel from palm oil in Indonesia and Malaysia. In each of these cases, biofuel production utilizes feedstock crops that can be used for human food. As a result, commodity prices for maize, sugarcane, and vegetable oil have risen dramatically. Farmers have responded to high prices by increasing area planted to biofuel crops. In the USA where there is little scope for increasing total crop area, there has been a dramatic shift out of soybean and cotton to maize. Sugarcane area in Brasil and oil palm area in Indonesia and Malaysia are also expected to rise substantially.

These responses mark the first phase of a biofuel revolution that will likely continue into the foreseeable future if petroleum prices remain high or go even higher. The most notable feature of this revolution is that the price of food crops that can also be used to produce biofuel will be determined by their energy conversion content rather than by their value as a human food or livestock feed. This marked change in the valuation of agriculture raises a number of critical issues concerning the impact on global food security and the ripple effects on environmental quality, protection of natural resources, and climate change. These issues will be considered in this presentation, followed by a discussion about the need to refocus national and international agricultural research portfolios to ensure that the biofuel revolution does not compromise food security or environmental services.

HOW CAN BIOCHAR CONTRIBUTE TO A SUSTAINABLE FUTURE?

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The application of biochar to soil represents a novel approach to remove carbon dioxide from the atmosphere. Biochar is produced by the thermal conversion of biomass by pyrolysis and can be combined with the production of bioenergy products.

Conversion of biomass to biochar stabilizes about 50% of the C originally in the biomass, compared to the low amounts that remain after burning (3%) or biological decomposition in soil (<10–20% after 5–10 years).

The size of the biochar C sink may be both regionally and globally significant. Lehmann (2007) demonstrates that 10% of the annual US fossil fuel emissions of 1,638 Tg carbon could be sequestered as biochar annually by any one of the following (1) utilization of 3.5 tons per hectare of residues or thinnings from US forest land for timber production; (2) sustainable harvest of fast-growing vegetation on all idle cropland in the US; or (3) return of bio-char from 5.8 tons crop residues per hectare of all US cropland. By contrast converting all cropland in the US to Conservation Reserve Programs or no-tillage would sequester only 3.6% of the US emissions per year during the first few decades after conversion in a non-permanent form**!**

Apart from the stabilization of C, application of biochar to soil delivers benefits through improved soil fertility, reduced diffuse pollution and increased agricultural production. This results in reduced greenhouse gas emissions from soil and the use of fewer agricultural inputs.

Comparing scenarios, including purpose grown energy crops and the use of crop wastes for feedstock production, we found that the avoided emissions (2 – 19 Mg CO_2 ha^{-1} y^{-1}) were between 2 and 5 times greater when biochar was applied to agricultural land than when used solely for fossil energy off-set. The additional emission reductions are related to stabilization of C in biochar, offsetting fossil fuel use for energy, fertilizer savings and avoided soil emissions of nitrous oxide.

Despite promise, the biochar vision has yet to be demonstrated on a commercial scale? My presentation considers issues facing us as we take the next steps toward delivering this vision, with a focus on both the role of C markets and some thoughts of regarding the opportunities for biochar in New Zealand.

A NOVEL APPROACH, USING ^{13}C NATURAL ABUNDANCE, FOR MEASURING DECOMPOSITION OF BIOCHARS IN SOIL

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There is growing interest in the use of artificially-produced biochar (black carbon) as a soil amendment, with potential to increase soil carbon (C), reduce greenhouse gas emissions, improve soil properties, and enhance agricultural productivity. However, promoting the use of biochar for increasing soil C sequestration will depend on demonstrating its ability to persist in soil. The biochar produced during incomplete combustion of biomass at temperatures > 200ºC, and under limited oxygen supply (pyrolysis), is considered highly resistant to biological degradation due to its increased chemical recalcitrance (aromaticity) compared with the parent feedstock. Despite some exceptions, C in natural biochar has been shown to posses turnover time of a few 100 to >1000 years in soil. However, little research has been undertaken to: (i) document turnover rate of artificially-produced (in thermal reactors) biochars applied to soil, (ii) measure and account for any priming effect of biochar addition on turnover of 'native' soil C, and (iii) elucidate stabilisation mechanisms of biochar C in soil.

In order to precisely determine the magnitude and rate at which biochar C is decomposed in soil and released as CO_2, we have initiated a long-term (up to 5 years) incubation experiment using a novel method that is based on measuring the inherent differences in ^{13}C isotope content between biochar and soil. Briefly, biochar materials from a range of C_3-vegetation feedstocks (blue gum wood and leaves, paper sludge, poultry manure on rice hull, and cow manure), and produced at different temperatures (400ºC or 550ºC) and activation level (activated or non-activated), were applied to soil collected from a C_4-pasture (*Astrebla* spp.) field. Soil respired CO_2-C and microbial-C and their associated $\delta^{13}C$ values are being measured periodically. Additionally, detailed chemical characterisation of organic C fractions (separated physically) is being performed periodically to gain insights into the causes of biochar C stability in soil.

Early results show decomposition of biochar C in soil in the first 41 weeks of incubation varied from 0.1% to 6% of biochar C applied, depending on the biochar types tested. Biochar application did not change the initial (day zero) microbial-C in soil and on day 196, microbial-C in biochar- and non-amended soils was not significantly different. However, total bacterial and fungal counts on day 196 determined by the viable plate count method were significantly higher in most of the biochar-amended soils than in the non-amended soil.

We will present preliminary estimates of turnover rate of C in different biochar types, determined by fitting the two-pool kinetic model to the cumulative CO_2-C evolved from biochar C after 41 weeks of incubation. Furthermore, implications of biochar C turnover rate on GHG mitigation through biochar application to soil will be discussed.

POTENTIAL FOR COLLABORATION IN BIOCHAR RESEARCH BETWEEN AUSTRALIA AND NEW ZEALAND

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Biochar refers to all products made from the process of pyrolysis that decomposes organic materials at temperatures generally between 350 to 500°C in the absence of oxygen. Biochar is high in organic matters, can be added to soils, with or without additional nutrients (such as nitrogen, phosphorus, and potassium). As a soil amendment, biochar can improve the structure and fertility of degraded soils, mimicking the *Terra Preta* (dark earth) soils of the Amazon Basin.

Research on Biochar in Australasian region is in its infancy and although initiatives have come from NSW Department of Primary Industries of Australia in collaboration with BEST Energies in NSW, a joint working group is proposed with the expertise of both Australia and New Zealand researchers to carry out research to realise the full potential of biochar as soil amendment. Some of the potential benefits of biochar to soils are: reducing greenhouse gas emissions, reduction in nutrient leaching; improve soil structure, water retention and higher crop productivity.

Given that 75% of Australian soils have < 1% organic carbon, and continued decline in soil structure through land degradation and further decline in carbon levels, locking carbon in soil through the application of biochar seems a novel idea. The situation in NZ is slightly different, where most soils have > 3% carbon; however pH can range from around 4.5-6.5, so liming is often required. Applying biochar could also reduce lime use as well as obtaining other benefits.

Focus for this poster is to give an overview of current research being undertaken in Australia and how New Zealand researchers can play a part to compliment each other to achieve a common goal. Climate change is high on agenda in both countries priority lists and given reducing nitrate leaching in NZ is also one of the top priorities within government and private sectors; it is timely that a coherent approach be adopted with involvement of scientists from both countries to tackle this issue.

It is proposed that Landcare Research in collaboration with the Australian researchers would investigate the soil responses to biochar application emphasising the reduction in nutrient leaching, reduction in N_2O emissions and improving the soil quality/health to obtain greater crop production.

N-MINERALISATION IN TWO APPLE ORCHARDS IN HAWKE'S BAY: THE IMPACT OF SOIL CARBON MANAGEMENT AND ENVIRONMENTAL CONDITIONS

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During N-mineralisation, soil microbes decompose soil organic matter that contains N. The end product of this reaction is mineral N, which can be taken up by plants. Intensive production of high-quality fruit requires sufficiently high concentrations of mineral N. This can be either achieved by applying synthetic fertilizers or by relying on N-mineralization.

The objective of this study was to understand better N-mineralization in orchards. We investigated the impact of two soil carbon management strategies and the role of environmental conditions on N-mineralisation in two orchard systems.

One system is an organic apple orchard using regular compost applications and growing pasture in the tree row. The other system is an integrated apple orchard with drip irrigation and a herbicided strip in the tree rows, and no external inputs of organic matter. Both orchards have operated in these ways for at least 10 years. Both have the same soil type and they were both previously used for market gardening. The soil organic carbon contents, and microbial activities were significantly higher in the organic orchard.

We compared the net N mineralization of undisturbed soil cores taken from the top 100 mm within the tree rows in the laboratory. We applied different environmental conditions using different temperatures (10, 15, 20 °C), and different soil moistures (30, 100, 300 kPa). We measured the hot-water extractable carbon contents of each sample at the start, and again at the end of the experiment. Hot-water extractable carbon is a measure for the labile, microbially available carbon in soil. It is an indicator for soil carbon management.

Net N mineralisation of the soil in the organic orchard was significantly higher than that in the integrated orchard.

Using multiple regressions we quantified the significance of carbon management and of environmental conditions on N mineralisation. N-mineralisation was found to be a function of both temperature and hot-water extractable carbon contents. However, soil moisture was not a significant factor under our experimental conditions.

This indicates that specific carbon management practices such as regular compost applications which increase the concentrations of labile carbon in the soil can be used to manipulate and account for soil N-mineralisation rates.

IMPACT OF SOIL CARBON MANAGEMENT ON SOIL AGGREGATE CHARACTERISTICS UNDER ORCHARD AND PASTORAL LAND-USE

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Recently a widespread loss of soil organic carbon (SOC) has been reported for New Zealand soils. Here, we focus on the potential consequences of the SOC loss on the soil's filtering functions.

The filtering capacity of structured soils depends on the properties of soil aggregates. As a first step, we investigated biological, physical and chemical properties of soil aggregates and their correlation with soil SOC contents. We selected two pairs of sites that have different SOC concentrations, and different land-use, but the same soil type and texture. The first pair of sites included soils from an organic and an integrated apple orchard (Hawke's Bay), and the second pair of soils a camp and a non-camp site under permanent pasture (Waikato). We analyzed the properties of four macro-aggregate fractions (>4.75 mm, 2.8-4.75 mm, 1.0-2.8 mm, 0.25-1.0 mm) that constituted more than 80% of the total soil mass.

The ranking of SOC concentrations within the different aggregate size fractions was similar in the integrated orchard and the non-camp site pasture. The SOC concentrations in the organic orchard and the camp site pasture were highest in the smallest aggregate size fraction.

The ranking of C-mineralization rates within the macro-aggregate classes followed the ranking of the SOC concentrations and at all sites was highest within the smallest aggregate size. However, the ranking of microbial biomass did not follow that of SOC concentrations, and was highest in the organic orchard.

The sorptivities of intact aggregates for water sampled at the end of summer varied by two orders of magnitude between the different sites. Soil hydrophobicity greatly reduced the sorptivity at the pastoral sites and was most pronounced at the camp site pasture containing the highest SOC concentrations.

To date our results suggest that it is not straightforward to relate the SOC concentrations, and, thus, carbon management to the filtering capacity of structured soils. Higher SOC concentrations were associated with higher C-mineralization rates, and, therefore, indicated a higher degradation potential for organic contaminants. However, the higher SOC contents were also associated with the occurrence of soil hydrophobicity, and indicated a greatly limited physical filtering capacity (= sorptivity of water).

