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BALANCING OPTIMUM FERTILISATION AND N LOSSES IN DAIRY SYSTEMS

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Abstract

A simulation study was carried out to investigate the effects on nitrogen (N) losses in dairy farming when fertilisation rates are targeted to achieve high pasture yields. The simulations were done for an irrigated, ryegrass-only pasture in the Canterbury region of New Zealand using the Agricultural Production Systems Simulator model (APSIM). A previously developed algorithm was used to determine monthly required N fertilisation rates as a function of pasture N content prior to fertilisation. In this study the algorithm targeted 90% of the potential monthly yield, this was compared with a scheduled fertilisation rate of 400 kg N/ha/year. These fertilisation rules were evaluated on a dairy farm by running APSIM to simulate the grazing rotation over a ten-year period. This provided yield and N loss estimates from both non urine and urine affected areas. The results from the two fertiliser regimes indicated an increase in yield and a reduction in N losses when N fertilisation rates were controlled by the algorithm compared to a scheduled fertiliser regime. This result occurred despite the similar annual amount of fertiliser applied. This work demonstrates the potential of using the algorithm in conjunction with tools such as remote sensing of pasture N concentration to improve pasture nutrient management.

Keywords: APSIM modelling, pasture N content, optimum N fertilisation rate, N leaching.

Introduction

Nitrogen (N) is an essential element required for plant growth. Highly productive pasture-based dairy farms must use nitrogen fertiliser to ensure pasture production matches feed demand. This fertiliser replaces the N that is removed through the export of animal products (e.g. milk) and other loss pathways such as leaching and gaseous emissions. However, there are close relationships between excessive application of nitrogen fertilizers and environmental problems such as eutrophication (Smith et al., 1999). Traditionally fertiliser management methods have followed either an annual schedule or were based on either soil or plant analysis. The simple schedule does not account for spatial or temporal variation. While methods using soil and plant measurements can account for field N variability, they are destructive, expensive and time-consuming. Better targeting of fertiliser applications to plant needs would result in increased productivity and reduced N losses to the environment.

Because soil fertility can affect the plant N concentration, the use of remote sensors which can rapidly access the spatial variability within a field is a potential N management tool. Various instruments based on spectral reflectance techniques are been developed, and are becoming more accurate and cheaper (Botha et al., 2007; Darvishzadeha et al., 2008). However, for these tools to improve fertilisation, information on N requirements for optimum pasture growth is needed (Pembleton et al., 2013). Based on the approach described by Lemaire and Salette (1984) and using a comprehensive simulation study, Vogeler and Cichota (2017) demonstrated the close relationship between pasture yield, plant N concentration, and fertilisation rate. This was described by a multi-variate model producing a 3D response curve. Based on this an algorithm was developed to define N fertilisation requirements in ryegrass pastures.

The aim of this work was to evaluate an implementation of the algorithm in a simulated farm system. The algorithm would enable variable rate fertilisation, depending on the spatial and temporal plant requirements and supply by the soil. It uses current pasture N concentrations and expected seasonal yield responses to provide optimum nitrogen fertilisation rates for a targeted yield. The algorithm was compared to a scheduled 400 kg N/ha annual fertilisation rate in order to assess the impact on yield and N losses.

Method

Algorithm Design:

An algorithm was developed (as described in Vogeler and Cichota, 2017) to determine N fertilisation rate dependent on the month and the pasture N concentration prior to fertilisation. The algorithm was developed using the Agricultural Production System Simulator (APSIM version 7.7). The APSIM simulations were set up for an irrigated grass only pasture in Lincoln, Canterbury with climate data obtained from the Virtual Climate Station database (Tait and Turner, 2005), and with a Lismore silt loam. Pasture in the simulation was harvested monthly down to a residual dry matter of 1500 kg/ha. Irrigation was applied from October to April using a centre pivot system at a rate of 6 mm/d whenever the soil water deficit (SWD) in the upper 300 mm soil profile was ≥ 30 mm, and stopped when the SWD ≤ 5 mm. In the simulations a range of different fertilisation rules were set up using fertiliser amounts ranging from 0 to 150 kg N/ha, applied on the 15th of every month. These rules were run over 20 years, giving approximately 29,000 combinations with a wide range of pasture N contents and pasture growth responses for each month. Monthly yield data from the various simulations were fitted to a 3D surface response function. This provided the basis for the algorithm, which defines the required fertiliser rate depending on the N content of the pasture after harvesting.

