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Development and evaluation of equations in the Cornell Net Carbohydrate and Protein System to predict nitrogen excretion in lactating dairy cows

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ABSTRACT

Nitrogen excretion is of particular concern on dairy farms, not only because of its effects on water quality, but also because of the subsequent release of gases such as ammonia to the atmosphere. To manage N excretion, accurate estimates of urinary N (UN) and fecal N (FN) are needed. On commercial farms, directly measuring UN and FN is impractical, meaning that quantification must be based on predictions rather than measured data. The purpose of this study was to use a statistical approach to develop equations and evaluate the Cornell Net Carbohydrate and Protein System's (CNCPS) ability to predict N excretion in lactating dairy cows, and to compare CNCPS predictions to other equations in the literature. Urinary N was overpredicted by the CNCPS due to inconsistencies in N accounting within the model that partitioned more N to feces than urine, although predicted total N excretion was reasonable. Data to refine model predictions were compiled from published studies (n = 32) that reported total collection N balance results. Considerable care was taken to ensure the data included in the development data set (n = 104) accounted for >90% of the N intake (NI). Unaccounted N for the compiled data set was 1.47 ± 4.60% (mean ± SD). The results showed that FN predictions could be improved by using a modification of a previously published equation: FN (g/d) = [{[NI (g/kg of organic matter) × (1 − 0.842)] + 4.3} × organic matter intake (kg/d)] × 1.20, which, when evaluated against the compiled N balance data, had a squared coefficient of determination based on a mean study effect $\left(R^2_{MP}\right)$ of 0.73, concurrent correlation coefficient (CCC) of 0.83 and a root mean square error (RMSE) of 10.38 g/d. Urinary N is calculated in the CNCPS as the difference between NI and other N excretion and losses. Incorporating the more accurate FN prediction into the current CNCPS framework and correcting an internal calculation error considerably improved UN predictions (RMSE = 12.73 g/d, R^2_{MP} = 0.86, CCC = 0.90). The changes to FN and UN translated into an improved prediction of total manure N excretion (RMSE = 12.42 g/d, R^2_{MP} = 0.96, CCC = 0.97) and allows nutritionists and farm advisors to evaluate these factors during the ration formulation process.

Key words: nitrogen excretion, dairy cow, modeling

INTRODUCTION

Dairy producers in the United States are currently under pressure to use production systems that are more cost efficient and have a smaller environmental footprint. Central to this debate is the management of nutrients, such as N and P, due to their key roles in ground- and surface-water pollution (Dou et al., 1998). Nitrogen is of particular concern on farms, not only because of its effects on water quality, but also because of the subsequent release of gases such as ammonia and nitrous oxide to the atmosphere (NRC, 2003). To date, no direct cost has been associated with the amount of N excreted by farms in North America. However, certain European countries (Belgium, Denmark, France, and the Netherlands) tax farmers based on the amount of N excreted on the farm (OECD, 2004). This type of regulation could occur in the United States and could shift the nutritional formulation and management goals on many farms (NRC, 2003).

To comply with future environmental standards, robust methods that quantify N outputs from dairy farms will be required (NRC, 2003). Directly measuring urinary N (**UN**) and fecal N (**FN**) on commercial farms is impractical, meaning that quantification must be based on predicted rather than measured data. Equations are available that predict manure N excretion based on diet characteristics, milk yield, and MUN (Nennich et al., 2005; Nennich et al., 2006). These equations are useful and are approved for use in estimating manure N excretion in establishing manure management plans.