CONSERVING SOIL (AND C) ON ERODIBLE SLOPES – KEY FINDINGS FROM SLURI

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Hill slope erosion through slippage transfers productive topsoil from upper slopes to lower slopes, and can bury lower slope topsoil. The resulting loss of production could be described as an expensive option for C sequestration. Conservation plantings target C retention on slopes through soil stabilisation and improved soil organic matter through root exudate and turnover at depth.

Recent work has focussed on developing understanding of poplar root distribution with age and with position on the slope, and the slope aspect is reported here. Mechanical reinforcement by poplar root systems aids slope stabilisation, particularly when the roots are anchored into the fragipan or underlying rock. Total root length, mass and distribution of coarse roots (≥ 2 mm diameter) were determined for three *Populus deltoides × nigra* 'Veronese' trees in their twelfth growing season after being planted as 3 m poles at upper slope (TU), mid-slope (TM) and lower slope (TL) positions on an erodible hillslope near Palmerston North in the southern North Island. Most of the roots were distributed in the top 40 cm of soil. Depth of penetration of vertical roots was dependent on slope position and limited by the available depth of the soil above the bedrock (0.35 m at the upper slope to 1.4 m at the lower slope). Roots penetrated the bedrock at the upper slope position where the soil depth was shallowest, and at the mid-slope, but not the lower slope position. Total coarse root length was 287.9 m for TU, 1131.3 m for TM and 1611.3 m for TL, and total coarse root dry mass (excluding root crown) was 8.15 kg for TU, 38.77 kg for TM and 81.35 kg for TL.

The results show a very good relationship of both coarse root mass and coarse root length with tree diameter at breast height (1.4 m). However root distribution around the trunk is less predictable being determined by such probable factors as soil depth, bulk density and moisture availability.

EFFECT OF CULTIVATION AND FERTILISER MANAGEMENT ON SOIL CARBON AND NUTRIENT STATUS

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A long-term fertilisation trial at the Federal Agricultural Research Centre Braunschweig, Germany was set up in 1985 to evaluate the influence of tillage systems and phosphorus (P) fertilisation on soil physical and chemical properties, P accumulation in soils, yield, and P uptake. Two tillage systems, conventional and conservative were implemented in 1998, and three different fertiliser regimes, with and without P, started in 2000. After 8 years conservation tillage showed a better pore connectivity and a higher saturated hydraulic conductivity compared with conventional tillage. The SOM contents increased in all treatments since 1998, and were generally higher under conservation compared with conventional tillage. Increases were higher in the upper 150 mm compared with the 150-300 mm depth. P-fertilisation at a rate of 45 kg ha^{-1} a^{-1} resulted in a build up of plant-available P in the top soil compared with non fertilised plots. P-fertilisation also resulted in a slightly higher P-plant uptake. This did, however, not affect yield, suggesting that P is not limiting and that the soil has sufficient plant available phosphorus even without additional P fertiliser application. Differences in yield between the two tillage treatments were only small. Conservation tillage resulted in slightly lower yields in the years 2002 and 2004 with rape seed and maize as the crops. Thus a reduction in tillage intensity changed, after 8 years, the soil's pore system and connectivity, and increased the soil organic matter content but this affected the yield only slightly.

CONSERVING SOIL CARBON UNDER NO-TILLAGE: BENEFITS FOR NZ FARMERS

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A review of New Zealand research trials and evidence from farmers' soil testing results shows that no-tillage generally conserves soil organic carbon compared with cultivated cropping. Soil carbon quantities (t C/ha) in the topsoil (0−10/20 cm) under long-term no-tillage cropping are generally 5−15% higher than under conventional cultivation but 5–15% less than under permanent pasture. Soil carbon levels under long-term cropping using conventional tillage systems compared with permanent pastures show losses from 4 to 30 tC/ha, but typically about 10−11 t C/ha (generally for 0−20 cm). However, there is a paucity of comparative soil carbon information from tillage/no-tillage comparisons to the international protocol of 0–30 cm. Higher organic matter levels in no-till cropping soils provide additional benefits to carbon storage, such as better soil structure, improved trafficability, more earthworms, higher water-holding capacity, erosion control, etc.

Reduced CO_2 emissions under no-tillage seeding compared with cultivation have been well demonstrated overseas. For tillage versus no-tillage under New Zealand farming conditions, however, there is insufficient information on comparative CO_2 emissions over the growing season for reliable estimates to be made.

The NZNTA estimates no-tillage currently comprises about 20% of the total annual seeding area of 800 k to 1 M ha on New Zealand farms (includes 2 sowings/yr for forage and arable cropping but not the multiple sowings for some vegetable crops). No-tillage adoption rates are well behind those in the Americas and Australia. European and North American estimates on soil carbon gains (sequestration and reduced CO_2 emissions) from no-tillage range from 0.25 to 0.77 t C/ha/yr. Based on European data, no-tillage has the potential to reduce CO_2 emissions in NZ by 2.4−3 Mt CO_2/yr (0.65−0.8 Mt C/yr),. A PhD project at Massey University, funded by the no-tillage sector, aims to provide the information required for no-tillage farmers to carbon trade.

THE IMPACT OF CARBON MANAGEMENT ON THE SOIL'S MACROPORE STRUCTURE IN AN ORCHARD

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Sustainable fruit production depends, inter alia, on the integrity of various soil functions. These soil functions in turn directly depend on the soil's structure. A necessary step to create eco-efficient techno-gardens for the future is to identify how we can preserve and manipulate soil structure by management practices.

We investigated the impact of soil carbon management on soil structure by comparing the soil structure in the top 100 mm of the soil in the tree row of two adjacent apple orchards in Hawke's Bay. One is an organic apple orchard that conserves carbon by regular compost applications and growing pasture in the tree row. The other is an integrated apple orchard without any external input of organic matter, with regular herbicide applications in the tree row, and drip-irrigation. Both orchards have operated in these ways for at least 10 years, and both have the same soil type and they were both previously used for market gardening. The soil organic carbon contents, microbial activities and density of anecic earthworms in the topsoil were significantly higher in the organic, rather than in the integrated apple orchard.

We used the geometry of the macropores (>0.3 mm) as an indicator for the soil's structure. The 3D macropore networks of three undisturbed soil cores were derived with X-ray computed tomography for each orchard system. We found that both the macro-porosity and the connectivity of macropores was significantly higher in the organic orchard. However, the macro-pore size distribution was similar in both systems.

We interpret the higher porosity and connectivity of macropores in the soil of the organic orchard as the superior soil structure. Therefore, we recommend the soil carbon management of the organic orchard as a strategy to preserve and enhance soil structure.

SOIL MINERAL NITROGEN PROFILES UNDER MAIZE CROP: STATUS SURVEY AND DYNAMIC MODELLING FOR PRECISE MANAGEMENT

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The AmaizeN Calculator is a decision support tool for optimising nitrogen (N) management of maize crops. Its main functions include forecasting site-specific N fertiliser demand, and the prediction of consequences of user management decisions, both on profitability and environmental impact (N-leaching). Accurate simulation of the soil mineral N profile is crucial for achieving these purposes.

Sixteen maize crops that received different N fertiliser rates (Farmer's practice, AmaizeN's recommendation, and Low and High rates) were used for validating the system. Using pre-planting soil mineral N measured to a depth of 1.2m, AmaizeN predictions of silage and grain yield, plus the end-of-season mineral N profile, matched well with measurements from the experimental crops. AmaizeN-guided N fertiliser strategy also proved to be more cost-effective than the farmer normal practice. On average, the calculator recommended fertiliser rates were 85 kg N/ha less than farmers' application on the 10 crops with no yield reduction; its recommended higher N rate on another crop caused a significant yield increase.

Determination of the pre-planting mineral N in deep soil is important, but labourious. Effects of measuring depth on the accuracy of estimating initial soil mineral N were examined using an independent soil mineral N dataset from a survey of 63 paddocks at 23 maize crop sites across major maize-growing regions. Median values for 30 cm layers to 1.2 m were extracted from the survey, and the patterns were used to estimate the values in subsoil if only top soil N was measured. This allowed users to run it with only top soil N test, but with the sacrifice of some accuracy associated with the wide variation in soil mineral N profiles. For the 12 experimental crops, the pre-planting mineral N estimated using this method had an average difference of 23 and 16 kg N/ha respectively from the measured values if the measuring depth were 30cm or 60cm in comparison with that was 1.2m (equivalent to a difference of 19% or 13%, RMSD/Mean), while the estimation for other 3 crops was unreliable. More accurate estimation may be achieved by incorporating the effects of previous land use. Users should be aware that a deeper N test produces a better prediction.

QUANTIFYING THE EFFECTS OF SOIL AND CROP MANAGEMENT HISTORY ON SOIL QUALITY

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Understanding the effects of soil and crop management practices on soil quality and crop production, is essential to maintaining a profitable and environmentally sustainable farming enterprise. While many 'best practice guidelines' are available there are very few decision support tools that predict the effects of management changes on soil quality on a paddock specific basis. This paper describes a method for deriving quantitative measures from descriptive soil and crop information to enable such predictions. The method is being used to derive the model coefficients that underpin the Land Management Index (LMI), a decision support tool under development by Crop and Food Research. The LMI is designed to monitor the effects of current management practices on soil quality over time or to run "what if" scenarios to assist with planning future management at a paddock scale. Descriptive tillage information is converted using the 'soil disturbance rating' approach, which evaluates each tillage implement by the degree of soil disturbance associated with: inversion, mixing, lifting, shattering, aeration and compaction. Descriptive crop type information is converted by assigning a weighting based on its rooting characteristics, organic matter returned and nitrogen fixation potential. This information is then summarized for the 10 year period preceding measurement of soil quality by applying a time weighting factor. The resulting tillage and crop scores have been used to investigate how much of the variability in soil quality parameters can be explained by these management history factors. For example, in the case of aggregate stability (a common soil structure indicator), only 26% of the variation in this indicator could be explained by soil type and climatic data (i.e. texture, soil order and LENZ level 1 descriptors). However, when the time-weighted soil and crop management history data were included, a further 43% of the variation is explained, giving a total variation explained of 69%. This result suggests that soil and crop management information can be useful in explaining variability in soil quality data, information that may be applied to the development of soil management decision support models.

ARE YOU MAKING THE MOST OF THE NITROGEN AVAILABLE IN YOUR SOIL?

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Nitrogen (N) is an essential plant nutrient and is generally applied at relatively high rates to kiwifruit compared with other perennial horticultural crops. High levels of plant-available N encourage strong vegetative growth and may impair fruit quality in kiwifruit. This, coupled with the potential increase in leaching losses under a high N loading, justifies the need for research to improve our understanding of how N can be managed for maximum benefit without environmental compromise. In a three-year trial funded through the Sustainable Farming Fund, we investigated the impact of either higher or lower application rates of N compared with standard practice on high-yielding 'Hort16A' kiwifruit vines. This trial highlighted the potential for the soil at the trial site (pumice-derived Kaharoa ash) to deliver N through mineralisation processes. Vines receiving no additional N application over the 3 years continued to have good fruit size and yield. Vegetative growth was reduced in the Zero-N vines, but in this vigorous crop, reduced vigour is desirable.

Samples of top soil collected periodically at the trial site showed that up to 100 kg N/ha/y was available in the Zero-N treatment during the season. We evaluated the potential for the trial site soil to deliver N under optimised conditions in the laboratory: a temperature of 20°C and soil moisture at 80% field capacity.