Algorithm Evaluation:

For the evaluation of the developed algorithm APSIM simulations were set up for a simulated 165 ha Canterbury farm, based in general on data from the Lincoln University Dairy (LUDF) farm. The LUDF is a high-performing irrigation dairy operation managed by the South Island Dairying Development Centre (SIDDC; www.siddc.org.nz) with a stocking rate of 3.9 cows/ha. These simulations were run over 10 independent years to investigate yield and N losses from both non urine and urine affected areas of a dairy farm system. These were aggregated to obtain paddock scale N leaching losses. Two different fertilisation regimes where compared: scheduled fertilisation of 400 kg N/ha/year, applied monthly between August and May (Fert400), or fertilisation based on the developed algorithm aiming to achieve 90% of the potential yield (Target90).

The stocking rate for the two different fertilisation regimes was modified so that cow requirements were met by the total feed produced in an average year, thus minimizing the need for feed imports. Using the APSIM simulated average annual metabolisable energy (ME) provided by the grass grown on the farm for the two fertiliser regimes and comparing with the annual ME requirement by a cow, the stocking rate was calculated. To make data analysis and comparisons easier, a rotation grazing length of 1 month was assumed. Surplus pasture was conserved as silage and fed in winter months, with an assumed ME of 10 MJ/kg DM and an N content of 25 g N/kg DM. Monthly feed surplus/deficit were computed across the simulated 10 years, any further feed deficit in years with low pasture growth was supplemented with maize silage, with an ME of 10.5 and an N content of 11.5 g/kg DM. Graphical illustrations of the feed balance for both fertiliser regimes are shown in Figure 1.

