
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Exploring the relationships between plant chemical composition and nitrogen partitioning in lactating dairy cows fed ryegrass-based diets

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ABSTRACT

Data from experiments in which cows consumed ryegrass-based diets were used to evaluate the effects of plant constituent concentrations and nutrient ratios on the partitioning of nitrogen (N) secreted into milk and excreted as waste products (urine + faeces). The data set used from 32 publications with 170 treatment means, was derived from studies where freshly-cut or grazed pasture comprised more than 70 % of the total diet on a dry matter basis. The objectives were to identify suitable predictors of N partitioning, both across and within studies, and to examine the relative weight these predictors have on the partitioning of dietary N. Total excretion of N (g/d) and urinary N (g/d) were best predicted by the single predictor crude protein concentration, but better relationships were obtained by adding water soluble carbohydrate (WSC) and neutral detergent fibre concentrations to the models. Although significant across studies, no single plant constituent variable was selected using the meta-analytical approach. The most reliable predictions of N in waste products and urine required measures of N intake for urinary N excretion, or in combination with total OM intake for total N excretion.

Keywords: nitrogen partitioning; efficiency of nitrogen utilisation; ryegrass.

INTRODUCTION

Renewed interest in strategies to improve the efficiency of nitrogen (N) use from ryegrass-based diets has surfaced in synchrony with enhanced environmental concerns and the drive for sustained increases in productivity from pastoral dairy farming. Carbohydrates and protein should be supplied in a ratio that optimises microbial protein synthesis and flow of microbial N to the small intestine, and maximises N capture by the ruminant. These effects have been largely addressed in supplemental or confinement-type feeding systems (Nocek & Russell, 1988), but remain elusive in most grazing situations (Kolver, 2003). Because nutrition from intensive, pastoral dairying is frequently characterised by a shortage of energy and an excess of protein relative to production requirements, a significant proportion of dietary N can be lost from the rumen as ammonia due to the inability of ruminal microorganisms to capture readily-available N released from plant crude protein (Dijkstra *et al.*, 2007). Excess ruminal ammonia will contribute both to increased energy required to metabolise ammonia into urea in the liver, and to increased excretion of N in urine, a major contributor to environmental pollution (Kebreab *et al.*, 2001). Water soluble carbohydrates (WSC) provide the most readily available source of energy for grazing ruminants (Miller *et al.*, 2001). Increasing the supply of WSC and/or a more balanced consumption of crude protein (CP) and WSC have resulted in reduced ammonia loads and enhanced proportions of glucogenic precursors such as propionate, in the rumen (Lee *et al.*, 2003). The former potentially reduces urea production and the need for increased energy associated with this process, as well as potentially reducing urinary urea N excretion. The latter makes available additional energy to the animal as glucose.

The supplementation of fermentable carbohydrates (Carruthers *et al.*, 1997), the provision of diets with a larger proportion of rumen undegradable protein (RUP) (Hoekstra *et al.*, 2007), and more recently, the use of high sugar grasses (Miller *et al.*, 2001; Moorby *et al.*, 2006) have proven effective as means of improving N utilisation in grazing ruminants. Other successful strategies include reduced N input from N fertilisation (Peyraud *et al.*, 1997), prolonged regrowth periods (Delagarde *et al.*, 2000) and afternoon versus morning grazing (Cosgrove *et al.*, 2007b). The suitability of some of these strategies, however, remains to be evaluated under practical grazing conditions. Information on the interactions between forage constituents affecting N utilisation by rumen microbes and the ruminant is still under scrutiny. Hence, reliable predictions of the responses to increased WSC require a better understanding of how additional WSC interrelate with other chemical constituents of the forage, and how these associations are reflected in improved N utilisation. A data set derived from lactation performance and N partitioning in lactating dairy cows was used to examine the effects of selected plant constituents on N intake and N utilisation in lactating dairy cows. The objectives were to identify suitable predictors of N partitioning, and to examine the relative weight these predictors have on the partitioning of dietary N into milk and waste products namely urine and faeces.

