Otago Regional Council

Document Id:

MEMORANDUM

To:	**Dolina Lee, Senior Policy Analyst**
From:	**Mark Crawford, Land and Soil Scientist**
Date:	**20/11/2023**
Re:	**Nitrogen limits and their impact within Otago region:**

Name	Role	Date Completed
Dr Erik Button	Land and Soil Scientist	23/04/2024

Purpose

The Policy Team sought advice from the Science Team regarding the proposed Land and Water Regional Plan. The questions posed were:

1. Do you advise the continued use of a nitrogen limit for pastoral farming systems?
2. Is it appropriate to use a nitrogen limit for vegetable growing and arable production?

Methods

To answer the questions outlined above, the memorandum aims to:

1. Highlight the key aspects of the nitrogen cycle and its relation to plant yields.
2. Demonstrate the difference in nitrogen applications made in pastoral and arable farm systems and identify the risk for nitrogen loss between the various farm systems relating them to the Otago region.
3. Evaluate evidence from Otago systems to assess the risk nitrogen use has on the environment across different farm systems in Otago.

Discussion

Nitrogen Use:

Nitrogen (N) is an essential element for photosynthesis and is an important part of amino acids which are the building blocks of proteins for all living things.

N also exists in many differing chemical forms and in large amounts within the biosphere and air (McLaren & Cameron, 1996). Atmospheric N must be fixed by soil micro-organisms or by chemical manufacturing processes before it can be taken up by plants. Most N in the soil is in soil organic matter which is unavailable to plants. Plants can access available inorganic N in the forms of nitrate and ammonium by the process of soil organic matter mineralisation (Figure 1).

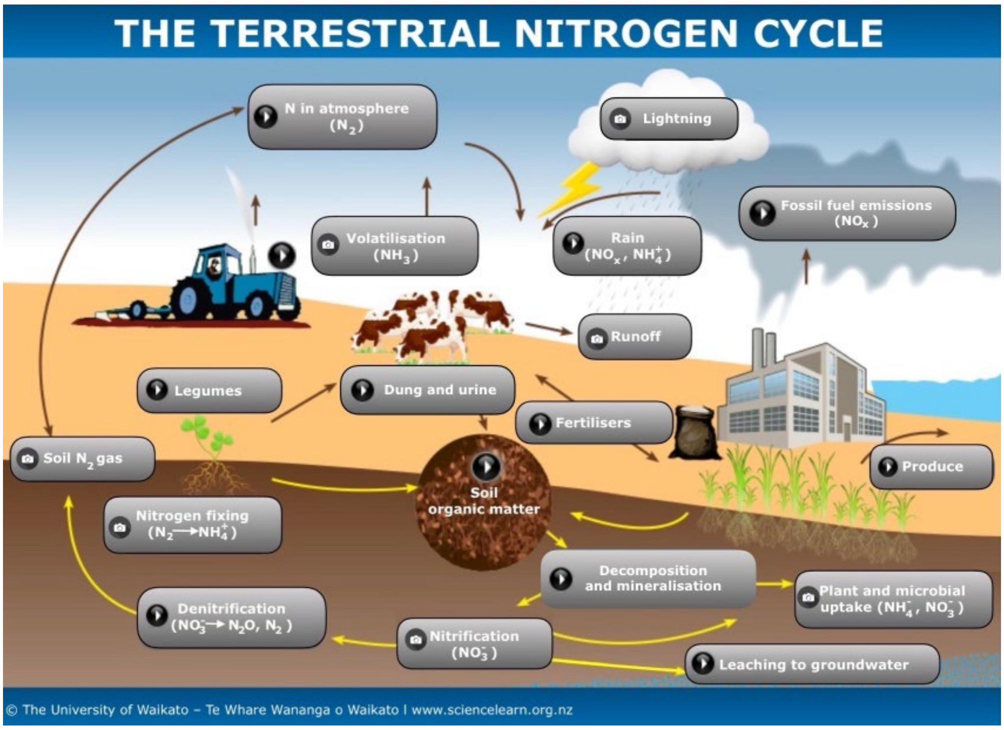

Fig. 1 The Terrestrial Nitrogen Cycle (The University of Waikato, 2013).

