The effect of dietary nitrogen on nitrogen partitioning and milk production in grazing dairy cows

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ABSTRACT

Two experiments were conducted during spring (8th October to 12th November 2009) as part of a larger study, to study the effects of increasing levels of crude protein (CP) in pasture on milk production, dry matter intake (DMI) and nitrogen (N) partitioning in dairy cows.

The first experiment was undertaken over 25 days (8th October to 1st November 2009), where fifteen multiparous, rumen fistulated, early lactation Holstein-Friesian cows (505 ± 10.4 kg liveweight; 4.1 body condition score ± 0.044, mean ± standard deviation) were assigned to one of three urea supplementation treatments: Control (0 g/day urea; ~20% CP), Medium (350 g/day urea; ~25% CP) and High (690 g/day urea: ~30% CP). Urea was supplemented to the pasture-based diet to increase CP content while maintaining similar concentrations of all other nutrients across treatments. All cows were offered ~20 kg dry matter (DM)/day perennial ryegrass-based pasture (CP = 20.6 ± 0.56% DM; metabolisable energy (ME) = 11.8 ± 0.06 MJ/kg DM). Cows were acclimated to their urea treatment over a 25 day experimental period. The objective of this study was to determine the effect of increased dietary CP in grazing cows on DMI and milk yield.

Dry matter intake was estimated using a back calculation method from the energy requirements of the cows. The results indicate a complex interaction between DMI, milk yield and urea intake. As dietary CP increased, the milk yield increased; however, as urea's contribution to total dietary CP concentration increased, the increase in both DMI and milk yield was less. Milk yield decreased when urea supplementation increased beyond 350 g/day, and the interaction evident in milk yield was mirrored in yields of fat, CP and lactose ($P < 0.001$). The addition of urea had no effect on milk fat, protein and lactose percentages.

The second experiment was conducted over 22 days (22nd October to 12th November 2009), involving ten multiparous, rumen fistulated, early lactation Holstein-Friesian cows (520 ± 5.6 kg liveweight; 4.15 body condition score ± 0.078, mean ± standard deviation). This experiment was undertaken to study N partitioning in pasture-fed grazing dairy cows using urea supplementation as a non-protein N (NPN) model to ensure all other nutritional characteristics of the forage remained the same. All cows were offered ~19 kg DM/day of perennial ryegrass-based pasture (CP = 18.4 ± 0.64% DM; ME = 11.4 ± 0.06 MJ/kg DM). Cows were assigned to one of two experimental groups: Control (0 g/day urea; ~18% CP), and a Urea supplemented group (350 g/day urea; ~23% CP). Cows were acclimated to the diets and metabolism stalls for 14 days, and a further 7 days were used for total collection of urine, faeces and milk.

Increasing dietary CP content had no effect on DMI, milk yield, milk composition, and faecal N. Urinary urea N (UUN) and urine N yield and concentrations increased as dietary CP content increased however, urinary creatinine, ammonia (NH_3), calcium and magnesium were not affected. Rumen urea and NH_3 concentrations were increased as CP content increased. Milk urea N showed trends for linear responses to increasing N intake ($P < 0.001$, $R^2 = 0.47$). A 16.5% increase in N intake resulted in a 42.5% increase in milk urea nitrogen (MUN) concentration; however, the relationship was restricted to low MUN concentrations. Urinary N increased linearly as a result of N intake, although the relationship was restricted due to the underestimation of urinary N and the limited range of N intake values. The 28% increase in urinary N excretion resulted from a sharp 3.6% decline in N efficiency as dietary N content increased.

The main conclusions of this thesis were the ability for excessive urea intake to reduce milk yield in grazing dairy cows. Further research is needed to determine if high soluble NPN concentrations in fresh pasture would affect DMI and milk yield in the same way. Increasing N intake results in linear increases in MUN, urinary N and UUN. These relationships could provide useful tools to predict urinary N excretion due to the strong relationships between these variables. Further research is needed to develop robust prediction equations for the relationships between these variables in grazing dairy cows before they could be used as regulatory tools.

INTRODUCTION

Farming has played an important role in New Zealand's economy for over 100 years (PCE, 2004). Dairy and meat products are the single biggest export earners and currently comprise ~50% of New Zealand's export income (Statistics NZ, 2012). Overall, farming contributes over 5% of gross domestic product in New Zealand and is significantly important to the economy (Statistics NZ, 2012).

There are, currently, around 60,000 farms in New Zealand, with more than half of New Zealand's land area used for farming including production forestry (PCE, 2004; Statistics NZ, 2012). As illustrated in Figure 1, the dominant land use is sheep farming; however, dairy farming also makes up a significant portion of the land use and is the largest industry (~$15.8 billion) in New Zealand, accounting for 25% of export income (Statistics NZ, 2012). The New Zealand dairy industry is the largest single contributor to internationally traded dairy products, with a trade value of nearly US$ 8 billion (United Nations, 2014).