In order to relate the trial site findings to other kiwifruit producing sites, soils from five other kiwifruit orchards were collected and mineral N was routinely evaluated during a period of constant soil temperature (20°C) and moisture (80% of field capacity). The incubation period was either 120 days (3 soils) or 180 days (2 soils). In addition to soils collected from kiwifruit orchards, two contrasting vineyard soils were also evaluated: the rate of N delivery from these typically impoverished wine grape soils contrasted with that from the kiwifruit soils. Predictions of N mineralised under these incubation conditions using SPASMO (Soil Plant Atmosphere Model, developed by HortResearch) matched well with measured values. Data presented here show that many soils producing kiwifruit have a high potential to supply N for plant growth, especially during the growing season when *in situ* soil moisture and temperature conditions are favourable for N mineralisation. Additionally the available N supply can be reliably predicted using SPASMO.

AN APPLICATION OF A MODELLING APPROACH FOR SUSTAINABILITY ANALYSES TO ORGANIC ORCHARD SYSTEMS IN NEW ZEALAND

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In this study, a conceptual framework to assess environmental sustainability of organic orchard systems in New Zealand is developed. Insights from the thermodynamic principles have been drawn upon to study environmental sustainability at the orchard system level. Sustainability in this framework is based on the principle of non-degradation of the environment. Sustainability of the orchard system is therefore considered to be lowered when degradation caused by an orchard system exceed the assimilative capacity of the environment. Management decisions, which bring in inputs of material and energy from the environment, are seen as the primary driving forces that result in environmental damage from the orchard system. The beneficial effects of the orchard system are the assimilation of CO_2 in the process of photosynthesis and the addition of organic matter to the soil through plant biomass and compost application. Secondary data are gathered from the literature and used in conjunction with the primary data collected from the growers in order to estimate impacts on the environment. Overseer® nutrient budget software and Stella® software are used as tools to model the link between organic kiwifruit and organic apple production systems and their environmental impacts, over one growing season. The methodological approach can be further developed by adding other aspects of the environment such as effects on biodiversity and by developing a dynamic approach to sustainability modelling of the orchard systems.

PADDOCK HISTORY AND THE RESPONSE OF MAIZE TO N FERTILISER

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The aim of this project is to determine the response of maize to fertiliser N in a high soil N environment. A trial was conducted near Dargaville on a Kaipara clay soil. It used two paddocks, one cropped for maize for 6 years (cropped paddock), the other in long-term pasture (pasture paddock). Both have high potentially mineralisable soil N levels (0-15 cm). Each paddock has six replicates of two N fertiliser rates applied to a maize crop (hybrid N48K2, sown 9 November 2005): Low N (45 kg N/ha) and Full N (183 kg N/ha).

- Pre-trial measurements in September found soil mineral N (0-30 cm) was greater in the maize paddock.
- The Full N rate increased maize silage and grain yield in the cropped paddock but not in the pasture paddock.
- At grain harvest in both paddocks, soil mineral N was greater in the Full N treatment than in the Low N treatment.
- Soil mineral N increased from September to grain harvest at all depths under both fertiliser treatments in the pasture paddock.
- Except in the top 30 cm of the Full N treatment, there was no increase in soil mineral N from September to grain harvest in the maize paddock.

The lack of yield response and the increase in soil mineral N (even in the low N treatment) in the pasture paddock emphasises the N-supplying ability of paddocks in the first year out of long-term pasture. Growers should use considerably less fertiliser N on paddocks coming out of long-term pasture than on paddocks with a long cropping history.

To determine N fertiliser requirements, growers can use AmaizeN (a yield and N fertiliser forecaster) which will be released in time for the 2008-09 season.

THE RISK OF FERTILISER N LEACHING FROM MAIZE CROPS IN GISBORNE

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Nitrogen fertilisers are important inputs for maize growers. We aimed to identify the risk that rain will cause leaching of fertiliser N from Gisborne maize crops by analysing long term weather data from the NIWA database to determine:

- The long-term pattern of rainfall through the year
- The chances of rain on any chosen day of the year
- If it does rain, how much rain can be expected.

We ran a simulated the soil water balance which calculated the *earliest* date at which fertiliser leaching losses below 1m could occur. These calculations were made for fertiliser applied at sowing and side-dressed 28 days after sowing.

In the worst season for leaching (1992-93), fertiliser N applied at sowing moved below 1m on 3 December but not much further. Fertiliser applied 28 DAS moved below 1m on 25 February, by which stage the crop would have taken up most of the N applied.

We also measured soil mineral N amount and distribution in long term maize (> 10 years), short term maize (< 6 years) and long term pasture paddocks. Fifteen paddocks were sampled for soil mineral N to 1.80 m in 30 cm increments. We found no difference between land uses at any of the depths sampled. Repeat sampling of soil mineral N after a 300 mm rainfall event showed N movement to 60 cm but not below. This movement of N was similar to that estimated from drainage calculations.

This study strongly suggests that there is little chance of significant leaching of fertiliser N from maize crops around Gisborne provided that growers apply only enough N fertiliser to meet the crop’s needs after allowing for soil N supply.

REDUCING SURFACE RUNOFF AND SOIL EROSION FROM CROPPING SYSTEMS USING FURROW DIKING

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Creating soil dikes in the wheel tracks of raised cropping beds is a simple grower management option that can significantly reduce surface runoff during rainfall and irrigation events. This practice (known as furrow diking) can dramatically limit soil erosion and nutrient loss, and prevent localized within-field flooding, problems that continue to have significant agronomic and environmental implications. In 2007, two sites were established in the Hawke's Bay to compare furrow diking with the standard industry practice (no diking). One site represented over-winter fallow conditions, the second a summer-grown commercial onion crop. At both sites furrow-diked and control plots were set up in 50-75m sections of row and surface runoff and sediment loss measured during rainfall and irrigation events. Slope in these areas of the field was minimal (< 1°). At the second site the effect of localized flooding on onion yield was also quantified in low lying sections of the field. Over-winter furrow diking reduced surface runoff volume by > 90% compared to the undiked control; seasonal flow (rainfall and irrigation combined) was equivalent to approximately 170mm. Furrow diking also reduced over-winter sediment loss by approximately 66% on a concentration basis (kg sediment lost/L runoff) and > 95% on a mass balance basis (kg sediment lost) compared to the control. At the summer site, localised flooding in the crop caused during irrigation reduced onion populations by 35-70% compared to adjacent unflooded areas. Average bulb size and overall yield in these areas was also significantly less. While the extent of yield and profit loss can vary considerably depending on field contours, these results indicate that practical techniques that reduce surface flow still confer significant grower and environmental benefit.

WINTER COVER CROPS AFFECT SOIL MINERAL N LEVELS AND NITRATE LEACHING

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Experiments were conducted at Hawke's Bay and Waikato over two seasons (2002 to 2004) to investigate the effects of winter cover crops on maize production and key environmental sustainability indicators. In the second season (2003-04), soil mineral N and nitrate leaching was measured from a range of winter cover crop treatments including legume (tickbeans and blue lupins) and non-legume (Italian ryegrass, oats, barley, triticale) crops, and a winter-fallow control.

There were significant differences between treatments in soil mineral N (0-60 cm) at the start of the second season (winter 2003), presumably the result of differences in management and productivity of the previous years treatments. In spring 2003 there were significant differences between treatments with a trend for lower total mineral N levels in non-legumes than legumes and fallow at both sites.

Leachate sampling throughout winter 2003 indicated leachate N was correlated with soil mineral N levels at the start of the winter season. At both sites, between 80 and 90% of the variation in leachate N at the first two sampling dates could be explained by differences in the amount soil mineral N present in the 30cm of the soil profile that contained most of the mineral N at the start of winter (before sampling commenced). Leachate nitrate concentration decreased over the winter except under the legumes where it increased on the last 2 sample dates, probably as a result of N fixation. We conclude that the soil mineral N at the start of winter and the choice of winter cover crop has a direct impact on leaching losses and soil mineral N levels at the end of the winter.

GREENHOUSE NUTRIENT SOLUTION MANAGEMENT - ISSUES AND OPPORTUNITIES

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Nutrient solution discharge from hydroponic greenhouse operations has been considered as a potential pollution source by New Zealand regional authorities. In 2006, to assist greenhouse growers to comply with regional requirements, Vegfed launched the "Code of Practice for The Management of Greenhouse Nutrient Discharges" (COP).However, growers current practises were not well documented.

To aid further development of the COP, Vegfed funded a multiple-case study designed to investigate the nutrient solution management and disposal practices of New Zealand greenhouse tomato growers and, further, to investigate whether or not the growers' practices met the guidelines given in the COP.

Three growers were selected as case studies to represent the hydroponic greenhouse tomato industry. Nutrient solution management information about theses operations was obtained by interview. The results show that none of the case study growers' practices fully met the guidelines given in the COP. The case study growers lacked appropriate nutrient solution disposal strategies.

The main issues identified were:

1. Urban growers lacked suitable release sites for disposal of their nutrient solution on to land;
2. None of the case study growers released their nutrient solution when soil conditions at the disposal site were optimal as they lacked storage capacity;
3. None of the case study growers kept adequate records of disposal activities.

The research results indicated that using "high tech" recirculating systems can most readily meet the environmental requirements likely to be laid down by regional authorities. However, as greenhouses located in rural areas have better access to appropriate sites for land disposal than their urban counter parts, future industry development should be focussed in these areas. Further, unless growers located in urban areas are prepared to pay for disposal of waste nutrient streams in sewers, it is unlikely that they will ever meet the guidelines described in the Code of Practise. Further, because of the relatively large volumes of liquid involved, and hence cost of transport, and the irregularity of release, it is unlikely that a viable by-product industry can be developed to utilise this waste stream. Meeting regional environmental regulations will continue to be an industry responsibility, growers will need to design their systems appropriately.

BALLANCE AGRI-NUTRIENTS APPROACH TO SUSTAINABLE FERTILISER USE

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Ballance Agri-Nutrients has made, and continues to make, considerable investment in encouraging sustainable fertiliser use, both in terms of human resource capability, as well as in product and service agronomic R & D.

With the advent of nutrient budgeting and the migration towards nutrient management plans, there is an ever-increasing service time per client. To ensure we can deliver on shareholder expectation, Ballance field staff (TSRs) numbers have grown considerably over the last five years. Internal and external technical training is a major focus for Ballance, being designed to increase the rate at which staff upskill and build confidence. Ballance has the goal of ensuring that 100% of TSRs have passed the Intermediate level Sustainable Nutrient Management (SNM) course within 18 months of employment, and that a rolling 80% of all TSRs have passed the Advanced SNM course.

Ballance funded research into nitrification inhibitors has proven equivalence between granular and liquid versions of dicyandiamide, with research results having been built into the new version of Overseer 5 (due for release early 2008). Trial work on agrotain (a urease inhibitor) -coated urea has shown small, non-significant increases in N response efficacy relative to standard urea, with this response improvement attributable to an ammonia volatilisation suppression mechanism. Phosphorus loss mitigation research has shown the benefits of Serpentine super, whereby incidental P-runoff (and in rare circumstance P-leaching) can be considerably reduced, without a reduction in agronomic performance. Funding of crop growth and nutrient response models has been a priority for Ballance, in an effort to improve nutrient requirement forecasting, particularly important in regard to N use.

A life cycle assessment carried out by Ballance indicated that locally manufactured Superten is more energy efficient and has lower global warming potential (GWP) than imported TSP or RPR. Manufacture of urea at Kapuni has lower GWP than importation of urea, largely due to reduced CO_2 emissions associated with transportation. Dry blend NPK fertiliser (imported DAP/SOA/KCl) was shown to have lower GWP than imported compound NPK fertiliser, however agronomic implications regarding precision of nutrient delivery must also be taken into account.