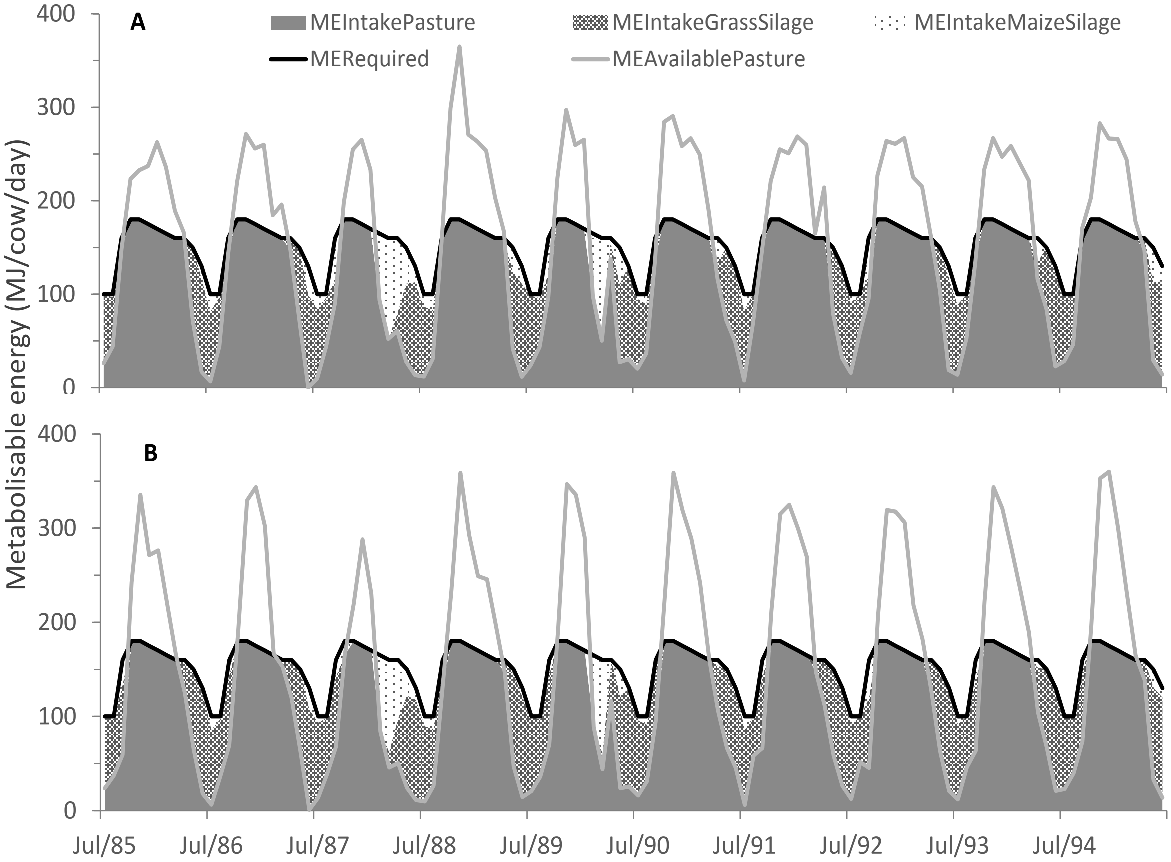

Figure 1A & B: ME available pasture, ME required by cow, ME Intake Pasture, ME Intake grass silage, ME intake maize silage, over 10 years for the Fert400 treatment (A) or fertilisation using algorithm targeting 90% of potential yield- Target90 (B)

To calculate the monthly N load in the urine patches for the two fertilisation regimes, the mechanistic and dynamic model for N partitioning in dairy cows developed by Kebreab et al. (2002) and tested by Vibart et al. (2013) was used. Using the monthly average N intake in the diet (Figure 2), which varied depending on the proportion and N concentration of the various feed sources, and the average monthly milk protein production the model provided estimates the amount of N retained in body tissues and excreted as urine and dung for each cow. When multiplied by the paddock scale stocking density the total urinary N load for each grazing event could be calculated (Figure 3). APSIM simulations with these N loads were then set up, in separate simulations, for each month and year. Simulations without urine, representing areas not affected by urine, were also set up. To estimate the area affected by urinations after each grazing event (15^{th} of each month) based on the stocking density, an urination frequency of 10/cow/day and a urine patch area of 0.35 m^2 were assumed. N losses and yield from each of the two fertilisation regimes were then compared for analysis. N leaching was defined as the amount of N leached past a depth of 1 m.

