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DETERMINATION OF NITROGEN FERTILISER REQUIREMENTS IN DAIRY PRODUCTION SYSTEMS BASED ON EARLY INDICATORS

Iris Vogeler, Rogerio Cichota

AgResearch, Grasslands Research Centre, Palmerston North, New Zealand

Abstract

Early estimates of nitrogen (N) fertiliser requirements are desirable to ensure an adequate N supply for targeted pasture growth, as well as to minimise N losses. High spatial and temporal variability of both N supply by the soil and demand by the plant means that synchronising these is very challenging, and early indicators are lacking. To manage this variability in N requirements by plants effectively, various methods have been developed to determine optimum fertiliser application rates based on the N nutrition status of the plant. The use of remote sensing for mapping spatial variations in crop N status offers potential for fertiliser management practices tailored to spatial variability in the field. This can improve nitrogen use efficiency resulting in environmental and economic benefits.

To determine optimum N fertilisation rates which will maximize plant growth based on the pasture N content and environmental conditions, a simulation study was done using the Agricultural Production Systems Simulator (APSIM). The APSIM model, with a refined version of the pasture module (AgPasture), which allowed N remobilisation to occur from different tissue maturity stages, was set up for an irrigated ryegrass pasture in the Canterbury region of New Zealand. Simulations comprised 10 different fertilisation rates (ranging from 10 to 100 kg N/ha), applied monthly at alternating rates, resulting in 90 different fertiliser treatment combinations. These were run for 20 consecutive years giving a total of 1800 combinations of pasture N contents and pasture growth responses for each month. Based on statistical analysis, the optimum N fertilisation rate dependent on pasture N content and environmental conditions was determined. For example in October, the optimum fertilisation rates at which 90% of the maximum yield was achieved was estimated to be 160 kg N/ha if the pasture N content was below 2.4%. However, at much higher pasture N contents (between 3.6 and 4%) only 60 kg N/ha was required to obtain the same yield, reflecting the much higher supply of N by the soil.

Using pasture N content and environmental conditions as early indicators for guiding N fertilisation offers potential for improved management of the spatial and temporal variability in N demand and supply. Further model testing under different conditions linked with experimental studies is required to validate this approach.

Keywords: APSIM modelling, Pasture N content, optimum N fertilisation rate.

Introduction

Highly productive pasture-based dairy farms require a regular supply of mineral nitrogen (N) to replace the N removed through consumption and the export of animal products (e.g. milk) and other loss pathways such as leaching and gaseous emissions. Information on N fertiliser requirements for optimum pasture growth is, however, lacking (Pembleton *et al.*, 2013). 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. Well-managed fertilisation will not only increase nutrient use efficiency and economic results, but also help to minimise environmental risk associated with over-fertilisation, especially direct nitrate leaching from fertilisers and indirect leaching from urine patches (Grindlay, 1997). As well as increasing pasture dry matter (DM) production, N fertilisation can also increase the plant N concentration. In contrast, when the N supply is suboptimal growth may be reduced. Plants may compensate this by remobilising N from mature leaves into new growth (Gastal and Lemaire, 2002; Lehmeier *et al.*, 2013)

Fertilizer management methods are traditionally based on either soil or plant analysis, both of which are expensive and labour-intensive. Remote sensing is increasingly being used as a timely and non-destructive tool to estimate the nitrogen nutrition status of plants and to rapidly assess the spatial variability within a field based on the canopy reflectance (Baghzouz *et al.*, 2006; Li *et al.*, 2014). As such, remote sensing can help adjust crop and fertiliser management practices to temporal and spatial N demand (Roberts *et al.*, 2015). This, however, requires information on the optimum N fertilisation rate based on pasture N concentration and environmental growth conditions.

Computer models are increasingly being used to aid farm nutrient management. Predicting seasonal and inter-annual variations in water and nutrient demand, as well as pasture growth under variable weather/soil conditions and in response to different management systems requires a process-oriented modelling approach. One such approach is the Agricultural Production Systems Simulator, APSIM; (Holzworth et al., 2014) with AgPasture for simulating mixed species pastures (Li *et al.*, 2011). A modified AgPasture module that accounts for remobilisation from different tissue maturity stages (Vogeler *et al.*, 2015) was used to derive, via deterministic modelling, optimum N fertiliser rates based on early indicators, such asplant N concentration and prevailing environmental conditions.

