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Empirical assessment of the CNCPS model to predict performance of dairy cows fed pasture with silage supplements.

A.V. CHAVES[1, 2], I.M BROOKES[2], J.L. BURKE[2], G.C. WAGHORN[1, 2] AND S.L.WOODWARD[3]

[1]AgResearch Grasslands, Private Bag 11008, Palmerston North

ABSTRACT

The goal of this work was to determine the accuracy and utility of the Cornell Net Carbohydrate and Protein System (CNCPS) model to predict milk production from diets based on pasture and forage supplements. Data were obtained from studies in which pasture was complemented with contrasting silages including maize, pasture, sulla, lotus and forage mixtures, comprising 30-40% of dry matter intake (DMI). Twelve diets were used in this evaluation. DMI, live weight (LW), days in milk, and diet composition were determined during the trials and used as inputs in the model. Across all diets, a significant ($P<0.01$) relationship existed between predicted and actual values for DMI ($r^2=0.63$), milk yield ($r^2=0.64$) and LW change ($r^2=0.57$) but there were still large unexplained sources of variation and the slopes of the regression lines were significantly ($P<0.01$) different than 1. No significant mean bias was observed for any of the variables, but the slope of residual differences against predicted values was significantly different from zero ($P<0.01$ for milk yield and LW change; $P<0.06$ for DMI). The results indicate a satisfactory prediction of milk production when cows are neither gaining nor losing weight, but that a systematic bias exists probably because of the CNCPS model's failure to account for nutrient partitioning.

Keywords: CNCPS; dairy cows; diet formulation; modelling; nutrients requirement.

INTRODUCTION

The Cornell Net Carbohydrate and Protein System (CNCPS) is a computer model that predicts dairy cow performance on the basis of feed composition, digestion and nutrient supply. The model requires feed ingredients and more specific data on feed components, rates of rumen degradation and an understanding of the efficiency with which absorbed protein and energy is used. Nutrient inputs are compared with estimated requirements for target milk production, and differences in metabolisable energy (ME) are accounted for as liveweight change. The CNCPS model has been developed for various purposes: exploring the principles of ruminant nutrition, ration evaluation, research planning and understanding ruminal kinetics, rather than simply predicting cattle requirements (Fox *et al.*, 1992; Russell *et al.*, 1992; Sniffen *et al.*, 1992).

There are numerous statistical tools available for evaluating the accuracy and precision of models that predict animal performance. These tools include plots of predicted and observed values (Kolver *et al.*, 1996; Kolver *et al.*, 1998), mean squares prediction error analysis (Bateman *et al.*, 2001; Kohn *et al.* 1998; Smoler *et al.*, 1998), and analysis of residuals (predictions from the models minus actual data) against predictions (Kohn *et al.*, 1998; St-Pierre, 2003).

The aim of this study was to determine the utility and accuracy of the CNCPS model to predict milk production based on pasture and silage supplements, using data obtained from *in sacco* incubations and two dairy cow trials conducted in mid-lactation when pasture was complemented with contrasting silages.

MATERIALS AND METHODS

Cow trials used for model evaluation

The data against which the model predictions were tested were derived from twelve rations (treatments means) in two trials carried out in Hamilton (Chaves *et al.*, 2002; Woodward *et al.*, 2002). Each trial comprised 60 Friesian cows (10/treatment) averaging 528 ± 17 kg live weight (LW); 17 ± 2.4 kg milk/day; 156 ± 15 days in milk. Cows grazed ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pasture complemented by contrasting silage supplements contributing 30-40% of DMI. Each trial was four weeks in duration and silage supplements included maize (M; *Zea mays*), sulla (S; *Hedysarum coronarium*), pasture, lotus (LC; *Lotus corniculatus*) and mixtures of M and S.

Cows in each treatment group were given a new break of pasture (up to 70% of total diet) once daily using electric fences; silages were fed from mobile troughs, so intakes could be recorded. Water was always available.

Pasture intakes by each treatment group were estimated by using a rising-plate meter to estimate pre- and post-grazing herbage mass. This was done three times per week for each treatment group. Weekly pasture cuts (pre- and post-grazing of representative pasture) were made to ground level for calibrating the rising-plate meter and determining chemical composition (e.g.: protein, fibre, ME, minerals) of material on offer by NIRS analyses (Corson *et al.*, 1999).