Of all plant macro nutrients, N is needed in the largest quantities with it typically making up 2-4 % of plant biomass (McLaren & Cameron, 1996). Increasing this proportion can increase plant growth until a plateau is reached beyond which there is limited increase in growth (Figure 2).

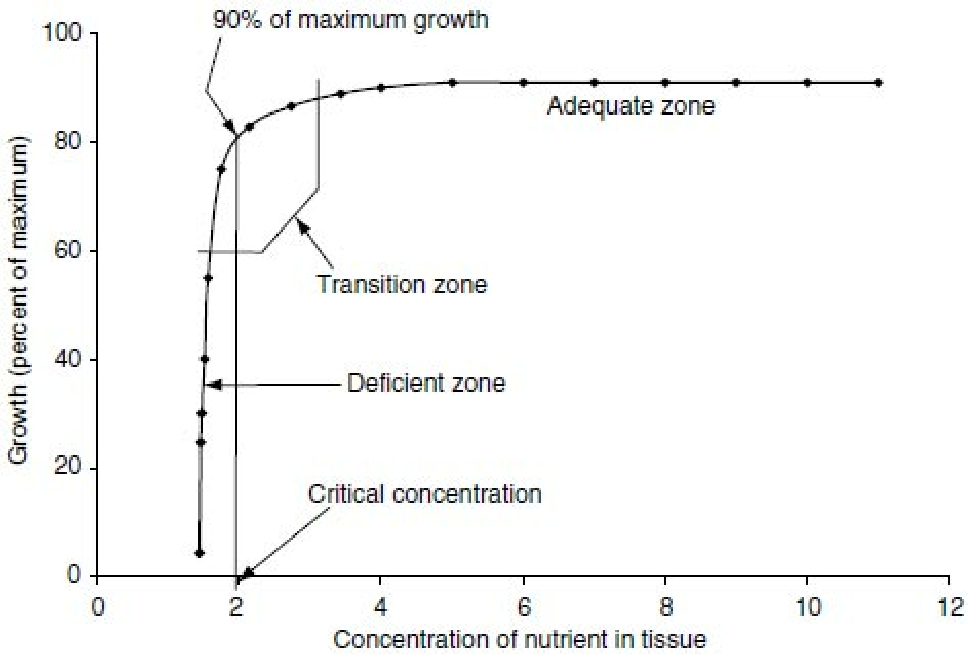

Fig. 2 A generalised model of a plant growth response to an increase in plant tissue nutrient. Units are random and for illustration only. From Biocyclopedia (2024).

The minimum nutrient concentration within the plant that corresponds t the greatest (90%) plant growth is termed the critical concentration. Any concentration beyond this is in the adequate zone and is known as 'luxury uptake', where the concentration within the plant increases with limited effect on growth. This occurs because the nutrient is no longer limiting and the next most limiting nutrient or biological input (e.g. water, temperature, other nutrients) is limiting plant growth.

A typical high producing pasture would be between 3 to 4% in Nitrogen, much like cereal grains, with legumes being higher at 4 to 5 %. Vegetable crops are in a similar range of between 3.5 to 5 %. All follow a similar pattern of adequacy and insufficiency within their plant tissue.

Nutrient uptake and yield are mutually dependent. The amount of N required by a crop to achieve an actual yield close to its potential depends not only upon an optimum supply of nutrients, but also excellent soil physical conditions, growing season (temperature, sunlight and moisture), control of pests and diseases and a perfectly timed harvest (Reid & Morton, 2019). Even if the yield potential is realised, the final marketable yield will always be lower due to yield losses from harvesting and grading, and this being the yield that determines nutrient inputs (Figure 3).

