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The role and value of diverse sward mixtures in dairy farm systems of New Zealand: An exploratory assessment

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ABSTRACT

New Zealand dairy farm systems mostly rely on ryegrass-white clover pastures. The inclusion of diverse sward mixtures within these systems offers a novel strategy to improve economic and environmental outcomes. However, the degree to which these mixtures offer advantages over traditional pastures is unknown. This analysis seeks to explore the role and value of diverse mixtures to New Zealand dairy farms, through integrating the results of recent experimental research involving diverse sward mixtures with an existing whole-farm model. An exploratory assessment is required to determine further investment in these species, guide further data collection and experimental design, and understand traits of high value to farming systems. Model output suggests that the economic incentives associated with the use of diverse swards are too weak on their own to motivate wide-scale adoption under standard conditions. This finding is highly robust to changes in the milk price. However, given societal concern pertaining to water-quality deterioration, reductions in the levels of nitrogen lost from dairy farms are found to add substantially to the value proposition offered by alternative sward species. Reductions in nitrogen leaching of about 40% were predicted here when all the sward area on the farm is sown to diverse sward mixtures, compared with standard mixtures. This is mainly derived from a reduction in the concentration of nitrogen present in urine, and to a much lesser extent by a reduction in the total amount of urinary nitrogen excreted by cows. Overall, diverse swards appear to be a cost-effective way to reduce nitrogen leaching, which is relevant for a dairy sector facing regulatory constraints. Nevertheless, the need to understand and improve the persistence of diverse swards is important to reduce the cost of pasture establishment.

1. Introduction

The agricultural sector in New Zealand (NZ) is a primary source of regional and national income. For example, dairy production based on pastures generates around a quarter of merchandise exports each year (Statistics New Zealand, 2015). However, there has been increasing societal concern surrounding improving water quality, partly driven by declines in water quality observed in some regions (Mueller et al., 2016) due to the intensification of agriculture over the last 25 years (Ministry for the Environment and Statistics New Zealand, 2015). This societal pressure led to the recent introduction of the *National Policy Statement for Freshwater Management 2014* (Ministry for the Environment, 2014), which charges regional environmental authorities to reduce the impact of human activity on freshwater throughout New Zealand. Accordingly, there is much interest in the development and uptake of strategies to reduce contaminant loss from farms, while also helping to maintain or improve their capacity to satisfy the goals important to producers and their broader communities, such as profitability and production (Monaghan and de Klein, 2014).

Urinary deposition is the main source of nitrogen (N) leaching in pastoral systems. High concentrations of N in the urine lead to high N loads in urine patches deposited on pastures (Haynes and Williams, 1993; Romera et al., 2012; Cichota et al., 2013; Selbie et al., 2015). High rates of nitrate loss can therefore occur during periods of excess drainage, particularly during autumn/winter when rainfall is high and evapotranspiration losses are low (Monaghan et al., 2007). A number of strategies to mitigate N losses have been identified (de Klein et al., 2010; Doole, 2015). However, the search for promising mitigation strategies continues, as economic analysis continues to highlight a dearth of profitable means to reduce N loss on pasture-based NZ dairy farms (Doole and Kingwell, 2015).

Historically, Perennial ryegrass (*Lolium perenne* L) and white clover (*Trifolium repens*) have been the most-widely utilised species in New Zealand grazing swards (Brooking and Pawson, 2010; Charlton and Stewart, 1999). Accordingly, in recent years, the value of increasing pasture-species diversity has been explored as a means to increase farm-systems performance. Plants like chicory (*Cichorium intybus*), plantain

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(*Plantago lanceolata*), lotus (*Lotus* spp.), and lucerne (*Medicago sativa*) are among the key species being investigated (Pembleton et al., 2015). Diverse swards may be more drought resistant relative to standard swards, showing higher growth potential in the summer-autumn period when low soil moisture typically constrains herbage growth throughout New Zealand (Mason et al., 2016; Nobilly et al., 2013; Woodward et al., 2013; Sanderson et al., 2005). For example, Woodward et al. (2013) measured similar annual dry matter yields for diverse and standard swards, but with 12% more yield during summer and autumn. Such diverse sward mixtures[1] can also decrease N leaching by reducing the amount and concentration of N excreted in the urine (Pembleton et al., 2015). This can arise from several mechanisms: the lower N content of diverse swards, an improved ratio between water-soluble carbohydrates and protein, or the presence of plant secondary compounds that may increase water intake and urination volumes (Totty et al., 2013). In addition, chicory and plantain tend to have higher water contents than grasses and may act as diuretics, increasing the total volume of urine and hence diluting the N content of urine patches (Pembleton et al., 2015). As a result, the inclusion of diverse swards in the diet of cattle has been shown to achieve reductions in the excretion of total urinary nitrogen (UN) (Woodward et al., 2012). This, together with observed increases in urine volume, has led to 20–60% reductions in N concentrations observed in the urine of cattle grazing diverse swards (Edwards et al., 2015; Totty et al., 2013; Woodward et al., 2012).