COMBINING UREASE AND NITRIFICATION INHIBITORS TO DECREASE N LOSSES IN AN INTENSIVE GRAZED PASTURE SYSTEM

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Losses of nitrogen (N) from urine patches such as gaseous emissions of ammonia (NH_3) and nitrous oxide (N_2O) into the atmosphere along with nitrate (NO_3^-) leaching into surface and ground waters, are one of the major contributors to environmental degradation in the New Zealand landscape. Treating urine patches with N inhibitors (urease and nitrification inhibitors) have the potential to mitigate such N losses. A lysimeter experiment near Lincoln on a permanent pastoral site is currently underway to quantify these N losses. The nitrification inhibitor dicyandiamide (DCD) alone, or in combination with the urease inhibitor N-(n-butyl) thiophosphoric triamide (nBTPT) or "Agrotain" i.e. double inhibitor (DI) were applied to undisturbed lysimeters at different rates with cow urine (600 kg N ha^{-1} rate) in autumn and spring. Gaseous emissions of NH_3 and N_2O, NO_3^- leaching and pasture production were monitored following the application of treatments during each season. Nitrogen losses and pasture dry matter varied with the type and rate of the applied inhibitors during the 2 seasons. Over all during the 2 seasons, DCD application reduced N_2O emissions and NO_3^- leaching losses but increased NH_3 emissions. Treatments receiving both inhibitors (Agrotain + DCD) were more effective in reducing losses of NH_3, N_2O and NO_3^- leaching as well as increasing pasture production. These results suggest that applying Agrotain + DCD (at a ratio of 1 l/ha Agrotain + 7 kg DCD/ha) may provide the best hope for both mitigating N losses and improving pasture production in intensively grazed systems.

BREEDING FORAGE PLANTS TO MINIMISE LOSSES OF NITROGEN AND PHOSPHORUS

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Phosphorus (P) and nitrogen (N) fertilisers are very significant costs in New Zealand farm budgets, and there are increasing concerns about the negative impacts of N and P losses from pastures on water quality. Breeding forage grasses that retain more N in the production cycle, and forage legumes that are productive with lower P inputs are relatively recent initiatives. In Waikato pastures about 80% of ryegrass roots are located in the top 10cm of soil, so breeding plants with deeper roots seemed an obvious target for interception of mobile ions like nitrate. Root depth profiles have proved to be extremely variable at the genotype level, and this is probably a mechanism to reduce intra-specific root competition. Increased rooting depth is not going to be readily achieved by conventional breeding because of low heritability for the trait. For nitrate retention, increasing root length frequencies is effective, and this has been demonstrated both practically and by simulation modelling. Shoot and root size are not closely linked in ryegrass. Heritability estimates for root mass in ryegrass suggest the potential to select for high root mass without compromising shoot growth. White clover roots are relatively coarse and non-branching compared with ryegrass roots. This makes clover a poor competitor for P. Development of clovers with extensive, fine root systems would enable pastures to be productive with lower P inputs than those used currently. Phenotyping studies of white clover root systems have shown potential genetic variation for a range of root traits. This indicates the possibility of genetic improvement through conventional breeding. Genotypes with high expression of key traits such as number of root tips have been identified. These genotypes may improve P uptake as their highly branched roots will explore a large volume of soil per unit root weight. It is concluded that there is considerable potential to develop new grass and clover cultivars with root systems that optimise capture of N and P.

THE ROLE OF THREE DIFFERENT MODEL TYPES FOR ESTIMATING NUTRIENT LOSS IN PASTORAL FARMS

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Models have been increasingly applied in the estimation of nutrient loss from agricultural fields in New Zealand. Models have shown to be useful tools for addressing both economic and environmental issues. Nonetheless, the use and acceptance of models have been restricted due misconceptions and lack of information about their potential. It is necessary, on the other hand, to recognise their limitations in order to avoid misuse and to continue their development.

In New Zealand, due to farming intensification and the consequent increase on the number of animals and fertilizer use, nutrient losses are becoming an increasing concern. Tools for the assessment and monitoring of these losses are in demand. Several models of varying complexities are being used in the country to estimate nutrient loss. This multitude of options is a consequence of the different level of detail and scales at which nutrient losses can be reported, and the varied intended use for such reports. For a good outcome, thus, it is necessary to choose a model that can handle the natural processes at the level of detail and uncertainty required for a given purpose.

Using three models of varying complexity as examples, we review the process of selecting a model and discuss the best way to communicate their results. We intend to show that the existing models are best view as complementary instead of competing. For this we focus on their strengths and complexities. We also point on the limitations and, especially, on the lack of information about the models that seems to constrain their use.

Modelling is an important scientific technique and ever more become available for use as support tool for farm management and policy making. Thus, it is important to consider their different scopes for selecting the appropriate model for an intended use. It is, however, more important to know what type of information, including uncertainty level, is suitable for the analysis being made.

NITROUS OXIDE EMISSIONS FROM DAIRY FARMLETS, AS AFFECTED BY USE OF A WINTER RESTRICTED GRAZING STRATEGY AND A NITRIFICATION INHIBITOR: YEAR 1

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This study, funded by the New Zealand Pastoral Greenhouse Gas Research Consortium (PGGRC), is examining nitrous oxide (N_2O) emissions from "Prototype farms for dairy farming's future". The experimental farmlets are at Dexcel's Scott Farm near Hamilton, New Zealand and represent highly productive dairy pasture. We are using two farmlets: Control farmlet with a stocking rate of 3.0 cows ha^{-1} and managed under a rotational grazing regime and "Tight N" farmlet with a stocking rate of 3.0 cows ha^{-1}. The grazing regime on this farmlet is similar to that on the control farmlet, except during the non-lactating period between late autumn and early spring when cows graze for about 6 hours per day on pasture with the remaining 18 hours on a stand-off pad or in a herd home. A nitrification inhibitor (Eco-N) is applied onto the "Tight N" farmlets on 3 occasions in winter and early spring. A soil chamber technique is being used to measure N_2O emissions in several paddocks from each farmlet during three contrasting seasons of the year.

During late spring/early summer 2006 and autumn 2007, N_2O emission rates were generally similar between the two farmlets, except for the measurement period during November 2006 when the rates were higher from a "Tight N" farmlet paddock than those simultaneously measured from a control farmlet paddock. During winter/early spring 2007, N_2O emission rates were lower in the "Tight" N farmlet than in the control farmlet. It is estimated from these results that the use of a restricted grazing regime and a nitrification inhibitor reduced N_2O emissions from the dairy farmlet by 43-55% during the winter/early spring season. These should be viewed as preliminary data from three sampling seasons only, and further measurements are being conducted to determine any differences between the two farmlets.

ONE-STEP, ON-TRUCK FLUIDISATION AND SPREADING OF FERTILISER OPTIMISES PASTURE AND CROP RESPONSE WHILE MINIMISING NUTRIENT LOSSES TO THE ENVIRONMENT

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The doubling and even tripling of most fertiliser prices in the past year has added fresh impetus to finding ways to use nutrients more efficiently. The environment will benefit from this.

Granular urea is the cheapest form of fertiliser nitrogen (N) per unit in most countries, including New Zealand. Intensification and expansion of dairy farming is the main reason for the 5-fold increase in its use in the last decade. Unfortunately however, urea is susceptible to a variety of significant losses, including ammonia volatilisation, nitrate leaching, and nitrous oxide and dinitrogen gas emissions. Consequently, plant uptake of applied urea-N seldom exceeds 50%.

Coating granular urea with the urease inhibitor NBPT (trade name Agrotain) greatly reduces ammonia volatilisation and, as an indirect effect, substantially reduces nitrate leaching. However, it has only a minor effect in reducing losses of the serious greenhouse gas nitrous oxide. Incorporation of the nitrification inhibitor dicyandiamide (DCD) substantially reduces this form of loss.

Recent research has demonstrated that the efficiency of both urea, and urea coated with Agrotain, are massively increased if they are crushed to a fine form before application to pasture. However, up until recently, these fluidised or "fine-particle" products have to a large degree been available for application only from helicopters or fixed-wing aircraft fitted with tanks and booms, and supported by trucks which crush and fluidise the material, and keep it in suspension by stiring until loading - at only a tonne or so at a time - into the aircraft. This capital and staff-intensive operation is a high-cost one, and has consequently tended to limit the market to large applications in either steep and or wet areas, and where fertiliser N was a high priority.

It was therefore considered that, for dairy farming in particular, where relatively small quantities of fertiliser N are applied frequently, in order for the agronomic and environmental benefits of fluidised application to be realised cost-effectively, it would be necessary to somehow process the product "on-truck" during the spreading operation. The Quinspread "Fluidator" is the outcome of two years research and development of a solution to this problem.

MANAGEMENT PRACTICES TO MINIMISE WIPE-OFF LOSSES FROM BORDER-DYKE IRRIGATED LAND

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The application of water to land using border dyke irrigation comes with a large risk of over watering: resulting in surface runoff overflowing designated strip lengths. The generation of such run-off is termed 'wipe-off'. Wipe-off water typically contains large concentrations of contaminants, in particular phosphorus and faecal bacteria. The Canterbury region includes some large areas of border dyke irrigated land. Wipe-off water from the Amuri Plains of North Canterbury and the Waitaki plains of South Canterbury has been identified as a considerable contributor to poor water quality measured in local water bodies. Previous research on a heavy soil type in the Waikakahi catchment of South Canterbury on some difficult-to-manage old borders found that wipe-off losses were in the order of 50% of the inflow irrigation volume. Therefore it is the reduction of volume of wipe-off water that will best decrease contaminant load to fresh water.

In order to decrease the impact of wipe-off water, the following mitigations have recently been evaluated in both North and South Canterbury:

1) Pond and Spray - Capture of all wipe off water on a farm scale and subsequent ponding for intended re-use via spray irrigation to either a previously poor performing border dyke area or to an area not previously watered.

2) Restricted watering times - Careful clock and pasture cover calibration to adjust watering times for each border dyke strip across the farm.

3) Wide laser levelled borders – Re-engineering old narrow borders to improve water use efficiency.

At a whole farm-scale the pond and spray mitigation was proven successful at eliminating all wipe-off loss. Restricting water times resulted in whole farm wipe off losses of approximately 10% of irrigation input water. A paddock scale assessment of wide laser levelled borders showed a considerably improvement upon traditional narrow borders with a range of wipe off losses recorded from 0.3% to 10%.

A STUDY OF NITROGEN LEACHING LOSSES UNDER WINTER FORAGE CROP GRAZED LAND

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In the Southern regions of New Zealand, large numbers of sheep and cattle graze paddocks sown in forage crops during winter that allow pastures in the reminder of the farm to be rested from stock pressure. However, grazing forage crops during winter can lead to soil physical damage and contaminant losses. Limited data exists on nitrogen (N) leakage in rolling Pallic soil landscapes with impeded drainage under different stock types. We utilised a trial site in North Otago (Mottled Fragic Pallic soil - Timaru silt loam) with three years of prior history of sheep and cattle grazing on winter forage crops to measure potential N losses in leachate from shallow lysimeters (15 cm diameter and 24 cm deep). In addition to stock type, the nitrification inhibitor, DCD was also trialled as a mitigation option to decrease potential N loss. While there has been considerable research of the benefits of DCD use in a New Zealand pastoral context, little work has examined the effectiveness of DCD under a grazed winter forage crops and none examining its effectiveness under sheep grazing. Treatment comparisons have been made to determine the relative potential decrease in nitrate-N losses with and without DCD.

DEPTH DISTRIBUTION OF FORMS OF MINERAL NITROGEN IN A HILL SOIL AFTER THREE YEARS OF FERTILISER NITROGEN APPLICATION

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Fertiliser nitrogen (N) use in hill country has increased in recent years, but there is little information on the environmental impacts of an increased N supply in this relatively nutrient limited high carbon environment.

