Exclusion zones for variable rate nitrogen fertilisation in grazed dairy pasture systems in New Zealand

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Abstract

To assess the variability of total soil nitrogen (TN) on grazed and irrigated pastures, TN was quantified from spatially distinct “areas” within the paddock (irrigated and non-irrigated areas, around the gates, and around the troughs) on two dairy farms located in Canterbury, New Zealand. During soil sampling, each area was sub-divided and multiple soil samples were taken to ensure adequate spatial representation of each area. The results showed there were no differences in TN between the farms, but differences were detected between the paddocks ($P < 0.001$), largely due to the significant interaction between the areas (gates and troughs) in different paddocks ($P < 0.001$). The greatest variability in TN was around the gates, due to either much higher or lower TN near the entrance of the gates. The TN levels returned to concentrations that were similar to those in the surrounding pasture after 4 m distance from the gates. This study shows while TN concentrations are relatively consistent spatially within pastures, there is high variability in TN in proximity to some farm infrastructure, such as gates and troughs.

Background

New Zealand dairy farming has intensified over the last three decades resulting in increased use of fertiliser, feed, and irrigation to support higher stocking rates and production. Increased use of synthetic nitrogen (N) fertilisers has led to higher N surplus per hectare (ha) causing N loss to the external environment via nitrate leaching and greenhouse gas emissions (Foote *et al.,* 2015; Pinxterhues et al., 20 15). In addition, nutrients in pasture soils are spatially heterogeneous due to soil characteristics, fertiliser application patterns, and distribution of animal urine and dung deposition. In grazing pastures, heterogeneity is enhanced by grazing behaviours of cows, which cause accumulation of nutrients in non-productive areas such as water troughs and feeders (Sanderson *et al,.* 2010; West *et al.,* 1989). However, synthetic fertilisers are applied across the pastures without considering nutrient distribution related to the farm management and farm infrastructure, which can lead to reduced N use efficiency.

High N areas should be considered when deciding nutrient balances in pasture systems (West *et al*., 1989). Quantification of spatial N distribution and nutrient balances can help to develop a variable N-fertilisers application system, thereby avoiding fertiliser application to high N areas and minimising the environmental impacts. Total N is a good representation of variation in N supply in pasture soils (Shepard *et al*., 2015). There is little information available regarding how spatial variability of TN concentrations are affected by farm infrastructure.

A preliminary study to gather information about the spatial distribution of N around farm infrastructure (i.e. water troughs, gates, fences, tree-hedges) was completed in 2016/17. Rules for identifying spatially distinct areas were derived from a combination of expert interviews, targeted field surveys, and analysis of Google Earth satellite images. Using geo-images and targeted GNSS-field survey data in GIS, the spatially distinct areas were calculated.

A strategy is needed to quantify spatial variation of TN within intensively grazed pastures defined by farm infrastructure-related influences. The objective of this paper is to determine how TN varies around farm infrastructure features in grazed pastures.

Methods

Experimental Site

Two experimental sites were chosen for this study; a farm in Rolleston (43°34'03.0" S, 172°19'24.0" E), and a farm in Lauriston (43°42'21.2" S, 171°44'28.0" E), Canterbury, New Zealand. Both farms are irrigated, commercial dairy farms that use a pasture-based rotational grazing system with supplementary feed. Both farms were regularly irrigated with a center pivot irrigator during the growing season, when required, and received regular applications of N fertiliser after each grazing from September 2016 to April 2017.

The soil at the Rolleston farm was classified as free-draining Lismore silt loam pallic firm brown soil (Hewitt, 2010). The pasture consists of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). The paddocks were grazed with a herd of 630 Friesian cows, maintaining a stocking density of 3.6 cows per ha. The grazing rotation cycle was variable throughout the year, at 26, 35 and 40 day rotations for March, April and May 2017, respectively. Cows receive supplementary feed (silage, baleage, straw on paddocks and grain in milking shed) as required.

