NUTRIENT LEACHING UNDER CONVENTIONAL AND BIOLOGICAL DAIRY FARMING SYSTEMS

G.N. (Guna) Magesan and Gifford McFadden

NZ Biological Farming Systems Research Centre, PO Box 12103, Rotorua 3045, NZ
Email: BiologicalFarming.Systems@gmail.com

Abstract
Interest in, and support for, biological farming systems is growing in New Zealand. This is because some farmers are anxious about the increased use of synthetic fertilisers that has caused both economic (e.g. increase in fertiliser costs) and environmental concerns (e.g. water quality). In the Central North Island, New Zealand, nutrient leaching has become a risk to the viability of many farming ventures as farmers are compelled to reduce nutrient losses.

The Rotorua Lakes and Land Trust (RLLT) – a joint venture between Te Arawa Federation of Maori Authorities and Rotorua/Taupo Province of Federated Farmers – is interested in exploring if biological farming systems can be used to achieve the same financial results as current farming practices while lowering nutrient leaching. Recently, the RLLT organised a national conference on biological farming systems, and announced the formation of NZ Biological Farming Systems Research Centre.

Farmers using biological farming systems have observed positive changes to soil, and improvements in plant and animal health. Scientific investigation is warranted to establish the mechanisms and processes responsible for these observed improvements in economic and environmental performance and to ensure that potential benefits can be more widely adopted.

The RLLT set up two experimental sites, one at Reporoa and one at Edgecumbe. At each site sets of 12 drainage flux-meters were installed on a biological and a neighbouring conventional dairy farm. The drainage flux-meters were used to measure amounts of drainage and nitrate concentrations in the soil water. In addition to nitrate, concentrations of ammonium, dissolved organic nitrogen and dissolved organic carbon were also measured in the soil water.

Here, we report preliminary leaching results of nitrate and dissolved organic carbon from two experimental sites. The results showed that, in general, the biological farms had significantly lower nitrate concentrations than the conventional farms in both farms. In Edgecumbe site, which had biological farming for a longer period, the leaching of dissolved organic carbon was greater in the biological farm than in the conventional farm. More research is needed in this area of biological farming systems.

Keywords
Biological farming, grazed pastures, nitrate, dissolved organic carbon, water quality.

Introduction

In recent years, water quality has become an important issue in New Zealand. The increased use of synthetic fertilisers, such as urea, has not only been expensive to farming systems, but also considered as one of the causes of water quality degradation (Magesan et al. 1996; Di and Cameron 2002; Monaghan et al. 2007; Mulvaney et al. 2009).

New Zealand farmers are under sustained pressure from regulatory bodies to reduce nutrient leaching from farms to stream and rivers, to the extent of seriously restricting farming in sensitive areas, such as the Taupo catchment, the Rotorua lakes catchment and the hydro catchments of the Upper Waikato. Nutrient leaching is one of the risks to the continuation of farming in the Central North Island, New Zealand.

New Zealand farming needs solutions to nutrient leaching that are simple to implement and easy to monitor. The Rotorua Lakes and Land Trust (RLLT) – a joint venture between Te Arawa Federation of Maori Authorities and Rotorua/Taupo Province of Federated Farmers – was set up in 2005 for Central North Island farmers to establish and find solutions to nutrient loss from farms. The RLLT has been looking at various solutions to nutrient loss from farms. With support from the Sustainable Farming Fund, RLLT had successfully researched watercress to remove nutrients from water bodies; and using flat areas to reduce P movement in the surface runoff. They are now interested in exploring how biological farming can be used to achieve the same results as current farming practices. Interest in, and support for, biological farming systems is growing in New Zealand.

One biological farming option is to increase soil biota and rooting depth to capture and recycle nutrients, particularly N. This method is currently used by some farmers on a number of Central North Island farms. Instead of urea application, biological farming maximises natural cycles such as the clover cycle. Soil health is achieved by applying finely ground volcanic rock, processed organic matter, a wide range of minerals and essential elements (e.g. calcium and magnesium), and ground bark inoculated with specifically selected soil-friendly microbes (fungi and bacteria). Application of essential elements is important for clover in intensive pastures. Clover is able to provide sufficient nitrogen for high producing intensive dairy farming (e.g. Ledgard, 2001). More clover grown means: higher total milk, meat, and wool yields; less nitrogen fertiliser required; and lower overall costs.

