N CONCENTRATION IN PASTURE AS A TOOL FOR GUIDING FERTILISER REQUIREMENTS

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Abstract

Highly productive pasture systems require a regular supply of mineral nitrogen (N) to replace the N removed through the export of animal products and other loss pathways such as leaching and gaseous emissions. 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. A simulation study, using the Agricultural Production Systems Simulator (APSIM), aimed to verify the critical N concentration curve as an early indicator for guiding N fertilisation, which maximizes plant growth while minimising environmental impacts.

APSIM with a refined version of the pasture module (AgPasture) was used to determine average optimum fertilisation rates for different seasons for a ryegrass pasture in the Canterbury region of New Zealand. Simulations comprised 20 different fertilisation rates ranging from 0 to 250 kg N/ha. Improvements in AgPasture included the definition of ideal N concentration for tissues of different ages (growing, mature, senescent and dead) and allowing nitrogen (N) remobilisation to occur from all the different tissue stages.

Highest pasture yields one month after fertilisation were achieved with N application rates of 20, 30, 140 and 160 kg N/ha for winter, autumn, summer and spring. The pasture N contents (%N) corresponding to the standing dry matter of the pastures in the different seasons were similar to the critical N curve when constant fertilisation rates were applied throughout the year, however lower critical N concentrations were obtained for autumn and winter.

Before the critical N reference curve can be used to guide optimum N fertilisation for pastures further experimental studies and model testing and parameterisation is required. It is also possible that season specific critical N curves need to be established for pastures.

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 in 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). Apart from increasing pasture DM production, N fertilisation can also increase the plant N concentration. In contrast, when the N supply is suboptimal, growth may be reduced, but plants will try to compensate that by remobilising N from mature leaves into new growth (Gastal and Lemaire, 2002; Lehmeier *et al.*, 2013)

Fertilizer management methods are traditionally either based on soil or plant analysis, which are both expensive and labour-intensive . Direct plant analysis in the field, which involves the measurement of the N nutrition status of the plant, include the NO_3 (nitrate) sap test and chlorophyll meters. As an alternative to these traditional plant testing methods remote sensing has recently been 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; Shaver *et al.*, 2011; Li *et al.*, 2014) . As such remote sensing, via e.g. handheld or tractor-mounted sensors can help adjusting crop and fertiliser management practices to temporal and spatial N demand; but this requires knowledge of critical N concentrations.

With adequate soil N supply, crop N uptake is to a large extent determined by the crop growth rate. At non-limiting N supply, N concentration will decrease as more plant biomass accumulates. The decreasing N content of plants with increasing biomass has been used to derive the concept of critical N concentration by Lemaire and Salette (1984). The critical N concentration corresponds, at any moment of vegetative growth, to the minimum concentration of N necessary to achieve the maximum aboveground biomass. This is represented by the critical concentration curve:

$$Nconc_{crit} = a\,DM_{\mathrm{stand}}^{\;-b},$$

where DM_{stand} is the total shoot biomass (t/ha), $Nconc_{\mathrm{crit}}$ is the total N concentration in the shoot biomass (%), and a and b are positive constants. For perennial ryegrass Lemaire and Salette (1984) suggested values of 4.8 for a, and 0.33 for b.

The critical N concentration curve is the boundary between two different N statuses of the biomass: below the curve growth is limited by N, while above it plant growth is not limited by N; the curve, therefore, represents the optimum N concentration (Figure 1).

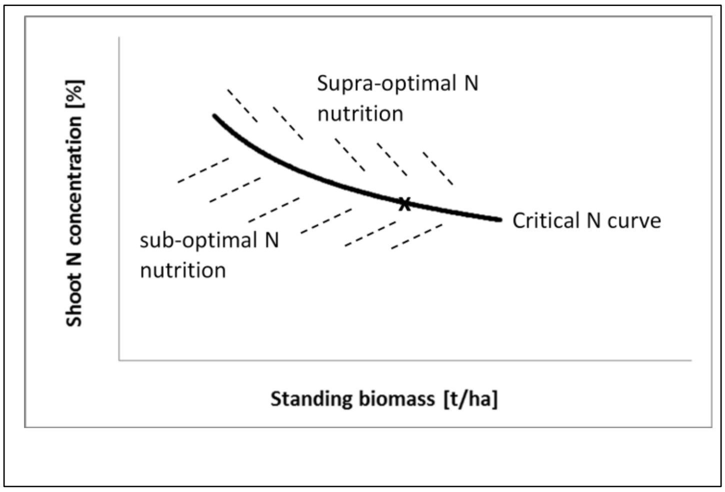

Figure 1. Principle of the critical N concentration curve adapted from Lemaire and Salette (1984).

Computer models of varying complexities are increasingly being used to quantify and understand the N cycle in pastoral systems and 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, such as the Agricultural Production Systems Simulator, APSIM; (Holzworth et al., 2014) with AgPasture for simulating mixed species pastures (Li *et al.*, 2011). The original AgPasture was based on the pasture model in DairyMod (Johnson *et al.*, 2008) and remobilisation of N from leaves is assumed to only occur during the change from the senescing into the dead tissue stage, but not during the intermediate development stages. Thus this N is not available for new growth, even if in supra-optimal concentrations, contradicting findings from various studies (Gastal and Lemaire, 2002). Thus, as first step of this work, AgPasture was modified to include a more sophisticated description of N remobilisation.