To be more practical, it would be appropriate to have equations that were integrated into ration evaluation and balancing software so that the nutritionist could be made aware of the excretion predictions of particular diets under farm-specific conditions. The Cornell

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Net Carbohydrate and Protein System (**CNCPS**) is a mathematical model designed to evaluate the nutrient requirements of cattle over a wide range of environmental, dietary, management, and production situations (Fox et al., 2004; Tylutki et al., 2008). The CNCPS also includes estimates of N and P excretion, enabling integration with whole-farm nutrient management plans (Fox et al., 2004; Tylutki et al., 2008). An important constraint imposed during the development of the CNCPS was that the inputs used must be routinely available on most farms so the CNCPS has broad relevance for both research purposes and commercial farms. Currently, the model predicts total manure N (**MN**) adequately but the ratio of UN to FN is underpredicted (Fox et al., 2004). For the CNCPS to be used effectively in nutrient management plans, more accurate estimates of UN and FN are required. The purpose of this study was to evaluate the current CNCPS predictions for UN and FN excretion and compare these to other relevant equations from the literature and developed updated equations to be used in the model.

MATERIALS AND METHODS

Data Set Development

Data for this evaluation were compiled from published studies that completed total collection N balance trials on lactating dairy cows. Observed study data for N intake (**NI**), milk N, FN, and UN were compared with CNCPS predictions using version CNCPS 6.1. Studies were selected that presented the dietary and animal information required to run a simulation in the CNCPS. This included a description of housing conditions, milk yield, milk fat, milk protein, BW, stage of lactation, and stage of pregnancy. If stage of pregnancy and stage of lactation were not given, CNCPS default values were used. Required dietary information included DMI and a description and chemical analysis of the ration fed for each treatment. Studies often provided chemical analyses for forages and the complete ration, but not for the concentrates. If concentrate composition was not given (72% of studies), ingredients were selected from the CNCPS feed library, and used without alteration. If an ingredient was not present in the CNCPS feed library, its composition was obtained from the NRC (2001). Some studies presented a chemical analysis of the complete ration, but not the forages (28% of studies); in this case, forage CP and NDF concentrations were back calculated from the complete ration composition presented by the study, and concentrate compositions from the CNCPS feed library. The calculated CP and NDF concentrations were then compared with corresponding forages in the CNCPS feed library and the closest match was selected. Minor adjustments were subsequently made to CP and NDF to get an exact match. When making adjustments, consideration was given to the level of variation expected from different types of feeds and the proportion of each feed in the ration. For example, forages generally made up >50% of the ration and were generally less homogenous than concentrate ingredients. Therefore, small adjustments to forage composition within the expected range of variation were more effective and considered more realistic than large changes to specific concentrate ingredients. For example, in the study of Weiss and Wyatt (2006) information was presented on the chemical composition of forages and total diet, but not concentrates. Using feed library values for the concentrates, and the values provided for the forages, CP in the DP (dual-purpose) silage, high CP treatment was calculated to be 16.9% DM. However, the study reports 17.1% CP. To reconcile the calculated and reported values, corn silage in the ration was shifted from 8.06% CP to 8.36% CP. To achieve the same change using corn grain, which was the next largest dietary component, CP would have had to be changed from 9% DM to 10% DM. We deemed it more likely that the corn silage was 8.36% CP than the corn grain 10% CP.

Our objective was to evaluate the CNCPS and alternative models for their ability to partition MN into FN and UN. To avoid confounding the prediction of FN and UN, it was important that NI and milk N reported by the study were consistent with that accounted for by the model. Conflicting data on milk yield and milk protein composition compared with milk N output were presented in some studies. Nitrogen balance trials were often run in conjunction with larger production trials. Cows might have decreased milk yield when housed in metabolism stalls for the N balance component of the study compared with freestall or tie-stall housing in the production trial. Therefore, when milk yield for the N balance period was not presented, milk yield was adjusted to ensure milk N output reported by the study was the same as that accounted for by the model. For example, in the study of Haig et al. (2002), milk yield and milk CP was reported as 25.3 kg/d and 3.3%, respectively, for the low treatment. Using these data, milk N is calculated to be 131 g/d; however, the study reports 120 g/d. Back calculating milk yield from milk N using 6.38 as the correction factor yields 23.2 kg/d. To ensure the amount of intake N partitioned to milk in the model was consistent with that reported by the study, the back calculated milk yield was used.

Nitrogen that could not be accounted for in the milk, feces, or urine was generally reported by the study as retained N. Retained N was sometimes unrealistically high, suggesting losses during the collection or analysis