The RLLT is aware of a number of dairy, deer and sheep farms on different soil and climatic conditions that have been following biological farming systems for over 5 years. Some of these farms are intensively monitored by farmers.

Farmers using biological farming systems have observed positive changes to soil (e.g. increase in clover number and root mass, and decrease in soil compaction), and improvements in plant and animal health. These systems have resulted in savings in fertiliser costs and improved environmental outcomes (70-90% drop in urea use), without losses in productivity. Other observations include reduction in soil compaction, decrease in bare patches and fertility patches in paddocks, decrease in the damage caused by grass grub, beetle, and clover flea, and faster reincorporation of dung into the pasture soil – often within three weeks.

These observations warrant scientific investigation to establish the mechanisms and processes responsible for these improvements in the economic and environmental performance of these farms so that any potential benefits can be more widely adopted. Also, it is important to explore the reasons for such changes and to ensure they are not short term fluctuations that compromise long term production.

Biological farming definition:
Biological farming is a mix of conventional and organic farming practices involving careful crop and soil monitoring to ensure optimum yields, nutritional density and humus production. It focuses on re-establishing mineral balance and enhancing beneficial microbiology in the soil in order to promote good soil, healthy crops, and healthy animals (Zimmer, 2000).

Gary Zimmer in his book The Biological Farmer states:-

> "*Biological farming utilises resources of both science and nature in a superior farming system. It works with natural laws, not against them…. Biological farming improves the environment, reduces erosion, reduces disease and insect pressure, and it accomplishes this while working in harmony with nature….. Sustainability is a key factor in becoming a biological farmer....*

Please note that the terms "conventional" and "biological" dairy farming cannot be precisely defined as it probably means quite different things to different people. For example, conventional farming encompasses a wide range of practises that include variations in stocking rate, pasture management, and fertiliser inputs. Also any definition of a biological dairy farming may also apply to a conventional dairy farming however the difference between a well-managed biological enterprise and a conventional one is immediately evident to people familiar with farming. However, some meaningful generalisations can be made, as given in Table 1.

Table 1. A simple comparison between conventional and biological dairy farm systems

Features	**Conventional Farming**	**Biological Farming**
Use of synthetic fertilisers	Yes	Nil or minimal amount
Imported supplements	Yes	May or may not have
Legume content in pastures	Low	High
Soil structure	Poor	Good
Soil biology	Inactive (suppressed)	Active
Cycling of organic matter	Impaired	Active

Typically the conventional farming perspective is that there is little connectedness between soil health, plant health, animal and human health, whereas the biological farmer believes that all aspects of health are interdependent with soil health the base on which plant, animal and human health is founded.

Our working definition for biological farming is "The application of products that stimulate soil biology ensuring at least the same quantity of pasture to be sustainably grown without fertiliser nitrogen as is presently grown on conventional properties where fertiliser N is regularly applied throughout the growing season."

Aim:
The Vallance project (biological farming) is requested by farmers, directed by farmers, for the benefit of farmers. The goal of this project is to establish “Proof of Concept” that

biological dairy farming systems offers advantages over conventional dairy farming systems with respect to its overall environmental and economic sustainability.

The project has four hypotheses:

(1) Significantly less leaching of N below the main root zone occurs in a biological dairy farm system compared to the current practice dairy farm system.

(2) The practices of the biological dairy farm system leads to a significant increase in soil and pasture quality and animal health.

(3) Carbon sequestration increases in biologically farmed soils.

(4) The biological dairy farm system economically is as viable as the current practice dairy farm system.

This paper focusses on the first hypothesis. To the best of our knowledge there is no study in New Zealand or elsewhere that has analysed if and by how much a biological dairy farm system can reduce nitrate leaching (Duerer et al. 2009).