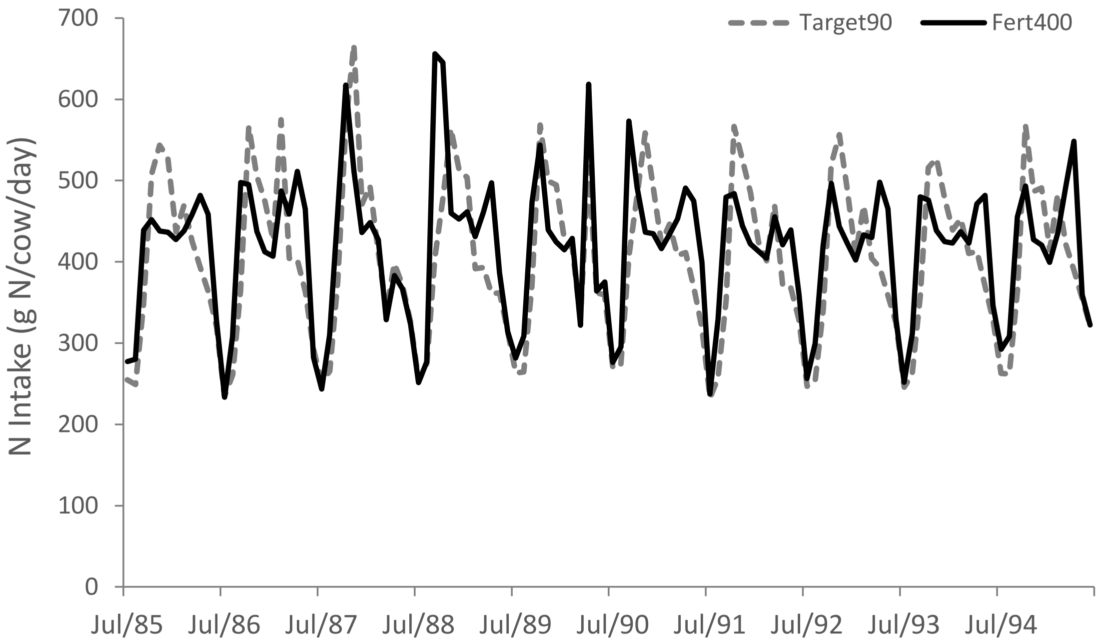

Figure 2: Seasonal N intake (g N/day) of cows over 10 years for the Target90 treatment and Fert400 treatment.

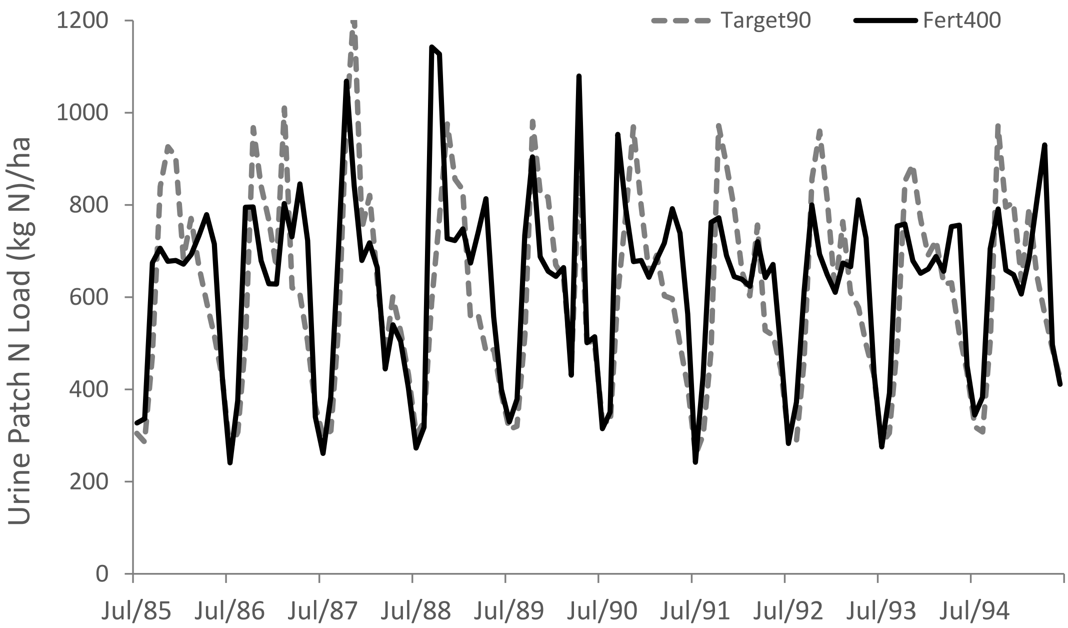

Figure 3: Seasonal urine patch N load (kg N/ha) over 10 years for the Target90 treatment and Fert400 treatment.

Results and Discussion

Algorithm Design:

Simulated monthly yield data, were fitted to a three dimensional model relating pasture yield responses to pasture N content and N fertilisation rate. An example of the fitted response function is presented in Figure 4 for November.

