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Simulated seasonal responses of grazed dairy pastures to nitrogen fertilizer in SE Australia: Pasture production

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ABSTRACT

Many nitrogen (N) fertilizer recommendations for grazing livestock enterprises are based on cutting experiments, excluding the influence of recycled N in excreta. Grazing experiments are expensive to conduct, and so compromise on variables such as number of N fertilizer rates, replication and number of years of investigation. Biophysical modelling provides an efficient and effective approach to address many of the complexities of field studies. Our study, using the biophysical whole-farm systems model DairyMod, examined the effect of a range of N fertilizer rates on pasture production for five dairy sites through south-eastern Australia over 18 years under both cutting and grazing regimes. The study aims were to highlight the variation in pasture N responses between cutting and grazing experiments and compare results to current best management practice (BMP) guidelines for N fertilizer management. Annual and seasonal maximum and optimum pasture production, defined as 90% of maximum production, N fertilizer rate to achieve optimum pasture production and the slope of the response rate curve between two fertilizer application rates were estimated. For all five sites, at the lower N rates, there was a divergence in annual pasture production between the grazing and cutting management regimes. However, once N was no longer limiting pasture production for the cutting regime, annual pasture production under cutting and grazing converged. For most sites and seasons, current BMPs of applying between 20 and 50 kg N ha^{-1} post grazing will ensure efficient use of N applied, assuming soil moisture is not first limiting growth. However, this study has refined these recommendations across all sites and seasons. For some seasons and sites, there was high variability in pasture N response rate between years that need to be taken into consideration. At Elliott in Tasmania, an irrigated site, there was merit in increasing N fertilizer rates above the current recommendation above 50 kg N ha^{-1} post grazing during spring and summer. In contrast, at the rainfed sites of Ellinbank and Terang in Victoria, the recommendation would be to not apply N fertilizer during autumn and only in selected wetter summers.

1. Introduction

Australian dairy farms maintain their economic competitiveness due to their efficient production and utilization of grazed pastures. Appropriate and efficient use of key inputs such as nitrogen (N) fertilizer are an important element to maintaining the competitive advantage of pasture based dairy production systems. The proportion of Australian dairy farmers using N fertilizer has increased from 28% in the early 1990's to > 70% in the early 2010's (Stott and Gourley, 2016). During this time, the intensity of use has also increased with typical average annual applications of approximately 200 kg N ha^{-1} annum^{-1}, and in some locations, management systems and years, rates have increased up to 400 kg N ha^{-1} annum^{-1} (Gourley et al., 2012). With a continued upward trend in N fertilizer usage, there is increased recognition of the need to review N usage on farm, from both a productivity and profitability perspective. In addition, livestock industries are also under increasing pressure to limit their environmental footprint (Godfray et al., 2010; Capper, 2013; Rawnsley et al., 2016; Angus and Grace, 2017). In many agricultural regions of the world, there is increasing scrutiny of fertilizer inputs, including regulation of fertilizer N usage. In New Zealand, all regional councils have set quality limits on ground and surface water bodies (DairyNZ, 2013; MFE, 2017). To

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achieve this, for example, in the Waikato Regional Council area, while not regulated yet, recommendations are that the maximum N loading rate not exceed 150 kg N ha^{-1} $annum^{-1}$ for animal effluent irrigated pastures (Waikato Regional Council, 2017). In 1991, environmental legislation with the European Nitrates Directive was adopted to reduce water pollution by nitrates (NO_3) from agricultural sources and to prevent further pollution (Van Grinsven et al., 2016), with applications of manure not exceed 170 kg N ha^{-1} $annum^{-1}$ on arable lands within NO_3 vulnerable zones (EEC, 1991; Henkens and van Keulen, 2001).

For many dairy farms in Australia, grazed pastures constitute the greatest proportion of livestock energy requirements (Dillon, 2006; Wales and Kolver, 2017). It is well established that farm profitability is related to the amount of homegrown pasture consumed by grazing dairy cows per unit area (Holmes, 2007; Chapman et al., 2008, 2014). Nitrogen fertilizer remains the most efficient way to increase production at times of the year when N from N_2-fixation or mineralization is insufficient to meet plant demand (Whitehead, 1995; Vogeler and Cichota, 2015). Owing to the uncertainty that still surrounds the pasture N responses for a range of combinations of soils, climate and season interactions (Eckard et al., 2001; Pembleton et al., 2013Gourley et al., 2017), farmers revert to a recipe approach.