Model simulation setup

All APSIM (Version 7.7) simulations for this study were derived from a base simulation by varying either the simulation year or fertilisation rate. Simulations were run with daily weather data for Lincoln (-43.625S, 172.475E) obtained from the Virtual Climate Station database (Tait and Turner, 2005), with a Lismore silt loam. The pasture simulated contained ryegrass only, which was harvested monthly down to 1500 kg/ha DM. The pasture was irrigated from October to April using a centre pivot system with a return period of 10 days. Irrigation was applied 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. For the modified remobilisation procedure in AgPasture, optimum N concentrations of 2.8% for mature and 2% for senescing tissue was used (Vogeler et al., 2015). Simulations comprised 10 different fertilisation rates (ranging from 10 to 100 kg N/ha), applied on the 15th of every month after harvesting at alternating rates, resulting in 90 different fertiliser treatment combinations. These were run for 20 consecutive years, giving a total of 1800 combinations of pasture N contents and pasture growth responses for each month. The results of these simulations were used to determine the optimum fertiliser rate depending on the N concentration of the standing biomass after harvesting. Only results obtained for October are discussed here. For the analysis pasture N concentrations were grouped into six different categories: Category 1: 2.0 to 2.4% N; Category 2: 2.5 to 2.8% N; Category 3: 2.9 to 3.2% N; Category 4: 3.3 to 3.6% N; Category 5: 3.7 to 4.0% N and Category 6 > 4.0%.

Results

Pasture Yield

The harvested DM one month after fertilisation was dependent on the pasture N concentration of the biomass prior to fertilisation. This is shown in Figure 1 for two selected pasture N categories following fertilisation in October and harvested in November. Fertilisation at 60 kg N/ha gave an average yield of 3088 kg/ha DM when the pasture N content of the standing biomass ranged between 2.5 and 2.8% (Category 2), whereas an average yield of 3826 kg/ha DM was obtained when the N content ranged between 3.7 and 4% (Category 5).

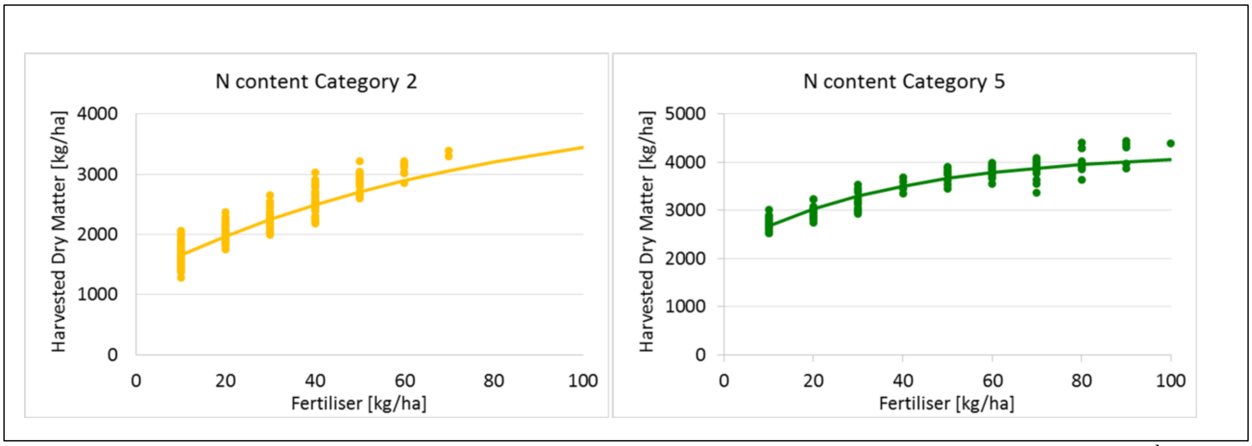

Figure 1. Dry Matter (kg/ha) one month after N fertilisation application on the 15th of October. Category 2, 2.5 to 2.8% N; Category 5, 3.7 to 4% N. Simulations were done over a period of 20 consecutive years (1994 -2013) for an irrigated ryegrass pasture in Canterbury.