Materials and methods

Two paired farms (biological with a neighbouring conventional dairy farm) were chosen in Reporoa and Edgecumbe, respectively. The soils of the experimental paddocks belong to the same soil order and have similar climate, altitude, aspect and landscape position.

The soil in the Reporoa site is light brown pumice soil, while the Edgecumbe site has light brown pumice over peat. Severe funding restrictions did not allow individual farm analyses as first proposed.

Drainage flux-meters

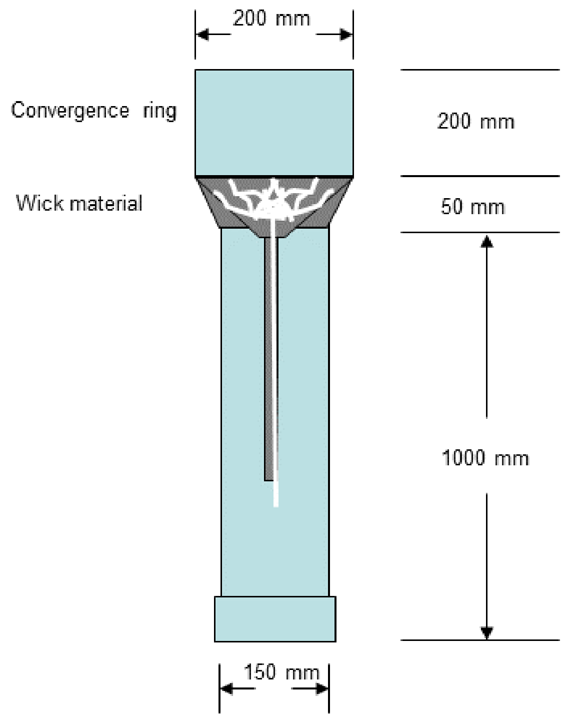

Figure 1. Passive wick lysimeter to monitor water and nutrient fluxes.

Drainage flux meters are recently developed devices that are used to monitor and better understand solute transport in unsaturated soils (Duerer et al. 2008). Passive-wick drainage flux meters were supplied by Tranzflo Ltd to monitor water and nutrient losses under these conventional and biological farms. The basic device is similar to that of Gee et al (2003), consisting of a convergence tube, a funnel, a hanging wick and a subterranean reservoir (Fig. 1). A nearly-fixed tension on the soil is maintained using an inert wicking material made from fiberglass (Holder et al. 1991). A hanging water column is created, and drainage water is pulled out of the lysimeter while the lower soil-boundary is "passively" maintained at a pressure less than atmospheric, so the soil stays unsaturated. The degree of unsaturation depends upon the wick length, the flux rate, and the soil type (Zhu et al. 2002).

The wick "passively" controls the pressure head in the soil at a value approximately equal to -60 cm (i.e. the length of the wick). A soil-filled control tube is placed directly above the wick to minimize divergent or convergent flow.

Preparation and installation of drainage flux-meters

The wicks of the meter were spread evenly around the base of the meter and then placing about a cup full of diatomaceous earth over the wick. Water was added to the diatomaceous earth to form clay like consistency which allowed the diatomaceous earth to be moulded over the wick ensuring the entire wick was covered. A pre -measured amount of fine silica industrial sand (20 micron grain size) was then placed into the drainage flux meter. This was used as a filter and also helps to ensure hydraulic contact with the soil profile.

Using a fence pole driller, holes were made to install each drainage flux meter so that the rim of the drainage flux meter sat slightly above /level with the ground. Figure 2 shows the installation process.

Collection of soil drainage water and chemical analyses

In our experiment, twelve drainage flux-meters (Gee et al. 2009) were installed in each farm to measure amounts of drainage and nutrient concentrations in soil water collected from both conventional and biological farming systems. The soil water samples from all drainage flux meters were collected monthly and they were sent to Veritec, an analytical laboratory within Scion, on the same day for the chemical analyses. Monitoring of soil water data will continue for three years in order to get robust and practical time series data on nutrient leaching, which will allow understanding of different seasonal effects.