Digestion kinetic data (rates and extent of digestion) were obtained from *in sacco* incubations (Burke *et al.*, 2000; Chaves *et al.*, 2002). Both kinetic data and chemical composition of feeds were entered into the feed library of the model. Neutral and acid detergent fibre insoluble nitrogen required by the model to estimate the amount of slowly degraded and unavailable protein in each feed, ruminal rates of soluble carbohydrate and protein fermentation, and amino acid composition (Tedeschi *et al.*, 2000) for pasture and silages for all treatments were obtained from the CNCPS library files.

CNCPS evaluation

In this study, principal outputs assessed from the

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[2]Massey University, Private Bag 11222, Palmerston North.
[3]Dexcel Ltd, Private Bag 3221, Hamilton.

model were: DMI, milk production predicted from the first limiting of either metabolisable energy (ME) or metabolisable protein (MP), LW change and dietary ME concentration.

Animal characteristics (animal type, age, breed type, days pregnant and since calving, number of lactation), inputted milk production, LW, management practices, environmental aspects and feed composition (e.g.: protein, fibre, lignin, starch, mineral concentrations) from the twelve rations were used as inputs in the CNCPS model. The data were used to examine the model predictions for trial means (four weeks each trial) over all treatments.

Model evaluation and statistical analysis

The model used in this evaluation was CNCPS Version 5.00.20 (updated August 2002). Model evaluation should include a rigorous statistical component and in this study three different methods have been used to evaluate the CNCPS predictions.

Method 1: Linear regression. Most often, predictions are evaluated by regressing actual values versus predicted responses.

Method 2: Measures of deviation. Alternatively, Kohn *et al.* (1998) showed that a measure of how well model predictions fit observed data can be calculated as the root mean square prediction error (RMSPE):

RMSPE $\sqrt{[\sum(\text{predicted} - \text{actual})^2/\text{number of observations}]}$

This term is the square root of the estimate of variance of actual values about the predicted values. The RMSPE is comprised of two terms that identify systematic problems with models: the mean bias and the residual error. The mean bias represents the average inaccuracy of model predictions across all data and the residual error is the remaining error in model prediction after accounting for the mean bias. The residual error is also referred to as prediction error excluding mean bias.

Mean bias = $\sum$ (predicted – actual)/number of observations

Residual error =$\sqrt{[\sum \text{RMSPE}^2 - (\text{mean bias})^2]}$

As a summary measure of the relative degree of deviation, either mean bias or RMSPE can be used (Mayer & Butler, 1993).

Regressions of the residuals (predicted values minus actual values) against the predicted values were used to identify whether or not the magnitude of the bias increases or decreases with the magnitude of the predicted values (Draper & Smith, 1981).

Method 3: Systematic bias. This method of evaluating model prediction is based on milk yield predicted from the first limiting of either ME or MP available. The difference between milk predicted from allowable ME or MP and actual milk (residual) was regressed against dietary variables affecting milk production. These included dry matter intake (DMI), LW change and dietary composition (crude protein (CP); fibre (NDF); ME; and fermentable carbohydrates).

RESULTS

Mean predictions (Pr) of cow performance, based on model simulations from dietary composition, DMI, and LW, compared with actual (A) values are shown in Table 1. The model under-predicted mean DMI (13.69 vs. actual 15.07 kg DMI/cow/day) and mean dietary ME (9.98 vs. actual 10.5 MJ ME/kg DM) and over-predicted milk production based on ME or MP content of the diet (15.08 vs. actual 14.85 kg milk). ME was first limiting for cows fed restricted and unrestricted pasture allowance and pasture with lotus silage, whereas MP limited milk production by cows given pasture with maize silage. Predicted milk yields by the CNCPS model from diets with sulla or pasture silages was limited to a similar extent by ME and MP.

TABLE 1: º Actual (A) and predicted (Pr) values, regressions, correlations, bias and errors for dry matter intake (DMI), milk production, live weight (LW) change (all kg/cow/day) and metabolisable energy (ME) dietary concentration (MJ ME/kg feed DM). Predictions for milk production are based on the first limiting factor: allowable metabolisable energy (ME) or allowable metabolisable protein (MP) for all diets.