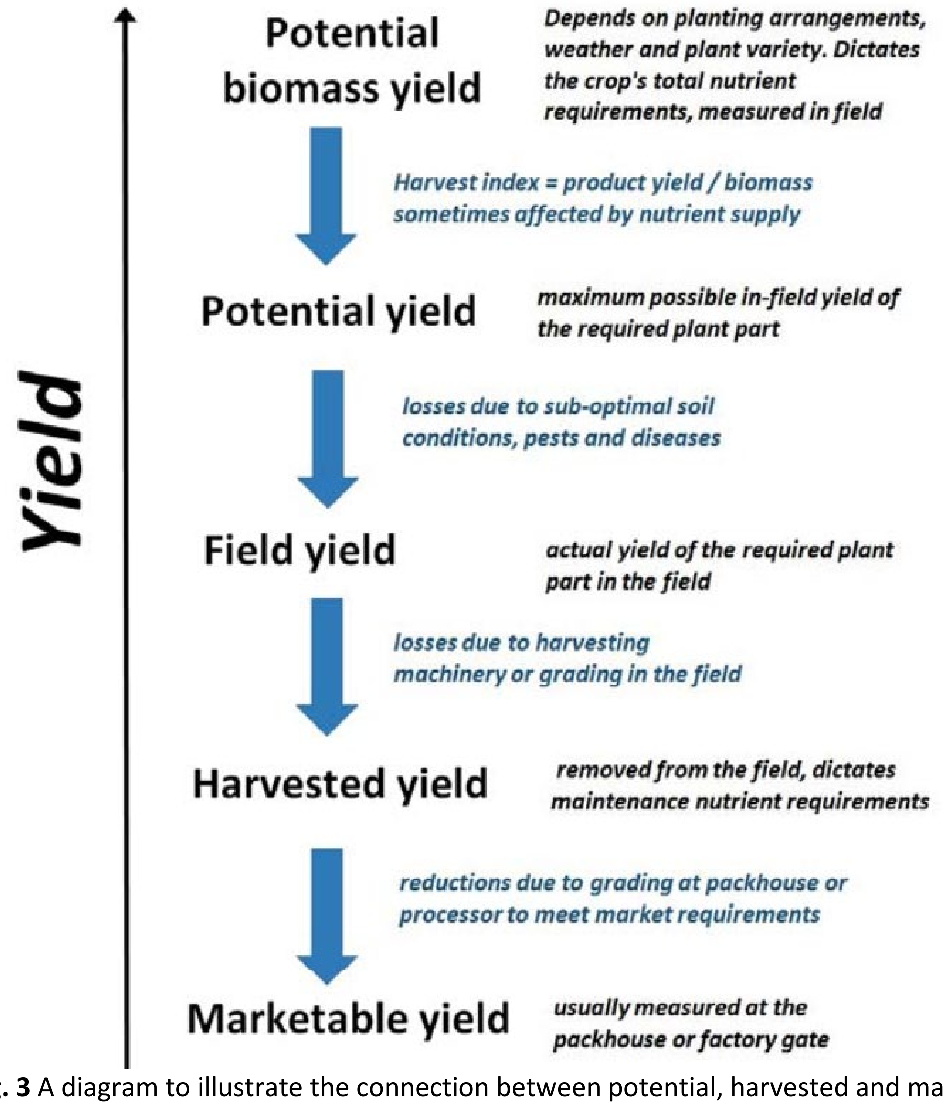

Fig. 3 A diagram to illustrate the connection between potential, harvested and marketable yield in vegetable crops. It is also relevant for arable crops and for pastoral production. From Reid & Morton (2019).

The factors that limit reaching the potential yield cannot be compensated for by applying more N fertiliser. Applying higher rates of fertiliser when the nutrient is not limiting plant yield will mean it will not be taken up and will likely lead to increased N losses to the environment.

Economics:

The amount of fertiliser required to obtain the maximum crop yield is unlikely to be the same as the amount that will give the highest economic return (Figure 4). The cost of fertiliser increases linearly with the amount applied but the increase in the value of the crop follows a curvilinear pattern of the yield response of the crop (Figure 4) like the curve in Figure 2. The optimum economic rate of fertiliser application (^{x}econ; Figure 4) will therefore be where the difference between the cost of fertiliser and the increase in the value of the crop is at its greatest. As such, a reduction in the unit cost of fertiliser or an increase in the value of the crop will justify the application of a higher rate of fertiliser and vice versa (Morton, 2017).