Veritec use standard methods for the determination of water and wastewater, APHA 20th Edition. Veritec reported monthly results for nitrate, ammonium, total nitrogen (TN), dissolved organic nitrogen (DON) and dissolved organic carbon (DOC). Different forms of nitrogen were determined by using the Skalar segmented flow auto-analyser. For the oxidised forms of nitrogen (nitrate and nitrite), the reaction that occurs on the auto-analyser is exactly the same except for the cadmium reduction.

Ammonia-N, total Kjeldahl nitrogen (TKN) and dissolved organic nitrogen (DON) used the same method. Total Kjeldahl nitrogen and Dissolved Kjeldahl nitrogen were measured after the water samples were acid digested (with the latter being filtered also) which in the process converting all the organic nitrogen to ammonium. Total nitrogen (TN) is the sum of nitrate-nitrite and Total Kjeldahl nitrogen (TKN) being the sum of ammonia-nitrogen plus organically bound nitrogen. Dissolved organic nitrogen (DON) was calculated as the difference between dissolved kjeldahl nitrogen (DKN) and ammonia-N (i.e. DON = DKN – NH_4-N).

Dissolved organic carbon (DOC) values on filtered samples were determined by high-temperature combustion using a Shimadzu TOC-VCSH analyzer. Samples were prepared and analyzed automatically according to procedures described in the TOC-VCSH User Manual (Shimadzu Corporation, 2001).

Figure 2. Preparation and installation of drainage flux meters

Results and discussion

Nitrate-N concentrations

Drainage flux meters were used to collect soil water in both biological and conventional dairy farms. As expected, most of the drainage occurred over the winter period (data not reported here). However, some drainage occurred in February 2011.

Mean nitrate concentrations (mg L^{-1}) were significantly less under biological dairy farming systems compared with conventional dairy farming systems in the period reported in this paper (Figures 3a and 3b). Except for one sample in each site, mean nitrate concentrations under biological dairy farming systems were less than the 10 mg L^{-1}, drinking water standard, while the mean nitrate concentrations under conventional dairy farming systems exceeded the drinking water standard on many occasions. This indicates that under similar climatic conditions, there is a greater potential risk of polluting drinking water sources with conventional dairy farming systems in comparison to the risks with biological farming systems.