Larger than expected amounts of mineral N (ammonium-N (NH_4-N) and nitrate-N (NO_3-N)) leaching have been measured using small (150 x 300mm) *in situ* lysimeters in an N fertiliser trial on a mottled argillic pallic hill soil at the Ballantrae Research Station (southern Hawkes Bay). The proportion of mineral N leached in the NH_4-N form has also been higher than expected.

In June and August 2007 a soil sampling campaign was conducted to determine if the movement of mineral N down the soil profile measured via the *in situ* lysimeters was an artefact of the method used to measure N leaching, or whether this movement was real. Mineral N was extracted from individual soil cores in 100mm increments down to 400mm (June) or 500mm (August).

In June, NH_4-N was present in 80% of soil samples at the 300-400mm depth in both the control (0N) and the 500 kg fertiliser N/ha.year (500N) treatments. Nitrate was present in 100% of soil samples at this depth for both 0N and 500N. There was no significant difference in the amount of NH_4-N present between depths or between the two fertiliser N treatments but there was more NO_3-N present ($p<0.001$) at all depths in the 500N treatment than in the 0N.

In August, NH_4-N was present in 60% and NO_3-N in 95% of soil samples at the 400-500mm depth for all of the N fertiliser treatments sampled (0, 100, 200 and 400N). The 200N and 400N treatments had greater amounts of both forms of mineral N present at most of the depth increments than the 0N and 100N treatments ($p<0.02$ for NH_4-N and $p<0.001$ for NO_3-N).

These results raise questions regarding the conventional understanding of the movement of mineral N, and particularly NH_4-N, in hill soils; and have relevance for future research on N fluxes in hill country.

THE IMPACT OF UREASE INHIBITOR ON THE UPTAKE OF GRANULAR UREA IN RYEGRASS

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Urea is a widely used nitrogen (N) fertilizer but under some circumstances has been associated with relatively poor N use efficiency due to losses after application. The objective of this glasshouse-based study was to investigate the potential of incorporating urea fertilizer with urease inhibitor (N-(n-butyl) thiophosphoric triamide (nBTPT) - "Agrotain®") to enhance fertilizer N efficiency and reduce N losses in pasture applications. Topsoil (0-7.5 cm soil depth) from a permanent pasture site was collected at Lincoln, Canterbury, and ryegrass was grown from seed in standard plant trays maintained at approximately 80% field capacity. Three weeks after sowing, ryegrass in each tray was treated with different N forms (urea, Agrotain-treated urea, ammonium nitrate, ammonium sulphate and sodium nitrate). Fertilizer in granular form was uniformly applied to the soil surface at rates equivalent to 25 or 50 kg N/ha (with 4 replications). Pasture was harvested to a height of 4 cm to assess dry matter production and total N. The sum of two pasture cuts (21 and 42 days after fertiliser application) showed that both pasture dry matter and N uptake were significantly ($P<0.001$) increased in response to N fertilizer application compared with controls. Urea fertilizer treated with Agrotain improved pasture production in comparison with urea alone by 15, 19 % and performed significantly ($P<0.001$) better than all other fertilizer treatments. Agrotain-treated urea @ 25 and 50 kg N/ha also significantly ($P<0.001$) increased the N efficiency (dry matter production per kg of N applied) of the pastures compared with urea alone (by 66 and 68%, respectively). Total N uptake was significantly ($P<0.001$) greater when pastures were supplied with Agrotain-treated urea than in response to fertilization with other N forms. Nitrate reductase activities (NRA), tissue ammonium and nitrate concetrations were also assessed and were found to be within previously established optimal ranges. Treating urea with Agrotain has potential to increase N use efficiency and pasture production. Further research is now investigating the mechanisms involved.

IMPROVING THE EFFICIENCY OF N FERTILISERS

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Increasing environmental pressure, along with increasing world fertiliser prices are putting pressure on farmers to find alternative technologies and fertiliser management techniques to improve efficiency and potentially reduce both inputs and losses. Five field trials were conducted under various soil and climatic conditions in the North and South Islands of New Zealand (two sites in the Waikato and three in Canterbury) to assess the potential of the urease inhibitor Agrotain™ for improving nitrogen (N) responses from urea fertiliser. Two fertiliser regimes were tested, where either urea or urea + Agrotain (SustaiN Green) were applied at 50kg N/ha after every two pasture cuts, or split to apply 25kg N/ha after every pasture cut. This technique allowed for both the effect of fertiliser form and method of application to be compared and assessed. Each trial was run for different periods of time ranging from 6 months to 16 months. The results show that in general the split application of 25 kg N/ha gave similar N responses to the single 50kg N/ha rate in both the urea (range of 11 – 24 kg DM/kg N) and SustaiN Green (range of 15 – 32 kg DM/kg N) treatments. In every trial, the SustaiN Green treatments produced better N responses (not always statistically significant) than the comparative urea application rate. On average SustaiN Green improved N responses by 41% (range 23 – 72%) compared to ordinary urea. These results are in line with other work comparing the two fertiliser types and shows that there is considerable potential for using urease inhibitors as a technology to improve the N responses from urea fertiliser under a range of soil and climatic conditions.

TOOLS TO DETERMINE IMPACT OF ANIMAL BEHAVIOUR ON NITROGEN LEACHING AND NITROUS OXIDE EMISSIONS

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Greatest N losses from grazed pastures are nitrous oxide gas and leached nitrate emitted from urine patches. These losses increase exponentially as the load of N excreted in the urine patch increases. Mitigating these environmental pollutants may become easier if we know where urine is excreted so that management practices can be targeted, especially in systems where animals create stock camps that become critical source areas of pollution. This paper describes the use of a urine sensor used with sheep to log the time of day of each urination event. A GPS worn by these animals logged sheep movement and located urine patches within the field. A locally calibrated canopy reflectance spectra (350-2500 nm) was used to map variation in pasture mass and quality. Polygon (10 m grid cell) data layers describing the patterns of pasture mass and quality, elevation, slope, aspect, animal movement and urination sites were analysed by multiple regression to create prediction equations of where sheep spent their time (*Tmin*) and where they urinated (*Uevents*) in this hill country pasture. We employed a geographically weighted regression (GWR) approach that allows the regression model parameters to vary in space, and compared the model performance with ordinary least square (OLS) regression. For *Tmin*, greater model performance was obtained using the GWR model (R^2 = 0.86) than the OLS model (R^2 = 0.30). Elevation, slope, aspect and the standing mass of sulphur were factors that significantly influenced *Tmin* grid cell values within this paddock. A Monte Carlo significance test indicated that these parameters and the standing mass of potassium had significant spatial variation in the local parameter estimates for the *Tmin*. When predicting *Uevents*, similar results were obtained and there was a significant improvement in model performance when using GWR (R^2 = 0.87) over OLS (R^2 = 0.30) with the same parameters. However, *Uevents* was strongly correlated with *Tmin* (R^2 = 0.78), and the GWR model predicting urine distribution patterns from *Tmin* alone (R^2 = 0.82) suggesting *Uevents* was strongly dependent upon *Tmin*. Moreover, using Moran's *I* index, strong spatial dependencies were observed both for *Tmin* (0.56) and *Uevents* (0.56), indicating that values for *Tmin* and *Uevents* for any polygon cell were influenced by similar variation within variables in neighbouring cells. From these results, we conclude that spatial variability of *Tmin* and *Uevent* has spatial autocorrelation and heterogeneity, and can be modelled by environmental factors applying local regression in GWR. Furthermore, our results provide useful insights for future regression analyses on spatial non-stationary relationships, especially when interpolation is required in strongly heterogenic environments, such as in hill country pasture.

MANAGEMENT FACTORS AFFECTING SOIL ORGANIC CARBON IN NZ PASTURES: A REVIEW

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Soil organic carbon levels are dynamic and trend to quasi-steady state levels which reflect the balance of carbon inputs and outputs from the soil system. A large number of soil management and environmental factors including moisture, temperature, fertiliser inputs, irrigation, cultivation, grazing intensities affect carbon inputs in the turnover rates of the carbon cycle and stabilisation of soil organic matter. The net effect of these factors on soil carbon storage could be negative or positive depending on the baseline carbon values in soils. Pasture development on previously degraded or virgin soils typically results in a rapid increase in soil carbon levels for up to 100 years. It was a widely accepted view that an increase in pasture production would result in an increase in soil carbon. However, some of the recent studies both in New Zealand and overseas suggest that carbon sequestration in pasture soils is probably not as much as was previously thought.

Re-sampling by Tate et al (1997) of soil survey sites showed that there was little change in soil carbon levels on most pastoral farms during the period of 1950 to 1990. These results were supported by long-term monitoring of topsoil carbon on the Winchmore rates of fertiliser experiment, but contradicted by results from the Ballantrae long-term fertiliser experiment where topsoil carbon levels declined. A more recent re-sampling of soil survey sites by Shipper et al (2007) found evidence of a decline in soil C levels from 1980 to 2004. It has also been observed (Ghani et al, 1996 & 2003) that soil carbon levels tend to be lower on dairy farms than sheep/beef farms. These results tally with experimental evidence that intensification of pastoral management through frequent irrigation and increased stocking rate may result in a net loss of soil carbon. There is also evidence from overseas long-term cropping experiments that increased nitrogen fertiliser use can lead to a decrease in soil carbon. These observations can be explained by the effects of management practices on components of the carbon cycle.

SOIL CARBON AND NITROGEN:
WHY ARE WE LOSING CARBON AND NITROGEN FROM NZ PASTURE SOILS

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There are increasing concerns that pastoral soils in temperate regions are losing soil carbon (C) and nitrogen (N). The aim of this study was to quantify the influence of some of the factors that may be contributing to these losses in soils. We examined the effects of three factors that may influence the changes in C and N observed in a subset of six pasture soils that were originally sampled by Schipper et al (2007). In these soils we examined (i) movement of dissolved organic carbon (DOC) and nitrogen (DON) beyond the rooting depths, (ii) effects of respiration rates both under sieved and intact conditions and influence of temperature (5, 10, 20 and 30ºC), and (iii) examined the relationship between root biomass and structure and changes in soil C and N in these soils.

Lysimeter studies using intact soil columns (230 mm diameter x 250 mm depth) showed that a significant proportion of dissolved organic matter (DOM) in the form of DOC and DON can be lost through leaching beyond the rooting depth. We measured between 332-1834 kg C ha^{-1} yr^{-1} leaching as DOC and between 42-127 kg N ha^{-1} yr^{-1} leaching of DON. These leaching losses of DOC and DON could account between 13-65% loss of total C and 17-30% loss of total N in these soils that was estimated by Schipper et al (2007). The gley (poor draining) soils lost significantly greater amounts of DOC and DON than the free draining allophanic soils. These soils tended to have significantly less root biomass in 0-500 mm depth compared to the free draining allophanic soils.

Soil temperature can have significant influence on microbial activity and hence on the CO_2 respiration rate. In our study, soil temperature between 5-30ºC had a significant influence on respiration rates in all soils. We estimate that an increase of 1ºC from the annual mean temperature (13ºC) in soil temperature could cause additional loss of 0.2-0.7 t C through respiration.

ENVIRONMENT WAIKATO'S ROLE IN CARBON MANAGEMENT

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The Waikato region has many opportunities for both bio-sequestration of carbon and soil carbon increases and for environmental benefits related to carbon management to be realised. This link between managing carbon and achieving other environmental objectives is recognised and built into the government's land management and climate change policies released in 2007.