The Lauriston farm site is situated on well-drained Lismore silty loam pallic firm brown soil (Hewitt, 2010). The pasture is a mix of perennial ryegrass and white clover, and some paddocks growing plantain. The herd is comprised of Fresian, Jersey, and Fresian/Jersey cross bred cows which are pasture grazed, and receive supplements consisting of grass, lucerne, maize, grass silages, as well as barley, soy and molasses, which is fed in the shed. During the growing season, the cows are pasture grazed on a 21-30 day rotational basis from September until March. Cattle are barn housed during the winter.

Soil Sampling

Three representative paddocks with an area of 5.1 to 5.5 ha from each farm were selected for soil sampling. Soil cores were collected to a depth of 15 cm within each of the spatially distinct areas including a main gate, a water trough and low productive (non-irrigated) areas. These areas were all located under the centre pivot irrigator. Soil sampling was carried out four to 12 days after grazing and before fertilisation in April and May 2017.

Each selected spatially distinct area was sub-divided using a grid-like system in accordance with their proportions and shape (Fig.1). Sampling procedures developed were different for each spatially distinct area of the paddock. The grid-like system at the main paddock gate was in an arc divided into three segments, extending from the gate to the main paddock area at increasing distances of 2, 4, 8, 12, 24 and 32 m (Fig. 1). At the water troughs, circular rings were marked, starting from the trough at 2, 4, 8 and 12 m and subdivided into four equal sections (Fig. 1).

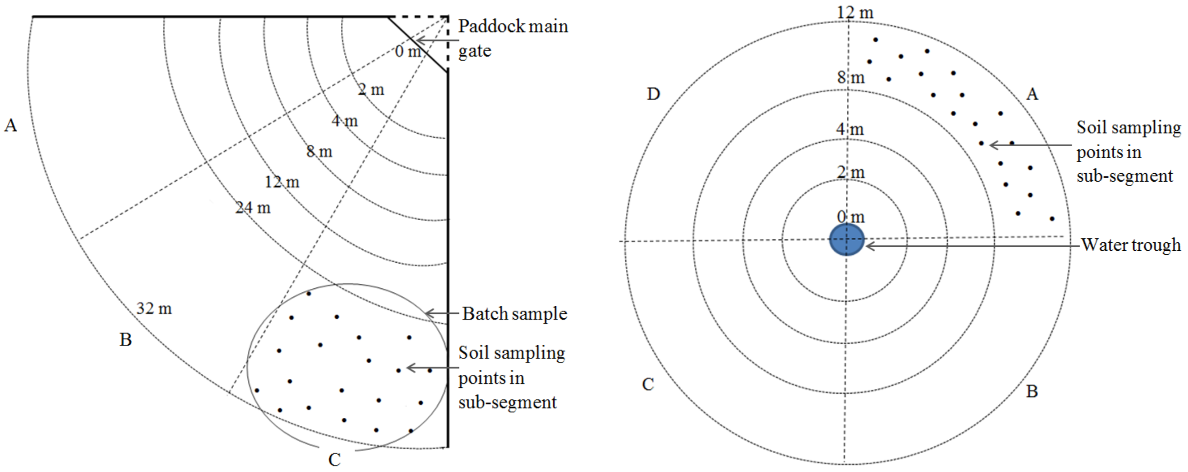

Figure 1. Illustration of sampling procedure at paddock main gate (left) and around water trough (right)

The normal paddock area was divided into nine rectangular grids excluding non-irrigated areas. When sampling in the normal paddock area, a buffer zone of ≈50 m was allocated around gates, water troughs, and non-irrigated areas. The non-irrigated areas in the paddocks were first identified in Google Earth images, and divided into ten equal segments. These areas are distinguishable in the paddock with lower pasture density and atypical canopy cover compared to the irrigated paddock areas. Visible urine and dung patches were excluded during soil sampling.

Twenty spatially random soil cores were collected within each divided grid-block. Respective soil cores were homogenised to represent each grid-block, giving a total of 18 samples for the main gate, 16 samples for the water trough, 9 samples for the normal paddock area, and 10 samples for the non-irrigated area, from within each paddock.

All samples were kept in cool storage in-field until they were transported to a freezer (0 ^{0}C) for laboratory storage prior to analysis.