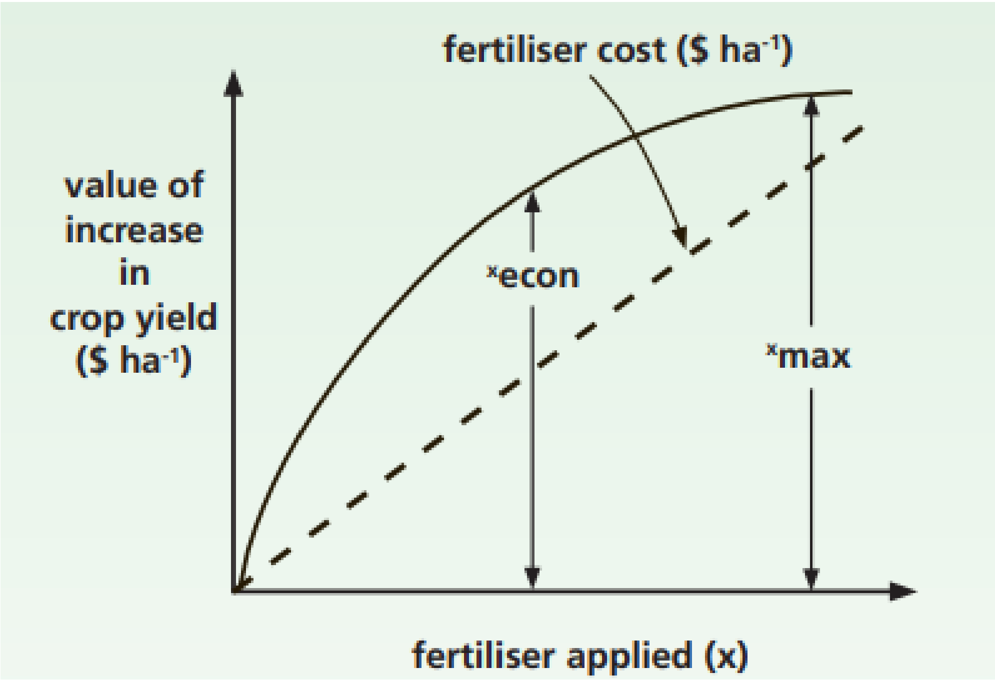

Fig. 4 A simplified diagram of the relationship between the rate of fertiliser applied (x) and the value of a crop yield. ^{x}econ denotes the largest difference between the fertiliser cost and increase in crop yield value; and ^{x}max is the maximum amount of fertiliser applied above which there is no increase in crop yield value.

The fertiliser rate that gives the best return is unique for each crop type, the season, and the farm situation. Price for the crop, fertiliser costs, crop response to fertiliser and soil test values all impact upon economic return (Reid & Morton, 2019).

Pastoral systems are different to arable and vegetable cropping as the responsiveness of pasture to N fertiliser is also affected by the animal production targets and the level of pasture utilisation that is desired. In addition, the amount of N available from clover production is also an influencing factor. In general, fertiliser N trials have highlighted that better N responses in late winter/early spring are due to plants being N deficient. Along with artificial drainage during the winter removing plant available N, this is because lower temperatures restrict clover growth and soil microbial N fixation and mineralisation, resulting in lower plant available N contents. In contrast, the poorer response of plant growth to N in late summer/autumn is due to limited soil moisture, higher soil mineral N concentrations and a higher proportion of clover supplying N to the pasture (Gray, 2023). The timing of fertiliser N application is a strategic management tool used to help produce additional feed to meet foreseeable animal feed supply demands. Thus, the economics are reliant not only on the cost of fertiliser but the level of animal production being achieved from an amount of feed (both quality and quantity), the returns from this production, and the costs associated with achieving that production, in particular the farm working expenses. As such, an arable or vegetable growing operation is not equal to a pastoral system in the requirement and use of N and should not be treated as equivalent.