MATERIALS AND METHODS

Data from experiments in which cows consumed ryegrass-based diets were used to evaluate the effects of plant constituent concentrations (g/kg dry matter (DM)) and nutrient ratios of ash, WSC, CP, neutral detergent fibre (NDF), non-fibre carbohydrate (NFC), WSC/CP, NFC/CP, on the partitioning of N into milk and waste products of urine and faeces. Partitioning of N was considered in terms of daily amounts secreted in milk (g/d) and excreted in urine plus faeces (g/d); as well as the efficiency of N utilisation (g N/g of N intake). The data set, which used 32 publications with 170 treatment means, was derived from studies that used freshly cut or grazed pasture that comprised a minimum of 70 % of the total diet (DM basis) (Table 1). With the exception of one study (Reis & Combs, 2000) which was 50% grass and 50% legumes, all pastures were predominantly grass-based pastures. Most were perennial ryegrass (*Lolium perenne*)-based pastures, except for the studies by Bargo *et al.* (2002) which was smooth bromegrass (*Bromus inermis*), Berzaghi *et al.* (1996) which was tall fescue (*Lolium arundinaceum*) and Ruiz *et al.* (2001) which was orchardgrass (*Dactylis glomerata*). Due to the limited number of published studies on forage breeding effects that have examined the use of high sugar grasses and N partitioning (n = 65 treatment means), a second group of studies was added to the model comprising the effects of differential N fertilisation, regrowth periods, seasonality, or a combination of the above as environmental effects (n = 105 treatment means), and coded separately (Table 2). Additional codes included stage of lactation divided as early lactation (55.6 ± 24.7 (standard deviation) days in milk, mid lactation, 135.7 ± 24.8 days in milk and late lactation, 220.2 ± 16.1 days in milk, amount fed (*ad libitum* versus. restricted) and form fed (grazing versus. zero-grazing). Significance of these codes were examined using mixed models procedures of SAS version 9.1.3 (SAS, 2005). A reduced subset from the original data set was used to examine the impact of the same explanatory variables on the partitioning of N into urine (uN) and faecal N (fN).

TABLE 1: Authors, objectives, and pasture type and form fed from lactating dairy cows fed pasture-based diets included in the data set (n = 170 treatment means).

Authors	Aim[1]	Pasture Type[2]	Pasture Form fed[3]
Astigarraga *et al.* (2002)	E	PR	Gr
Bargo *et al.* (2002)	E	SB	Gr
Berzaghi *et al.* (1996)	E	TF	Gr
Carruthers and Neil (1997)	E	PR	SF
Carruthers *et al.* (1997)	E	PR	SF
Cosgrove *et al.* (2007a)	B	PR	Gr
De Visser *et al.* (1997)	E	PR	SF
Kennedy *et al.* (2007)	E	PR	Gr
Mackle *et al.* (1996)	E	PR	SF
McEvoy *et al.* (2008)	E	PR	Gr
Miller *et al.* (2000)	B	PR	SF
Miller *et al.* (2001a)	B	PR	SF
Miller *et al.* (2001b)	B	PR	Gr
Moorby *et al.* (2006)	B	PR	SF
Mulligan *et al.* (2004)	E	PR	Gr
O'Donovan *et al.* (2004)	E	PR	Gr
O'Donovan and Delaby (2005)	E	PR	Gr
O'Mara *et al.* (1997)	E	PR	SF
Pacheco *et al.* (2003)	E	PR	SF
Peyraud *et al.* (1997)	E	PR	SF
D.H. Rearte, Unpublished data	E	PR	SF
Reis and Combs (2000)	E	MS	Gr
Ruiz *et al.* (2001)	E	OG	SF
Tas *et al.* (2005)	B	PR	SF
Tas *et al.* (2006b)	B	PR	Gr
Taweel *et al.* (2005)	B	PR	SF
Taweel *et al.* (2006)	B	PR	Gr
Valk (1994)	E	PR	SF
Valk *et al.* (2000)	E	PR	SF
Van Vuuren *et al.* (1992)	E	PR	SF
Van Vuuren *et al.* (1993a)	E	PR	SF
Van Vuuren *et al.* (1993b)	E	PR	SF

[1]Aim: B = Forage breeding, E = Environmental management effect.
[2]Type: MS = Mixed sward, OG = Orchardgrass (*Dactylis glomerata*), PR = Perennial ryegrass (*Lolium perenne*), SB = Smooth brome grass (*Bromus inermis* L.), TF Tall fescue (*Lolium arundinaceum*, (Shreb.)).
[3]Form fed: Gr = Grazing, SF = Stall fed.