Soil Sample Analysis

Soil samples were analysed to measure the spatial distribution of TN in the laboratories at Centre for Soil and Environmental Research, Lincoln University, Lincoln. A 0.5 g (±0.007) subsample of the air-dried soil was placed into a crucivil and TN was determined by the Dumas combustion method using a vario Max CN Element Analyser (elementar Analysensysteme GmbH, Germany).

Statistical Analysis

When comparing the different areas in the paddocks, since the data were unbalanced, variation in TN was analysed using the general linear model (GLM) procedure in Minitab v17, with the explanatory model including the terms farm, paddock, and area, which represents categorised spatially distinct areas within each paddock (irrigated, non-irrigated, gates, and troughs), treated main factors, with paddock nested in farm, and the interaction term between paddock and distinct area. When looking for relationships between TN and distance from troughs and gates, the GLM procedure included paddock and distance as explanatory factors in the model. Differences among paddocks, between different distinct areas, and between different distances from the troughs or gates were assessed using Fisher's unprotected LSD ($P < 0.05$). Data summaries in text represent the mean ± standard deviation (sd).

Results

Comparison of farms, paddocks and distinct areas

There was no significant difference in TN between the two farms (Lauriston, 0.292 ± 0.053; Rolleston 0.295 ± 0.086; $P = 0.789$). There was, however, highly significant differences between paddocks ($P < 0.001$), and a significant interaction between paddock and distinct area ($P < 0.001$).

Overall, paddocks L-A and R-B had lower TN, compared with paddocks R-C, L-B and L-C, and TN was highest within 4 m of the gates (0.315 ± 0.153) compared with the normal region of the paddock (0.291± 0.020), and within 4 m of the water trough (0.272 ± 0.04; Fig. 2). Total N was considerably more variable near the gate than in the normal paddock: the mean CV% per paddock for N within 4 m of a gate was 39.1%, over six times that of the normal paddock (6.1%; Fig. 2).

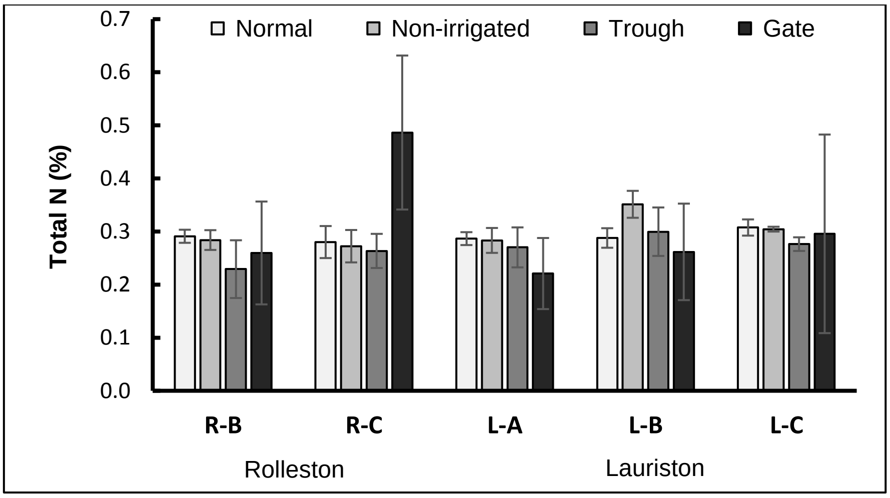

Figure 2. Variation in total soil N (%) among four areas, in five paddocks, over two farms in the Selwyn District of Canterbury, New Zealand (mean ± sd), where "R" in the label represents the Rolleston farm, and "L" in the label represents the Lauriston farm.

For the series of samples taken at distances from water troughs, there were significant differences among paddocks (*P* = 0.001) and significant effects of distance (*P* < 0.001). Soil N was highest in paddocks R-A and L-B (> 0.3%) and lowest in paddocks R-C and L-A (< 0.28 %). The patterns in TN with distance from the water troughs in the three paddocks at Lauriston were very similar to each other (Fig. 3 b). The paddocks at Rolleston were more variable as distance from the troughs increased (Fig. 3 a). With regard to distance from the trough, the combined data indicated that TN tended to be lowest in soil samples taken close to the trough (2 m; 0.250 ± 0.031%) and was highest at 4 m (0.321±0.052%) and 8 m (0.304 ± 0.034%) away from trough (Fig. 3 a,b).