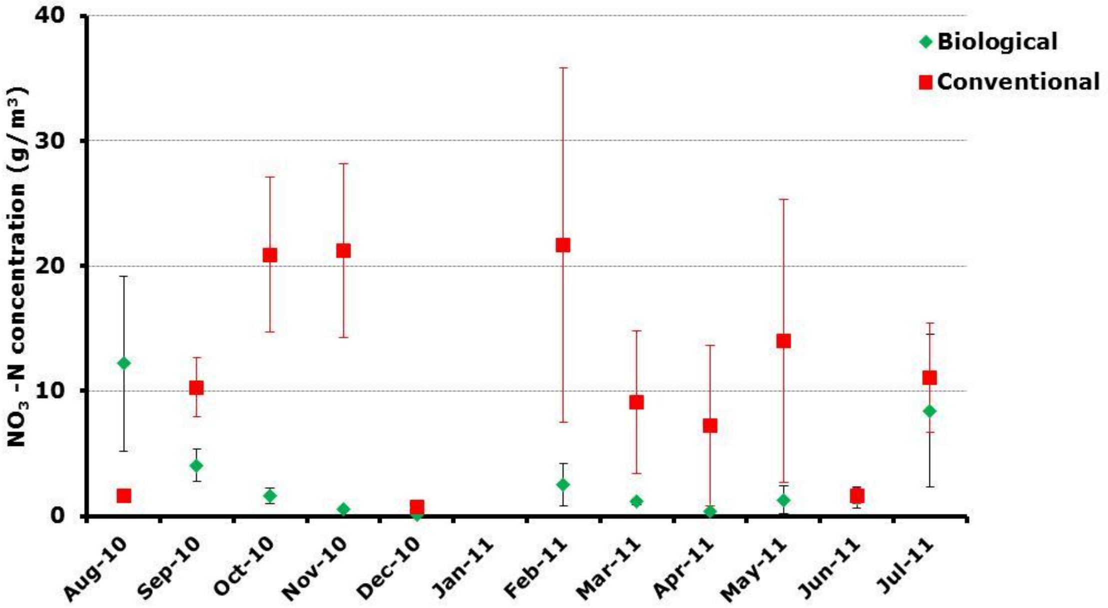

Figure 3a. Nitrate-N concentrations in soil water from Reporoa site

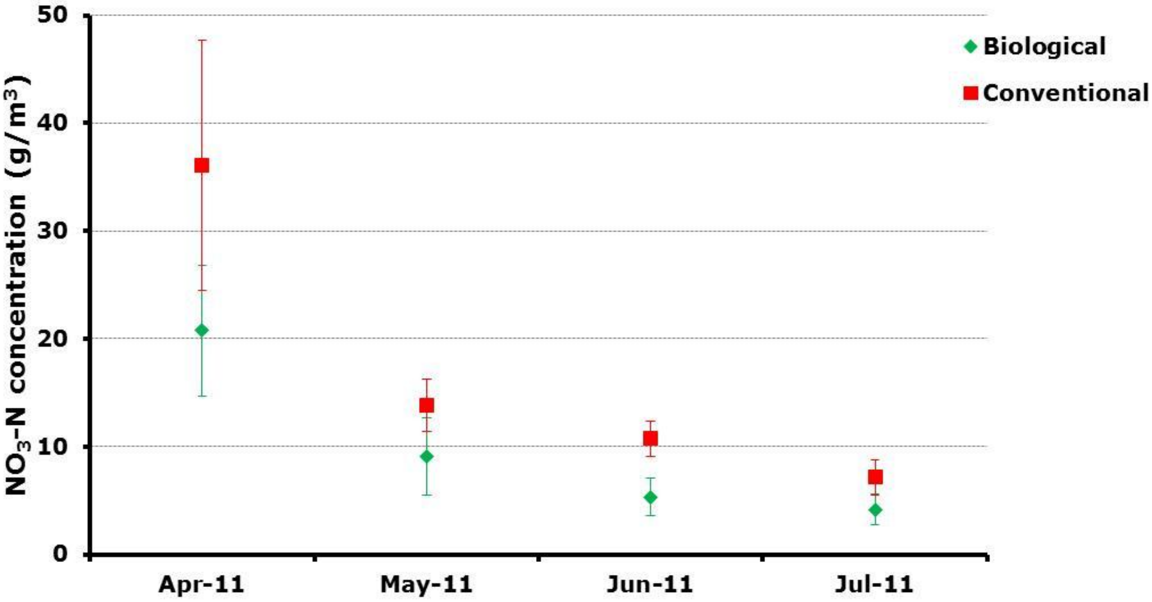

Figure 3b. Nitrate-N concentrations in soil water from Edgecumbe site

Overseas studies have also shown similar results. Oquist et al. (2007) conducted research to investigate the potential use of alternative farming systems such as organic management practices, species biodiversity, and/or practices that include reduced inputs of synthetic fertilisers to improve water quality. They reported that alternative farming practices reduced nitrate-N losses by between 59% and 62% compared with conventional practices. Similarly, research conducted in Norway on loamy and silty sand soils showed that 42% more nitrogen was lost in subsurface drainage from conventionally farmed land than from organically farmed land (Korsaeth and Eltun, 2000).

Another important observation in this study, as shown by the error bars, the variability in nitrate concentrations was high in conventional dairy farms when compared to biological dairy farms. Variability in grazed pastures can occur for many reasons. One of the key reasons is due to “hotspots” such as urine- and dung-affected areas. Although both farms were grazed, more variability was observed in conventional farms than the biological dairy farms. This probably suggests that the N concentrations in urine and dung samples from conventional farms could be higher compared to biological farms, but this needs to be researched and verified. The study carried out by Massey University has shown that the N contributions in urine from dairy cattle in organic farms was 645 kg/ha compared to about 1000 kg N/ha from conventional farms.

