Does spring application of fertiliser urea reduce dairy cow performance?

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Abstract

This paper reports a field experiment and a farm survey, which aimed to find out if there is evidence that elevated herbage crude protein (CP):sugar levels have negative effects on dairy cow performance. Differences in herbage CP levels were induced by using nitrogen (+N) or withholding (-N) applied as fertiliser urea for two groups of 20 dairy cows in early lactation (August to November 2003). Cows fed urea-fertilised herbage had elevated milk urea levels (-N = 5.4 mmol/l, +N = 8.3 mmol/l, $P<0.001$). A feed conversion efficiency (FCE) index was calculated as the ratio between theoretical daily metabolic energy (ME) requirement based on measured live weight and milksolids (MS) production data, and the observed mean daily ME intake over a 74 day observation period. Using this index, the apparent FCE was approximately 10% lower for the +N than for the –N group of cows. A survey of 16 farms indicated an association between elevated milk urea and decreased MS production per cow per day, consistent with the experimental result. It is concluded that although fertiliser urea does appear to reduce FCE, urea use can still be a viable strategy to improve the overall performance of a dairy farm system.

Keywords: dairy cow performance, feed conversion efficiency, fertiliser urea, metabolisable energy, milksolids production

Introduction

In New Zealand and Australia, nitrogen (N) fertiliser is applied during spring on a majority of dairy farms (Mackle *et al.* 1995; McGrath *et al.* 1998; Jacobs *et al.* 2002). This practice increases pasture availability at a time when high dry matter (DM) intake requirements of animals in early lactation are not fully met by early spring herbage accumulation rates (Garcia & Holmes 1999).

The increase in herbage accumulation with N fertiliser use is accompanied by various changes in herbage composition. For example, N fertiliser increases herbage metabolisable energy (ME) content (Jacobs *et al.* 1998; McKenzie *et al.* 2003), crude protein (CP) concentration (Jacobs *et al.* 1998; Jacobs *et al.* 2002; McKenzie *et al.* 2003), and organic matter digestibility (Jacobs *et al.* 1998; Salaun *et al.* 1999). Several New Zealand and overseas authors have identified high levels of dietary CP as a factor associated with reduced milk volume and milksolids (MS) production (Mackle *et al.* 1995; Mackle *et al.* 1996), a more negative energy balance (Butler 1998; Chapa *et al*. 2001), and inferior reproductive performance (Butler 1998; Chapa *et al.* 2001).

One of the mechanisms by which it is proposed that high CP intake depresses cow performance, is through the energy cost to the cow of metabolizing surplus ammonia and urea resulting from ruminal protein metabolism (NRC 1988; Twigge & Gils 1988; Westwood *et al.* 1998). Hence, it has been suggested that the ratio of CP to soluble sugars and starch (SSS) is more important than the absolute level of CP in determining if there will be negative effects on the animal from a given diet. According to this view, high CP intakes can be offset by increasing the energy availability for rumen microorganisms, leading to a higher assimilation of the ammonia from protein breakdown (Hoover & Stokes 1991; Kenny *et al.* 2002; NRC 1988; Oldham 1984; Staples *et al.* 1993). It is well known that CP:SSS ratios in excess of 2:1 can lead to excretion of excess dietary N as urea in milk and in urine of grazing animals (Moller *et al.* 1993). This paper reports a field experiment and a farm survey, both aimed at assessing whether there is evidence for an association between N fertiliser usage in early spring, and impaired performance of lactating dairy cows.

Materials and methods

Field experiment

Trial design

A three month trial was conducted at Massey University No. 4 Dairy Farm near Palmerston North from 18 August to 28 November 2003. The experimental strategy was to obtain for dairy cows in early lactation, a 'snapshot in time' of a comprehensive suite of data describing forage on offer, milk production, and physiological status of the animals. The experimental design aimed to create a differing herbage CP level, and consequently a differing ratio of CP: SSS for two groups of cows, with minimal perturbation of other farm system components. It was decided to achieve this difference in herbage composition through use of N fertiliser. One group of 20 cows was fed perennial ryegrass-white clover dominant pasture that had received no recent fertiliser N (–N), while a second group was fed similar pasture receiving approximately 35 kg N/ha as urea, soon after each grazing (+N). A defined priority of the experimental protocol was that both groups of cows received equal pasture allowance (kg DM/cow/day), as determined by daily rising plate meter readings on each part-paddock grazed. Rising plate meter (RPM) calibration cuts were taken three times during the trial to assess whether different equations should be used for calculating herbage mass on –N and +N paddocks. To achieve equal allowance despite the application of N fertiliser, the +N treatment was allocated 7.57 ha in 4 paddocks, while the –N treatment was allocated 9.68 ha in 5 paddocks. Four pairs of similar paddocks, all on a Pallic Tokomaru silt loam, were identified across the Massey No. 4 Dairy Farm, and one paddock in each pair allocated to each of the two treatments, with a fifth paddock allocated to the –N treatment to make up the larger area required for this treatment.