With this modification to AgPasture the objectives of this modelling study were (i) to derive, via deterministic modelling, optimum N fertiliser rates for different seasons that result in the maximum pasture dry matter growth rates over a set period of one month, (ii) to use these seasonal optimum rates to derive critical N concentrations based on the standing biomass of the pasture, and (iii) compare these critical N concentrations to the critical N curve developed by Lemaire and Salette (1984). These critical N concentrations curves can then be used to guide optimum N fertilisation for grazed pastures.

Model simulation setup

All APSIM 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), and the Wakanui silt loam. The pasture simulated contained ryegrass only, which was harvested at intervals of 30 days down to a standing dry matter of 1700 kg/ha. The pasture was irrigated according to a centre pivot system, with the irrigation period from October to April, and 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. These were based on findings by Thornton and Millard (1997) and Lehmeier et al. (2013).

Fertilisation was set at 20 different rates ranging from zero to 250 kg N/ha, applied in the middle of July (winter), October (spring), January (summer) and April (autumn), on the same days as cutting occurred. Note that such high fertiliser application rates, especially in winter are not standard. Each fertiliser application rate and timing was simulated in a separate model run, and was run, also in separate simulations, for 10 different years (2002 to 2011). The results of these simulations were used to determine the optimum fertiliser rate for each season, defined as that which results in the maximum yield in the first cut, 30 days, after fertiliser application.

Results

Pasture Yield

The harvested amount of pasture following fertilisation was, as expected, highest in spring (October), and lowest in winter (July), Figure 2. From these results, N fertilisation rates which resulted in highest DM amounts one month after fertilisation were identified as 160 kg N/ha for spring, 140 kg N/ha for summer, 30 kg N/ha for autumn, and 20 kg N/ha for winter. This indicates that highest annual pasture yields would be achieved by an annual fertilisation rate of 350 kg N/ha. This annual rate is in line with observations which have shown linear responses in pasture yield to annual application rates of up to 200–400 kg N/ha (Whitehead, 1995).

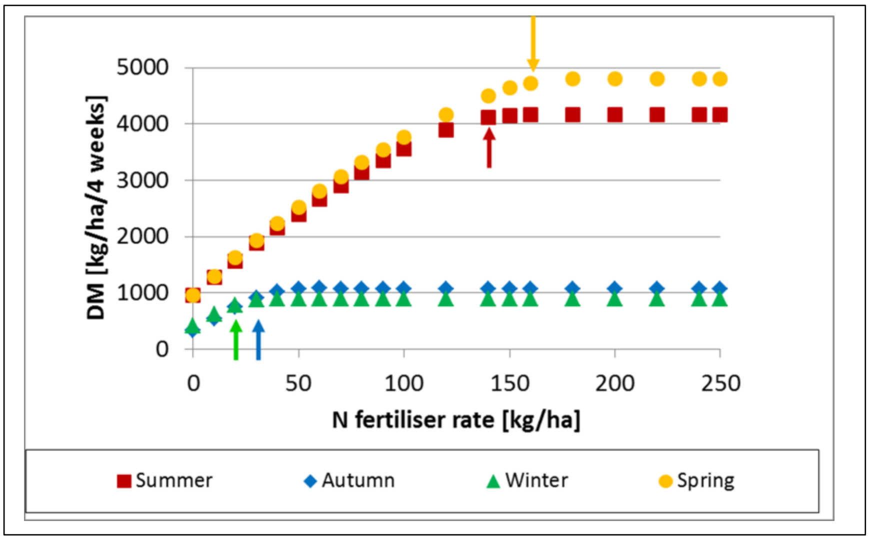

Figure 2. Dry Matter cut one month after N fertilisation application at different rates in either October (spring), January (summer), April (Autumn), or July (winter). Averages from simulations done over 10 years are shown, the errors indicate the optimum fertilisation rate.

Pasture N concentration

Simulated pasture N concentrations in the leaves of the standing dry matter before cutting, 30 days after fertilisation, increase with increasing rates of N fertilisations (Figure 3). Optimum N concentrations in the growing leaves of 4% are reached at the fertilisation rates identified for giving highest yields in the various seasons. Higher fertilisation rates result in luxury uptake, with N concentrations in the growing leaves increasing up to 5%. Concentrations in mature and senescing tissue also increased with increasing N supply but were lower compared to those in growing leaves due to remobilisation of N into growing leaves. These findings are in agreement with observations by Wilman *et al.* (1994) found decreasing concentrations with leaf development stage for ryegrass, even with increasing N fertilisation. The average N concentrations of all the leaves follow a similar trend the maturing tissue, and the standing biomass, which includes sheath and stem tissue has a lower N concentration.