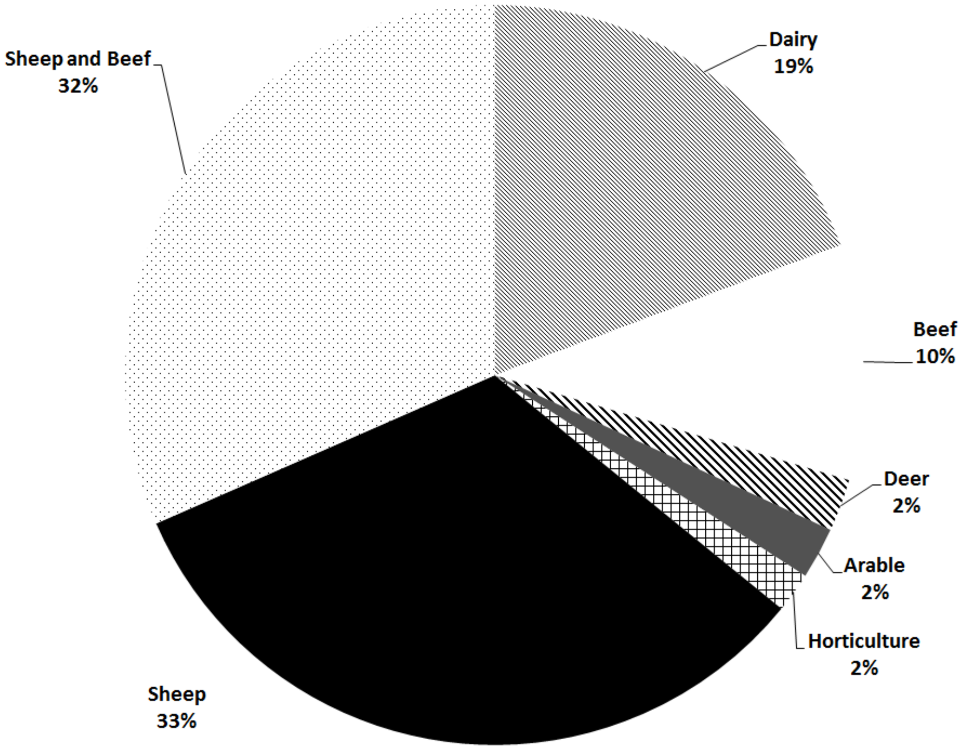

Figure 1: New Zealand land area distribution for different farming types in 2012; excluding forestry and 'other' usage, adapted from (Statistics NZ, 2012).*Viticulture is included within horticulture, as vineyards make up only about 0.4% of the total land area farmed in New Zealand. The total area of land used for farming is approximately 14 million hectares.

New Zealand's dairy farming has traditionally centred on a seasonal, low-cost pasture-based system, where cows calve in late winter/early spring and are subsequently milked during spring, summer and autumn, but ‘dried off’ (a management technique to cease lactation) during late autumn/winter when pasture growth is minimal (Ulyatt, 1997; PCE, 2004). This results in a large volume of milk available during spring/early summer. As a result, the global demand for milk products is a key driver of production in New Zealand due to the domestic market being too small to utilise the milk product available (Scarsbrook and Melland, 2015). The pasture-based system allows New Zealand to remain competitive on the international market due to the associated low cost of production (Ulyatt, 1997). Dairy farmers in New Zealand are paid in relation to the fat and protein supplied and the price paid is consistent throughout New Zealand. However, this price is dependent on world market prices, and is therefore difficult to predict (Penno and Kolver, 2000). Combinations of increasing global demand for milk products, along with ongoing financial pressure to increase efficiency both on farm and throughout the industry, have driven the intensification of dairying in New Zealand (PCE, 2004; Scarsbrook and Melland, 2015).

To illustrate this intensification, in 1993/94 there were 2.7 million cows on 1.1 million hectares in New Zealand and 20 years later in 2014/15 there were 5.0 million cows on 1.7 million hectares (LIC and DairyNZ, 2015). Along with this substantial increase in cow numbers and area under dairy farming in New Zealand, the milk yield per hectare increased due to both an increase in stocking rate and an increase in milk yield per cow (Table 1) (LIC and DairyNZ, 2015). As a result, the total milksolids yield increased 157% between 1994 and 2015 (Table 1).

Table 1: Comparative dairy industry figures highlighting potential drivers of environmental impact. Information is sourced from LIC (1994) and LIC and DairyNZ (2015).