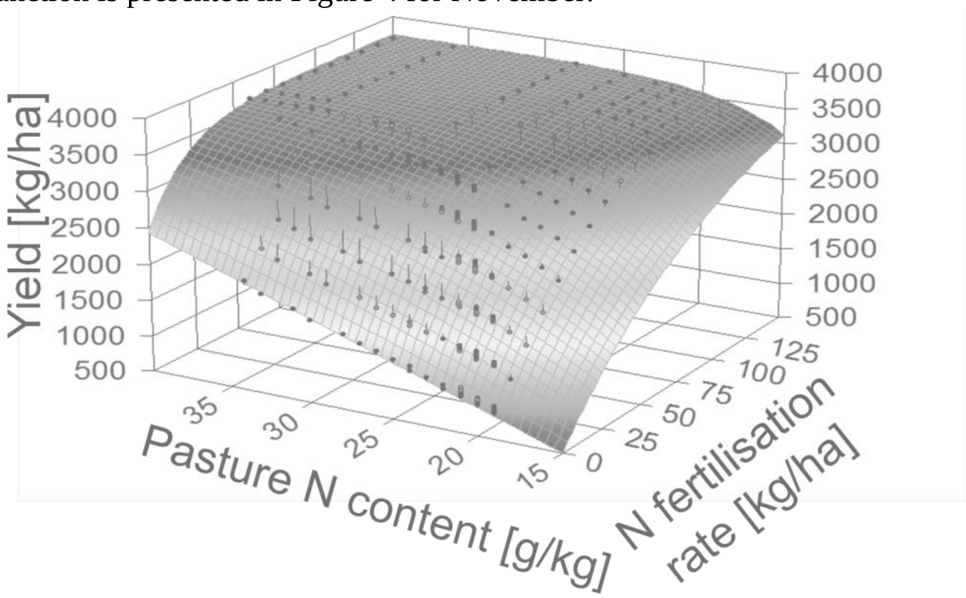

Figure 4. Fitted response surface function for simulated yield data as function of N content and fertilisation rate for an irrigated ryegrass pasture in the Canterbury area for November.

By using the inverse of the 3D model for each month, N fertilisation rates that aim to achieve a given pasture production were derived (Figure 5). An example of its use, to achieve 90% of the maximum yield in November 130 kg N/ha fertiliser would be required when the pasture N content prior to fertilisation were 25 g/kg. To achieve the same yield when the initial pasture N content were 40 g/kg, only 60 kg/ha of fertiliser would be required.