Nitrogen Application Rates:

For a crop there are two major components of a N fertiliser recommendation:

1. How much N is required to grow a crop, and
2. How much N is needed for maintenance (will be needed to replace what is removed in the crop offtake).

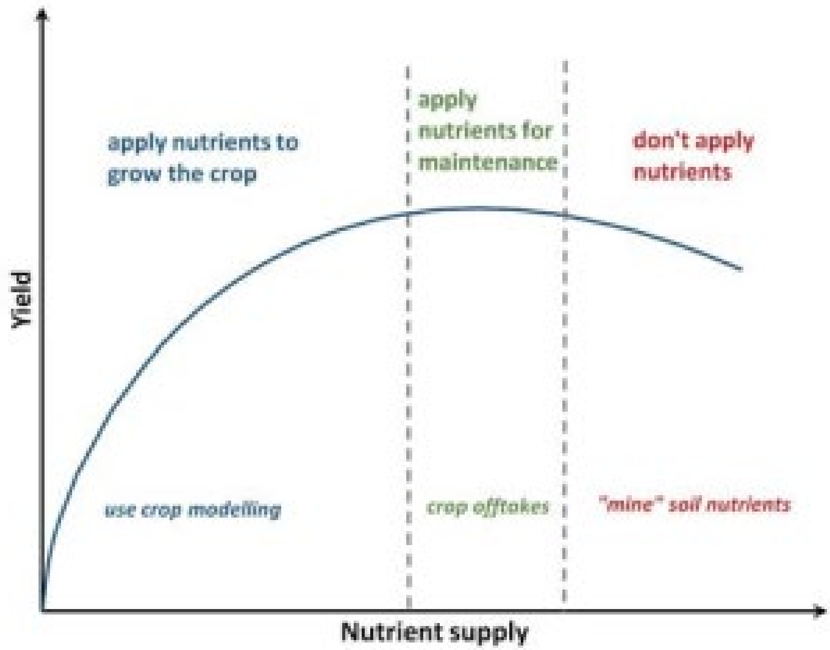

Fig. 5 A simplified diagram demonstrating the response of crop yield to a single nutrient supply. This applies for nitrogen as well as other macro nutrients. From Reid & Morton (2019).

The amount of extra N required to achieve a target yield equals the amount required for the target yield minus the soil N supply as determined by soil testing. In general, when soil test values are either high or within the target range, apply below maintenance to maintenance rates, or if low, crops may yield best at fertiliser N rates that exceed their actual uptake, likely due to either the crops having sparse root systems and a short growing season, or a capacity for luxury uptake. This disparity between uptake and the added fertiliser rate for best yield is mitigated by careful placement and timing of such applications (Reid & Morton, 2019). Nevertheless, applying higher rates of N than can be taken up by plants carries a substantial risk of N leaching into waterways contributing to eutrophication and decreases in water quality.

For pastoral systems, a maximum single application rate of 50 kg N/ha is generally recommended because of the reported decline in N response efficiency at higher rates, and importantly the negative effect on clover growth and N leaching loss risk (Gray, 2023). However, the recommendations for arable and vegetable crops, as can be seen from Table 1, industry recommended N application rates are all above this and the 190 kg N/ha threshold for pastoral agriculture (NES FW, 2020).

Table 1. Industry agreed N application recommendations for different vegetable and arable crops to achieve expected yields.

Crop	**Maximum recommended N application rate (kg N/ha)**	**Expected yield (t DM/ha)**	**Reference**
Potato	260	100	(Reid & Morton, 2019)
Maize	260	30	(Reid & Morton, 2019)
Carrot	210	170	(Reid & Morton, 2019)
Wheat	200-260	12.5	(Nicholls et al, 2012)

Nitrogen Loss Rates:

Total annual amounts of N use are less of an indicator of N losses, rather it is the rates and timings of the applications which determines the direct losses from N fertiliser applications.

