

Farming Profitably Within Environmental Limits

18 May 2017 by [Dr Christine Jones](#)



Cows relishing a diverse sward containing radish, chicory and plantain. Photo: Max Purnell, Waitakaruru.

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Globally, over \$100 billion of inorganic nitrogen fertilisers are applied to crops and pastures every year (1). Between 10 and 40% of the applied N is taken up by plants. Much of the remaining 60% to 90% is returned to the atmosphere as ammonia or nitrous oxide - or leached to aquatic ecosystems as nitrate.

The use of inorganic N in agriculture is recognised as a highly inefficient - and polluting - practice. Due to its high mobility, inorganic nitrogen has become a key stressor for terrestrial, freshwater and marine environments in numerous locations around the world.

Around 800,000 tonnes of nitrogen fertiliser are applied annually in New Zealand, at a cost of over \$400 million. Volatilisation and leaching losses of 60 to 90% equate to annual wastage somewhere between \$240 million to \$360 million, representing a high economic cost to farmers.

The costs to the wider environment are orders of magnitude greater. Removing toxic nitrates from drinking water, for example, has been estimated at up to \$10.7 billion (2).

In contrast to most other OECD countries - in which rates of fertiliser application have decreased in recent years - the amount of inorganic nitrogen applied to agricultural land in New Zealand increased 41% over the period 2000 to 2010 (3). By comparison, France, Germany, and the United Kingdom have maintained high yields with forty to fifty percent less fertiliser than used in the 1980s (4).

Is there a solution to New Zealand's nitrogen dilemma?

The answer is a resounding YES!!!

Distinguishing between inorganic and organic nitrogen

Nitrogen is a component of protein and DNA and as such, is essential to all living things. But not all forms of nitrogen are the same. It is important to make a distinction between inorganic nitrogen, such as nitrate and ammonia – and organic nitrogen, such as amino acids and humic compounds.

Many decades of industry-funded research have resulted in a deeply held belief - among farmers, agronomists and some sections of the scientific community - that plants preferentially uptake N in the inorganic form (most usually as NO_3^- or NH_4^+). While it is certainly true that plants can utilise N in these forms (albeit with very low efficiency), very little N exists in these configurations in highly productive non-polluted natural ecosystems - or in highly productive biodiverse crops and pastures.

Much of the nitrogen currently used in agriculture derives from the Haber-Bosch process, developed in the early 1900s. This process catalytically combines atmospheric nitrogen with hydrogen derived from natural gas or gasified coal, to produce ammonia under conditions of high temperature and pressure. The Haber-Bosch process uses non-renewable resources to produce a product that is expensive to manufacture, transport and apply.

Supporting biological nitrogen fixation

The atmosphere is around 78% nitrogen, which equates to roughly 78,000 tonnes of dinitrogen gas above every hectare of land. The key to productive and profitable farming is to create - through the establishment of biodiverse crops and pastures and use of biology-friendly fertilisers - a soil environment that supports the presence of free-living and associative nitrogen-fixing soil microbes.

Chlorophyll is part of a protein complex that contains nitrogen, hence wherever you see green plants (any kind of green plant, not just legumes), some form of microbial nitrogen fixation is taking place.

The reason vast numbers nitrogen-fixing microbes have gone unrecognised is that the majority are not able to be cultured in the laboratory. However, recent bio-molecular methods for determining the presence of the *nif* genes that code for nitrogenase reductase have revealed a dizzying array of free-living and associative nitrogen-fixing bacteria and archaea living in a wide range of soils. These microbes are associated with every kind of crop and pasture plant, including grasses and non-legume herbs.



Herbal ley. All green plants form associations with nitrogen-fixing bacteria. This phenomenon is not restricted to legumes. Photo: Max Purnell, Waitakaruru

In well-functioning soils, 85-90% of plant nutrient uptake is microbially mediated and N is no exception. The first-formed product of biological nitrogen fixation, NH_3 , is rapidly converted (within milliseconds) to non-toxic NH_4^+ , which in turn is rapidly transformed to amino acids in healthy soils.

Amino forms of N are the most metabolically efficient for plant uptake. Further, in a closed N cycle, nitrogen cannot leach to waterways, volatilise to the atmosphere, or form toxic nitrates that poison stock (and people). The presence of nitrogen in the organic form also reduces the likelihood of soil acidification.