When examining the patterns for TN in relation to distance from gates, there were no overall differences among paddocks (*P* = 0.097) or effects of distance (*P* = 0.285). In four paddocks, except R-A and R-C, TN was lowest nearest the gate (2 m) (Fig. 3 c,d). However, for one paddock (Paddock R-C, Rolleston) TN was consistently high (0.774% to 0.676%) at 2 m (Fig. 2; Fig 3.c). There was no soil TN data available for Paddock R-A within 4 m of the gate.

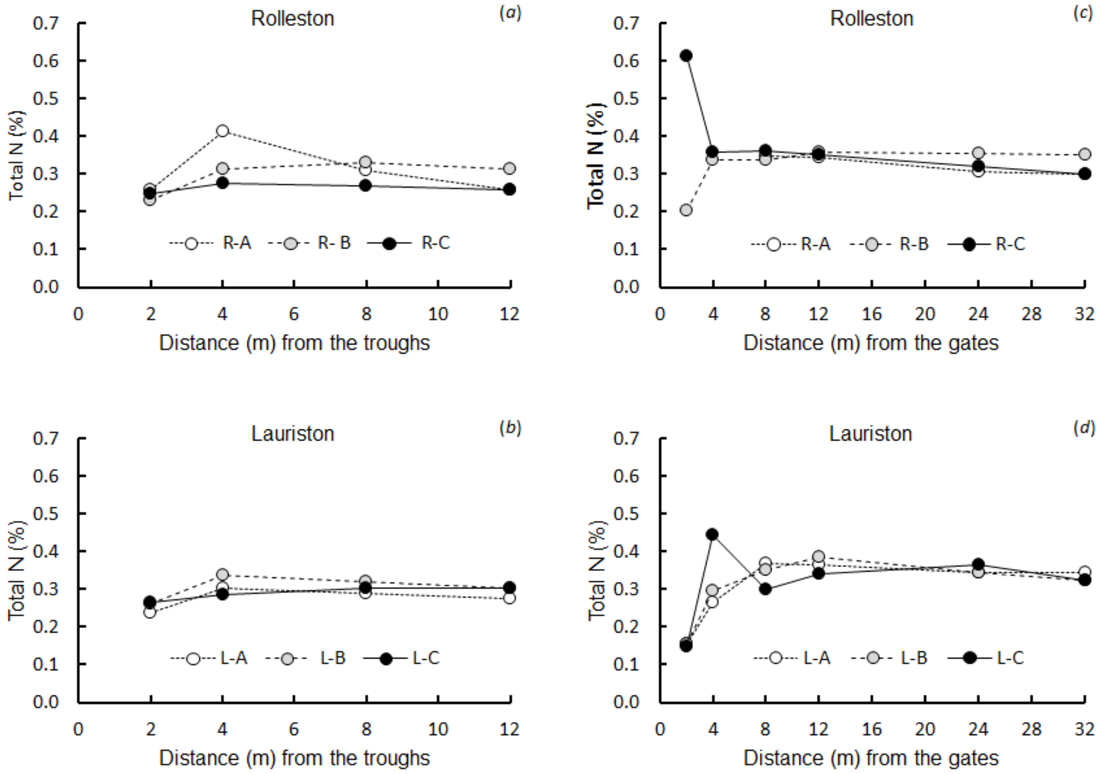

Figure 3. Patterns in total soil N (%; mean) with increasing distance from water troughs (*a, b*) and gates (*c, d*) in six paddocks of pasture at farms at Rolleston and Lauriston.

Discussion

The TN concentrations are not immediately affected by application of N from fertiliser or urine as the inorganic N is available for leaching, denitrification and ammonia volatilization (Cecagno *et al.*, 2017). Therefore, any recent differences in stocking rates or fertiliser regimes are unlikely to significantly affect TN. This explains the lack of difference in mean TN between the two farms. The TN concentrations are larger, and are considered to be relatively stable compared to the inorganic N fraction of the soil (Ellington, 1986). However, TN concentrations are affected by factors such as land use.