Some of the data were incomplete and required calculations or assumptions to derive the required data. Non-fibre carbohydrate (NFC) was calculated as NFC (g/kg DM) = Organic matter (OM) – (CP + NDF + fat), assuming 40 g/kg DM as fat (Tas *et al.*, 2006a). Milk yields were expressed in terms of kg/d and fat- and protein-corrected milk (FCPM) (kg/d) = ((0.337 + (0.116 x (Milk fat, %)) + (0.06 x (Milk protein, %)) x (Milk yield, kg/d))). N intake was calculated from grass dry matter intake (DMI) and supplemental DMI and corresponding N (CP/6.25) concentrations. The efficiency of N partitioning was calculated as N in milk (CP yield/6.38) or waste products (urine + faeces) as a proportion of N intake, assuming no N retention in the body, unless stated otherwise. Regression (across-study analysis) and mixed models (within-study analysis) were performed using the REG and MIXED procedures of SAS version 9.1.3 (SAS, 2002), respectively. Across studies, multiple regression models were explored using the stepwise selection method, constrained to P ≤0.05 for variables to enter and remain in the model (Table 3). Additional variables,

TABLE 2: Number of treatment means, mean ± standard deviation, and range of plant components and selected animal performance and N partitioning variables in lactating dairy cows fed pasture-based diets. DM = Dry matter, WSC = Water soluble carbohydrate, CP = Crude protein, NDF = Neutral detergent fibre, NFC = Non-fibre carbohydrate, OM = Organic matter, FPCM = Fat and protein corrected milk, N = Nitrogen.

Variable	Number of treatment means	Mean	Minimum	Maximum
Full data set				
Ash (g/kg DM)	170	100.7 ± 15.7	55.0	124.1
WSC (g/kg DM)	170	152.3 ± 44.3	30.2	271.0
CP (g/kg DM)	170	189.1 ± 38.0	91.7	283.0
NDF (g/kg DM)	170	451.7 ± 49.0	331.0	589.0
NFC (g/kg DM)[1]	170	218.8 ± 52.7	41.9	330.0
WSC/CP	170	0.86 ± 0.41	0.13	2.34
NFC/CP	170	1.24 ± 0.53	0.19	3.31
Pasture content (% of diet)	170	89.8 ± 8.6	71.8	100.0
Grass DM intake (kg/d)	170	15.5 ± 2.0	10.2	21.2
Total DM intake (kg/d)	170	17.3 ± 2.4	10.3	21.5
Total digestible OM intake (kg/d)	170	12.7 ± 2.2	7.6	17.2
Milk yield (kg/d)	153	22.7 ± 4.7	9.6	32.7
FPCM (kg/d)[2]	147	22.9 ± 4.1	11.2	33.0
Milk fat yield (g/d)	147	919.3 ± 154.7	499.2	1,272.0
Milk protein yield (g/d)	153	734.6 ± 143.0	358.0	1,001.3
N intake (g/d)	170	515.9 ± 105.1	263.0	736.6
Milk N (g/d)	153	115.1 ± 21.9	56.0	156.9
Milk N (g/g N intake)	153	0.23 ± 0.05	0.10	0.37
N in urine + faeces (g/d)	153	397.8 ± 102.7	159.0	629.6
N in urine + faeces (g/g N intake)	153	0.76 ± 0.06	0.55	0.90
Reduced data set				
N intake (g/d)	54	459.8 ± 112.6	263.0	726.0
Milk N (g/d)	54	108.0 ± 23.8	56.0	152.0
Milk N (g/g N intake)	54	0.24 ± 0.06	0.15	0.37
Urinary N (g/d)	54	214.3 ± 87.8	64.0	437.0
Urinary N (g/g N intake)	54	0.45 ± 0.11	0.18	0.62
Faecal N (g/d)	54	122.1 ± 22.9	82.0	193.0
Faecal N (g/g N intake)	54	0.28 ± 0.06	0.21	0.44

[1]Non-fibre carbohydrate = OM – (CP + NDF + fat) assuming 40 g fat/kg DM.
[2]Fat- and protein-corrected milk = (((0.337 + (0.116 x (milk fat, %)) + (0.06 x (milk protein, %)) x (milk yield, kg/d)))) (Taweel *et al.*, 2006).