Unfortunately, many biological functions, including natural nitrogen fixation, are compromised by commonly used agricultural practices. The application of high rates of inorganic N, for example, inhibits the microbial communities formed by associative diazotrophs and mycorrhizal fungi that are able to fix and transport atmospheric N for free. This makes agricultural production even more dependent on N inputs. Once soils become 'addicted' it is hard to kick the nitrogen habit.

The other – often overlooked factor – is that a reliance on monoculture crops and low diversity pastures simplifies the soil microbiome. Lack of functional diversity produces a raft of negative consequences including an open invitation to pests and diseases, ultimately leading to increased use of fungicides and pesticides. Inevitably, loss of soil

function results in more chemicals being applied, more damage to the wider environment and less profit for farmers.

Soil as a bio-filter

In addition to being a key stressor for freshwater and marine environments off-farm, the application of high rates of inorganic nitrogen has many unintended negative consequences on-farm. These include deterioration of the water-stable aggregates important for soil structural stability. Reduced aggregation results in loss of porosity, lower soil water-holding capacity, compaction, low rates of infiltration in dry times and the propensity for water-logging in wet times. Poor structure also impedes root extension, reducing mineral and trace element acquisition by plants.

Soil saturation occurs when all the soil pores are water-filled. Once soil is saturated, any additional moisture either runs off or percolates to groundwater. Soil becomes saturated far more quickly when compacted due to compromised aggregate stability.

By inhibiting soil microbial communities, the application of high rates of inorganic N reduces the ability of soil to act as a bio-filter – creating a situation in which N applied in excess of the crop or pasture's immediate requirements is leached or volatilised even more rapidly than might otherwise have been the case. Poor soil structure also impedes infiltration and exacerbates the intensity of flooding.

Why are intensively managed NZ soils LOSING carbon?

Trends in soil carbon provide an excellent indicator of soil health. If carbon levels are trending down, levels of stable organic nitrogen, mineral and trace element availabilities, soil porosity and structure will decline. If carbon levels are trending up, levels of stable organic nitrogen, mineral and trace element availabilities, soil porosity and structure will improve.



Soil carbon is essential for good soil structure. Photo: Christine Jones

Research into soil carbon dynamics in New Zealand's pastoral soils reveal that many soils are not in 'steady state' with respect to carbon, as had previously been believed.

Professor Louis Schipper and five colleagues recorded soil carbon losses averaging 21 tonnes per hectare (21 tC/ha) in the top one metre of soil at 31 sites on flat to rolling pastoral land in New Zealand. In their paper entitled '*Large losses of soil C and N from soil profiles under pasture in New Zealand during the past 20 years*', the authors noted that their findings confirmed studies in other temperate parts of the world where similar soil carbon losses had been recorded. These losses were associated with an intensification of land use and commonly extended to depths of one metre or more (5).

Schipper and colleagues concluded "... large losses of soil C and N cause concern because of the likelihood that they contribute to increases in atmospheric CO₂ and the eutrophication of waters by reactive N" (5).

A more recent study undertaken by Schipper and colleagues (6) involving analysis of 83 sites, found that significant amounts of soil carbon were lost where dairy cattle grazed flat land. In contrast, carbon levels improved under drystock grazing on hill country, while no significant changes were observed under drystock on flat land or under tussock grasses in high country.

Andisols - inherently fertile volcanic soils once thought to be protective of soil carbon - lost similar amounts of carbon to other soil orders under intensive dairying (6). In other words, the changes in the level of soil carbon were management related rather than a function of soil type.

One of the key findings to emerge was that the largest soil carbon losses in the intensively managed dairy soils occurred in the 20cm to 80cm increment of the soil profile, while the improvements on North Island hill country grazed by dry stock were most evident in the 30-60cm increment (6).

These findings support those of Baisden and Parfitt (7) with regard to deep carbon being more reactive than originally considered. The results also suggest that factors other than pasture biomass are responsible for soil carbon changes observed at depth.

While deeply sequestered carbon alleviates subsoil constraints, improves farm productivity, enhances hydrological function and improves mineral density in plants, animals and people, the loss of deep carbon has the opposite effect.

