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Evaluation of the Cornell Net Carbohydrate and Protein System for dairy cows fed pasture-based diets

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ABSTRACT

This study evaluated the Cornell Net Carbohydrate and Protein System (CNCPS) for dairy cattle consuming pasture-based diets. Data was obtained from four grazing, and four indoor pasture feeding experiments (23 dietary treatments) with dairy cattle in New Zealand and the United States. ME requirements for maintenance were adjusted to account for grazing activity. The model gave a reasonably good prediction of changes in condition score (R^2=0.79, slope not significantly different from 1), energy balance (R^2=0.76, slope not significantly different from 1), blood urea nitrogen (BUN) (R^2=0.91, underprediction bias of 0.4%), microbial nitrogen flow (R^2=0.83, slope not significantly different from 1), and milk production. The model underpredicted DM intake (R^2=0.80, 11% bias), and overpredicted ruminal pH (R^2=0.47, 1.8% bias). These results indicate that the CNCPS can be used to make realistic predictions of ruminal fermentation and performance of dairy cows offered good quality pasture.

Keywords: Simulation model; nutrition; dairy cow; pasture.

INTRODUCTION

Animal research is increasingly using simulation models to set priorities for research, and to aid in the design and interpretation of experiments. One such simulation model is the Cornell Net Carbohydrate and Protein System (CNCPS; Fox et al., 1992). The prediction of cattle performance by the CNCPS has been validated over a wide range of cattle, feed, management, and environmental conditions (Fox *et al.,* 1992, 1995; Sniffen et al., 1992). Commercial use of this model in North America, and the proposal to integrate the CNCPS with NRC recommendations (D. G. Fox, pers. comm.), reflects the wide acceptance of this model for research as well as on-farm application. The CNCPS incorporates both high and low levels of aggregation, and uses several physiological and metabolic submodels to predict animal performance on any given diet. These submodels include intake, ruminal fermentation, intestinal digestion, absorption, excretion, heat production, and nutrient partitioning.

The use of the CNCPS in a pastoral dairying system has not been reported. Recent, and sometimes conflicting, reports of the likely constraints of pasture for high per cow milksolids production (Edwards and Parker, 1994; Mackle and Bryant, 1994; Moller *et al.,* 1993; Ulyatt and Waghorn, 1993) would suggest a need for such a nutritional model. The CNCPS could potentially be used to identify the qualitative and quantitative constraints of pasture over a wide range of scenarios, and subsequently be used to develop appropriate strategies to achieve these high levels of production.

Before the model can be used in this way, the predictive ability of the CNCPS must be tested for pasture diets. Consequently, this paper uses current research data to evaluate the ability of the CNCPS to predict the performance of dairy cows consuming a pasture-based diet.

MATERIALS AND METHODS

Model-predicted and observed animal responses were determined from eight studies from New Zealand and the United States, representing 23 different pasture-based diets (Table 1). Studies selected were those that had sufficiently described dry matter intake (DM intake), liveweight, condition score (CS), days in milk, milk production and composition, and feed composition. Pasture offered in these experiments was of high quality (crude protein, CP: 18.8-33.1%; neutral detergent fibre, NDF: 39.4-55.2%; dry matter digestibility, DMD: 63.6-81.4%). The United States studies were based on grazing (Holden, 1993; Holden *et al.,* 1994a; 1994b; 1995; Hongerholt, 1995), or feeding pasture indoors (Kolver *et al.,* 1995) to lactating and non lactating dairy cows at various stages of lactation. Pasture consisted primarily of orchardgrass (Dactylis glomerata L.). The New Zealand studies (Carruthers *et al.,* 1996; Mackle *et al.,* 1996; Kolver, unpublished) used ryegrass (Lolium perenne L.) and white clover (Trifolium repens L.) pasture which was fed to housed cows in early lactation. Inclusion of supplements ranged from 0% to nearly 50% of DM intake.

Diet composition was typically reported in terms of DM, CP, soluble CP, soluble non protein nitrogen (NPN), degradable intake protein (DIP), NDF, and nonstructural carbohydrate (NSC). Ruminal rates of carbohydrate fermentation, protein degradation, digesta passage rate, and amino acid composition of the undegraded feed protein were obtained from the CNCPS orchardgrass library file. In this evaluation, four library parameters were modified to aid in the prediction of the energy content of high quality pasture. These changes resulted in energy contents of 11.4-11.6 MJME/kg DM being predicted for the ryegrass/white clover pastures, and 9.5-10.9 MJME/kg DM being predicted for the orchardgrass based pastures; these being in good agreement with the observed energy (MJME/kg DM)

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values.