Measurements

For each paddock grazed on both –N and +N treatments, herbage was hand-sampled from the grazing horizon and submitted for NIR analysis (AgResearch Palmerston North, FeedTech). Milksolids production of all cows was measured weekly using standard herd test procedures. Animal live weight was also recorded weekly. Return to oestrus was determined by ultrasound scanning all cows each alternate day, –N cows on one day, and +N cows the next day. Blood samples were collected regularly from cows and analyses undertaken included serum urea, albumin, non-esterified fatty acids (NEFA), insulin-like growth factor (IGF-1), and growth hormone levels. Whole milk samples were collected during ultrasound scanning, and frozen for later analysis of progesterone levels. In mid-September additional whole milk samples were collected from all 40 cows for analysis of milk urea. Samples were analysed at Alpha Scientific Ltd., Sunshine Ave. Hamilton.

Statistical analysis

Most statistical probabilities for pasture measurements reported in Table 1 were derived using PROC Mixed of SAS (Version 8.02), with treatment group as a fixed effect and measurement date as a random effect. Milk urea, live weight, CS, and MS were analysed using Proc Mixed of SAS (Version 8.02) with a linear model that considered the effect treatment group, week of measurement and their interaction and the random effect of animal within treatment group (Littell *et al.* 1996). Using Akaike's information criterion, a compound symmetry error structure was determined as the most appropriate residual covariance structure for repeated measures over time within animals. Least squares means and their standard errors were derived to test the null hypothesis that there was no difference between the two groups of cows. It should be borne in mind when interpreting results, that although +N and –N treatment paddocks were paired for similarity, there is a possibility that paddock factors other than N fertiliser (for example renovation two or three years prior to the experiment, of one paddock in a pair) could have influenced the means for either group of cows.

Farmer survey

We wished also to ascertain if patterns of association between measured variables and N fertiliser policy observed in the field experiment above, were consistent with a wider industry pattern. Accordingly a small farm survey was conducted. Questionnaires were distributed to 20 Manawatu and Southern Hawkes Bay dairy farms in early-September 2003, and by arrangement with Fonterra, milk samples from these same farms were obtained from milk collected on 14 September. Samples were sent for milk urea analysis as above, with a repeat sampling on 23 September.

Survey respondents were asked to report MS production (kg cow/day) for their property on 14 September, and other details of their farming system. Data collected included cow intake (kg DM/cow/day, from farm monitoring), amount of supplement (kg DM/cow/day), planned date of start of calving, proportion of cows calved on 14 September (i.e. a measure of calving date spread), the rate of urea last applied to paddocks grazed during the previous week and date of urea application, the number of milkings in the last 7 days where cows had grazed Italian ryegrass paddocks and the breed of the herd. Sixteen responses were received, and these data together with the two sets of milk urea data were compiled into a matrix of 12 variables x 16 farms. The matrix was then subjected to principal component analysis (PCA, using the command PCA of Minitab version 10.5) to determine patterns of association across farms, among the various components of the farm system.

Results and discussion

Field experiment results presented in this paper are based on a 74 day observation period from 18 August to 30 October, because there was more variation in pre- and post-grazing herbage mass, as flowering tillers emerged, after 1 November. However, mean separations reported in Table 1 change little when recalculated for the entire 102 days of the experiment, to 28 November.

Table 1 Cow diet and performance, averaged for a 74 day observation period, and feed conversion efficiency index for cows grazing –N and +N paddocks from 18 August to 30 October 2003. Theoretical ME requirement (MJ/day) is calculated as (kg MS x 66 MJ/kg) + 0.6 x (live weight)$^{0.75}$.