It is unfortunate to see losses in soil carbon occurring in soils under intensively managed dairy pastures in New Zealand, a country blessed with vast tracts of inherently fertile land. The average soil carbon loss of 1 tC/ha/yr (5) would result in a cumulative loss of 50 t/ha of soil carbon in a 50 year period.

Schipper and colleagues noted that dairy systems receive higher fertiliser inputs than drystock systems, particularly with respect to N (6). Fertiliser N in dairy systems was in the order of "50-150 kgN/ha/yr" while drystock pastures "tended to receive no urea" (6).

Is it possible that differences in rates of application of high-analysis fertiliser explain the large contrast in soil carbon losses and gains recorded in NZ pastures under different management regimes? Or are other factors also involved?

Soil as an ecosystem: microbes matter!!

A healthy agricultural system is one that supports all forms of life. All too often, many of the life forms in soil have been considered dispensable. Or more correctly, have not been considered at all.

In parallel with research into the human gut microbiome, understanding and supporting the functioning of the soil microbiome is being increasingly recognised as the future for agriculture.

Sadly, many of the microbes important for soil function have gone missing in action. Can we get them back? Some producers have achieved large improvements in soil health in a relatively short time. What are these farmers doing differently?

They diversify.

The power of diversity

The belief that monocultures and intensively managed systems are more profitable than diverse biologically-based systems does not hold up in practice. Monocultures need to be supported by high and often increasing levels of inorganic fertiliser, fungicide, insecticide and other chemicals that inhibit soil biological activity. The result is even greater expenditure on agrochemicals in an attempt to control the pest, weed, disease and fertility 'problems' that ensue.

Every plant exudes its own unique blend of sugars, enzymes, phenols, amino acids, nucleic acids, auxins, gibberellins and other biological compounds, many of which act as signals to soil microbes. Root exudates vary continuously over time, depending on the plant's immediate requirements. The greater the diversity of plants, the greater the diversity of microbes and the more robust the soil ecosystem.

A global soil health revolution is taking place, based on plant diversity. Due to the soil priming effects of multispecies crops and pastures, farmers in many parts of the world are finding they are able to significantly reduce or even eliminate the need for inorganic fertiliser.

As well as improving soil function, multispecies crops and pastures provide habitat and food for insect predators. Recent research has shown that as the diversity of insects in crops and pastures increases, the incidence of insect pests declines, hence avoiding the need for insecticides (8).

Common mycorrhizal networks

An aspect of plant community structure that is gaining increased research attention is the presence of 'common mycorrhizal networks' (CMNs) in multi-species cover crops, cash crops grown with companion plants and high-diversity pastures. It has been found that plants in communities assist each other by linking together in vast underground superhighways through which they can exchange carbon, water and nutrients (9, 10). Common mycorrhizal networks increase plant resistance to pests and diseases (11) as well as enhancing plant vigour and improving soil health.

In my travels I've seen many examples of monocultures suffering severe water stress while diverse multi-species crops beside them remained green.



Triticale monoculture (left foreground) suffering severe water stress while triticale sown with other species (background and right) is powering. In addition to triticale, the 'cocktail crop' contained oats, tillage radish, sunflower, field peas, faba beans, chickpeas, proso millet and foxtail millet. Chinook Applied Research Association (CARA), Oyen, Alberta. Photo: Christine Jones

For a humorous insight into how diverse mixes of plants collaborate with soil life to rejuvenate soil and enhance drought tolerance, see reference (12) at the end of this document.

How does this relate to New Zealand dairy pastures?

New Zealand dairy is largely based on low-diversity, shallow-rooted, short-lived ryegrass/clover pastures. Low plant diversity and inadequate root architecture contribute to poor soil function. Further, the crude protein content of the forage is far higher than required by lactating dairy stock. Excess dietary N results in elevated levels of blood urea nitrogen (BUN) and milk urea nitrogen (MUN), which have been linked to an increased incidence of lameness, mastitis and infertility. In addition to animal health issues, excess dietary N is excreted as urinary N, causing environmental pollution (13)

In comparison to ryegrass/white clover pasture, diverse swards containing herbs such as chicory, plantain, lucerne and red clover have been shown to not only improve animal

health and provide a more even distribution of the quantity and quality of feed through the year, but also significantly reduce the excretion of urinary N while maintaining - or often improving - milk production (14, 15, 16, 17).