other than plant constituents, were included after exploring and identifying variables that most likely affect N partitioning in lactating dairy cows. Collinearity diagnostics included the use of tolerance and variance inflation factors (Neter *et al.*, 1990). Nonlinear relationships were also evaluated but no additional variation was explained by nonlinear analysis compared with those obtained in a linear fashion. To avoid extrapolating general response equations from single experiments (across-study analysis), response equations were examined by combining results from different experiments using statistical meta-analysis methods (St-Pierre, 2001), where intercept and slope for each study were considered random effects (within-study analysis) (Table 4). The significance for these regressions indicated the consistency of the relationship within studies, whereas the relationships established across studies (simple and multiple regressions) assess the predictive ability of plant constituents and other explanatory variables on N partitioning and utilisation efficiency for similar, upcoming scenarios (Kolver & Veth, 2002).

RESULTS

The pasture-based diets offered to cows in these studies were of high quality (79.9% OM digestibility, 73.5% CP digestibility, 79.6% NDF digestibility). The mean pasture content was 90% of the DM intake (Table 2). Total N intake (Mean ± Standard deviation) (516 ± 105 g/d) was partitioned into N in milk (115 ± 22 g/d) and N into waste products (398 ± 103 g/d). For the reduced data set that included uN and fN, N intake (460 ± 113 g/d) was partitioned into milk N (108 ± 24 g/d), uN (214 ± 88 g/d) and fN (122 ± 23 g/d). Excretion of N in urine was 63.7% of total N excreted as waste

TABLE 3: Selected across-study relationships between N partitioning variables (Y) and plant constituents (X) for lactating cows fed pasture-based diets[1]. The R^2 value is adjusted for the number of independent variables in the model. RMSE = Square root of the mean squared errors as a measure of the difference between values predicted by the model and the values actually observed as a single measure of predictive power. N = Nitrogen, NDF = Neutral detergent fibre (g/kg DM), CP = Crude protein (g/kg DM), WSC = Water soluble carbohydrate (g/kg DM).

Best single predictor and multiple regression equations[2]	Adjusted R^2	RMSE
Full data set		
Milk N (g/d)		
NDF	0.14	20.34
$190.8_{(15.3)} - 0.166_{(0.03)}$NDF	0.14	20.34
Milk N (g N/g N intake)		
CP	0.59	0.032
$0.359_{(0.017)} - 0.0009_{(0.00006)}$CP $+ 0.0003_{(0.00005)}$WSC	0.65	0.029
N excreted in urine + faeces (g/d)		
CP	0.65	61.12
$428.3_{(86.4)} + 1.67_{(0.14)}$CP $- 0.588_{(0.13)}$WSC $- 0.569_{(0.12)}$NDF	0.70	56.58
N excreted in urine + faeces (g N/g N intake)		
CP	0.39	0.049
$0.87_{(0.07)} + 0.0007_{(0.0001)}$CP $- 0.0006_{(0.0001)}$WSC $- 0.0003_{(0.00009)}$NDF	0.51	0.044
Reduced data set		
Urinary N (g/d)		
CP	0.56	58.09
$443.3_{(99.3)} + 1.137_{(0.17)}$ CP $- 0.680_{(0.15)}$ NDF $- 0.638_{(0.14)}$WSC	0.71	47.25
Urinary N (g N/g N intake)		
Ash	0.51	0.080
$0.039_{(0.06)} + 0.0033_{(0.0005)}$ash $+ 0.001_{(0.0002)}$CP $- 0.0005_{(0.0001)}$WSC	0.73	0.059
Faecal N (g/d)		
NDF	0.15	21.03
$-339.7_{(162.2)} + 0.657_{(0.25)}$CP $+ 0.534_{(0.16)}$NDF $+ 0.434_{(0.21)}$NFC	0.27	19.51
Faecal N (g N/g N intake)		
CP	0.44	0.048
$0.173_{(0.06)} - 0.001_{(0.0001)}$CP $+ 0.0006_{(0.0001)}$NDF	0.60	0.041