This paper discusses the approach Environment Waikato is taking towards carbon management in the region, in order to take advantage of these opportunities in the new central government policy environment. Having a targeted, co-ordinated approach to carbon management is important - the region has approximately 1.5 million ha of agricultural land, in excess of 100,000 ha of highly erodible, Kyoto compliant land and approximately 50,000 ha of nutrient constrained land in the Lake Taupo catchment. There is therefore real scope to contribute to meeting New Zealand's climate change commitments as well as achieving regional environmental co-benefit improvements.

Current projects related to carbon management are described. There is a large intersect between these projects and those relating to other aspects of soil and water management as inputs that affect land based carbon emissions are the same inputs that affect other nutrient losses.

In addition, the paper outlines the community and legal imperatives for Environment Waikato to respond both to climate change and to carbon management. Underpinning the Council's approach to carbon management, in part, are climate change principles of adaptation and mitigation - adapting to changes in climate that are already happening and taking actions that mitigate future effects to avoid climate change at scales that we cannot adapt to. The paper concludes by discussing the 'fit' between these principles and those relating to environmental co-benefits such as improved soil conservation, improved water quality, downstream flood protection, improved biodiversity and protection of infrastructure.

ENVIRONMENTAL PROTECTION BY A CONSTRUCTED WETLAND DURING AN ACCIDENTAL EFFLUENT SPILL

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Man-made wetlands have been constructed to receive and treat a wide range of organic and inorganic effluents, including drainage water. A constructed wetland (CW) system on a dairy farm was designed to treat the sub-surface drainage water exiting an irrigation area receiving dairy shed effluent. Previous studies had demonstrated its effectiveness at reducing nitrate, however, its capacity to reduce faecal bacterial numbers was less clear. CW effluent frequently contains a minimum of 50-100 *Echerichia coli* per 100 mls, despite incoming effluent containing comparable or sometimes lower numbers, making tracing bacterial removal problematic. At the time of this study the pipe to the irrigator broke, discharging raw dairy shed effluent into the CW system for a period of up to 10 days.

Effluent entered the first wetland as overland flow and via the subsurface drainage system, both of which were flowing at about 100 ml s^{-1}, giving a theoretical HRT in the first CW of 16–17 days. The effluent entering as overland flow had a median *E. coli* concentration of $1.1x10^8$ MPN 100 ml^{-1}, while that which had infiltrated through the soil profile into the subsurface drainage system carried a significantly lower concentration of bacteria, with a median of $3.7x10^6$ MPN 100 ml^{-1}. After passing through the first CW, *E. coli* concentrations had reduced by between 0.5–2 orders of magnitude, to a median of $1.4x10^6$ MPN 100 ml^{-1}. Concentrations were reduced by a further 3–4 orders of magnitude after passage through the second CW (median of 528 MPN 100 ml^{-1}; HRT of 12 days). Overall removal of *E. coli* within the whole CW system was around 5-6 orders of magnitude.

Despite the significant volume of untreated effluent entering the CW's, effluent concentrations were largely unaffected. Thus the CW provided a high degree of buffering and protection of the environment from a potentially serious effluent spill.

CAN HYDROPHOBICITY EXPLAIN THE DRY-PATCH-SYNDROME OF HAWKE'S BAY HILL COUNTRY PASTURES?

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A soil is hydrophobic if it repels water. Soil hydrophobicity is increasingly being found to occur in soils of different texture, land-use, and under a variety of climatic conditions when they dry out. The most important effect of soil hydrophobicity is its importance as a controlling factor in soil water dynamics close to the soil surface. Water does not infiltrate into hydrophobic soil, instead the water runs off. As a consequence hydrophobic soil cannot store water and this in turn will limit pasture production.

We have identified a connection between the increasing incidence of the Dry-Patch-Syndrome (DPS) and soil hydrophobicity on eight pasture sites on a farm in the Maraetotara district, Hawke's Bay. In summer the pasture sites had "dry" patches within the pasture with little or no pasture growth. At the end of summer all soil samples taken within the dry patches and adjacent pasture were hydrophobic. However, the degree and persistence of soil hydrophobicity was higher within the dry patches (contact angles of about 100°) than in adjacent pasture (contact angles of about 98°). Soils become hydrophobic if they dry out below the so-called critical water content. We analyzed the critical water content for the pasture site where the DPS was most pronounced (contact angles of about 105°). Within the dry patches the critical water content was 0.35 g/g, which was higher compared to the adjacent pasture at 0.22 g/g. Consequently, the soil within the dry patches becomes hydrophobic much earlier in the season than in the adjacent pasture limiting the storage of water within the dry patches. Pastures dry off earlier in the season and pasture production during summer is compromised. In autumn, the higher persistence of soil hydrophobicity within the dry patches, delays the rewetting of the soil. Water runoff is exacerbated with all its consequences and pastures are slow to recover.

Predicted changes in climate change may lead to a more regular occurrence of droughts in non-irrigated hill country pastures in Hawke's Bay and elsewhere in New Zealand. As a consequence, soil hydrophobicity could have major economic implications for the pastoral industry in those areas.

THE MEASUREMENT OF SULPHUR STATUS OF PASTORAL SOILS

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In the early 1990s, researchers at AgResearch developed the two soil sulphur (S) tests, sulphate-S (SO_4-S) and extractable organic-S (EOS). The sulphate-S test measures the immediately available S while on the same extract the easily mineralisable component of soil organic-S, is determined using a difference technique.

Studies done by AgResearch indicated that SO_4-S was the most variable soil test when compared to other major soil tests Olsen P, QTK and pH. It was shown the between-year coefficients of variability for hill country and flat to rolling land was 37.4% and 45.8% respectively for SO_4-S.

When developing the two S tests scientists proposed the quasi-equilibrium theory i.e. an equilibrium exists between SO_4-S, EOS and the large soil organic-S pool. Given that over 95% of the total S in soils are organically bound therefore assessment of the total S pool may be a good indicator of the S status of New Zealand pastoral soils.

This study investigated whether the total S pool in soil could be a better measure of the S status than SO_4-S or EOS. Total S accounted for 71% of the variation when compared with Relative yield for 43 field trials, whereas mineralisable-S accounted for 58% and SO_4-S accounted for 59%. The SO_4-S is easily influenced by sources such as urine and dung from grazing animals, leaching, fertiliser and atmospheric inputs. On average Organic-S accounted for 97% of the TS (Total Sulphur) of which 3% was EOS. The SO_4-S component was on average 3% of TS. The total S pool, because of its magnitude, is not influenced by external sources to the extent that EOS and SO_4-S in particular, can be. It is therefore proposed, that total S is a better and more robust measure of the S status for New Zealand pastoral soils.

THE EFFECT ON SOIL CONDITIONS FOR PLANT GROWTH OF THE GRANULATION OF LIMING MATERIALS

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A field trial was conducted to evaluate the performance of a granulated agricultural liming product in comparison to ordinary powdered agricultural lime at application rates of 500, 1000, 2000 and 4000kg of applied material/ha. The granulated product was manufactured using standard aglime, hydrated lime, sugar and potassium sulphate, the latter two being added to assist with granule binding.

Soil tests were taken at application, and one, three, six and twelve months after application. At no stage were there significant differences in soil pH between the two materials at any rate of application, although there was an early trend for the granulated product to increase pH faster than aglime at the high, but not the lower, application rates.

Despite the site having an initial soil pH of 5.4, there were no significant responses to liming until the final harvest one year after commencement. This response was to the rate of material applied, with no difference between the forms of lime.

CARBON BASED FERTILISER FORMULATIONS

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Carbon based products in the form of various composts and worm worked organic materials (vermicast) can positively influence soil quality parameters and increase crop yields. Often however large volumes are required to achieve notable results and so one way of reducing these large volumes, yet still achieving results is to supplement carbon based products with certain inorganic nutrients according to crop requirements.

Some international studies suggest that a greater overall nutrient efficiency can be achieved for both nitrogen and phosphorus when present in an organic-inorganic formulation. Specific studies relate to the addition of inorganic nitrogen to compost and the addition of RPR to vermicast. For nitrogen possible mechanisms for the increased efficiency include having a more balanced carbon:nitrogen ratio, lower nitrification rates and enhanced compost mineralization as stimulated by inorganic nitrogen. For phosphorus it is suggested that the increased nutrient efficiency results from phosphorus solubilizing microbes present, or added to the vermicast, that increase the availability of phosphorus in RPR. It is also well documented that vermicast, when supplemented with inorganic nutrients can increase yield, compared to equivalent nutrient rates of inorganic nutrients alone. This additional growth, independent of any nutrient effect, is attributed to humic compounds present in the vermicast.

The combined approach to soil fertility involving both organic carbon based products and inorganic nutrients is known as Integrated Nutrient Management and holds significant promise for agronomic and environmental sustainability.

MEASURED AND MODELLED CARBON DIOXIDE FLUXES FROM A GRAZED DAIRY PASTURE

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The process-based denitrification-decomposition (DNDC) model simultaneously models fluxes of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) from agricultural soils. This model has been modified and adapted for New Zealand grazed pastoral systems and the adapted version (called NZ-DNDC) has been successfully used to simulate nitrous oxide emissions from two dairy-grazed pastures on soils contrasting in texture and a sheep-grazed pasture. NZ-DNDC was recently used to produce upscaled regional estimates of agricultural nitrous oxide emissions for the Manawatu-Wanganui region and has also been used to simulate CH_4 fluxes with chamber measurements from a sheep-grazed pasture.

In this study we compare the CO_2 flux predicted using NZ-DNDC with measurements from a dairy-grazed pasture and investigate the suitability of NZ-DNDC for predicting long-term changes in soil carbon. NZ-DNDC predicted CO_2 fluxes that were similar, on average, to the measured fluxes. However, NZ-DNDC does not yet account for plant respiration.

EFFECTIVENESS OF CURRENT BMPS TO ACHIEVE FAECAL MICROBIAL WATER QUALITY STANDARDS

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The key question that agricultural industries are currently asking is, "if we implemented all currently available BMPs (best management practices) to reduce faecal microbial losses from farms, could we achieve recreational water quality guidelines in agricultural streams?" To answer this question we conducted a model analysis of a hypothetical farm in the Toenepi catchment to calculate total losses of *E. coli* from the farm. Expressed on an annual basis, the losses of *E. coli* from the farm are dominated (approx. 70 %) by overland flow from grazed pastures. Furthermore, losses from overland flow and artificial drainage account for >80 % of the annual load. However, these sources only occur for short time periods during storm events. Unfortunately, current BMPs are not effective at reducing *E. coli* numbers in overland flow or artificial drainage. Under the more frequently occurring base-flow conditions, the amount of *E. coli* that can be deposited by a farm must be less than the in-stream attenuation of the *E. coli* in the stream length flowing through the farm; otherwise water quality will deteriorate downstream as the water flows from farm to farm. An in-stream attenuation rate was estimated from literature data and this was applied to a model stream to calculate a median daily load for *E. coli* inputs for the stream. The effectiveness of current BMPs was then assessed for their ability to reduce farm outputs below this daily load value. This model analysis showed that fencing off streams, bridging animal crossings and the use of a deferred effluent irrigation strategy would be required to achieve recreational water quality standards under base-flow conditions. However, if the water quality management target is to meet the standards at all times (including storm flow), then current BMPs will not be effective. Future research should target reducing loads of faecal microbes in overland flow and artificial drainage during storm events. However, a significant amount of work on understanding faecal microbial sources and transport processes will be required before we can determine the effectiveness of any new BMPs targeting storm flow conditions.