Estimates of the effective NDF (eNDF) content (Sniffen *et al.,* 1992) of high quality orchardgrass and ryegrass/white clover pastures used in this evaluation were 50% and 40%, respectively. These eNDF values were estimates based on comparisons with eNDF of other feeds (Sniffen *et al.,* 1992), and on the predicted passage rate and energy content of the diet.

The higher digestibility of the ryegrass/white clover pastures compared to the orchardgrass pastures (mean of experiments; 80% and 69% DMD, respectively) indicated that a greater rate of fibre digestion (the B2 carbohydrate fraction) was required. A rate of 13%/h was used, which is somewhat higher than the NDF degradation rate of 9%/h reported by Hoffman *et al.,* (1993). Orchardgrass pastures with a DMD greater than 70% were assigned a B2 carbohydrate digestion rate of 8%/h (Hoffman *et al.,* 1993). CNCPS file values were used for orchardgrass pastures with a DMD less than 70%. In addition, the lignin content as a percent of NDF of the ryegrass/white clover pastures was reduced from 7.7% (orchardgrass) to 6% (Waghorn and Barry, 1987).

The B2 protein digestion rate used for ryegrass/white clover (22%/h) and for orchardgrass pasture with a DMD greater than 70% (18%/d) were based on the data of Hoffman *et al.,* (1993). The B2 protein is defined as feed protein with an intermediate rate of degradation (this value does not include rapidly soluble, slowly degrading or unavailable protein; Sniffen *et al.,* 1992). The CNCPS file value (11%/h) was used for lower quality orchardgrass pastures (DMD less than 70%).

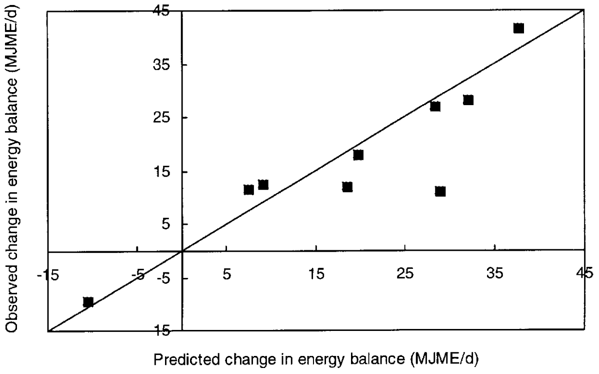
Statistical analysis

The statistical procedures followed those described by Fox *et al.,* (1992). The model-predicted animal response was regressed on the corresponding observed response to determine the variation accounted for (adjusted R2), precision (Sy.x), and bias (regression coefficient when the intercept is 0) of the relationship. Regression analysis was performed with Minitab version 10.0. Deviation in the regression slope from 1 (P<0.05) was assessed using a two-tailed t-test

RESULTS AND DISCUSSION

Changes in model-predicted and observed condition score were used to predict the overall energy status of dairy cows in mid-late lactation (Figure 1), according to the condition score tables presented by Fox *et al.,* (1992). The model explained 76% of the variation in the observed changes in energy balance. The slope of the regression line did not differ significantly from 1. Analysis included an adjustment for grazing activity (NRC, 1989) and for efficiency of ME used for maintenance in late lactation (Roseler, 1994). These adjustments allowed the model to account for more of the variation in observed condition score change; 79% with adjustment vs. 53% without adjustment. The ability of the model to account for a significant proportion of the observed variation in energy status indicates that the model is relatively robust, as the energy status of an animal is the result of many diet, animal, and environmental interactions.

FIGURE 1: Relationship between observed and predicted change in energy balance (Y = 1.04 + 0.85X, SE = 7.05, R^2 = 0.76, slope not significantly different from 1)[1].

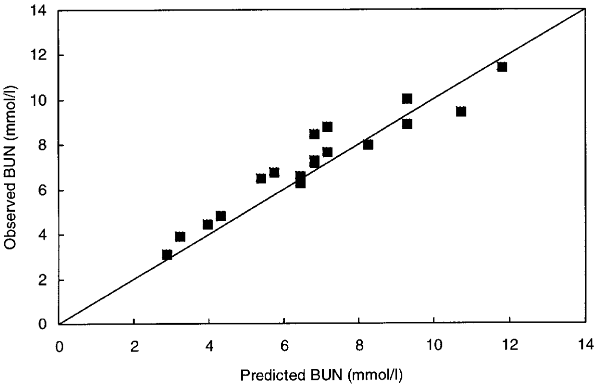


[1]From the data of Holden (1993), Holden *et al.,* (1994), and Holden *et al.,* (1995).