[1]Explanatory variables selected according to adjusted coefficients of determination (adjusted R^2) and the RMSE. Model = $b + m_ix_i + ... + m_px_p$ for multiple regression analysis, where i = single predictor, p = last predictor included.
[2]Selected single (1st row) and multiple (2nd row) predictors (plant constituents only): intercept and slope $_{(SE)}$. Single (P <0.001) and multiple (P <0.05) predictors selected were significant.

products. Efficiencies of N utilisation were similar for both data sets (P >0.2; 0.23 versus 0.24 g milk N/g of N intake from the full and reduced data sets, respectively). Stage of lactation had a significant impact (P <0.001) on the partitioning of N into milk and the efficiency of N utilisation, both milk and waste product N as a proportion of N intake for the full data set. Stage of lactation had a significant effect, indicating that the linear regression was different for at least one stage of lactation: mean N in milk was 122, 115, and 78 g N/d for the early, mid, and late lactating cows, respectively (efficiencies of N utilisation of 0.23, 0.24, and 0.17 g milk N/g N intake).

Across studies, a weak, but significant (P <0.001), quadratic relationship between CP and WSC was obtained: WSC, g/kg DM = 452.2 (± SE 53.9) − 3.01 (±0.59) CP + 0.0072 (±0.0016) CP^2 (adj. R^2 = 0.18; root mean square error (RMSE) = 40.2). Within studies, the overall relationship was best described (P <0.001) by the linear equation WSC = 304.4 (± 30.01) – 0.844 (± 0.167) CP. The meta-analysis also showed a significant relationship (P <0.001) between WSC and NDF concentration: WSC = 561.7 (± SE 72.4) – 0.863 (± 0.157) NDF. Among the plant constituents considered across studies, a measure of plant fibre concentration (NDF) was the best single predictor of milk N (P <0.001, no other predictor was selected using multiple regression analysis) whereas CP was the best one in terms of milk N efficiency (P <0.001; Table 3). Excretion of N in waste products (g/d and g/g N intake), urinary N (g/d), and faecal N (g/g N intake) were best predicted by the single predictor CP (P <0.001). However, better relationships (increased adjusted R^2 and reduced RMSE values)

TABLE 4. Selected within-study relationships including equations include intercept and slope (Standard error) between N partitioning variables (Y) and plant constituent and other selected dietary variables (X) for lactating cows fed pasture-based diets. N = Nitrogen, MPY = Milk protein yield (g/d), FPCM = Fat- and protein-corrected milk (kg/d), NDF = Neutral detergent fibre (g/kg DM), tOMI = Total organic matter intake (kg/d), Ni = Nitrogen intake (g/d), Ni/dOMI = Nitrogen intake (g/d)/Digestible organic intake (kg/d), CPD = Crude protein digestibility (%).

Equation[1]	P value			AIC[1]
	Intercept	Slopes		
Full data set				
Milk N (g/d)				
$4.81_{(2.36)} + 0.15_{(0.004)}$MPY	0.05	<0.001	-	785
$0.91_{(6.35)} + 4.95_{(0.29)}$FPCM	0.89	<0.001	-	868
$34.5_{(14.2)} + 4.72_{(0.31)}$FPCM - $0.059_{(0.02)}$NDF	0.02	<0.001	0.009	869
$105.7_{(36.5)} + 5.86_{(1.58)}$tOMI - $0.17_{(0.056)}$NDF	0.007	<0.001	0.006	1219
N excreted in urine + faeces (g/d)				
$42.7_{(31.8)} + 0.91_{(0.02)}$Ni - $8.05_{(2.10)}$tOMI	0.19	<0.001	0.001	1271
$-76.8_{(19.5)} + 0.62_{(0.18)}$CP + $0.67_{(0.75)}$Ni	<0.001	0.002	<0.001	1272
$28.0_{(22.6)} - 0.38_{(0.08)}$WSC + $0.81_{(0.03)}$Ni	0.22	<0.001	<0.001	1312
$-57.4_{(16.7)} + 0.87_{(0.04)}$Ni	0.002	<0.001	-	1389
Reduced data set				
Urinary N (g/d)				
$-0.91_{(2.49)} + 0.19_{(0.015)}$Ni	0.72	<0.001	-	186
$-2.18_{(24.4)} + 0.14_{(0.038)}$MPY	0.93	0.008	-	282
$19.8_{(33.1)} + 1.75_{(0.70)}$Ni/dOMI	0.56	0.04	-	301
Faecal N (g/d)				
$-0.19_{(0.17)} + 0.0085_{(0.0022)}$CPD	0.26	0.002	-	112
$0.20_{(0.08)} + 0.0005_{(0.00016)}$Ni	0.02	0.007	-	114
$0.70_{(0.11)} - 0.019_{(0.0077)}$tOMI	<0.001	0.03	-	119