Measure	–N group	+N group	SEM	Signif[1]
Pasture allowance (kg DM/cow/day)	45.9	45.6	0.6	NS
Dry matter intake (kg /cow/day)	16.0	16.3	0.4	NS
Mean pre-grazing herbage mass (kg/DM/ha)	2964	3052	37	†
Mean post-grazing herbage mass (kg DM/ha)	1923	1956	18	NS
NIR herbage ME (MJME/kg DM)	11.5	11.9	0.1	***
ME intake (MJ ME/cow/day)	184	195	4	†
NIR crude protein (CP, %)	21.5	25.4	0.2	***
CP: SSS	2.0	2.4	0.07	***
CP intake (kg/cow/day)	3.5	4.3	0.1	***
Milk urea (mmol/l)	5.4	8.3	0.1	***
Cow live weight (kg)	466	460	7	NS
MS production (kg/cow/day)	2.0	1.9	0.04	NS
Theoretical ME requirement (MJ/day)	196	190	4	NS
Index of FCE (%)	107%	98%	-	-

[1] Tests if the two treatment groups have a different mean, but does not test if a difference is attributable to an N effect.
NS not significant; † $P<0.10$, *** $P<0.001$.

Field experiment

On cessation of regular N fertiliser application to create the –N paddocks, there was initially a serious yellowing of leaf colour in these paddocks, which persisted for the first two weeks of the experiment, presumably from development of a N deficiency attributable to changes in the soil microbial populations in response to changed soil N dynamics. Rising plate meter measurements of herbage production indicated 4185 kg DM/ha for –N paddocks and 5249 kg DM/ha for +N paddocks (125 kg N/ha total applied in 4 applications from 24 July to 19 September, response 8 kg DM/kg N). Multiplying these herbage production data by paddock areas indicated a total herbage supply for the experimental period of 40.5 and 39.7 tonnes DM for –N and +N cows, respectively. Pre- and post-grazing herbage mass assessed by RPM did not differ significantly (Table 1). Visually, the herbage on offer to +N cows appeared more superior than is indicated by the ME differential of only 0.4 units (Table 1). Despite the higher feed quality of herbage offered to +N cows, and similar cow daily intake for both treatment groups, MS/cow/day was not increased (Table 1), and this is the salient result for the experiment. To further explore this result, data for the experimental period were averaged for each attribute measured, and organised so as to allow calculation of the ratio between theoretical daily ME intake for the live weight and milk production measured, and the observed mean daily ME intake over the 10.5 week period considered. This ratio is effectively an index of feed conversion efficiency (FCE) for the two groups of cows grazing +N and –N pasture (Table 1). Based on established data for conversion of feed by grazing animals (66 MJ/kg MS, 0.6 MJ/day/(kg LW)$^{0.75}$), there was an observed difference in FCE index of almost 10%, in favour of the –N group of cows (Table 1).

In the first weeks of the experiment, blood NEFA concentration averaged 0.45 mmol/l for +N cows and 0.56 mmol/l for –N cows (SE 0.02 mmol/l, $P<0.01$). The elevated blood NEFA levels in –N cows are consistent with the visual check to pasture growth, on withdrawing regular N fertiliser applications to set up –N paddocks. No significant difference was found between the means of the high and the low CP groups in any of the reproductive parameters evaluated. For example, blood progesterone of +N and –N cows was 178.6 and 155.4 ng/ml, respectively, SE 17.5 ng/ml), while first oestrus was on average 53.9 days after calving in +N cows and 58.9 days after calving (SE 4.3 days) in the –N group. Although these latter results were not statistically significant, the direction of the trend observed is consistent with the elevated blood NEFA levels of –N cows.

Farmer survey

The first two principal components (PC's) accounted for 47% of the overall variation (Table 2), which is indicative of significant pattern in the data. A chi-square value for statistical significance of the PCA as a whole was calculated using a method based on Bartlett's sphericity test, as described by Cooley & Lohnes (1971), and was 104 (66 d.f., $P = 0.0004$). This test uses the product of the Eigenvalues of the PCA and essentially detects

Table 2 Largest 4 PC's from PCA of farm survey data, indicating patterns of association between MS production (kg/cow/day) and other farm system components. For the PCA as a whole, c^2 (66 df.) = 104 ($P < 0.0004$). In a PCA, each PC represents a feature of the data set independent of the other PC's. Coefficients less than 0.25 have been suppressed.