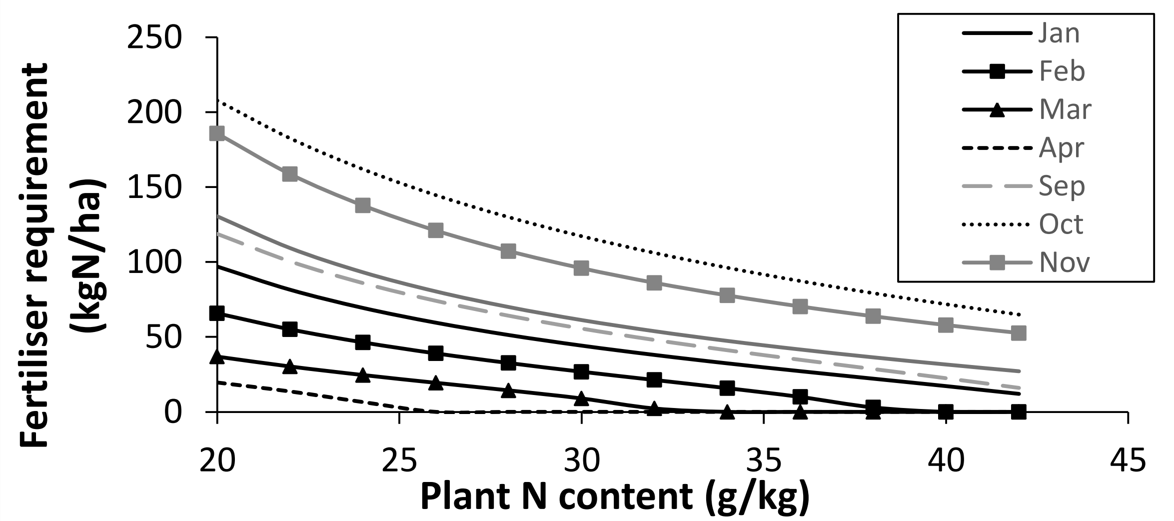

Figure 5. Nitrogen requirements for the various months, when fertilisation is set, for achieving 90% of the maximum yield for and irrigated pasture in the Canterbury area.

Algorithm Evaluation:

Yield and N leaching from Non-Urine Areas:

In areas not affected by urination there was an increase in yield and a considerable reduction in N losses when fertilisation was controlled by the algorithm (Figure 6). Pasture yield increased by 6.6% with the use of the algorithm (Target90) compared to the Fert400 treatment. Total fertiliser amounts were similar for the two treatments, with the Target90 treatment having an average application rate of 419 kg N/ha/year (Table 1). Even though fertiliser application rates were comparable, direct N leaching losses decreased from an average of 6.71 kg/ha/year in the Fert400 treatment to 1.57 kg/ha/year for the Target90, a reduction of 76%. This shows that the developed algorithm is a viable and promising approach for fertilisation management, with improved matching of fertiliser rates to plant N requirements and reducing N losses to the environment. This implies that the algorithm could be used successfully, at least in a cut and carry system. Further field testing of the algorithm in this type of farming system is granted as it may allow considerable improvements in fertiliser management, increasing production whilst minimising environmental impacts.

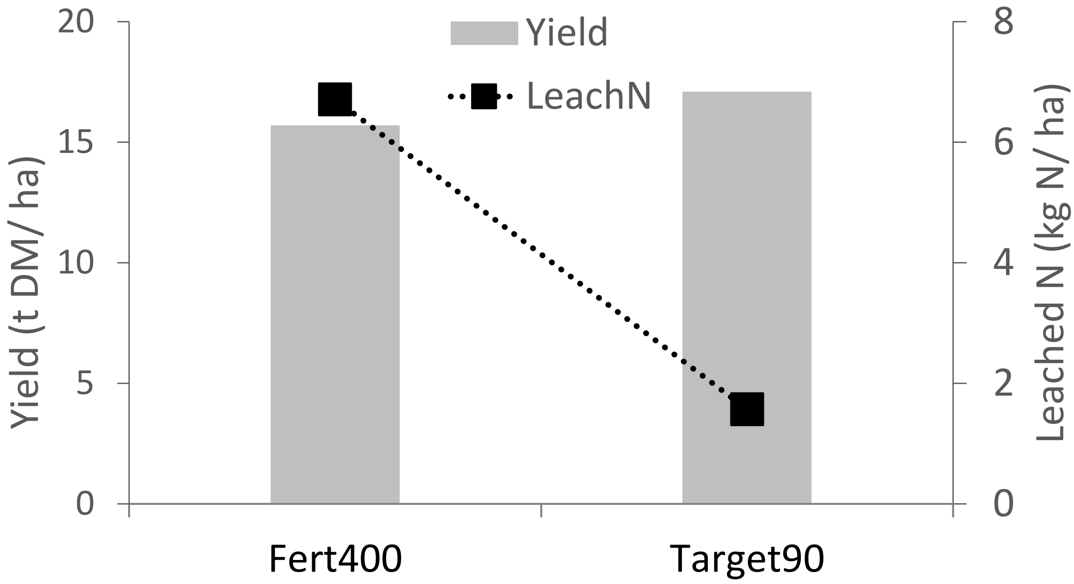

Figure 6: Average annual yield (t DM/ha) and N leaching losses (kgN/ha) from Non-Urine affected areas for the Target90 and Fert400 treatments.