Total	**Industry estimate 2014-2015**	**% Change over time 1994-2015**
Dairy cows, million	5.0	82%
Area under dairy, million ha	1.7	55%
Milk yield, million kg milksolids	1890	157%
Average		
Stocking rate, cows/ha	2.87	18%
Herd size, cows/farm	419	123%
Milk yield, kg milksolids/cow	377	36%
Milk yield, kg/ha	1082	53%

ha = hectares

This intensification is due to a large area of sheep, and beef farms and some forestry in the South Island being converted to dairy, due to the availability of water resources for irrigation (PCE, 2013). In 1994, the South Island contained 12% of the total dairy cattle population in New Zealand (LIC, 1994). This increased by 28% from 1994-2015, resulting in a total dairy cow population in the South Island of 2.0 million (LIC, 1994; LIC and DairyNZ, 2015). The current distribution of the New Zealand dairy herd by region is presented in Figure 2 (LIC and DairyNZ, 2015).

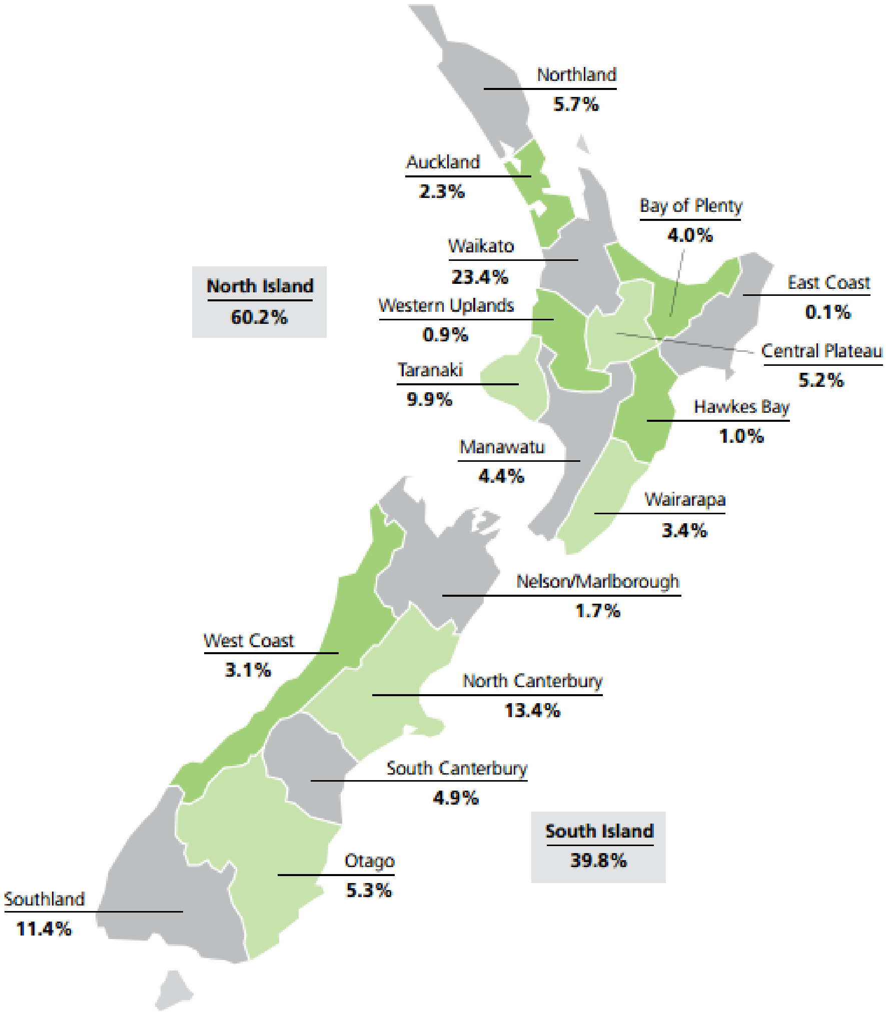

Figure 2: Regional distribution of dairy cows (percentage of total herd) in New Zealand (2014/15) (LIC and DairyNZ, 2015).

New Zealand's pasture-based system results in the feeding of pasture that often contains high concentrations of crude protein (CP) (Ulyatt, 1997), which, in excess, is not utilised efficiently by the dairy cow. These high concentrations of CP are a result of the timing of grazing and are further excacerbated by nitrogen (N) fertiliser inputs (Van Vuuren *et al.*, 1991; Lambert *et al.,* 2004). The growth and intensification of dairying in the past 20 years has resulted in a 17% increase in stocking rate (Table 1) and an almost 7-fold increase in the use of N fertiliser (from 75,800 t in 1993 to 511,074 t in 2013) (Statistics NZ, 2012).