	PC1	PC2	PC3	PC4
MS production (kg/cow/day)	0.36	0.41	-	-0.25
Total intake (kg DM/cow/day)	0.33	0.36	-	-
Supplement intake (silage etc., kg DM/cow/day)	-	-	0.56	0.28
Grazing intensity[1] (cow days/ha)	-	-	-0.38	-
Proportion of herd calved at 14 September	-	0.27		0.67
Calving date (days in relation to 1 August)	-	-0.37	0.32	-0.35
Italian ryegrass use[2]	-	-0.25	-	-0.28
Urea use[3] (kg/ha)	-0.29	0.25	0.41	-
Urea timing (days since last application)	-	-0.50	-	0.28
Jersey herd[4]	-0.51	-	-	-
Milk urea on 14 September (mmol/l)	-0.43	-	-	-
Milk urea on 23 September (mmol/l)	-0.30	-	-0.38	-
Variation explained	26%	21%	19%	11%

[1] Defined as animal grazing days/ha in each grazing event; measures difference between pre- and post-grazing herbage mass.
[2] Number of milkings in the previous 7 days for which an Italian ryegrass paddock was used.
[3] Rate (kg/ha) last applied to paddocks grazed within the last 7 days.
[4] Entered into the PCA as a discrete variable, 1 = Jersey, 0 = other breeds.

reduction of variance in the lower-order PC's. As a precaution the same test was applied to a 12 x 16 matrix of random numbers, with the chi-square in this case being not significant. It was therefore concluded that there were indeed statistically significant patterns of association between farm system components, across the sample of farmers surveyed. Four of the 12 available PC's, explaining 77% of the overall variation in the data set are presented (Table 2).

PC1 indicates that farmers who reported higher MS production per cow per day were also likely to have reported higher per cow daily feed intake, lower urea use, and that they did not have Jersey cows. The latter is not necessarily a demerit, since Jersey cows tend to be smaller. Milk from farms in this category was likely to have lower urea levels (Table 2). The pattern described in this PC is consistent with that obtained from an earlier Waikato study of 33 farms (Moller *et al.* 1993), where a negative association between milk or blood urea and daily per cow production was also sufficiently strong to form the first PC in a PCA.

PC2 describes a second, independent pattern of association between farmers reporting high MS/cow/day, and components of their farm systems. In PC2, factors associated with higher daily per cow MS production on 14 September, are: higher per cow daily intake, recent urea application and greater urea use, earlier calving date and higher proportion of the herd calved.

Superficially, PC1 and PC2 appear to conflict, and care must be taken with the interpretation of both PCs. An intuitive explanation that seems to fit the coefficients presented in Table 2 is that PC1 reflects those farms with high urea application and low MS/cow, whereas PC2 reflects farms with high MS/cow through on-farm decisions that raise animal's daily energy intake, though these farms may coincidentally have high urea applications. In support of this, though certainly not definitive, three of the 4 farms with the highest N application rate (80 kg/ha) ranked 14th, 15th, and 16th, out of 16 for MS/cow/day (1.6 – 1.7 kg cow/day). The fourth farmer who reported application of 80 kg/ha N was also the individual farmer with the highest score in PC2. This farmer reported feeding 20 kg DM/cow/day, 2 kg DM/cow/day more than the next-highest respondent, and also has a policy of sourcing high-ME-value supplementary feeds. Despite reporting the highest per cow daily feed intake, and the focus on high-ME-value supplements, this farmer reported only the 3rd highest daily MS production for the survey date (2.1 kg cow/day).

PC3 appears, from examination of individual farm PC scores, to reflect a contrast between two particular farms with high supplement use and one farm with no supplements used, and should not be interpreted further. PC4 reflects an expected link between early start of calving and a higher proportion of the herd calved on 14 September.

Industry relevance

This trial has shown that elevated herbage CP:SSS ratios are associated with urea fertiliser use, and that a modest elevation of herbage CP:SSS ratio from an average of 2.0 to 2.4 translated to an elevated milk urea level in dairy cows (Table 1). In this experiment, apparent FCE was approximately 10% lower with the higher CP:SSS ratio (Table 1), though it is reiterated that paddock factors other than N fertiliser could have contributed to this result. That cow performance differences from the field experiment (Table 1) can be associated with N fertiliser use is supported by the fact that a corresponding association between urea-N fertiliser use and lower MS production was detected in a statistically significant PCA analysis of farm survey data (PC1, Table 2), and in a similar previous survey of 33 farms (Moller *et al.* 1993). The industry will be reassured, however, by the indication in PC2 (Table 2), that urea-N fertiliser effects do also contribute to high MS production, on some farms at least.

In summary, in this experiment, urea-N fertilised paddocks displayed a 25% increase in herbage growth, and a 3.5% increase in NIR-determined herbage ME, but these advantages were partly offset by a 10% decrease in efficiency of conversion of grass to milk. Overall the data indicate the positive effects of urea fertiliser in increasing feed supply that outweigh any loss in animal FCE. High MS/cow on our sample farms was more strongly associated with factors other than low pasture CP:SSS, and not necessarily incompatible with N fertiliser use.

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