Field experimentation examining pasture production response to N fertilizers often have used mechanical defoliation (*i.e.* cutting studies), whereas experiments that incorporate grazing by livestock are rare (Bolland and Guthridge, 2007; Monaghan et al., 2005; Staines et al., 2018). This is due to the difficulty and expense of large-scale grazing experiments, and further, such experiments are generally implemented over limited time-frames (generally one to three years and frequently short-term periods within years) and of a limited number of locations, replicates and N fertilizer treatments (Elliott and Abbott, 2003; Lowe et al., 2005; Bochi-Brum et al., 2011; Gourley et al., 2017). Grazed field studies are also often confounded by aspects such as management difficulties (*e.g.* moving stock, water access) and varying stocking rates resulting in variation in the amount and distribution of N returned to the soil *via* excreta (Cowan et al., 1995; Monaghan et al., 2005). There can be variation in initial pasture and soil conditions, including soil mineral N status, pasture species present, sward density, pest and disease incidence, all of which can never be replicated (Bahmani et al., 2003; Pembleton et al., 2013; Gourley et al., 2017). In addition, N fertilizer rates sometimes do not cover a sufficient range to define a curvilinear N response (Eckard and Franks, 1998; Gourley et al., 2017). Studies that incorporate grazing animals with varying N fertilizer rates, frequently examine production systems questions. For example, Macdonald et al. (2017) compared seven systems; a low stocking rate (3.35 cows ha^{-1}) with N fertilizer rate treatments of 0, 200 or 400 kg N ha^{-1} $annum^{-1}$, a high stocking rate (4.41 cows ha^{-1}) with N fertilizer treatments of 200 or 400 kg N ha^{-1} $annum^{-1}$, and two treatments of high stocking rate and 200 kg N ha^{-1} $annum^{-1}$ combined with either corn grain or corn silage, confounding the effects of stocking rate with N fertilizer rate responses.

In a meta-analysis by Gourley et al. (2017), of 920 independent N fertilizer field trials throughout all of Australia, the data was asymmetric. The only data over the summer months was from Queensland, data from other states of Australia was not available. In addition, for Queensland there was no data from the other three seasons. Over 90% of the data for autumn was derived from Victoria, with zero or minimal datasets from the other states. This confirms the void in data that modelling can overcome with a more meticulous, methodical analysis that contrasts N responses within each season across several sites. This also highlights the difficulty in using field data for developing N best management practices (BMP) for both temperate and subtropical regions where the pasture base may be different to that previously examined.

In the early 2000's, Eckard et al. (2001) compiled a list of BMP recommendations for N fertilizer management on intensive pastures. These were general guidelines for N management, in addition to recommendations around reducing N loss to the environment. The general recommendations included applying only when pasture is actively growing and can utilize N fertilizer, to not apply rates above 50 kg N ha^{-1} in a single application and that applying < 30 kg N ha^{-1} in a single application could produce unpredictable N responses. In addition, they developed a decision support system to ascertain likely monthly N response rates across three Victorian dairy regions and recommended that farmers need to ascertain the cost of pasture produced compared to other purchased feed options. Most of experimental results relied upon to make these recommendations were from field experiments undertaken in Victoria, with minimal N fertilizer treatments, and thus not necessarily relevant to other climate regions and alternative pasture swards. Several future research recommendations were made, including the need to expand the decision support system to include other dairying regions in south-eastern Australia. Therefore, more data from a range of soils, climate regions and pasture swards typical of the regions explored in this study, would improve industry and farmer confidence in promoting these BMPs across farming systems and regions.

Biophysical modelling provides an efficient and effective approach to address many of the complexities of field studies mentioned above. Management, soil and climatic conditions can be examined in isolation from each other to evaluate any interaction effect of these on pasture productivity and nutrient management. Assessments can be undertaken over a range of timeframes to encompass a variety of climatic conditions. Using models to explore N dynamics has the added bonus of being a 'closed' system; all aspects of the N cycle are accounted for.

The objectives of this study were therefore to (i) estimate, *via* mechanistic modelling of a range of N fertilizer rates, the pasture dry matter (DM) growth rates across all four seasons at five sites throughout south-eastern Australia, (ii) determine the N fertilizer rate required to achieve 90% of maximum DM growth rates for each season and site, (iii) estimate the nitrogen response efficiency between two recommended N fertilizer rates across all seasons and sites, and (iv) compare the findings with current BMP recommendations for the Australian dairy industry to confirm their validity across all seasons and sites examined here.

2. Materials and methods

2.1. DairyMod overview

DairyMod is a daily time-step, mechanistic, whole-farm system model that includes modules for soil water and nutrient flows, pasture production and utilization by grazing animals, and animal intake and growth for a range of pasture, irrigation and fertilizer management regimes (Johnson, 2016). DairyMod has been reliably used for the simulation of pasture growth under grazed conditions for a wide range of climate zones, pasture bases and management regimes (Cullen et al., 2008; Rawnsley et al., 2009; Bell et al., 2013; Christie et al., 2014), including N responses and N losses (Eckard et al., 2006; Smith and Western, 2013). DairyMod was chosen because it includes grazing animals and the dynamic and spatially explicit recycling of N through the animal back to the pasture and therefore allowed us to compare results between cutting and grazing defoliation.

The pasture module includes carbon (C) assimilation through photosynthesis and respiration for tissue growth, followed with turnover and senescence, as influenced by environmental conditions, soil water and nutrient status (Johnson 2016). Pasture phenology is not explicitly represented in the model, however for annual species, there are vegetative (emergence to anthesis) and reproductive (anthesis to maturity) growth phases that are defined by setting dates for these phases. The animal module simulates animal production based on protein, water, fat and energy intake that is utilized for maintenance, lactation, pregnancy and growth as appropriate, with the composition of the diet predicting N and digestibility dynamics with the recycling of feces and