Reduced loss of nitrate N under biological versus conventional dairy farming systems could be partially due to differences in fertiliser source, rate, and timing for the two systems, difference in N contribution in urine from the grazing animals, as well as increased nitrate N uptake by different plants (with longer rooting depth) in the biological farming systems. It is expected that nitrogen application rate and source are more likely to have the greatest effect on nitrogen leaching from the soil. In general, the N source in biological farming systems is clover when compared with conventional practices, where the source is predominantly applied N fertiliser. Alternative farming practices, such as biological farming systems, are a potential means to lessen agricultural impacts on surface water pollution (Oquist et al. 2007).

DOC concentrations

In the Reporoa site, there was not much difference between the dissolved organic carbon (DOC) concentrations in the soil water samples collected from both conventional and biological dairy farms (Figure 4a). However, the DOC concentrations from the biological farms were higher when compared to conventional dairy farms at the Edgecumbe site (Figure 4b).

The contrast between DOC concentrations found in soil water in these two sites accentuates the importance of duration of biological farming. The biological farm in Edgecumbe was under biological farming systems for a longer period (nearly 8 years) when compared to only two years for the biological farm in Reporoa. We speculate that longer the biological farming process, more the built up of organic carbon in the soil. This is only a speculation as we do not have soil carbon measurements from this site. Since the estimates of carbon leaching losses from different land use systems are few and their contribution to the net ecosystem carbon balance is uncertain (Kindler et al. 2010), it is worth conducting more research on DOC losses from biological farming systems. Chomyciaa et al. (2007) report that DOC has been largely unstudied under agricultural land management practices in spite of known secondary effects of high carbon loadings in ground water such as increased mobility of contaminants.

These elevated values highlight the potential importance of incorporating DOC monitoring in agriculturally impacted ground water that may be used for drinking water.