As a result of intensification of dairy farming in New Zealand, water quality has declined due to increased nutrient loading and subsequent eutrophication (Ballantine and Davies-Colley, 2014). Urine from farm animals is the major source of N in New Zealand's waterways draining agricultural catchments (PCE, 2013;). Over a 22 year time series (1990-2011), excreted N loads from dairy cows has more than doubled (102% increase) and nitrate (NO_3^-) concentrations in waterways have also increased (Figure 3) (Scarsbrook and Melland, 2015). Increased N fertiliser use has also resulted in increased dietary N intake and subsequent deposition of urinary N on pasture, due to inefficient N use by the dairy cow as well as smaller losses of N fertiliser (Monaghan *et al.,* 2005).

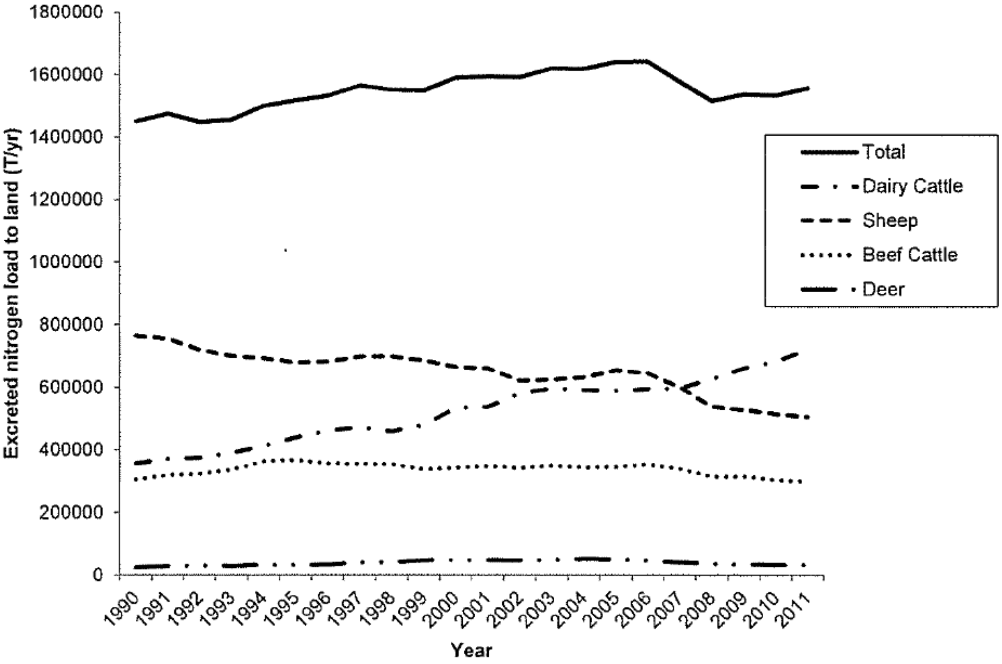

Figure 3: National trends in nitrogen excreted load to land (t/year) from all stock types for the period 1990-2011 in New Zealand (Scarsbrook and Melland, 2015).

The loss of NO_3^- due to its susceptibility to leaching from soil into groundwater is of major concern to freshwater ecosystems. Urinary N enters groundwater via drainage through soil and N fertiliser enters surface waterways via runoff or direct input (Clark, 1997). Together these have adverse effects on water quality due to accelerated eutrophication of surface water, resulting in the increased growth of algae and nuisance weeds, causing a shortage of oxygen for aquatic life (Gregg *et al.,* 1993). This can result in death of aquatic organisms, can have adverse effects on tourism, and increase treatment costs, for potable water (Di and Cameron, 2005; MFE, 2014).

The New Zealand dairy industry is striving for increased productivity, whilst maintaining or reducing the environmental footprint, with particular emphasis on reducing N leaching to waterways (Pacheco *et al.,* 2007). Consequently, research into the reduction of N losses from dairy farm systems is a high priority for the dairy industry to comply with environmental standards (DairyNZ, 2014). Animal nutrition is a major management tool to reduce the N lost through urine; however, a reduction in dietary N can also negatively affect animal production (Fanchone *et al.,* 2013). Therefore, it is important to understand N partitioning in the cow to provide guidelines and models to mitigate N losses through managing nutrition (Tamminga, 1992).

ABBREVIATIONS

ADF	Acid detergent fibre
ATP	Adenosine triphosphate
CP	Crude protein
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
H^+	Hydrogen ion
ME	Metabolisable energy
MJ ME	Megajoules metabolisable energy
MP	Microbial protein
MUN	Milk urea nitrogen
N	Nitrogen
NDF	Neutral detergent fibre
NIRS	Near-infrared spectroscopy
NPS-FM	National Policy Statement for Freshwater Management
N_2O	Nitrous oxide
NO_3^-	Nitrate
NH_3	Ammonia
NH_4^+	Ammonium
NPN	Non-protein nitrogen
OM	Organic matter
RDP	Rumen degradable protein
RUP	Rumen undegradable protein
SP	Soluble protein
TLI	Trophic level index
UUN	Urinary urea nitrogen
WSC	Water-soluble carbohydrates

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