				Method 1 (Linear regression)				**Method 2 (Measures of deviation)**				
		Mean value	**SD** [a]	**A versus Pr**	**r^2**	**MSE** [b]	**P^1**	**Mean**[c] **bias**	**Residual error** [d]	**RMSPE** [e]	**r^2**	**P^2**
DMI	A	15.07	2.2									
	Pr	13.69		$y = 2.04x - 12.79$	0.63	1.98	< 0.01	-1.40^{ns}	1.60	2.10	0.31	0.06
Milk	A	14.85	1.6									
production	Pr	15.08		$y = 10.14 + 0.31x$	0.64	0.96	< 0.01	0.23^{ns}	2.75	2.76	0.89	< 0.01
LW change	A	0.01	0.2									
	Pr	0.15		$y = 0.28x - 0.03$	0.57	0.02	< 0.01	0.14^{ns}	0.39	0.42	0.90	< 0.01
Diet ME	A	10.5	0.3									
concentration	Pr	9.98		$y = 12.15 - 0.16x$	0.03	0.62	ns	-0.54^{ns}	10.52	10.53	0.58	< 0.01

[a] Standard deviation.

[b] Mean square error (estimate of variance).

[c] Mean predicted minus mean actual. t-test $_{(5\%, n-2)}$ for mean bias different from zero.

[d] Model prediction error excluding that due to the mean bias.

[e] Root mean square prediction error.

P^1: P value of F-statistic for slope = 1.

P^2: P value of F-statistic for slope = 0.

ns = not significant.

Method 1 – Linear regression of actual against predicted values

Predicted values were significantly (P<0.01) correlated with actual values for DMI (r^2=0.63), milk production (r^2=0.64), and LW change (r^2=0.57), but predicted ME concentrations were not correlated with values measured by NIRS (r^2=0.03). However, there were still large unexplained sources of variation (residual variance or mean-square error (MSE)), and the slopes of the regression lines were significantly different than the theoretical value of 1.0 (Table 1). Information provided by simple regression analysis can be ambiguous and lack sensitivity (Mitchell, 1997; St-Pierre, 2001), and, thus, was not able to provide a proper interpretation of these relationships.

Method 2 – Deviation of predicted from actual values

When model predictions were tested using measures of deviation, mean bias was not statistically significant from zero for DMI, milk production, LW change or dietary ME. The residual error terms represent the error in prediction after accounting for the mean bias (Table 1; Figure 1).

The slope of the regression line was significantly (P<0.01) greater than zero for milk production, LW change and ME concentration, and this difference was close to significance (P<0.06) for DMI. This indicates a systematic bias, in which the residual differences increase at higher predicted values. For instance, the model under-predicted milk production of cows fed restricted pasture (PR) and overestimated performance when fed unrestricted pasture (FP) and pasture silage. Predictions of milk production for high pasture allowance and maize silage supplements were inconsistent. The relationships are shown graphically in Figure 1.

Method 3 - Systematic bias

Examination of systematic bias provides an insight into factors responsible for the deviation between predicted and actual values. The regressions of the residuals of milk production (limited by energy or absorbed protein) against actual DMI and LW change are plotted in Figure 2. A significant slope (different from 0) for the regression indicates a systematic bias in the model prediction, and the r^2 represents the fraction of the error (excluding mean bias) that can be explained by the slope bias (Draper & Smith, 1981).

Significant biases for CNCPS predicted milk production were observed for DMI and LW change (Figure 2; r^2=0.85 and 0.67, respectively; P<0.01). The differences between predicted and actual milk production increased by 1.19 kg milk/kg DMI and 11.91 kg milk/kg LW change (slope bias; Figure 2).

FIGURE 1. Residual (predicted – actual) versus predicted values for A: dry matter intake (DMI), B: milk production and C: live weight (LW) change using CNCPS. (◇) = individual treatments. Line (---) indicates mean bias. PR = restricted pasture, FP = unrestricted pasture. P value of F-statistic for slope = 0.

