

Evaluation of National Research Council and Cornell Net Carbohydrate and Protein Systems for Predicting Requirements of Holstein Heifers

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ABSTRACT

This experiment evaluated the effects of prepubertal energy intake and dietary protein source on average daily gain of Holstein heifers. Holstein heifers (n = 273) were assigned to one of three dietary energy treatments that were designed to achieve average daily gains of 0.6, 0.8, and 1.0 kg/d from 90 to 320 kg of body weight. Within each energy treatment, heifers were assigned to diets that were supplemented with animal and plant proteins or plant protein and urea. Diets were formulated using the Cornell Net Carbohydrate and Protein System. Actual mean daily gains by heifers on each energy treatment were 0.68, 0.83, and 0.94 kg/d and were not affected by protein source. Undegradable intake protein was predicted by the Cornell Net Carbohydrate and Protein System to be adequate to support the observed daily gain that was allowed by the amount of energy in the diet and was 13 to 25% lower than the recommendations for undegradable intake protein by the National Research Council. These results suggested that requirements for undegradable intake protein may be met at concentrations that are less than 35% of the dietary crude protein. Energy equations from the National Research Council and Cornell Net Carbohydrate and Protein System were evaluated and accounted for 87 and 86% of the variation in body weight gain that was allowed by the amount of energy in the diet with biases of -7.7 and -5.7%, respectively. The Cornell Net Carbohydrate and Protein System has the primary advantage of improved accuracy in the prediction of nutrient requirements in each unique production situation.

(**Key words:** growth, heifers, protein, energy)

Abbreviation key: ADG = average daily gain, AP = animal protein, BCS = body condition score, CNCPS

= Cornell Net Carbohydrate and Protein System, **DIP** = degradable intake protein, **LWG** = live weight gain, **MCP** = microbial CP, **ME** = metabolizable energy, **MP** = metabolizable protein, **MSPE** = mean square prediction error, **NDIN** = neutral detergent insoluble nitrogen, **NE_G** = net energy for gain, **NE_M** = net energy for maintenance, **PP** = plant protein, **PUN** = plasma urea nitrogen, **UIP** = undegradable intake protein.

INTRODUCTION

The nutrient requirements for dairy heifers as described by the NRC (31) were designed for large breed heifers to achieve average daily gains (**ADG**) of 0.6 to 0.8 kg and to reach acceptable postcalving BW while avoiding over-conditioning during the prepubertal growth period. The upper limit of ADG (0.8 kg) should ensure an age at first calving of 24 mo, assuming that no environmental stresses exist (19, 31). Recent studies (11, 21) have suggested that, if adequate protein is provided relative to energy, ADG may be greater than 0.8 kg during the prepubertal phase without overconditioning. For heifers from 3 to 6 mo of age, Kertz et al. (21) suggested that the dietary DM should contain 17% CP to achieve an ADG of up to 1 kg without overconditioning. Those researchers (21) further suggested that, for heifers that are 7 to 12 mo of age, the dietary DM should be composed of 15% CP to meet tissue requirements for ADG of 0.93 to 1 kg.

Current NRC (31) recommendations require that concentrations of undegradable intake protein (**UIP**) in the diet be greater than 50% of the CP intake for heifers that weigh less than 250 kg, which implies that light weight heifers produce considerably less microbial protein than is needed to meet tissue protein requirements. However, growth performance and feed efficiency have not been consistently improved in young, light heifers when supplemental UIP has been fed (4, 9, 26, 27, 33, 40).

The objective of this study was to evaluate the effects of supplemental UIP on body growth rates and

Received January 22, 1997.

Accepted August 25, 1997.

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the body condition of Holstein heifers at three ADG allowed by the amount of energy in the diet (energy allowable ADG) (0.6, 0.8 and 1.0 kg). An additional objective was to use the growth and feed composition data to evaluate the NRC (31) and Cornell Net Carbohydrate and Protein System (CNCPS) (3, 16, 34, 36, 41, 44) for predicting energy allowable ADG and the ADG allowed by the amount of protein in the diet (protein allowable ADG).

