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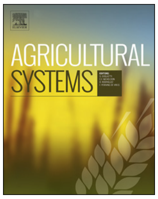

Fertiliser strategies for improving nitrogen use efficiency in grazed dairy pastures

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ABSTRACT

Evidence from farm level studies indicates that there is potential to improve nitrogen (N) use efficiency of the predominately pasture-based dairy farms in Australia. This is possible via several ways which includes modifying the timing and rates of N fertiliser applied to pasture. Traditionally fertiliser strategies have been based on a "recipe" approach where N fertiliser, primarily urea, is applied a set rate following grazing. The aim of this study was to compare the pasture dry matter response, N loss and response rate of fertiliser strategies which used increasing knowledge of plant and soil conditions in different ways. The study was conducted under grazing conditions using the biophysical model, DairyMod and repeated at several locations and farming systems in the dairy regions of Australia. In comparison to set rates this study showed that strategic approaches to N fertiliser have the potential to be more efficient in N use and lower both N inputs and N losses with little impact of pasture production. This was evident across all seasons and locations studied. Strategies that used the plant N status to trigger fertiliser timing and rates were more efficient and had lower environmental N losses than those that used fixed rates or soil N information. Fertilising per plant N requirements was the most efficient – and therefore should be the priority for development – particularly in view of the greater expense of fertilisers that are slow release. Precision fertiliser management strategies have the value in terms of reducing fertiliser use and loss during autumn and to a lesser extent in summer, with the least value in winter. However, for the strategies to be properly evaluated for pasture based dairy farms with grazing, a whole farm analysis needs to be conducted that incorporates other sources of feed. This is a necessary inclusion in any subsequent studies.

1. Introduction

Since the 1990s there has been a widespread and increasing reliance on nitrogen (N), in its many forms, for dairying in Australia (Stott and Gourley, 2016). Whilst the supply of N from legumes can be high (e.g. 150 to 200 kg N/ha/yr, Ledgard, 2001), in Australia the N supply from this source (< 20 kg N/ha/yr, Riffkin et al., 1999) is typically insufficient to sustain high yielding pastures. Consequently, for many dairy farms, the use of N fertiliser has become an indispensable element for increasing or sustaining high pasture and milk production (Gourley et al., 2012; Ho et al., 2013). An ongoing intensification of the production of grazed livestock systems however, comes at a time when there are increasing concerns over the environmental impacts of N losses from agricultural systems (Bouwman et al., 2013; McDowell et al., 2017; Scarsbrook and Melland, 2015). With declining agricultural terms of trade, there are increasing pressures for farmers to optimise input use efficiency (Angus and Grace, 2017; Powell et al., 2010). At the same time, the supply chain is increasingly demanding metrics to underpin claims of sustainable production, with N use efficiency (NUE) being one of the key metrics being sought (Monaghan and de Klein, 2014).

Australian dairy farming traditionally relied on the seasonal production of pasture to produce milk. This means there was a notable increase in milk production during spring with increasing pasture demand being aligned with a surge in pasture growth rates. Calving times were coordinated to synchronise animal demand with the available pasture. In modern times however, premium prices are paid for milk outside of this period to flatten the milk supply. Therefore many farmers are now seeking to derive high production in parts of the year for which there is limited information on pasture growth responses to N

Abbreviations: N, nitrogen; DM, dry matter; FR, flat rate; SM, seasonally modified; Ps, precision agriculture – soil; Pp, precision agriculture – plant; Dp, daily – plant; Ds, daily – soil; NUE, nitrogen use efficiency

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fertiliser (Gourley et al., 2017), high variability in terms of environmental conditions, and for which the risk of N losses are higher (Smith and Western, 2013).

Improving the management of N is a way to increase profitability and reduce N losses to the environment. In the recent decade there has been an increased number of farm N budgeting studies of different dairy farming systems (e.g. Bai et al., 2013; Cela et al., 2014; Cotching et al., 2017; Gourley et al., 2012). Those from pasture based dairy systems have identified that improvements in the efficient use of N fertiliser are necessary (Eckard et al., 2007; Gourley et al., 2012). Some of the reasons for poor fertiliser management include the uncertainty and high variability in pasture responses (Gourley et al., 2017), accessibility to relatively low cost fertiliser (Pannell, 2017), poorly estimated sources of soil N such as from soil legume-derived sources (Unkovich, 2012) and from livestock excreta (Pembleton et al., 2013) and the poorly understood mineralisation of N from soil resources.

It has been increasingly proposed that there is a need to move away from the recipe-type approach of applying flat rates of N fertiliser throughout the year, to a more informed approach allowing for a better outcome with respect to pasture production, NUE and N losses (Christie et al., in review). The adoption of new technologies and sensors linked with the internet of things is likely to transform the way in which N decisions are made on farm; for example, in recent years in Australia there has been a great research interest in enhanced efficiency fertilisers such as polymer-coated and those with nitrification and/or urease inhibitors (Chen et al., 2008). However, efficacy has been variable (e.g. Dougherty et al., 2016; Rowlings et al., 2016; Suter et al., 2013) and the adoption by pastoral farmers has been limited. The necessity for flexible management (in rainfed situations in particular) is required to capitalise on opportunities or limitations due to unseasonal climatic condition. This issue is likely to become more important for the dairy regions of Australia, where a future climate is predicted even more variable in terms of intra and inter seasonal pasture production (Harrison et al., 2016).