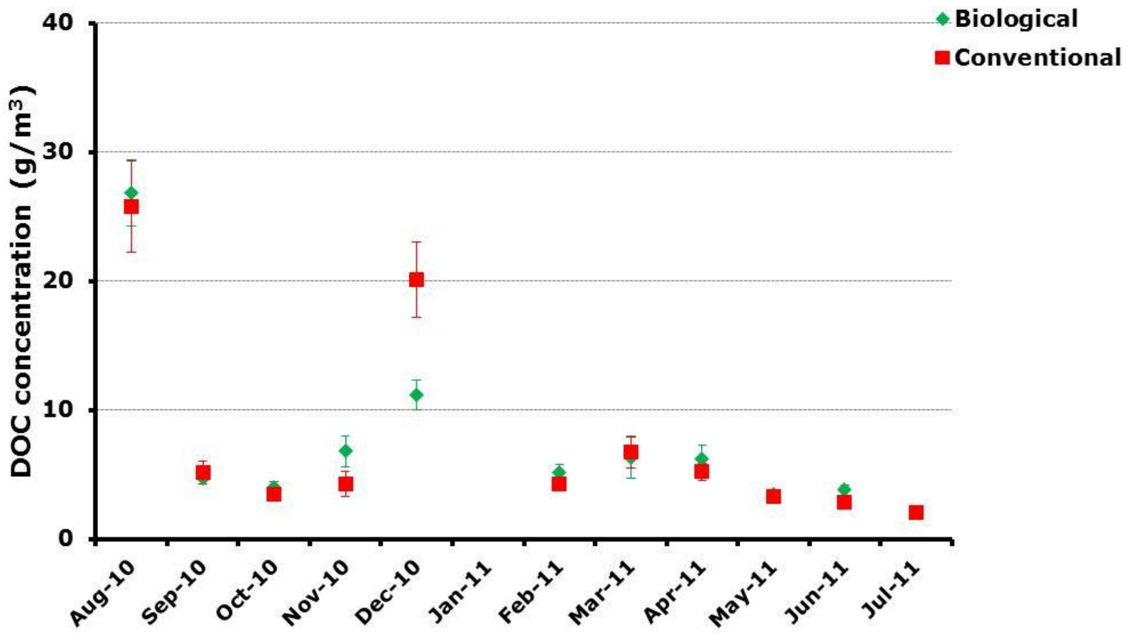

Figure 4a. DOC concentrations in soil water from Reporoa site

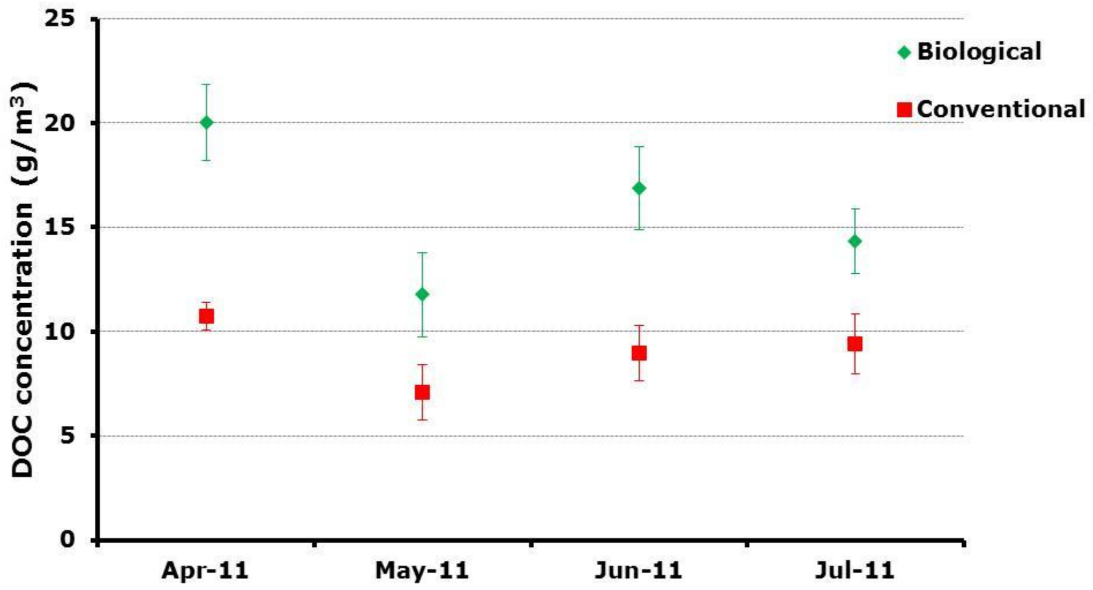

Figure 4b. DOC concentrations in soil water from Edgecumbe site

Summary
Accepted modern farming practises with outcomes such as steadily increasing animal numbers, high utilisation of pastures, and heavier use of fertiliser nitrogen, often appear at odds with farmers' notions of a healthy farming enterprise. An increasing number of farmers are not only questioning the accepted outcomes, but also implementing practises that are aligned to biological farming principles. These farmers have observed many benefits. However, a scientific understanding is essential to ensure that these changes are real, not short term.

Obtaining reliable measurements of unsaturated water and nutrient fluxes has been difficult in the past but new devices such as drainage flux meters offer a cost effective and reliable way of obtaining such measurements (Green et al. 2010).

The preliminary results from nutrient leaching studies are promising. Our preliminary results from two experimental sites showed that, in general, the biological farms had significantly lower nitrate concentrations than the conventional farms in both farms. In Edgecumbe site, which had biological farming for a longer period, the leaching of dissolved organic carbon was greater in the biological farm than in the conventional farm.

Once our project is completed, we aim to share the information with farmers, Maori landowners and incorporations, local and central government agencies, research providers and the general public. If the biological system can be shown to be financially viable then it would constitute a cost-effective way for mitigating nitrogen leaching into lakes and waterways and help to enhance the 'green-clean' image of New Zealand primary production.

Acknowledgment
Authors would like to thank the Rotorua Lakes and Land Trust, and the farmers for their support in this study. Dr Mark Kimberley for statistical analyses.

References:

Condron LM, Cameron KC, Di HJ, Clough TJ, Forbes EA, McLaren RG, Silva RG (2000) A comparison of soil and environmental quality under organic and conventional farming systems in New Zealand. New Zealand Journal of Agricultural Research 43: 443-466.

Chomyciaa JC, Hernes, PJ, Bergamaschib, BA. 2007. Land management impacts on dairy-derived dissolved organic carbon in ground water. Journal of Environmental Quality 37: 333-343.