Reductions in urinary N between 20% and 50% have consistently been reported for dairy stock consuming mixed pasture swards in New Zealand (14, 15, 16, 17).

Restoring biodiversity to agricultural soils

Comparisons of low-input high-diversity pastures with high-input low-diversity pastures indicate yields are either comparable - or higher - in low-input high-diversity systems. A German experiment in which fertiliser rates of 0, 100 and 200 kg N/ha/yr were applied to 78 experimental grassland communities of increasing plant species richness (1, 2, 4, 8 or 16 species; with 1 to 4 functional groups) showed higher diversity was a more important factor for pasture yield than nitrogen fertiliser (18).

Similarly, a UK study found that species rich-pastures averaged 43% higher herbage yield than species-poor pastures. Regression analysis showed that the variation in herbage yield was related to differences in the number of non-leguminous herbs, suggesting the increased yield reflected the greater range of life forms present (19).

In U.S. studies, Bruce Hungate and colleagues reported a strong link between plant diversity and carbon sequestration potential. The carbon storage capacity of native prairie with '11+' plant species was higher than the carbon storage capacity of CRP grasslands containing 5 or 6 species. The researchers suggested there would be economic, ecological and environmental advantages to increasing the number of species used in CRP plantings, despite the higher upfront costs (20).

In summary, enhanced above- and below-ground diversity

1. creates a robust soil microbiome and supports common mycelial networks
2. increases soil carbon sequestration and carbon storage capacity
3. improves aggregate stability, soil structure and function
4. enhances the capacity of the soil to act as an effective bio-filter
5. evens out feed availability throughout the year
6. maintains or improves herbage yield and milk production
7. reduces urinary N excretion by 20 to 50%
8. reduces reliance on high-analysis N and P fertilisers, herbicides, insecticides and fungicides
9. optimises soil, plant, animal, and human health, water quality and farm profit.

When the entire farm functions as a riparian buffer, catchment health and water quality are vastly improved. In addition to supporting a raft of ecosystem services, healthy soils underpin high-yielding agricultural production, farm profit and the wealth of the nation.

Two simple steps for farming profitably within environmental limits

- i) Incorporate as much pasture diversity as possible, particularly warm- and cool-season herbs and a variety of grasses.
- ii) Replace inorganic N fertiliser with biology-friendly products to enhance the innate capacity of soil microbial communities to fix atmospheric nitrogen. In the same way as it is important to 'feed the rumen not the cow' it is also important to 'feed the soil microbiome not the plant'

The future prosperity of the New Zealand nation will require ecologically sound agricultural production. Enhanced above and below-ground diversity may well provide the key to the restoration of profitable, environmentally-friendly farming. The costs involved in transforming high-input low-diversity pastures to low-input species-rich multi-functional pastures would be minimal in comparison to the benefits. Established and managed appropriately, a diverse sward should remain productive almost indefinitely.

Providing support to farmers to develop and implement a whole-farm approach to restoring soil biodiversity - so that N fertiliser is not needed - would be more beneficial to the New Zealand nation than attempting to regulate the use of N.

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About the author



To the pressing worldwide challenge of restoring topsoil, soil ecologist Dr Christine Jones offers an accessible, inspiring perspective. For several decades Christine has worked with innovative farmers and graziers implementing regenerative land management practices that enhance biodiversity, nutrient cycling, carbon sequestration, productivity, water quality and community and catchment health. Following a highly respected career in public sector research and extension, Christine received a Community Fellowship Award from Land and Water Australia in 2001 for 'mobilising the community to better manage land, water and vegetation.' Three years later she launched 'Amazing Carbon' as a means to share her vision and inspire change. In 2005 Christine held the first of five 'Managing the Carbon Cycle' forums to promote the benefits of soil carbon. Over the past decade she has gained international recognition as a speaker, presenting on 'The Fundamentals of Soil' at workshops, field days, seminars and conferences throughout Australia, New Zealand, South Africa, Western Europe, Central America, USA and Canada. For further information visit www.amazingcarbon.com