This study provides a preliminary assessment of the role and value of diverse swards, relative to standard swards, on intensive pasture-based dairy farms in the Waikato region of New Zealand, in terms of production, profit, and nitrogen leaching. Knowledge gaps still exist with regards to several aspects of the expected biological performance of diverse swards across New Zealand. This study fulfils an important role in this context through helping to identify (i) the situations that diverse pastures are tentatively most likely to be valuable within; (ii) the data gaps that are most important from a farm-systems perspective; (iii) the overall value of diverse swards, so as to guide future investment decisions; and (iv) traits of new pastures of the greatest economic value to farms in the study region.

A detailed non-linear optimisation model of a NZ dairy farm—the Integrated Dairy Enterprise Analysis (IDEA) framework (Doole and Romera, 2013)—is employed to provide insight into the implications of diverse swards for production, farm profit, and N leaching. This work extends the simulation modelling of Beukes et al. (2014) through the use of optimisation modelling. This has a number of benefits. First, this facilitates making even comparisons between alternative scenarios, as these options are all generated with one consistent objective (i.e. profit maximisation). Second, the structure of the optimisation model allows the evaluation of a much larger set of alternatives, due to its use of an automated search procedure. These benefits allow the identification of key information that extends previous farm-level evaluations of diverse swards in NZ dairy systems.

2. Materials and methods

This section first gives a brief description of the farm-level model (IDEA) used in this study. Second, it gives details of the pasture model that underpins the farm-system modelling. Third, it describes the treatment of N leaching in IDEA. Finally, it presents a series of modelling scenarios that were performed to study the inclusion of diverse swards on dairy farms.

[1] For simplicity, swards containing these non-traditional species are referred to as 'diverse swards' in the following. This does not detract from the fact that traditional ryegrass-clover swards used on NZ dairy farms are also naturally diverse.

2.1. Overview of the IDEA model

This section provides a concise overview of the IDEA model; full detail is provided in Doole and Romera (2013) and references contained therein. IDEA is an optimisation model focused on balancing the feed demand and feed supply for a given farming system. The optimisation process involves an automated search for a farm-management plan that maximises profit subject to the different constraints that describe the biophysical, economic, and technical environments in which the farm operates. The optimisation method is known as nonlinear programming and is coded in the General Algebraic Modelling System (GAMS, Brooke et al., 2016).

Through the optimisation process, IDEA identifies the feeding strategy that maximises annual profit. The model is defined over 26 fortnights to provide comprehensive insight into this feeding strategy across a typical management year. There are three primary sources of feed: (1) grazed pasture, (2) pasture silage and (3) supplements (e.g. palm kernel expeller, maize silage, maize grain, sward silage). Pasture silage can be made on-farm, or it can be purchased from off-farm suppliers. Supplements are all imported to the farming system. IDEA determines how much of each of these feeds is provided to the cow herd in a given fortnight, based on their requirements and how much feed is available. Surplus herbage is ensiled on-farm during periods when feed supply exceeds feed demand, especially in spring. Nitrogen fertiliser application promotes herbage growth, with the rate and timing of sward response varying across the year. Differential responses to N fertilizers for the two sward types are possible, although the lack of experimental data prevented us from considering this in our modelling. Ingestion of supplement complements herbage intake, and losses during harvesting (for pasture silage) and feeding (for all supplements) are accounted for in the model. However, the use of supplement compromises herbage intake through substitution, to a degree determined by the season, supplement type, cow liveweight, and level of herbage intake.

New Zealand dairy farms are rotationally grazed, with areas of the farm grazed at very high stocking densities (e.g. 50 to 300 cows ha^{-1}) and then rested for periods of 20–100 days, depending on the time of the year. Grazing management within these farming systems is assisted by observations of residuals (post-harvest herbage mass). The primary set of decision variables that describes the grazing rotation in IDEA determines the area grazed or cut for silage to a given residual in each period. For example, when cows consume less herbage and residuals are subsequently higher, this leads to reduced growth rates and lower herbage quality (Romera and Doole, 2015). Accounting for time since the last grazing and the residuals at the previous and current grazing and/or cutting events allows management to impact herbage digestibility (and therefore energy content) and growth. A simulation model of an age-structured, perennial sward is utilised to estimate the effects of grazing frequency and severity on herbage growth and digestibility (Doole and Romera, 2013). More detail of this framework is provided below in Section 2.2. The IDEA model allows for parts of the farm to be covered by different sward types. This is important in the context of this study, as it involves a comparison of both standard ryegrass-clover swards and diverse swards, which contain perennial ryegrass alongside species that are less-traditional in New Zealand, such as chicory and lucerne. The model represents key decisions pertaining to herd management. The model represents how well cows can be fed, relative to potential. This is important because cows are typically fed less than potential on NZ dairy farms, to maintain higher stocking rates and hence increase sward utilisation (Romera and Doole, 2015). Culling decisions impact the age distribution of the herd and subsequent impacts on production. Lactation length can also be fixed or optimised.

Feed demand and supply is reconciled by two constraints. A metabolisable-energy constraint is defined in each period and requires a sufficient amount of energy to be available to meet the herd's requirements. Also, an intake constraint ensures that cows cannot consume