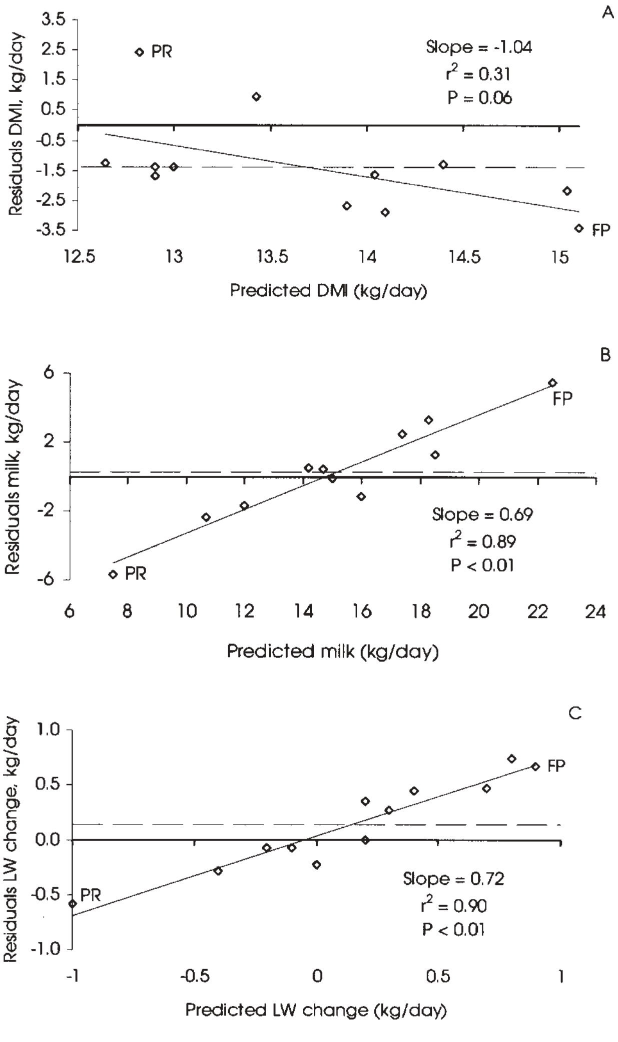
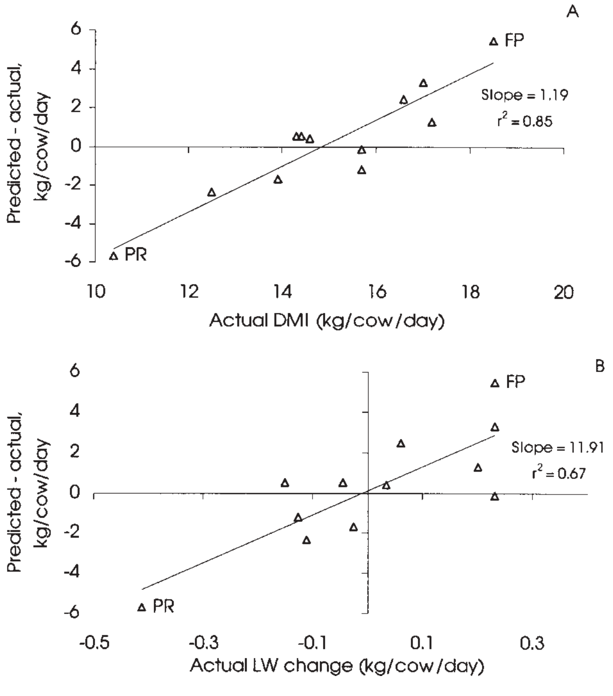


FIGURE 2. Milk production (kg/cow/day) predicted by the CNCPS model minus actual milk production (Y axis) versus A: actual dry matter intake (DMI) and B: liveweight (LW) change. PR = restricted pasture, FP = unrestricted pasture.



DISCUSSION

The CNCPS model is designed to predict nutrient supply, in terms of ME and MP, from rumen parameters, and recent data on digestion kinetics of fresh and conserved forages have been used as model inputs in this study. Because nutrient supply is difficult to measure in grazing animals, validation relies on a comparison of animal performance predicted from these estimates against that observed in practice.

The lack of a significant mean bias for any of the parameters examined would suggest very good model prediction. However, the analyses carried out showed that accurate prediction of mean values does not necessarily demonstrate good predictability for individual diets (residual error is large; Table 1), and may limit the utility of the CNCPS model for fresh forages. These concerns are illustrated by predictions of milk production.