MATERIALS AND METHODS

Assignment

Holstein heifers ($n = 273$) from the Cornell dairy herd were assigned to six treatments over a period of 17 mo. The heifers were housed in hutches until they were 6 to 8 wk of age. After weaning, the heifers were moved to a barn with an open front and pens to house 8 to 10 heifers. At the end of a 3-wk postweaning transition period, heifers were assigned, using a restricted randomization scheme, to one of three target categories of ADG, 0.6, 0.8, and 1.0 kg, and to two protein sources [all plant protein (PP) plus urea or plant and animal protein (AP)] within each category. In an effort to ensure that forage source and environmental factors did not vary by protein treatment, the next available pen of heifers was assigned to the same energy level and the alternative protein source until all treatment groups were formed.

Diets

A transition diet, delivered as a total mixed diet, was fed for ad libitum intake for approximately 3 wk after the calves were moved from outdoor hutches. The postweaning diet (20% CP) consisted of 30% chopped hay (mostly grass), 20% corn silage, and 50% concentrate mix (DM basis) (Hewitt Bros., Locke, NY). The concentrate mix fed during the transition period contained minerals and vitamins to meet NRC (31) requirements at a minimum intake of 1.4 kg/d. Sodium decoquinatate (Deccox[®]; Rhône-Poulenc Inc., Atlanta, GA) was included in all concentrate mixes as a coccidiostat to supply 0.5 mg/kg of BW. Fresh water and trace mineral salt blocks were continuously available.

Diets were formulated for energy and protein requirements using the CNCPS (Tables 1, 2, and 3). Minerals were balanced using NRC (31) requirements. The ruminal submodel of the CNCPS was used to compute ruminal ammonia and peptide requirements to optimize microbial growth. The following protocol was used to formulate diets with the CNCPS: 1) the chemical composition of feed ingredients was entered into the feed library; 2) heifer, management, and environmental inputs were defined; 3) ADG allowed by metabolizable energy (ME) in the diet (ME allowable gain) was met for the desired growth rate; 4) predictions of available am-

TABLE 1. Chemical composition of dietary ingredients fed to heifers and used in the evaluation of equations from the NRC (32) and the Cornell Net Carbohydrate and Protein System.

	Corn silage		Mixed silage		Mixed hay ¹		Soybean meal		Concentrate mix ¹²		Concentrate mix ²³		Animal protein mix ⁴	
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD
Heifers, no.	40		40		17		36		36		36		30	
DM, %	30.2	5.3	32.7	4.0	84.9	1.0	86.9	1.0	84.2	1.0	83.6	1.3	91.1	0.5
CP, % of DM	8.0	0.8	13.7	3.2	16.9	1.6	53.7	1.2	20.3	1.3	20.7	1.0	80.5	1.1
Soluble CP, % of CP	54.1	5.4	58.8	4.2	28.3	2.5	20.9	4.7	16.8	2.5	17.0	2.7	7.6	0.1
NDF, % of DM	45.2	3.9	59.7	6.4	49.4	6.6	8.1	1.0	17.6	1.6	16.8	2.3	17.6	1.6
NDF Insoluble protein, % of CP	12.2	24.0	19.3	5.1	30.0	8.7	2.9	0.6	11.1	1.9	7.0	1.4	42.3	1.5
ADF Insoluble protein, % of CP	6.6	1.4	9.6	2.1	5.5	0.9	1.4	0.4	2.7	0.4	1.7	0.4	4.2	0.8
Lignin, % of DM	8.6	1.2	17.6	2.7	17.2	2.3	14.2	2.7	9.8	2.1	8.2	1.5	0.0	...
Ether extract, % of DM	3.2	0.3	3.6 ⁵	...	3.0 ⁵	...	1.6	0.2	3.8	0.4	3.4	0.2	4.9	...
Ash, % of DM	3.0	0.4	6.7	1.6	8.2	0.6	6.9	0.3	6.5	0.8	6.3	0.9	13.4	...

¹Mostly grass. Hay was fed for the first 7 wk of treatment before switching to all fermented forages.

²Composition: 22.5% whole ear corn meal, 25% cracked corn, 22.5% rolled oats, 20.75% soybean meal, 7.75% dried molasses, 0.75% sodium chloride, 0.75% dicalcium phosphate, 0.5% limestone, and 33 ppm of sodium decoquinatate.

³Composition: 22.5% whole ear corn meal, 25% cracked corn, 22.5% rolled oats, 16.75% soybean meal, 2.5% blood meal, 7.75% dried molasses, 0.75% sodium chloride, 0.75% dicalcium phosphate, 0.5% limestone, and 33 ppm of sodium decoquinatate.