[1]Within each response variable, regression equations were ordered by Akaike's information criterion (AIC) where smaller to larger; smaller is better as a measure of the goodness of fit.

were obtained by adding either WSC as well as NDF (N in waste products, g/d and g/g N intake; uN, g/d), or NDF alone (fN, g/g N intake). Ash concentration (g/kg DM) was the best single predictor of uN, g/g N intake, followed closely by CP. Faecal N (g/d) was best predicted by NDF as a single predictor, however, the adjusted R^2 value only amounted to 0.15, and was increased to 0.27 when CP, NDF, and NFC were included in the model. The use of ratios (WCP to CP and NFC to CP) resulted in slight or no improvements towards attaining a better fit, hence, the results reported in Table 3 only include single plant constituents. Within studies, milk protein yield and FCPM were the best single predictors of milk N, followed by FCPM and total OM intake (tOMI), each in combination with NDF, whereas N intake was the best single predictor of waste product N (Table 4). In a similar fashion, urinary N was best predicted by N intake, whereas, expectedly, CP digestibility was the best single predictor of faecal N.

DISCUSSION

Mean estimates of pasture nutrient composition fell within the ranges typically reported for high quality cool-season grasses of 18 to 24% DM, 18 to 25% CP and 40 to 50% NDF (Waghorn *et al.*, 2007). The chemical composition of the herbage in cool-season pastures is influenced by a number of genetic factors such as components of the pasture mix and relative abundance, species and cultivar, and environmental factors such as weather conditions, soil type, source and availability of soil nutrients, fertilisation and grazing or harvesting management. Typically, a negative correlation is reported between CP and WSC concentrations in forage. Herein the correlation between CP and WSC was –0.287. In agreement with our findings, Tas (2006) described a quadratic relationship between WSC and CP for perennial ryegrass cultivars after four years of data collection in The Netherlands. The relationship reported by Tas (2006) suggested that the reduction in WSC concentration was greater with incremental amounts of CP at low CP concentrations, but further increases in CP concentration beyond 200 g/kg DM had a minor effect on WSC concentration. Similarly, in the current study increases in CP above about 190 g/kg DM became largely unresponsive to WSC concentration, but R^2 and RMSE values were lesser and greater, respectively. This indicates a poorer fit compared with that of the equation reported by Tas (2006). Unlike data reported by Tas (2006), the significant relationship between WSC and NDF concentration was most probably associated with the inclusion of studies that addressed forage breeding as well as environmental and management effects on N partitioning. Environmental effects such as increases in N fertilisation typically result in greater CP concentration in grasses, usually at the expense of WSC, with a smaller impact on structural carbohydrates (Peyraud & Astigarraga, 1998). Although increased regrowth periods result in shifts towards increased structural carbohydrates such as NDF and ADF, often at the expense of CP, genetic improvements in WSC accumulation frequently appear at the expense of NDF concentrations (Miller *et al.*, 2001; Moorby *et al.*, 2006). A WSC to CP ratio of 0.75 has been proposed as a base target in pastoral systems attempting to enhance N utilisation, above which the efficiency of N utilisation is increased linearly with incremental units of the ratio (Edwards *et al.*, 2007; Pacheco *et al.*, 2007). The WSC to CP ratio in the current study of 0.86 ± 0.41 corresponded with a N utilisation efficiency of 0.23 g milk N/g N intake, in close agreement with previous findings where there was a WSC to CP ratio of 0.90 associated with a similar N utilisation efficiency (Pacheco *et al.,* 2007).