CONTOUR GRASS FILTER STRIPS
– HYDROLOGY AND WATER QUALITY

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Contour grass filter strips (GFS) are a potential tool to improve runoff water quality on grazed pastures. Filter strips can remove pollutants from surface runoff by deposition, physical filtering, and infiltration. This paper presents year 1 results for contour GFS on a dairy farm at Lake Rerewhakaaitu and a drystock farm at Kaharoa, near Lake Rotorua. The trial includes adjacent 3 m wide GFS on planar hillslopes of retired ryegrass and *Phalaris aquatica* and unfenced controls. The inputs and outputs of surface runoff and suspended sediment (SS), total phosphorus (TP), total nitrogen (TN) and *E. coli* are measured from each GFS after runoff events.

At both sites surface runoff was more frequent during the winter months, particularly July and August 07. Surface runoff was generated on 17 days at Rerewhakaaitu (Sep 06-Jan 08) and 8 days at Kaharoa (Jan 07-Jan 08). Inflowing surface runoff concentrations were similar at both sites (20-40 samples per site), despite the different land uses. Suspended sediment concentrations were between 10 and 4000 mg/L. Median TN concentrations were the same at both sites (6.33 mg/L). Median TP concentrations were less than 2 mg/L, but concentrations ranged from 0.07 to 8.6 mg/L. *E. coli* concentrations measured in the inflow ranged between 400 and 2650 MPN/100 mL at Rerewhakaaitu, and 10 to 5 x 10^6 MPN/100 mL at Kaharoa. High (10^4-10^6) *E. coli* concentrations were measured in inflowing surface runoff at Kaharoa for three events after recent sheep grazing.

The ryegrass GFS performed better than the planted phalaris GFS and significantly better than the controls. Pollutant trapping was generally higher for smaller and medium sized runoff events. At Rerewhakaaitu the ryegrass GFS reduced median event concentrations of *E. coli*, TP and TN and SS and TP loads (relative to the control) by 20-60%. At Kaharoa, SS concentration and load reductions (relative to the control) for the ryegrass GFS are 60 and 35% and TP and TN concentration reductions are 15%.

These results suggest that hillslope GFS may be a useful best management practice to trap pollutants close to the point of generation. However, the relative importance of surface runoff as a pollutant pathway must be carefully considered and uncertainty still remains about the long term fate of trapped pollutants.

A PROGRESS REPORT ON CRITICAL SOURCE AREAS AND WATER QUALITY IN NZ HEADWATER CATCHMENTS

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Numerous catchment studies have highlighted that not all areas contribute equally to contaminant transport to surface water. For water quality management it is crucial to identify both (1) major transport mechanisms including subsurface flow, saturation excess and infiltration excess runoff, and (2) key source areas for contaminant transport such as near-stream locations, animal tracks and farm roads.

We have been monitoring the dynamics of shallow groundwater and the occurrence of surface saturation during storm events in three headwater catchments in Otago and the Waikato since October 2006 in order to identify near-stream areas prone to saturation-excess surface runoff. To corroborate the assumption of a critical width of these surface saturation areas we established perpendicular to the streams groundwater monitoring transects (25 - 40 m long) with four to five wells equipped with automated water level recorders. We also measured sediment and nutrients concentrations in surface waters adjacent to the groundwater monitoring transects and at several other locations in the catchments to further elucidate transport pathways through which contaminants reach surface waters.

Our observations indicate that the depth to the water table decreased during storm events with a gradient towards the streams. However, the water table only reached the surface and thus caused surface-saturation excess during extreme rainfall events occurring in wet periods. In these cases the water table reached the surface as far as 40 m away from the stream, and a close relation between contaminant concentrations in stream and surface runoff samples was observed. During the remainder of the year, the increased contaminant concentrations measured in the stream during rainfall events were ascribed to infiltration-excess runoff from animal tracks, farm roads and fence lines, subsurface flows from near-stream areas, and/or point sources including direct deposition in streams and influx from effluent ponds. We confirmed these sources and transport pathways with stream water quality measurements up- and down-stream of effluent ponds, and overland flow samples collected from runoff plots and surface samplers. The contributions of subsurface flow to streams as well as the dynamics of the connectivity between land and streams during dry and wet initial surface conditions will be analyzed in future research.

CLUES: DO WE HAVE ANY IDEA ABOUT THE NUTRIENT IMPACTS OF LAND USE CHANGE AT THE CATCHMENT LEVEL?

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CLUES (Catchment Land Use for Environmental Sustainability) is a GIS-based framework of models from a number of research groups, developed to predict average annual nutrient (N & P) loads and yields for any of, or all of, the New Zealand landscape. It has been calibrated and tested on large-scale nation-wide datasets. Nitrogen loss risk is also predicted, along with three economic metrics: GDP (gross domestic product -an estimate of the total value arising from the farming, horticulture, and pine plantation land uses), FTEs (full time equivalent employment - total employment on farms) and CFS (cash farm surplus- an indicator of on-farm profitability). The comprising models are SPARROW (NIWA/USGS), SPASMO (HortResearch), OVERSEER (Agresearch), Ensus (Landcare Research), with the economic components developed by Harris Consulting (Christchurch).

Ongoing funding (via Pastoral 21 and EnviroLink) is extending CLUES so that it can:

(i) operate at the farm scale (at present the minimum scale is on the order of 10 km^2);

(ii) incorporate both sediments and *E. coli*;

(iii) include mitigation factors;

(iv) calculate instream concentrations by season;

(v) identify sensitive catchments.

We will give an overview of the CLUES interface and show how it is being applied to identify sensitive catchments—including considerations of how instream processing of nutrients changes the *generated yields and loads* (directly off the land to waterways) into a *delivered yield or load* (received by a sensitive waterbody that may be some way downstream from where the load was generated). As a consequence, land areas with the highest generated load do not necessarily have the greatest impact on a downstream sensitive waterbody.

EXAMINATION OF THE NEED FOR AN ADDITIONAL DAIRY SOURCE TERM FOR NITROGEN IN CLUES

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The CLUES model uses a link to the OVERSEER nutrient budget model (OVERSEER-CLUES) to estimate loading for a given catchment. As actual on-farm data is not available to the CLUES model, the model estimates loading for 5 farm types (dairy, lowland sheep/beef, hill country sheep/beef, high country sheep/beef, deer) using typical default regional values as inputs into the OVERSEER nutrient budget model. The default values are based on regional MAF monitor farm data for sheep/beef and deer farms, and Livestock Improvement data for dairy farms.

CLUES also makes use of the SPARROW model to combine the loading from various pastoral and non-pastoral sources of nitrogen (N) in a catchment, and to attenuate the nutrient as it passes down the stream network. The parameters for this part of the model are derived from a regression procedure that fits the model predictions to total nitrogen loads measured at various locations in the stream network. The attenuation term takes account of loss and/or dilution of N from the source to the point of measurement, and is dependent on river size and distance from source to the point of measurement.

The SPARROW regression analysis has previously indicated that to develop the best fit to the measured data, losses from dairy land use needed to be higher than those estimated by the OVERSEER nutrient budget component of CLUES (the OVERSEER-CLUES model). This is shown by the requirement for an extra source term for dairy land use in the regression output.

The objective of this paper is to examine the reasons for this extra term in the SPARROW regression. The analysis indicates there are multiple reasons for this extra term, and these are discussed.

SURFACE WATER QUALITY AND NUTRIENTS: WHAT SHOULD THE FOCUS BE?

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The supply of nutrients is the key factor in the unwanted growth of aquatic weeds and algae. Often it is either the availability of either nitrogen (N) or phosphorus (P) which limits growth. In 1963 Redfield published data that indicated a molar ratio of N:P of 16:1 was required for growth, meaning that if more than 16 moles of N were present then growth was limited by P and if less than 16 moles of N were present then growth was limited by N. This ratio has been tested via bioassays in a few streams and lakes in New Zealand, and can be used in a modified form to make inferences about what nutrient controls biomass production and hence the influence on surface water quality.

We present a preliminary analysis of data from 1100 surface water quality sites sampled over the last 10 years. These represent all sites monitored by regional councils in New Zealand and cover a wide range of landuse, elevation, climate and flow regimes. Data is presented for median dissolved N and P concentrations and total N and P concentrations. This will give an indication of the importance of either N or P in limiting biomass production. The data raises questions over the effectiveness of BMPs in affecting surface water quality if aimed at the wrong nutrient and what the issue may look like in the future.

TRENDS IN NUTRIENT MANAGEMENT IN ARABLE FARMING SYSTEMS

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There are two key trends in nutrient management in arable crops in New Zealand; the use of deep soil N to define the nitrogen available to the plant and the application of nutrients, in particular nitrogen, in relation to plant growth and need. Deep soil N testing can be used to adjust fertiliser inputs to meet total plant nutrient needs. Crop models have been developed for some key crops and the models, or the crop nutrient response information used in the models, have allowed farmers to better relate nutrient requirements to crop needs and apply fertiliser accordingly. These trends have significantly reduced the chance of excess amounts of nitrogen being present in the soil profile, which significantly reduces the risk of leaching. Other cropping system changes, from predominantly spring cropping to predominantly winter cropping, means little land is fallow through the winter further reducing the risk of nitrogen loss through leaching.

As well as these key trends, research has led to other changes in fertiliser use. In trials, fertiliser use in peas has not resulted in yield increases and field demonstrations have now convinced growers to reduce fertiliser use. In ryegrass widespread use of a plant growth regulator has resulted in the need for research to define the interaction of nitrogen and PGR, with a subsequent reduction in the nitrogen requirement by the plant and nitrogen application by growers. Improvements in irrigation systems and increases in the irrigated crop area mean more land is irrigated after fertiliser application minimising volatilisation losses.

Research on precision agriculture has yet to pay dividends in the intelligent use of variable or targeted fertiliser application but there is potential for the use of remote sensing technologies, combined with guidance systems, to further improve the accuracy and efficiency of nutrient use in arable crops. Ongoing research and extension is needed to ensure the industry is well positioned to benefit from these and other technologies.

POTENTIAL FOR MAIZE TO RECYCLE LEACHED SOIL NITRATE

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Nitrate leaching to ground water is regarded as a serious problem in parts of New Zealand. One way to reduce leaching losses is to design cropping/farming systems that recover previously-leached nitrate from the subsoil. Our objective was to identify if maize (*Zea mays* L.) crops have significant potential for this.

We used exploratory calculations to help define how and when we can expect maize to be most effective. We calculated uptake rates of nitrate down the soil profile for a representative crop (1.2 m rooting depth) for a 15 day period after silking. Nitrate supply to the roots at each depth was calculated from either mass flow (water uptake times soil solution concentration of nitrate) or mass flow plus diffusion (using an adaptation of the steady state version of single-root theory). Actual nitrate uptake would likely be somewhere between the values obtained from these two models. Calculations were carried out for ten different scenarios combining five initial nitrate distributions with two initial distributions of soil water content.

Both the mass flow and mass flow plus diffusion models indicated substantial nitrate uptake from depths below 0.6 m although there would be little uptake from the bottom 0.3 m of the root zone. The mass flow model indicated strong interactions between nitrate and water uptake, so that dry topsoil conditions were especially effective at enhancing subsoil uptake of nitrate.

Our results suggest that maize crops have substantial potential to take up subsoil nitrate, and field experimentation to refine cultural practices is justified. However, if maize is grown to recycle subsoil nitrate there is a strong risk that yield will be compromised. The chances of successfully recycling subsoil nitrate are enhanced if:

- Substantial amounts of N fertiliser are *not* applied to the topsoil;
- Dry weather limits water and nitrate uptake from the topsoil;
- Heavy rainfall does not leach the nitrate into or beyond the bottom 0.3 m of the root zone.

At this stage, growers need to keep in mind whether they are growing the crop to recycle nitrate or to achieve high yields – achieving both will require sophisticated tools.