Deurer, M., Clothier, BE, Green, SR., Gee, G. 2008. Infiltration rate, hydraulic conductivity, preferential flow. In Soil Science: Step-by-Step Field Analysis. Logsdon et al. (editors). SSSA, Madison, USA. 221-234.

Di HJ, Cameron KC (2002) Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. Nutrient Cycling in Agroecosystems 64: 237-256.

Eaton, A.D., Clesceri, L.S., and Greenberg, A.E. Standard Methods for the examination of water and wastewater, 20th Edition, APHA, AWWA, WEF.

Gee, G. W., Z. F. Zhang, and A. L. Ward, (2003), A modified vadose-zone fluxmeter with solution collection capability, Vadose Zone J., 2, 627-632.

Gee, G.W., Newman, B.D., Green, S.R., Meissner, R., Rupp, H., Zhang, Z.F., Keller, J.M., Waugh, W.J., van der Velde, M., and Salazar, J. 2009. Passive wick fluxmeters: Design considerations and field applications. Water Resources Research 45: W04420, doi:10.1029/2008WR007088.

Holder, M., K. W. Brown, J. C. Thomas, D. Zabcik, and H. E. Murray, (1991), Capillary-wick unsaturated zone soil pore water sampler, Soil Sci. Soc. Am. J., 55, 1195-1202.

Kindler et al. 2010. Dissolved carbon leaching from soil in a crucial component of the net ecosystem carbon balance. Global Change Biology. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2010.02282.x/pdf

Korsaeth, A. and Eltun, R. 2000. Nitrogen mass balance in conventional, integrated, and ecological cropping systems and the relationship between balance calculations and nitrogen runoff in an 8-year field experiment in Norway. Agriculture, Ecosystems and Environment 79: 199-214.

Ledgard SF (2001). Nitrogen cycling in low input legume-based agriculture, with emphasis on legume/grass pastures. Plant and Soil 228, 43-59.

Magesan GN, White RE, Scotter DR (1996). Nitrate leaching from a drained, sheep-grazed pasture. I. Experimental results and environmental implications. Australian Journal of Soil Research 34, 55-67.

Magesan, G.N., Burton, P. and McFadden, G. 2010. Farmers invite scientists to scrutinise biological farming options. Proceedings of the conference “Whenua: Sustainable Futures with Māori Land” in Rotorua, New Zealand. July 21 – 23, 2010

Monaghan RM., Hedley MJ, Di HJ, McDowell RW, Cameron KC, Ledgard SF (2007) Nutrient management in New Zealand pastures - Recent developments and future issues. New Zealand Journal of Agricultural Research 50,181-201.

Mulvaney RL, Khan SA, Ellsworth TR (2009) Synthetic nitrogen fertilisers deplete soil nitrogen: A global dilemma for sustainable cereal production. Journal of Environmental Quality 38: 2295-2314.

Oquist, K.A., Strock, J.S. and Mulla, D.J. 2007. Influence of alternative and conventional farming practices on subsurface drainage and water quality. Journal of Environmental Quality, 36: 1194-1204.

Parfitt RL, Yeates GW, Ross DJ, Mackay AD, Budding PJ (2005) Relationships between soil biota, nitrogen and phosphorus availability, and pasture growth under organic and conventional management. Applied Soil Ecology 28: 1-13.

Sheppard, T. G. 2009. Visual Soil Assessment. Volume 1. Field guide for pastural grazing and cropping on flat to rolling country. Second Edition. Horizons Regional Council, Palmerston North. 119p

Sparling GP, Schipper LA, Bettjeman W, Hill R (2004) Soil quality monitoring in New Zealand: Practical lessons from a 6-year trial. Agriculture, Ecosystems & Environment 104: 523-534.

Zhu, Y., R. H. Fox, and J. D. Toth, (2002), Leachate collection efficiency of zero-tension pan and passive capillary fiber wick lysimeters, Soil Sci. Soc. Am. J., 66, 37-43.

Zimmer, G.F. 2000. The Biological Farmer: A Complete Guide to the Sustainable & Profitable Biological System of Farming. Acres USA.