⁴Composition: 50% blood meal, 25% meat and bone meal, and 25% feather meal.

⁵Forage ether extract values were taken from the Cornell Net Carbohydrate and Protein System (42) feed library.

monia and peptides from the ruminal submodel were supplemented as needed to meet or exceed predicted requirements for maximum microbial growth; 5) metabolizable protein (MP) was formulated at 5 to 10% above predicted requirements for the AP treatments using the AP mix in fixed amounts; and 6) the PP treatment diets were reformulated to be isonitrogenous with the AP diets. Diets were formulated to be 5 to 10% above predicted requirements so that protein was never the most limiting factor for growth.

Diets were fed once daily as a total mixed diet. Although the same dietary ingredients were used for all categories of ADG, differences in ADG were achieved by varying the proportions of ingredients and supplying enough DM to meet the predicted energy requirements for the target growth rate. Dietary composition within energy level and across protein treatments was formulated to be isocaloric and isonitrogenous. The basal diets were formulated with a mixture of corn silage and mixed silage (mostly grass); chopped grass hay replaced grass silage during the postweaning period and for approximately the first 7 wk of the treatment period to ensure adequate DMI.

Target growth rates were established based on the current range in recommended prepubertal ADG that allows for optimal milk yield during the first lactation. Previous work (14, 24) suggested that maximal milk yield during the first lactation was achieved when prepubertal growth was not greater than 0.6 kg/d. An upper limit of 0.8 kg/d was established by the NRC (31) for cattle with larger frames. To determine whether a higher ADG affected subsequent milk yield, a treatment with a target growth rate of 1.0 kg/d was included. At this rate of gain, the appropriate weight for puberty and breeding could be achieved by 12 mo to allow for a potential age at first calving of 21 mo. The treatment period was from an initial BW of 90 kg to a mean ending BW of 320 kg. The 320-kg BW was chosen to terminate the treatments before the heifers entered into the second allometric phase of mammary development, which has been demonstrated in the postpubertal period (38).

The AP in the AP treatments was formulated to be fed at a constant rate over the growth period. For an ADG of 0.6 kg, the rate was 114 g/d; for an ADG of 0.8 kg, the rate was 228 g/d; and for an ADG of 1.0 kg, the rate was 342 g/d. The AP source was 50% blood meal, 25% meat and bone meal, and 25% feather

TABLE 2. Ingredient content of diets fed to heifers at three rates of BW gain. Formulas represent means (percentages of DM) over the treatment period.

	Average daily gain					
	0.6 kg		0.8 kg		1.0 kg	
	Plant protein	Animal protein	Plant protein	Animal protein	Plant protein	Animal protein
Mixed hay ¹	8.4	8.5	12.5	12.0	4.8	6.7
Corn silage	48.4	46.2	40.8	41.0	54.7	53.4
Mixed silage	17.6	18.4	15.8	15.6	15.0	13.6
Soybean meal	4.3	3.5	5.1	2.7	5.7	3.3
Concentrate mix ^{1,2}	...	19.0	...	23.4	...	18.0
Concentrate mix ^{2,3}	19.4	...	24.3	...	18.3	...
Animal protein mix ⁴	...	3.1	...	4.3	...	4.5
Urea ⁵	0.5	...	0.5	...	0.5	...
Vitamins and minerals ⁶	1.4	1.3	1.0	1.0	1.0	1.0

¹Mostly grass. Hay was fed for the first 7 wk of treatment before switching to all fermented forages.

²Composition: 22.5% whole ear corn meal, 25% cracked corn, 22.5% rolled oats, 20.75% soybean meal, 7.75% dried molasses, 0.75% sodium chloride, 0.75% dicalcium phosphate, 0.5% limestone, and 33 ppm of sodium decoquinat.

³Composition: 22.5% whole ear corn meal, 25% cracked corn, 22.5% rolled oats, 16.75% soybean meal, 2.5% blood meal, 7.75% dried molasses, 0.75% sodium chloride, 0.75% dicalcium phosphate, 0.5% limestone, and 33 ppm sodium decoquinat.

⁴Composition: 50% blood meal, 25% meat and bone meal, and 25% feather meal.

⁵Feed grade urea (281% CP equivalent).