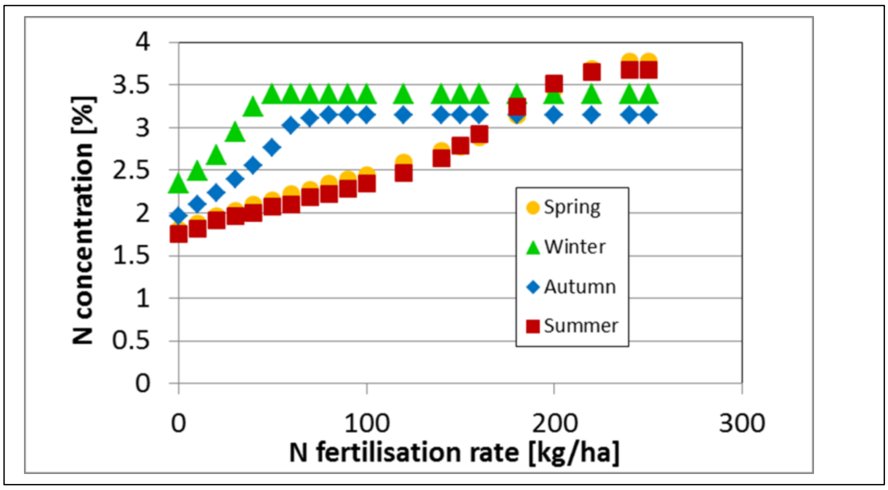

Figure 3. Simulated N concentrations in standing biomass (averages of 10 years) depending on N fertilisation rate and season.

The four different N fertilisation rates identified as being optimum for the different seasons were used to determine optimum N concentrations in the standing biomass of the pasture. While the trends in N concentrations with increasing biomass follow the critical N concentration curve of Lemaire and Salette (1984), with 4.8 $DM^{-0.32}$ for ryegrass, the simulations indicate that the critical N concentration in winter and autumn might be lower than inferred from the curve (Figure 4). While maximum yield was achieved at rates of 30 (autumn) and 20 (winter) kg N/ha, N concentrations in the pasture are lower than those according to the critical N curve.

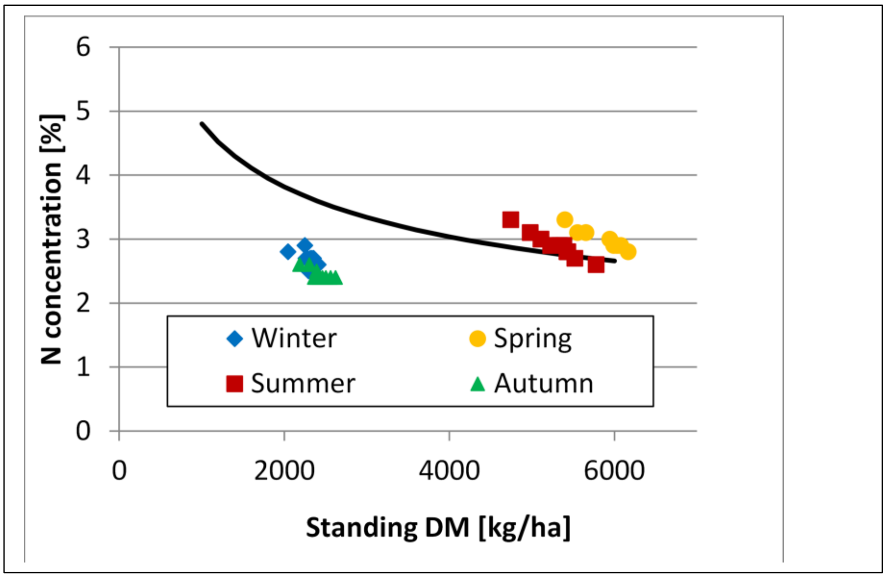

Figure 4. Simulated N concentrations in the standing biomass (10 different year) 30 days after fertilisation with 20 (winter), 160 (spring), 140 (summer) and 30 (autumn) kg N/ha. Also shown is the critical N curve of Lemaire and Salette (1984).

Conclusions

The simulation study has identified optimum N fertilisation rates which result in the highest pasture yield for an irrigated ryegrass pasture in Canterbury. The rates of 20, 160, 140 and 30 kg/ha were determined for winter, spring, summer and autumn applications; this would equate to annual fertilisation rate of 350 kg/ha.

The values found for optimum N concentration agreed reasonably with the critical N concept of Lemaire and Salette (1984) for spring and summer, but were lower for autumn and winter. The results were based on a modification of AgPasture, including remobilisation of N from older leaves to new growth. While this phenomenon is well known, the parameters for its description are not well quantified for grass species. Further studies are required measuring the nutrient concentrations in the various plant tissues at different times of the year for better parameterisation of AgPasture, especially the newly included process of N remobilisation described in the current study, including ideal N concentrations of the various tissues (growing, mature, senescent and dead), as well as the rate of remobilisation.

The critical N concentration as a tool for diagnosing N requirements seems promising, but needs further validation for ryegrass and under different environmental conditions, including different seasons.

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