NUTRIENT MITIGATION TOOLBOX: SELECTING THE RIGHT TOOL FOR THE JOB

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New Zealand's surface waters (streams, lakes, rivers, wetlands) and groundwater systems are coming under increasing pressure from intensive farming. There are a range of attenuation tools available to help attenuate pollutants once they have been mobilised, including wetlands, riparian management, and reactive filters and materials such as groundwater bioremediation trenches. However, often little guidance or consideration is given to identifying the major pollutant flowpaths and subsequently selection of the most appropriate attenuation tool. This paper presents the results of a stocktake of attenuation tools for pastoral farming, with specific reference to the dairy, sheep and beef industries. Emphasis is placed on potential sites for attenuation, attenuation tools and their applicability to New Zealand pastures. Appropriate attenuation options are then subject to cost-effectiveness analysis for a range of scenarios.

FARMERS TAKING CONTROL OF THEIR FUTURE: AN OVERVIEW

Gifford McFadden

Trustee: Rotorua Lakes and Land Trust

There will be no success in reducing nutrient loss from farming unless farmers can understand and take ownership of the solutions.

The farmer Trustees, when we saw our life's work and our capital being destroyed, were surprised to find areas of research that were being ignored. An example is the natural attenuation of N, this obscures the linkages of which leaching, on which individual farm, will finish up in waterways.

Therefore is nutrient leaching control best served by the markets or community schemes? Regulations alone are not solutions. What is needed are solutions that are backed by regulations. The solutions need to be cost effective, simple to implement and simple to monitor.

Variation 5 for Lake Taupo, being implemented by Environment Waikato and the Horizons One Plan, are problem solving by regulation. These will not work because it is being imposed with huge cost, and requires complex monitoring, it is likely at any time to lead to passive resistance.

Environment Bay of Plenty has taken the hard road of getting the farmers to take ownership of the solutions. There have been arguments, false starts and disagreements galore, but they will come out with a durable solution.

FARMERS TAKING CONTROL OF THEIR FUTURE: MINIMISING NITROGEN AND PHOSPHORUS FROM PASTURE LAND INTO ROTORUA LAKES

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This paper summarises the results of three years of research from the SFF funded project "Practical mitigation options to reduce nitrogen (N) and phosphorus (P) losses from farms into Rotorua lakes". Mitigation options for both N and P were chosen for research on-farm after a stakeholder workshop organised in May 2005. Measurements of N and P losses from farms, in conjunction with measurements of the extent to which they can be reduced through the use of mitigation practices were examined.

There were three specific aspects covered in this study; the first part was to evaluate the effectiveness of mitigation options applied to minimise N leaching from the Ngati Whakaue Wharenui dairy farm, the second dealt with the effectiveness of mitigation options applied to minimise P export from critical source areas from the Wharenui sheep and beef farm, and the third part of the study involved desktop scenario analysis of various management options to optimise production and to reduce N leaching. On the dairy farm, the three replicated treatments for mitigating N loss were: control (normal grazing and fertiliser regime); control with nitrification inhibitor (DCD) applied twice, following the May grazing and the subsequent winter grazing; and no grazing from May to the end of September (equivalent of two grazings) In 2005, when treatments were newly commenced, there was a trend for lower N leaching from DCD (-15%) and nil winter-grazing (-34%). In 2006, N leaching was reduced by 25% and 42% for the DCD and nil winter-grazing treatments, respectively. The DCD treatment also resulted in increased early-spring pasture growth (equivalent to 7% annual DM), due to an N response from saved N (due to reduced leaching) and N applied in the DCD.

Part 2 of the study was to characterise and quantify different fractions of P in run-off samples from non-grazed, sheep and bull-beef grazed plots and evaluate effectiveness of hay bale filter dams to reduce sedimentation loss of particulate P in the ephemeral stream. The run-off samples were analysed for dissolved reactive P (DRP), total dissolved P (TDP), total P (TP) and suspended solids. Results showed that there was more DRP, TDP, and TP lost from the grazed paddocks than non-grazed paddocks. Four hay bale filter dams were constructed across the flow path of the channel at 20 m intervals. This study showed rapid degradation of the grass-straw in the bales which, in fact, increased concentrations of all components of P which were measured below the bales.

The desktop modelling of scenarios to reduce N leaching from the Wharenui dairy farm and sheep & beef farm were estimated using UDDER, FARMAX and OVERSEER® models.

NUTRIENT MANAGEMENT AND THE ONE PLAN

Jon Roygard and Helen Marr

Horizons Regional Council

Horizons One Plan (2nd Generation Combined Regional Plan and Policy Statement) encompasses many very challenging resource management issues, but focuses on ‘The big four’: water quality, water quantity, biodiversity and unsustainable hill country land use.

The biggest of these big four challenges is water quality. The science available at the outset of the Plan development clearly identified this as a problem; a lot more science was required to identify if the problem was getting worse or improving, where this problem was coming from and what the most effective intervention would be. This science was delivered by Horizons science team working closely with their policy team and many other agencies, particularly crown research institutes. One of the challenges for all scientists involved was working closely with the policy makers and community to derive an approach to address the issue at hand.

This talk presents a brief overview of the science developed around nutrient management and the policy proposed in the One Plan.

Poor water quality in our rivers that’s getting worse is unacceptable to our community. But having identified intensive farming as the main source of this pollution in some parts of our region raises new challenges: how to tackle the cause of the problem without damaging our rural economy. We needed an approach in our policy that is targeted, endorses best management farming practices and that gives farmers and service providers time to implement changes.

This mix of new research and grounded policy goals has given rise to the One Plan FARM Strategy approach (Farmer Applied Resource Management Strategy). Horizons have been testing this on the ground to iron out the kinks and show that good nutrient management is usually good business sense.

SOURCES OF PHOSPHORUS IN THE MANAWATU RIVER AND IMPLICATIONS FOR THE ONE PLAN

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Horizons Regional Council is implementing both the sustainable land-use initiative (SLUI) to address erosion from farms and sediment in rivers, and the Farmer Applied Resource Management (FARM) strategy to target reductions in N and P loss from intensive land uses in priority catchments. Horizons asked us to develop a method to determine the potential for water quality improvement, and indicate whether erosion control or nutrient management should be the priority management target in a catchment.

We estimated both total and dissolved P losses for a large catchment (Upper Manawatu) by using the Overseer® and NZEEM models together. Then, with Horizons data for this catchment (77% sheep and beef, 16% dairy and 6% forest), we assessed the likely sources of these losses.

Most P comes down the rivers in eroded sediment from steeper land during major floods – about 511 tonnes of P per year goes under the bridge at Hopelands in sediment. 90% of the erosion occurs under pastures and 10% under forest. These particulate-bound P losses could be decreased to 280 tonnes by targeted planting of trees on highly erodible land. During low flows sediment on the bed of the river releases about 4 tonnes of dissolved P. This could be halved by decreasing erosion.

Dissolved P causes blooms of periphyton in summer. Most dissolved P comes from pastures. For sheep and beef farms this could be decreased from 14 to 10 tonnes with targeted planting of trees. For dairy farms it could be decreased from 9 to 5 tonnes with changes to management of effluent, limiting soil P to the optimum agronomic range, and excluding cows from streams. Dissolved P from point sources could be decreased from 7 to 2 tonnes with changes to management of effluent.

We recommend the two approaches - SLUI to reduce soil erosion and total P, and the nutrient management FARM strategy to reduce dissolved P during low flow - both be adopted. Monitoring of P in the river should be carried out to define a more precise base line, and to monitor improvements to water quality as SLUI and the FARM strategy programmes progress.

DEFINING NITROGEN-LOSS LIMITS WITHIN A WATER MANAGEMENT ZONE USING THE NATURAL CAPITAL OF THE SOIL

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Current nitrogen (N) loadings in the Upper Manawatu River and Mangatainoka are more than twice the water quality standard set for each Water Management Zone (WMZ) by Horizons Regional Council after consultation with the communities. Horizons have good data sets on the contribution of point-source N loadings to these two rivers. In a recent study of "Farm strategies for contaminant mitigation" for Horizons by SLURI, a direct link between land use and management decisions was established between N losses from farms and loadings in the Upper Manawatu river. SLURI found significant reduction in the N loading could be achieved by a focus on intensive land uses.

By limiting policy to existing intensive land uses, improvements to water quality would only accrue if there was no further expansion of intensive land uses in the balance of the catchment. Any policy approach would therefore need to consider all land in the catchment from the outset, and range from capping nutrient losses from current production systems, calculating an average nutrient loss limit for each hectare of land in the catchment, or allocating a nutrient loss limit based on the biophysical potential provided by the natural capital of the soil.

Of these various approaches, allocating a nutrient-loss limit based on the natural capital of the soil in the catchment offered a basis for developing policy that is linked directly to the underlying natural biophysical resources in the catchment. It is independent of current land use and places no restrictions on future land-use options. It also provides all land users in the catchment with certainty by defining a nutrient-loss limit based on the suite of soils they own.

We consider that this natural capital based approach for managing nutrient is a new methodology that should be at the forefront of sustainable development.

IS "ENVIRONMENTAL EFFICIENCY" A USEFUL CONCEPT IN IMPROVING AND REGULATING THE ENVIRONMENTAL PERFORMANCE OF PASTORAL FARMING SYSTEMS?

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Fertilizer and Lime Research Centre, Massey University

Pastoral farming is degrading the quality of surface and ground waters in many areas of New Zealand, through the leakage of nutrients such as nitrogen (N) and phosphorus (P). Some Regional Councils in affected areas are attempting to overcome the problem by capping nutrient inputs to water bodies at some threshold value, above which environmental damage is deemed unacceptable. Various approaches have been suggested for allocating these permissible nutrient losses amongst farms in a catchment. The advantages and disadvantages of these methods are discussed, and the concept of "environmental efficiency" is introduced as another possible way forward.

In a dairy farming context, one measure of "environmental efficiency" is

kg milksolids produced/kg N leached.

Such an index is easily calculated on most dairy farms from existing data, and Regional Councils can also calculate the current efficiency at a catchment level in at-risk catchments.

Regional Councils can then calculate the ratio that all farmers in the catchment would need to achieve in order to remain within the desired nutrient cap – assuming current production levels. If milksolids production within the catchment is to increase – either through intensification or converting more land to dairying – then guidelines could be developed to avoid an increase in N losses within the catchment. For example, any future increases in milksolids production would need to be matched by improvements in the "environmental efficiency" of dairy farming throughout the whole catchment.

The advantages and disadvantages of such a scheme are discussed.

WILL LEADERSHIP OVERCOME THE NEED FOR REGULATION?

Greg Carlyon

Horizons Regional Council, Palmerston North

Two years ago Horizons Regional Council came to the FLRC conference and in a pretty provocative way challenged the audience around environmental management. You would hope that with the passing of time and the increasing intensity of community feedback around the need for managing nutrient impacts, that we would have moved some way.

This is what we know. Our water quality is poor and getting worse. That nutrient inputs from pastoral systems are the number one unmanaged contaminant of our waterways. That our pastoral systems are intensifying along with their environmental effects at a rate that hugely outstrips our capacity to mitigate those environmental effects, and that we continue to prevaricate when it comes to decision-making around environmental performance.

The Horizons Regional Council team will talk about its science and its regulatory/non-regulatory response via the One Plan. For my part our challenge is not in the science, it's in our agricultural leadership. From those of us in local government, central government, our research institutions, farming lobby groups, and farmers themselves, we owe it to ourselves and our community to show some leadership which results in the maintenance and improvement of water quality through the stewardship of our terrestrial landscape.