The mean actual and predicted milk yields were similar (14.85 and 15.08 kg/day) and the regression explained 64% of the variance across the diets. However, a regression equation with a slope of +0.31 (theoretical value = 1.0) and an intercept of 10.14, (theoretical value = 0.0) has little biological meaning. When residuals were regressed against predicted milk production (Method 2), there was no significant mean bias, but residual differences increased for values above and below mean predicted milk production.

Further analysis (Method 3) demonstrated a systematic bias in predicted milk production with changes in DMI and LW change. Good predictions were obtained for a small number of diets, whilst a substantial under-prediction was evident for cows fed restricted quantities of pasture, and a substantial over-prediction occurred with high DMI. This approach assumes that actual DMI and LW change are measured without errors and attention should be taken to avoid flawed conclusions because it is difficult to obtain accurate measurements of both parameters, especially with outdoor grazing.

The inability of the model to predict milk production either side of the mean is a cause for concern (Table 1). The CNCPS model uses inputted milk production as a driving variable to calculate the ME, MP and other nutrients required to achieve that level of production. In this evaluation, the inputted milk production values were those observed for cows fed the experimental diets (Chaves *et al.*, 2002; Woodward *et al.*, 2002). The nutrients available to meet the requirements for these milk yields are estimated from DMI and predicted dietary ME or MP concentrations, less the amounts required for maintenance and pregnancy. The predicted milk production is determined by the first limiting nutrient (ME or MP). If ME supply is insufficient to meet the inputted milk yield, then the extent of liveweight loss required to fill the ME deficit is calculated. However, the extent of liveweight loss that will actually occur is not predicted.

When the supply of available nutrients is insufficient to meet the specified milk yield inputted (for example by feeding a restricted pasture allowance), the model does not allow extra nutrients to be partitioned between body reserves and milk production.

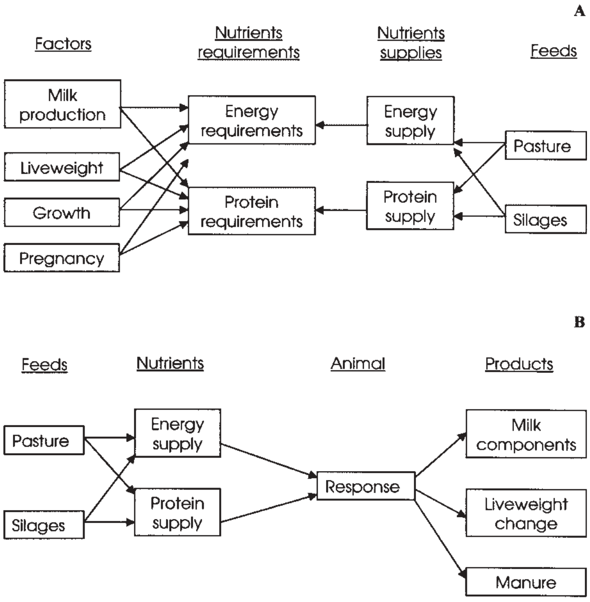


FIGURE 3. Schematic representation of the CNCPS requirement-based system (A) and B: production response system. Adapted from St-Pierre & Thraen (1999).

This inability of CNCPS to account for partitioning, accounts for the systematic bias in performance identified by the analysis. Model predictions of milk production are much closer when cows do not gain or lose LW (Figure 1C).

St-Pierre & Thraen (1999) highlighted that the CNCPS is a requirement system, not a response system. CNCPS will calculate the nutrients required to support a given level of milk production and composition (Figure 3A). Milk production is an input and is used to estimate DMI but constraints of digesta clearance from the rumen and the ability of cows to convert body reserves into milk may account for poor DMI prediction. In addition, the production responses (e.g.: milk production, live weight change; Figure 3B) is a function of feeding value (nutritive value of feeds x intake), animal response (genetic merit), environment and management factors and interactions between those. Nutrient requirement systems (e.g.: CNCPS) are unable to predict responses because they cannot account for partitioning of nutrients between the various productive processes (e.g.: milk production; LW change).

In conclusion, by using a more rigorous statistical analysis than simple linear regression of actual versus predicted values, systematic biases were shown to exist. Milk production was either over- or under-estimated, depending on the level of feeding. This probably results from model inability to account for partitioning of nutrients between milk production and liveweight change.

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