Analysis of BUN concentrations can give some indication of the ability of the model to predict nitrogen status of the animal. Figure 2 depicts a close relationship between predicted and observed BUN concentrations. The model accounted for 91% of the variation in observed BUN concentrations. The slope of the regression line was significantly different from 1, although the underprediction bias was small (0.4%). This comparison includes cows in New Zealand fed ryegrass/white clover pasture either as a sole diet or with supplements, and cows in the United States consuming orchardgrass diets with significant levels of concentrate feeding. As such, the model appears to adequately account for excess dietary nitrogen across a range of dairy cow sizes, milk production levels, and feeding regimes.

Observed DM intake is used by the model to predict

FIGURE 2: Relationship between observed and predicted blood urea nitrogen (BUN) (Y = 1.44 + 0.85X, SE = 0.66, R^2 = 0.91, underprediction bias of 0.4%)[1].

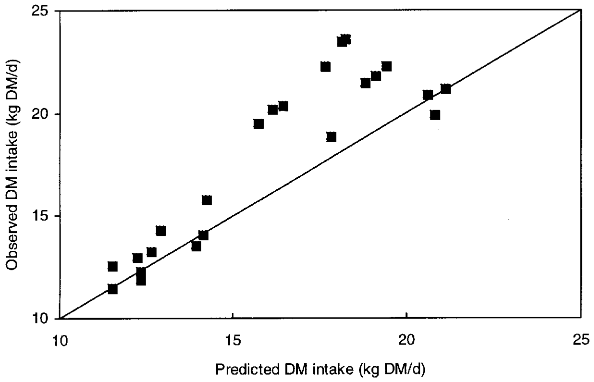


[1]From the data of Carruthers *et al.,* (1996), Holden (1993), Holden *et al.,* (1995), Hongerholt (1995), Kolver *et al.,* (1995), Kolver (unpublished), Mackle *et al.,* (1996).

energy and protein status of the animal. The model also predicts intake, which can be useful when the actual intake is difficult to determine. Results in Figure 3 indicate that 80% of the variation in observed DM intake could be explained by the model. DM intake was underpredicted with an 11% bias, which resulted in the slope of the regression line being significantly different from 1. The analysis of 28 studies with lactating dairy cows by Fox *et al.* (1992), also indicated that the CNCPS underpredicted with a bias of 5%, and that most of this bias occurred at intakes greater than 20 kg DM/d. The standard error of the Y estimate in the study of Fox *et al.,* (1992) (1.5 kg DM/d) is similar to the standard error indicated in Figure 3 (1.9 kg DM/d). It appears that the model underpredicts DM intake of lactating dairy cows, and that this bias is consistent across feeding systems.

An important feature of the model is the ability to determine nutrients that are limiting milk production. The model does not partition nutrients between milk production and body reserves; instead, the condition score loss or gain required to meet the observed milk production is calculated when the animal is in negative or positive energy balance. Mean milk production of dairy cows in 6 studies (17 diets) that where in either negative or positive energy balance is presented in Table 2. Statistically, there was no difference between observed and predicted values for milk production or condition score change, within each energy balance category. The model predicted a milk production of 27.5 kg/d for the positive energy balance group, and indicated the condition score required to be gained (0.94 % of 1 CS/d) in order to meet the observed milk production level (26.5 kg/d). The statistical and numerical agreement between the observed and predicted rate of condition score gain, therefore indicates a reasonable prediction of milk production. Prediction of milk production of cows in negative energy balance was similarly close to observed levels.

FIGURE 3: Relationship between observed and predicted DM intake (Y = -1.20 + 1.19X, SE = 1.92, R^2 = 0.80, underprediction bias of 11%)[1].



[1]From the data of Carruthers *et al.,* (1996), Holden (1993), Holden *et al.,* (1994a), Holden *et al.,* (1994b), Holden *et al.,* (1995), Hongerholt (1995), Kolver *et al.,* (1995), Kolver (unpublished), Mackle *et al.,* (1996).