Yield response curves for the different N categories were fitted with the Mitscherlich equation, which is widely used in agricultural science to relate yield response to nutrient supply. The equation can be written as:

$$Y = Y_{max} - (Y_{max} - Y_0) \exp -\beta N_r$$

where Y is the dry matter yield (kg/ha), Y_{max} is the maximum or potential yield under the climatic and edaphic conditions, N_r is the rate of N applied (kg/ha), Y_0 is the yield when no N is applied in the form of an external source ($N_r = 0$), and β is an 'activity' coefficient which is a measure of the availability of the applied nutrient to the crop. The maximum yield is an important parameter in the Mitscherlich equation and is assumed to be constant. The value for Y_{max} for the growth conditions in October/November was set as 4200 kg DM/ha, estimated from the simulated yield responses of the high N content category, and assuming that under irrigation N is the only limiting factor.

The fitted Mitscherlich response functions for the different N categories are shown in Figure 2. Note that these different N categories are not only a measure of pasture N status, but also reflect the N supply by the soil. These were used to determine optimum N fertilisation rates for the October/November period depending on the pasture N concentration of the standing biomass, which provide 90% of the maximum yield. This is indicated in Figure 2 for N Categories 2 and 5.

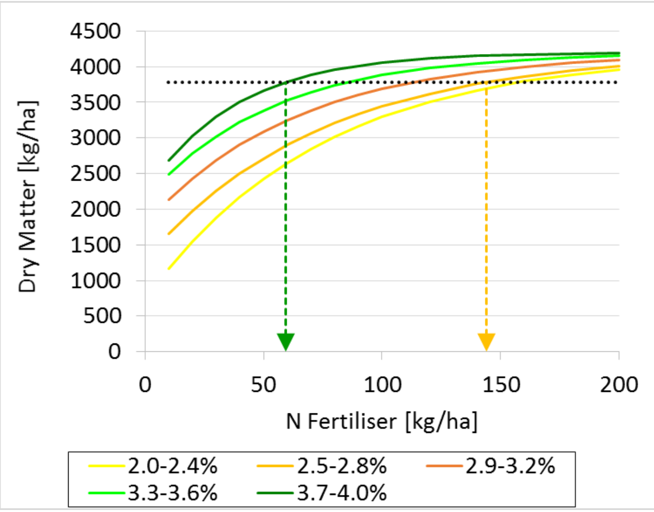

Figure 2. Mitscherlich Response Curves for different N pasture N concentration categories, with the arrows indicating optimum fertilisation rates that achieve 90% of the maximum yield following fertilisation in October.

As the value of Y_0 increases with increasing pasture N concentration of the standing biomass (partly to higher N supply from the soil), optimum fertilisation rates for the different N categories decrease (Table 1).

Table 1. Parameter values derived by fitting the Mitcherlich function to yield response rates for different Pasture N Categories and optimum N fertilisation rates which provide 90% of the maximum yield for the October/November period for an irrigated ryegrass pasture in Canterbury.

N Category	Pasture N conc. (%)	Y_0 (kg/ha)	β (kg/N)	Optimum N rate (kg/ha)
1	2.0-2.4	725	0.013	158
2	2.5-2.8	1286	0.013	144
3	2.9-3.2	1786	0.016	112
4	3.3-3.6	2134	0.019	85
5	3.7-4.0	2226	0.026	59

Conclusions

The simulation study has identified optimum N fertilisation rates that provide 90 % of the maximum yield one month after fertilisation in October, based on the pasture N concentration of the standing biomass. Optimum N fertilisation rates decreased from approximately 160 kg/N ha at very low pasture N concentrations (N Category 1: 2.0 to 2.4%) to 60 kg N/ha at high pasture N concentrations (N Category 5: 3.7 to 4%).

The current approach based on biophysical modelling to determine optimum N fertilisation rates dependent on N pasture N concentrations appears promising, but requires further testing using simulation results from other months or by using prevailing climatic growing conditions, such as rainfall and temperature for the analysis. The use of weather forecasting would enable estimation of optimum N fertilisation rates for individual years rather than for an average month. Further analysis, modelling under different environmental conditions and validation is required before the approach can be used to help adjust fertiliser management practices to temporal and spatial N demand based on the nitrogen status of the pasture.

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