⁶Mineral percentage includes minerals in the concentrate mix and the following supplements: 2.2% manganese, 2.2% zinc, 2.2% iron, 0.4% copper, 0.044% iodine, 0.066% cobalt, 0.0132% selenium, 544,465 IU/kg of vitamin A, 272,232 IU/kg of vitamin D₃, and 1815 IU/kg of vitamin E (Pillsbury Co., Minneapolis, MN). A trace mineral salt block was available at all times (97 to 98.5% sodium chloride; Cargill, Inc., Minneapolis, MN).

TABLE 3. Chemical composition of diets fed to heifers at three rates of BW gain.¹

	Average daily gain					
	0.6 kg		0.8 kg		1.0 kg	
	Plant protein	Animal protein	Plant protein	Animal protein	Plant protein	Animal protein
CP, % of DM	15.1	15.6	16.4	16.6	15.4	16.0
Soluble CP, % of CP	41.1	31.7	38.5	28.4	42.2	30.0
NDF, % of DM	38.7	39.8	36.9	38.4	38.5	39.4
NDIN, ² % of DM	11.3	18.6	11.3	19.9	10.2	19.7
NSC, ³ % of DM	38.8	37.7	39.7	38.5	39.2	38.6
Lignin, % of DM	4.4	4.6	4.3	4.4	4.3	4.2
Ether extract, % of DM	3.1	3.3	3.1	3.4	3.1	3.3
Ash, % of DM	6.0	6.5	5.7	6.3	5.2	5.8

¹Mean composition of diets over the treatment period across all replicates.

²Neutral detergent insoluble nitrogen.

³Nonstructural carbohydrates calculated as 100 - (NDF + NDIN) - CP - ether extract - ash.

meal. The ingredients in the AP mix were chosen based on insolubility and the slower rates of ruminal degradation reported for these feeds (13). The composition of the AP mix was determined based on the AA pattern that was supplied by the combination of ingredients relative to the tissue requirements predicted by the CNCPS. The AP sources were fed at a fixed rate to supplement the yield of microbial protein if deficient. As heifers matured, increased feed intake and microbial protein yield diluted the contribution of protein from the UIP source, which allowed evaluation of the requirements for UIP to meet tissue requirements in lighter weight heifers.

Diets were reformulated as needed to maintain target growth rates. The diets formulated for an ADG of 0.6 kg were consumed within 2 h, and the diets formulated for an ADG of 0.8 kg were consumed within 8 h. The diets formulated for an ADG of 1.0 kg were offered for ad libitum intake to ensure 5 to 10%orts based on the intake predictions of the CNCPS. Differences in the time of consumption were a function of the energy density and amount of ration offered to achieve and maintain the desired growth rates.

Feed Analysis

Dietary ingredients were sampled weekly and composited monthly for each treatment for chemical analyses. As a result, feed analysis data used in the CNCPS represented 15 to 36 samples. Feed samples were dried in a 60°C oven for 72 h and ground through a 1-mm screen in a Wiley mill (Arthur H. Thomas, Philadelphia, PA). Ground feed samples were analyzed in duplicate for DM, CP, soluble CP,

NDF, neutral detergent insoluble nitrogen (NDIN), ADF, ADIN, permanganate lignin, and ash. The DM content of the feeds was determined by drying at 105°C in a forced-air oven. The CP (nitrogen × 6.25) was determined by a modified macro-Kjeldahl method (5) that used boric acid in the distillation.

Feeds were analyzed for NDF as described by Van Soest et al. (46). Feeds containing high starch (i.e., corn silage, concentrate mixes) were subjected to 8 M urea for at least 4 h and 150 µl of Termamyl® (Novo Nordisk Bioindustrials, Inc., Danbury, CT), a heat-stable α-amylase, prior to NDF analysis. Because NDF procedures were developed for the plant cell wall, they are not appropriate for use with AP. However, the CNCPS requires the value of NDIN and ADIN to estimate the amount of slowly degraded and unavailable protein in each feed. The AP feed residue that was insoluble in NDF was analyzed for CP. The amount of CP in the residue was used to calculate a functionally equivalent NDF in the AP, assuming the NDF content cannot be greater than the protein content of the ash-corrected residue. Neither urea nor sodium sulfite was used in the samples to be analyzed for NDIN because both of these compounds dissociate proteins. Thus, two sets of samples were analyzed for NDF. Means were calculated for all duplicates and were used as inputs for the CNCPS.