TABLE 1: Characteristics of experiments used in model evaluation.

	n	Mean	Range	SE
No. of experiments	8	-	-	-
No. of different diets	23	-	-	-
Liveweight, kg	-	506	403-611	80.9
DM intake, kg/d	-	17.2	11.2-23.6	4.47
Milk production, kg/d	-	24.6	15.3-39.7	7.38

TABLE 2: Observed vs. predicted milk production and change in condition score (CS) (mean ± SE) for cows in positive and negative energy balance[1].

	Milk production (kg/d)[2]		Change in 1 CS (%/d)[3]	
	Observed	Predicted	Observed	Predicted
Positive energy balance	26.5 + 5.4	27.5 + 4.7	0.73 + 0.52	0.94 + 0.44
Negative energy balance	23.2 + 6.9	21.9 + 7.0	-0.68 + 0.7	-0.38 + 0.35

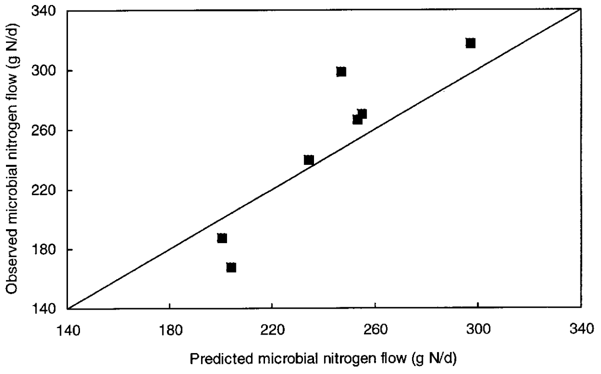
[1] From the data of Carruthers *et al.,* (1996), Holden (1993), Holden *et al.,* (1995), Kolver *et al.,* (1995), Kolver (unpublished).

[2] Predicted milk production does not adjust for predicted changes in condition score.

[3] US condition score scale 1-5 (Wildman *et al.,* 1982). For this evaluation 1 NZ condition score (1-10 scale) (Macdonald and Macmillan, 1993) was estimated to be twice one US condition score within the US condition score range 2-3.

Figure 4 depicts model-predicted and observed microbial nitrogen flow to the duodenum. The model accounted for 83% of the variation in observed microbial nitrogen flow, and the slope of the regression line was not significantly different from 1. Validation of the model by Russell *et al.,* (1992) reported a similar R2 of 0.88. Although the data set used to derive Figure 4 is limited, it includes both unsupplemented and supplemented ryegrass/white clover diets, at restricted and ad lib levels of feeding. In this paper, the same ruminal degradation rate of pasture carbohydrate and protein have been used for all the ryegrass/white clover diets. The prediction of microbial nitrogen

FIGURE 4: Relationship between observed and predicted microbial nitrogen flow to the duodenum (Y = -123 + 1.55X, SE = 22.63, R^2 = 0.83, slope not significantly different from 1)[1].



[1]From the data of Carruthers *et al.,* (1996), and Mackle *et al.,* (1996).

flow can be expected to be further improved by fine-tuning these degradation rates for the individual components. In this way, present animal performance can be used to estimate and validate critical inputs (Russell *et al.*, 1992).

Using the data reported by Carruthers et al. (1996), Kolver et al. (1995), Kolver (unpublished), and Mackle et al. (1996), ruminal pH was predicted. The model accounted for 47% of the variation in observed pH, with the negative intercept (-4.64) and the slope (1.74) indicating that the model overpredicted observed pH at low pH levels. When the regression line was forced through 0, the model overpredicted with a bias of 1.8%. The CNCPS assumes that nutrient intake is in steady-state (Sniffen *et al.*, 1992). The data set used in the prediction of pH is derived from confined cows fed pasture twice a day. It is possible that diurnal fluctuation in ruminal fermentation associated with twice daily feeding is responsible for the discrepancy between model-predicted and observed pH. Alternatively, the eNDF value of this type of pasture may be something lower than the 40% used in this analysis, although further reduction in eNDF results in the prediction of pasture energy values somewhat less than observed values.

CONCLUSION

These results indicate that the CNCPS model can give a realistic prediction of ME and protein supply, and of subsequent milk production of dairy cows fed a pasture-based diet. Further improvement could be achieved by defining the role of eNDF, the rate of degradation of the pasture carbohydrate fractions, and the frequency of pasture feeding on ruminal fermentation. Future modeling and in vivo research could use this model to help identify and overcome those nutritional characteristics of pasture which constrain high milksolids production.

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