A key finding from research on nitrate leaching is that while the amount of fertiliser N applied affects the amount of leaching, it is to a lesser extent than the leaching resulting from the N excreted by animals, particularly urine in intensively grazed pasture systems. This is because the application of N fertiliser generates more forage, enabling higher stocking rates, higher consumption, and thus more N excretion to the soil in dung and urine (Gray, 2023). Importantly, nitrate leaching continues even when there is no fertiliser N applied, as animal urinary excretion from the surplus protein that the animal eats still occurs and can be increased from the added supplementary N purchased. Research also shows that in general, the direct leaching of N from fertiliser in grazed pasture is low if application rates are not excessive (i.e. < 200 kg N/ha/year) and are synchronised with periods when pasture requires N and is actively growing (Gray, 2023).

In contrast to pastoral systems, most of the N losses from arable cropping and horticulture originates as fertiliser or plant residues (Larned et al, 2018). A six-year study of 11 vegetable and arable farms across New Zealand calculated an average leaching loss of 60 kg N/ha/year across all sites and years (FAR, 2021). At face value this appears high in comparison to other pastoral losses in Otago, however two thirds of the site losses were less than 60 kg N/ha/year, and the higher losses were associated with higher rainfall and drainage, followed by high soil mineral N and fallow ground. In addition, commercial vegetable growing is inherently hard to model N losses with via Overseer®, the most popular nutrient budgeting software in New Zealand (Bloomer et al, 2020). Bloomer et al. reported losses from intensive vegetable production between 46 to 60 kg N/ha/year on moderately well drained deep silt loam soils under a total rainfall of 1120 mm annually. In Otago annual rainfall is generally lower with a relatively high proportion of slower draining soils in the lowlands, likely leading to lower losses than found in this study. This interpretation is supported by a study that modelled N losses from 16 arable farms in Otago, where losses were in the range of 32-35 kg N/ha/year (Horrocks, 2023). This is consistent with other loss estimates from cropping (Welten et al, 2021) (Ledgard, 2000).

Arable losses are on average similar if not lower to dairying, dairy support, with higher losses likely from arable farms wintering dairy cattle (Rodway, 2020). Vegetable production enterprises are similar if not higher when compared to arable (Rodway, 2020), as they do involve longer fallow periods and fertiliser applications during at risk times but are unlikely to be wintering stock, especially cattle. Horticulture enterprises within Otago (pip and summer fruit) generally have low environmental impacts given their low water use and low N fertiliser use (Roberts & Robertson, 2023).

Conclusion

To conclude, the answers to the questions posed by the Policy Team are below:

1. Do you advise the continued use of a nitrogen limit for pastoral farming systems?

Yes. In pastoral systems, stock density is the main driver of N leaching losses which is limited by pasture yields. Therefore, allowing higher rates of N fertiliser (>190 kg N/ha/year) in these systems can lead to stock intensification and greater N losses. To avoid impacts on the environment and water quality, continuing the use of this limit is recommended.

2. Is it appropriate to use a nitrogen limit for vegetable growing and arable production?

No. In these systems, N is required in large amounts to reach profitable yields. Arable and vegetable production is required for the profitability and food supply of both the urban and rural populations as well as by the agricultural industry for export of seeds and feed supplements that contribute towards reduced N leaching (for example, wheat and barley grains fed in dairy sheds allows for more efficient capture of excess nutrients). Both the economics and land management practices mean that N losses are no greater than other land uses despite higher N application rates and depend more on factors such as soil drainage, soil mineral N availability and the crop rotations used rather than N application rates. As such, higher N rates on an arable or vegetable farm may not result in higher N losses within a rotation. It is therefore inappropriate to apply the 190 kg N/ ha limit (NES FW, 2020) to arable, horticultural, and intensive vegetable growing farms. The environmental impacts of these systems are best left to the mitigation of activities such as cultivation, reducing bare ground through cover crops and differing rotations, setbacks and grow back periods.

However, it may be that all farm types should have some form of permissive regulation or guidance that would enable them to show the decision-making criteria used in determining the application rates and times when N is applied throughout the season to ensure good management practices are being employed for these farm types.

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