The current N partitioning data set is comparable to a number of data sets published elsewhere (Castillo *et al.*, 2000; Nennich *et al.*, 2005; Wilkerson *et al.*, 1997; Yan *et al.*, 2006). The current study reported N excretions of 0.76 g N/g N intake from cows producing a mean milk yield of 22.7 kg/d. The N excretion value is greater than that reported by Castillo *et al.* (2000) (0.72 g N/g N intake), Wilkerson *et al.* (1997) (0.73 for cows producing 14 kg milk/d and 0.69 for cows producing 29 kg/d), and Yan *et al.* (2006) (0.72 for cows producing 21.4 kg milk/d). The lesser efficiency reported herein is most likely associated with the feeding systems used. Those described above were mostly confinement-type systems, with a greater proportion and variety of supplemental sources offered to lactating dairy cows, and most likely balanced for final diet energy and CP concentration, and rumen-degradable protein (RDP) vs. RUP.

Expectedly, when predicting milk N (g/d), plant constituents were replaced primarily by lactation performance indicators of milk protein yield and FPCM, and to a lesser degree by total OMI. The weak but significant negative across-study relationship between NDF and milk N (g/d) was most likely related to the close association between plant structural components and intake. Plant cell wall components have been the most consistent plant fraction related to intake, an important driver of animal performance (Van Soest, 1994), and both NDF concentration and total OMI were suitable within-study predictors of milk N (g/d). The efficiency of N utilisation increased with decreasing N intakes. The weak, but significant, positive across-study relationship between NDF and faecal N (g/d) is most likely related to the NDF-intake association mentioned above. Within studies, plant constituents were replaced with CP digestibility, N intake, and total OMI. All other predictors tested were poor predictors of faecal N excretion (g/d).

The most suitable, and overall similar, relationships across studies were observed between the response variables N excretion (g/d) and urinary N excretion (g/d) and plant constituent concentrations. Across studies, CP was the single best predictor of both variables, but a more precise fit included both WSC and NDF. The selection of all three plant constituents has biological implications. Prediction of urinary N was improved by adding total DMI to the model (adjusted R^2 = 0.77; RMSE = 42.3; *cf.* with values presented in Table 3). By regressing individual plant constituents with total DMI, the slopes of these relationships, partial regression coefficients, indicated the change in the mean response per unit increase in a certain explanatory variable when the other one was held constant, that is the effects of incremental CP, when total DMI was held constant. Coefficients of +1.63, –0.86, and –0.39 were obtained for CP, WSC, and NDF, respectively. In a similar fashion, but applying these concepts to milk protein yield, the corresponding coefficients were +0.40, +0.57, and –0.79. Pasture-based diets often provide a greater proportion of NDF that is readily fermentable compared with that provided by confinement-type diets (Steg *et al.*, 1994). This may also contribute in explaining why the use of perennial ryegrasses with greater WSC relative to standard varieties have shown improved efficiency of N utilisation in some (Miller et al., 2001; Moorby et al., 2006) but not all studies (Tas, 2006). A reliable method to manipulate the partitioning of carbon between soluble versus structural carbohydrates within the grazed plant may be required to improve the N partitioning in grazing ruminants. Conversely, the consistent inverse relationship between plant cell wall and intake may be behind the negative coefficients for milk protein synthesis and urinary N excretion. The relative weight that plant constituent concentrations have on both outputs are also most likely a consequence of high CP concentrations in grasses leading to high N intakes and the supply of metabolisable protein in excess of what is required for milk protein yield; the excess of protein is primarily metabolised and excreted via urine (Kolver & Muller, 1998). This is in agreement both with increased milk protein concentration and yield achieved from supplementing pasture-based diets with energy sources and with inconsistencies in lactation performance when RDP is replaced with RUP sources (Bargo *et al.*, 2003).

Results from the current analysis highlight the complex nature of N partitioning and the low efficiency of N utilisation in pasture-based dairy systems. Excretions of N in waste products and in urine (g/d) were best predicted by the single predictor CP, but better relationships were obtained when WSC and NDF were added to the models. The most reliable predictions of N in waste products and urine required measures of N intake for urinary N excretion, or in combination with total OM intake for total N excretion.

ACKNOWLEDGEMENTS

This project was funded by the Foundation for Research, Science and Technology and Pastoral 21. The authors thank Dr. Emma Bermingham for her contributions in statistical design and Dr. Dongwen Luo for his contributions in statistical analysis.

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