With the rapid developments in digital technologies and precision agriculture, it is likely in the near future that in situ sensors will routinely and reliably provide farmers with real-time information of available soil N status, plant N status, as well as soil moisture and pasture growth rates that will enable them to precisely determine when to apply N fertiliser. These data combined with projected data (forecasts) from weather services has the potential to predict system responses in the short to mid-term (Harrison et al., 2017; Wang et al., 2008).

Motivated by the increasing imperative to improve NUE and show action towards reduced environmental loss of N from dairy farming in Australia (de Klein et al., 2017), we conducted a modelling study to compare the dry matter response, N loss and NUE of fertiliser strategies which used increasing knowledge of environmental conditions in different ways. The hypothesis was that applying N fertiliser using strategies based on increasing levels of environmental information and technology will improve NUE, reduce N losses and reduce N inputs required to maintain production.

2. Materials and methods

This study used DairyMod v 5.7.5 (Johnson, 2016) and the same locations, soils, management and model parameters and initialisation as Christie et al. (in review). These are summarised in.

Table 1. Taree is located in a subtropical climate zone with summer dominant rainfall, whereas the remainder locations are classified as being temperate, with winter dominant rainfall. All locations were permanent pastures based of perennial ryegrass (*Lolium perenne*). At Taree, annual ryegrass (*Lolium multiflorum*) was oversown into a permanent kikuyu (*Pennisetum clandestinum*) base each year. Irrigation was applied (25 mm/application) when the cumulative rainfall deficit (rainfall minus potential evapotranspiration) was at least 25 mm.

Single paddock grazing studies with fertiliser additions were the basis of this study. For model initialisation, a long-term simulation (250 years) was run with cattle grazing. Grazing was followed with an application of 10 kg N/ha applied monthly until stabilisation of the N mineralisation rate, organic C pool, and C:N ratio of the fast (labile) and slow organic N pools. Soil conditions at the end of the initialisation period were used as the starting point for a ‘conditioning’ phase for each of the below-mentioned N fertiliser strategies for a period of two years (Christie et al., in review). This ensured that the starting conditions for the simulation were reflective of the treatments imposed. Once initialised and conditioned, the soil inorganic and organic N pools, and soil moisture were reset annually, to the end of the conditioning phase, on the 31 May each year. In all cases N fertiliser was assumed to be surface broadcast as urea.

As in Christie et al. (in review) single paddocks were grazed at fixed intervals (i.e. on the last day of each month) to a residual of 1.2 t DM/ha. The grazing management deliberately confounded stocking rate with N strategy, thus ensuring equal pasture utilisation across strategies, months and years, thereby avoiding the confounding of pasture utilisation with N strategy. While this may not represent on-farm grazing management, it allowed for an equitable comparison of the strategies across months and years. Most studies of pasture response to fertiliser used fixed intervals, and so this approach was followed in this study but using grazing for defoliation. Additionally, for comparisons of fertiliser use efficiency between seasons and strategies a fixed number of fertiliser events was necessary.

The animal intake of pasture was based on that for a lactating animal of normal mature body weight of 600 kg. The model includes the dynamic and spatially explicit recycling of N through the animal back to the pasture – therefore the concentration of N in the excreta relates to the pasture consumed. The animal module allocates N intake to growth, pregnancy and lactation, with surplus N then exponentially allocated to urine, while dung N remains constant. The model manages urine returns to the paddock through a simple 2-pool approach that simulates the bulk soil and a conceptual urine patch, with parameters for urine events per day and event area. The N allocated to the urine pool dynamically decays back to the bulk soil, while further grazing allocates urinary N to the urine patch.

2.1. Strategies

Seven contrasting N fertiliser strategies were investigated:

1. Zero rate (ZR): no fertiliser applied
2. Flat rate (FR): a rate of 40 kg N/ha/application applied after every grazing for the rainfed locations and 50 kg N/ha for locations with irrigation (these rates are aimed to ensure that N is not limiting throughout the year);
3. Seasonally modified (SM): The N rate varied according to season as shown in Table 2, with a fixed rate across all years based on the median results of Christie et al., in review for N90 (the N rate required to achieve 0.9 of maximum yield);
4. Precision agriculture - soil (Ps): N fertiliser was applied at 30 kg N/ha when the soil available N concentration (sum of ammonium and nitrate) fell below 20 mg N/kg in the top 15 cm, and then was not applied for at least 21 days;
5. Precision agriculture - plant (Pp): N fertiliser applied at 30 kg N/ha when live leaf N concentration drops below 90% of optimum (i.e. a level at which plant growth potential is 10% limited by a lack of N) and then was not applied for at least 21 days;
6. Optimal N daily - plant (Dp): as for Pp above except N fertiliser was applied daily at 7.5 kg/ha;
7. Optimal N daily - soil (Ds): as for Ps above except N fertiliser was applied daily was applied daily at 7.5 kg/ha;

For strategies 4 and 5 the N requirements were determined for the