Yield and N leaching at Paddock Scale including Urine Patch Areas:

The increased pasture production at a paddock scale enabled a higher stocking rate for the Target90 treatment. More cows per hectare resulted in increased milk production for the farm, but also increased the area affected by urination (Table 1). As a consequence, the difference in N losses between the two fertiliser regimes is much lower at a paddock scale when accounting for urine patches compared with the losses from non-urinated areas. This is because in general direct N losses from fertilisers applied to pastures are low, while the main source of N loss in grazed systems is from the urine patch areas (Ledgard et al., 2009). Nonetheless, improvements when the algorithm was used can still be seen and are substantial considering the increased stocking rate and area urinated. The Target 90 treatment leached 114.4 kg N/ha/year compared to 119.8 kg N/ha/year in the Fert400 regime. These N leaching values are quite high, but comparable to actual measured values. Menneer et al. (2004) reported nitrate leaching rates measured from NZ dairy farms following various N fertiliser applications, as ranging between 5-115 kg N/ha/year, with average losses of 65 kg N/ha/year. Many N leaching studies have, however, have been done on pastures with a legume component, such as clover. As these pastures receive added nitrogen from legume N fixation, generally less N fertiliser is applied, making it hard for a direct comparison with this study.

Table 1: Paddock scale values for the Fert400 and Target90 treatments when considering areas within paddocks affected by urine patches.

Scenario	Fertiliser (kg N/ha/yr)	Pasture Yield (t DM/ha/yr)	Stocking Rate (cows/ha)	Milk production (kg MS /ha /yr)	Fraction Area Urinated (%/grazing)	Average N Leaching (kg N /ha /yr)
Fert400	400	17.7	3.4	1593	3.6	119.8
Target90	419	19.5	3.7	1762	4.0	114.4

When the two fertiliser regimes are compared on a production basis (Figure 6), the Fert400 treatment had an N leaching loss of 75g N/kg MS versus 65 g N/kg MS for the Target 90 treatment, which is a 13% reduction for the Target90 treatment. This demonstrates that the use of the algorithm as a fertiliser management tool has great potential, farm production can be increased whilst reducing N losses.

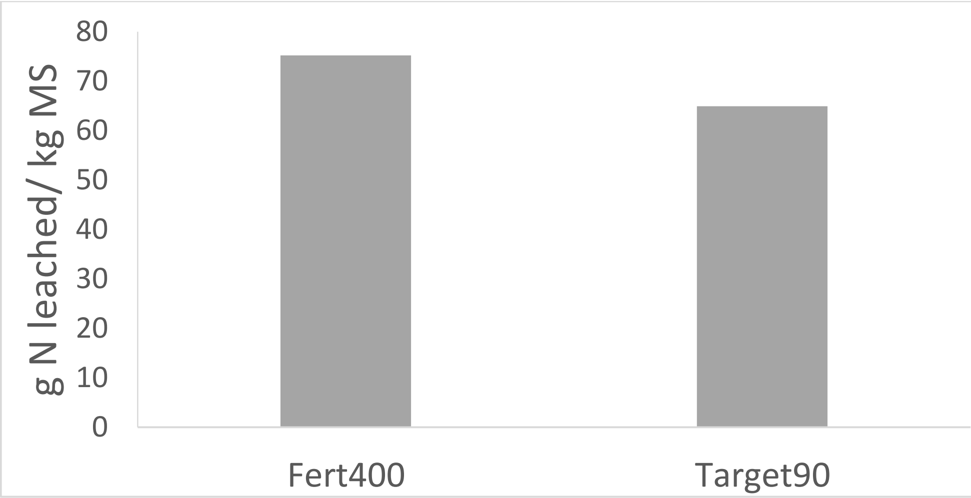

Figure 6: g N leached/kg MS for Fert400 and Target90 treatments.