Analysis of ADF was conducted in quadruplicate. Acid detergent residue was analyzed for ADIN and permanganate lignin (47). Insoluble CP was determined by using borate-phosphate buffer according to the method of Krishnamoorthy et al. (22) as modified by Licitra et al. (23) in which the buffer solution contained 10% tertiary butyl alcohol as a wetting agent and 1 ml of 10% sodium azide, which was used

to inhibit potential microbial growth. The CP was determined on the insoluble residue. Ash was determined following a minimum of 6 h in a muffle furnace at 550°C. Ether extract was determined for concentrates and protein feedstuffs (Northeast DHIA, Ithaca, NY), and tabular ether extract values from the CNCPS feed library were used for forages.

Degradability values were predicted from the CNCPS based on the composition of feedstuffs, fermentation rates, and calculated passage rates as described by Chalupa et al. (10). For comparison, undegradability values for the diets were calculated from the NRC (31) tabular values for each feed ingredient and were used in the NRC (31) prediction equations for protein allowable ADG.

Heifer Evaluation

Heifers were weighed, assessed for body condition score [BCS; five-point scale where 1 = thin to 5 = fat (12); increments of 0.25], and measured for hip and wither heights using a vertical standard with a cross-bar and level. Body measurements were taken approximately every 30 d. Growth rate data were used to adjust DMI to achieve the target ADG. Shrunken BW (feed and water restriction for approximately 15 h) were taken at the beginning and end of the treatment periods to minimize the effect of gut fill.

Blood samples were drawn 3 to 6 h after feeding for analysis of plasma urea nitrogen (PUN) to assess the protein status of the heifers. Samples were drawn from the jugular or coccygeal vein into heparinized 10-ml evacuated tubes and placed on ice. The samples were centrifuged at $3000 \times g$; then, the plasma was removed and frozen at -20°C . The PUN was determined by automated procedures using an Auto Analyzer[®] (Technicon Industries, Tarrytown, NJ) with 10-, 20- and 30-mg/dl standards and pooled plasma with a known urea nitrogen content.

CNCPS Evaluation

Observed growth period data were used as inputs for the evaluation of the predicted ME allowable ADG and the ADG allowed by the MP in the diet (MP allowable ADG) of the CNCPS and the NRC (31) systems. The growth data used to examine the model predictions were period means over all treatments and represented the average heifer at approximately 200 kg of BW. The DMI were based on the weighted means of diets fed per treatment period and averaged over the entire growth period. Mean BCS was an input variable in the CNCPS, which was used to adjust maintenance requirements (16).

The CNCPS requires a mature size variable to calculate the energy and protein requirements for growth relative to stage of maturity. The mature body size of the research herd was determined to be 641 ± 57 kg ($\bar{X} \pm \text{SD}$) by weighing all of the cows at third lactation or greater ($n = 107$) on 2 consecutive d after milking.

The CNCPS was developed for all classes of cattle and uses inputs to adjust for different breed effects. After adjustments are made for mature size, the CNCPS calculates a 12% lower requirement for net energy for gain (NE_G) for the diet and a 12% higher requirement for net energy for maintenance (NE_M) based on a higher maintenance requirement and lower efficiency of use of energy for gain reported for Holsteins (15). The CNCPS equations were evaluated with slaughter balance data that included Holstein heifers and accounted for 93% of the variation in energy and 69% of the variation in protein retained across the data file (44).

CNCPS Corrections and Modifications

Several changes were made in Version 3 of the CNCPS, which was released after the original diets were formulated and was used for the evaluation of the final data. Version 2 of the CNCPS, which was used to formulate the diets (16), used a stepwise calculation of the efficiency of the use of MP; the efficiency of protein usage was 75% for heifers with a BW less than 181 kg, 50% for heifers between 181 and 363 kg of BW, and 40% for heifers with a BW greater than 363 kg. The stepwise function was replaced in Version 3 by an equation that calculated the efficiency of protein usage on a continuous basis (3). Frame size was replaced with mature BW for growing cattle (44) to fit inputs to a continuous scale, which was used to compute the equivalent weight based on the NRC (29) equation developed for a medium frame steer. Use of mature BW to calculate the energy equivalent weight provided a more objective evaluation for users who were not accustomed to scoring cattle based on frame size (44) and allowed for the adjustment of mature size on a continuous basis. In the environmental submodel, which was used to adjust maintenance requirements, body surface area was calculated as $0.75 \times \text{metabolic BW}$; now body surface area is calculated as $0.67 \times \text{metabolic BW}$ because the 0.75 coefficient overestimated the surface area of the animal. Several corrections to the calculation of TDN have been made and are summarized in Table 4. These corrections decreased the calculated amount of energy available from feedstuffs.