Land use impacts TN by modifying the organic matter inputs and altering the rates of decomposition in the soil (Cambardella and Elliott, 1992; Wang *et al.*, 2009). The detected variability in TN between paddocks and distinct areas suggest that there are differences in inputs and/or microbial processes between the paddocks and areas that are equivalent to differences in land use. These differences have implications for exclusion strategies during precision fertiliser application. Prevailing practices use inorganic N measurements as an indicator of N requirements for plant biomass growth because mineral N is the plant available N form. However, there is some evidence suggesting that TN measurements are a good predictor of pasture response to applied N-fertiliser. Recent work has found that plant biomass growth following N-fertiliser decreased in areas with high TN concentrations (Shepherd *et al.*, 2015; Guinto *et al.*, 2016). Therefore, applying fertiliser to areas with high TN may have reduced economic returns. The influence of climatic factors such as temperature and precipitation, as well as typical agricultural management practices such as adding N-fertiliser, may confound the relationship between the plant biomass and TN over large spatial scales (Parfitt *et al.*, 2005). It may be that TN can serve as a good estimate for soil N supply when planning precision fertiliser application on a farm or paddock scale.

With little information available about how farm infrastructure affects the spatial distribution of TN, the observed variability around the gates and troughs are an important finding. Nitrogen mineralisation is the process responsible for converting organic N to inorganic, plant available N, and there is some evidence that net N mineralisation is strongly correlated to soil TN in the surface soil horizon (Parfitt *et al.* 2005). Areas of high TN may have adequate supply of potential inorganic N, and would not benefit from additional N fertiliser. The difficulty presented by these findings is that, with respect to the gates, the variability is due to TN values that are both higher and lower than the normal paddock area.

The variability of TN within the distinct areas may be attributed to a number of factors, including the effects of cattle treading on the soil physical structure which will also influence the soil N cycling. The cattle trodden areas around the gates and troughs are often more compact with increased bulk density, decreased hydraulic conductivity, and lower pasture yields than the surrounding paddock (Willatt and Pullar, 1983; Johnson *et al.,* 1993; Sheath and Carlson, 1998). Lower density of pasture cover around the gates and troughs likely leads to lower organic inputs into the soil, which contributes to the above-mentioned lower TN concentrations in some areas. The relatively lower TN may also be attributed to subtle changes to the soil composition. For example, some of the low TN areas may be instances where there is a relatively higher sand or gravel content, which has poor soil N retention (Benbi *et al.*, 1991; Huang *et al.*, 2009).

The areas proximate to the gates and troughs with higher TN than the surrounding paddock may be a result of frequent urine and dung excretion caused by the assembling of cows combined with the absence of pasture. Excessive trampling leads to bare soil patches and lower pasture density of these areas. Therefore, organic content from decomposition of historical cattle excreta may accumulate in these areas lack plants as a soil N removal mechanism, compared to the normal pasture area (Franzluebbers *et al.,* 2000). Total N and organic carbon are often positively related (Havlin *et al.*, 1989). This, combined with the heavily trafficked areas having lower vegetation growth, may partially explain the instances of higher TN. Future research should address the drivers of TN variability around farm infrastructure by exploring related factors, for example, spatial distribution of soil organic matter, and spatial variability in pasture vegetation density.

The methods developed for this study worked well for distinguishing TN around farm infrastructure. Relatively low variability of TN in all areas except the gates and troughs suggests that the spatial variably was adequately quantified, and that the selection of spatially distinct areas captured the areas of importance. The methods developed and employed were able to show not only that there is a high degree of variability of TN in the gates and troughs areas, but the strategy of sampling in a gradient of increasing distance away from the infrastructure showed that much of the variability in TN within those areas occurs within the first 4-8 m away from the infrastructure.

Conclusion

Showing that while there is relatively consistent TN between the farms, there is some variability between paddocks, which is driven by variability that was observed in spatially distinct areas, like the gates to the paddocks and the water troughs. The variability of TN in these areas was higher closer to the infrastructure. This study shows how farm infrastructure impacts spatial variability of pasture TN. Additional research is needed to understand the cause of the high variability in TN proximate to the gates and troughs. The results from this study have implications for the development of variable rate N fertiliser application for pastures excluding area of high TN in the paddock.

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