Comparing the nitrogen responses (Figure 7) between the two fertilisation regimes over the simulated years, showed that the Target90 treatment has higher nitrogen responses in 8 out of 10 years. It is only in 1988 and 1991 that the algorithm does not match the nitrogen required by the plants better than the scheduled regime. Overall, this shows that there is more efficient use of the nitrogen being supplied when the algorithm is used. It is important to note that these nitrogen responses are based on simulations from a pure ryegrass pasture. As with N leaching loss, the responses seen here are higher compared with those generally observed in ryegrass/clover pastures (Feyter et al., 1985; Bolland and Guthridge., 2009). They are however comparable to the range of those measured in England for pure ryegrass pastures (Morrison *et al.*, 1980).

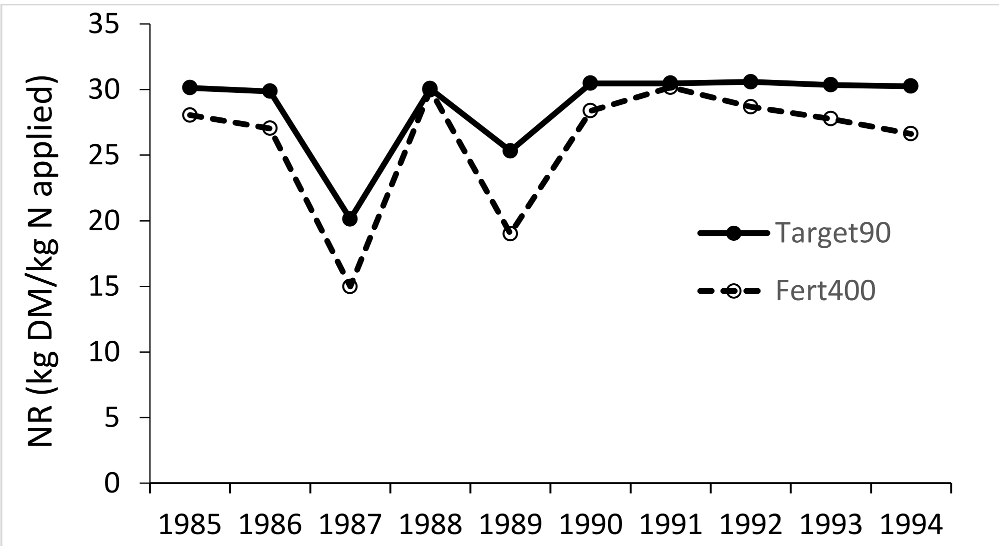

Figure 7: Nitrogen response (NR) to applied fertiliser N for 10 actual years, based on Fert400 or Target90 treatments.

The results shown here demonstrate the potential economic and environmental benefits when using the developed algorithm. It still needs to be fully validated in field tests, especially when linked to remote sensing measurements. The economic analysis of the algorithm usage within a farm system will be the next step. Further development and evaluation of the algorithm is needed in different environments, with varying soil and weather conditions. This study was done using a dairy farm system as a model, but could be easily modified to be used in other farming systems. This study is important as early estimates of N requirements are desirable to ensure fertilisation can be made at the right time to supply adequate N for targeted pasture growth.

Conclusion

Well-managed fertilisation will not only increase nutrient use efficiency and economic results, but also help to minimise environmental risk associated with over-fertilisation. An algorithm was developed that could be used in conjunction with remote sensing to aid fertilisation recommendations. The algorithm takes into account pasture N concentration prior to fertilisation, potential yield and the expected response to fertilisation. The approach was shown to be a viable concept and looks promising to increase yields and reduce N leaching while optimising fertiliser rates. The N loss intensity was reduced by 13%, when the algorithm targeting 90% of potential yield was compared a scheduled fertilisation of 400 kgN/ha. We have been able to demonstrate that there are potential economic and environmental benefits from using the developed algorithm.

Acknowledgements

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