TABLE 4. Corrections to equations in the Cornell Net Carbohydrate and Protein System published by Sniffen et al. (41).

Description of correction	Mathematical representation of correction
Digestibility of ash in feed was originally set to 0.	50% digestion coefficient was applied
Estimated endogenous contributions for protein, fat, and ash to fecal matter were not applied correctly and overestimated energy values of the feeds.	$FEENGF_j = 0.017 \times FD_j$ and $FEENGA_j = 0.119 \times FD_j$ where $FEENGF_j$ = amount of endogenous fat in feces from feedstuff j (grams per day), FD_j = feed DM consumed (grams per day), and $FEENGA_j$ = amount of endogenous ash in feces from feedstuff j (grams per day)
Previously, maintenance requirement for endogenous protein was calculated independently of the estimate of endogenous protein in feces. Currently, the maintenance requirement for endogenous protein is assumed to be equal to endogenous losses and is calculated as 9% of indigestible DM. Total fecal DM is calculated as described (46) with the following modifications.	$tmpFEPROT_j = FEFP_j + FEBCP_j$, $IDM_j = (tmpFEPROT_j + FECHO_j + FEFAT_j + FEASH_j)/0.91$ (implies 9% endogenous protein in the indigestible DM), $FEENGP_j = IDM_j \times 0.09$, and $FEPROT_j = FEFP_j + FEBCP_j + FEENGP_j$ where $tmpFEPROT_j$ = amount of fecal protein from feedstuff j (no endogenous material) (grams per day), $FEFP_j$ = amount of feed protein in feces from feedstuff j (grams per day), $FEBCP_j$ = amount of fecal bacterial protein from feedstuff j (grams per day), IDM_j = amount of indigestible DM in feces from feedstuff j (grams per day), $FECHO_j$ = amount of carbohydrate in feces from feedstuff j (grams per day), $FEFAT_j$ = amount of fat in feces from feedstuff j (grams per day), $FEASH_j$ = amount of ash in feces from feedstuff j (grams per day), $FEENGP_j$ = amount of endogenous protein in feces from feedstuff j (grams per day), and $FEPROT_j$ = amount of fecal protein from feedstuff j (with endogenous material) (grams per day)

Evaluation of the NRC Model

Equations used for evaluation according to the NRC (31) are listed in Table 5. The equations for large breed growing females were used. All NRC (31) equations required for the prediction of CP intake were applied to predict protein allowable gain according to the NRC. The NE_M and NE_G contents of the diets were calculated with the CNCPS. Feed for maintenance was calculated as required NE_M divided by feed NE_M . The DMI minus feed for maintenance was multiplied by the dietary NE_G . The NRC (31) energy equations used to predict the required NE_G for a particular live weight gain (**LWG**) cannot be directly rearranged to predict LWG from available NE_G . An iterative procedure was used to determine energy allowable LWG by substituting different ADG into the equation and calculating the NE_G requirement. We assumed that the ADG that yielded the available NE_G represented the predicted energy allowable ADG. Protein allowable ADG was determined from NRC (31) equations except for TDN and indigestible DM, which were taken from CNCPS calculations. The use of TDN as calculated by the CNCPS allowed the use of actual feed analysis to predict TDN available

and the comparison of the protein equations on an energy equivalent basis. Protein required for maintenance was similar for both systems because the same equations were used.

Statistical Analysis

Growth data (i.e., ADG, hip and wither heights) were analyzed as a 2×3 factorial arrangement with replication using the GLM procedure of SAS (37). Class variables used in the model were energy, protein source, and replicate. Initial BW was used as a covariate for ADG. An expected means square algorithm was used to identify the error term for the test by assuming energy and protein source were fixed and repetition was random. Interactions tested included energy and protein; replicate and energy; replicate and protein; and replicate, energy, and protein. If the analysis of variance was significant for a given class variable, then 1-df contrasts were conducted to compare specific treatment means. All tests were considered significant at $P < 0.05$.

The BCS were ordinal, noncontinuous data. Analysis of BCS data was conducted by using the nonparametric analysis of SAS (37). This procedure calcu-

lates Wilcoxon scores, which is a rank sum analysis. The mean scores were analyzed by the Kruskal-Wallis test, which is a chi-square approximation.

Comparisons of the accuracy of the CNCPS and NRC models were tested by regressing predicted

values on observed values as described by Rayburn and Fox (35). Data used for analysis of the systems were growth and feed intake; ingredient analyses for pens of 8 to 10 heifers were averaged over the treatment period. Twenty-eight pens represented 273 heif-

TABLE 5. Equations of the NRC (31) evaluated in this study.

Energy
$NE_G \text{ (megacalories per day)} = (0.035 \times BW^{0.75}) \times (LWG^{1.119}) + LWG$ where NE_G = net energy for gain and LWG = live weight gain.
$NE_M \text{ (megacalories per day)} = 0.086 \text{ Mcal/g of } BW^{0.75}$ where NE_M = net energy for maintenance.
$NEGLWG \text{ (megacalories per day)} = NE_G \times (LWG/1000)$ where $NEGLWG$ = net energy concentration in LWG .
Protein
$RPN \text{ (grams per day)} = (211 - 26.2 \times NEGLWG) \times (LWG/1000)$ where RPN = retained net protein.
$RPA \text{ (grams per day)} = RPN/0.5$ where RPA = retained protein absorbed.
$SPN \text{ (grams per day)} = 0.2 \times LW^{0.6}$ where SPN = scurf protein net and LW = live weight.
$SPA \text{ (grams per day)} = SPN/0.67$ where SPA = scurf protein absorbed.
$UPN \text{ (grams per day)} = 2.75 \times BW^{0.5}$ where UPN = urinary protein net.
$UPA \text{ (grams per day)} = UPN/0.67$ where UPA = endogenous urinary protein absorbed.
$FPA \text{ (grams per day)} = IDM \times FPAIDM$ where FPA = fecal protein absorbed (metabolic), IDM = indigestible DM predicted by the Cornell Net Carbohydrate and Protein System, and $FPAIDM$ = fecal protein absorbed (metabolic)/ IDM , which was equal to 0.090.
$BCP \text{ (grams per day)} = 6.25 \times (-31.86 + 26.12 \times BTDN)$ where BCP = bacterial CP and $BTDN$ = apparent total digestible nutrients as calculated by the Cornell Net Carbohydrate and Protein System.
$RAP \text{ (grams per day)} = BCP/BCPRAP$ where RAP = ruminally available protein and $BCPRAP$ = BCP/RAP , which was equal to 0.9.
$BTP \text{ (grams per day)} = BCP \times BTPBCP$ where BTP = bacterial true protein and $BTPBCP$ = BTP/BCP , which was equal to 0.8.
$DBP \text{ (grams per day)} = BTP \times DBPBTP$ where DBP = digestible bacterial protein and $DBPBTP$ = DBP/BTP , which was equal to 0.8.
$DUP \text{ (grams per day)} = AP - DBP$ where DUP = digestible undegraded protein and AP = absorbed protein.
$UIP \text{ (grams per day)} = DUP/DUPUIP$ where UIP = undegradable intake protein and $DUPUIP$ = DUP/UIP , which was equal to 0.8.
$\text{Intake protein (grams per day)} = DBP + dUIP$ where $dUIP$ is UIP predicted from the dietary ingredients using tabular values for UIP adjusted for an assumed digestibility of 0.8 ($DUPUIP$).
$\text{Protein for gain} = \text{protein supply} - (SPA + UPA + FPA).$
$\text{Protein allowable gain (grams per day)} = (\text{protein for gain}/RPA) \times LWG.$
$IP \text{ (grams per day)} = (RAP + UIP)/(1 + RIPIP)$ where IP = intake protein and $RIPIP$ = ruminal intake protein/ IP .
$RIP \text{ (grams per day)} = RIPIP \times IP$ where RIP = ruminal intake protein.
$IP33 \text{ (grams per day)} = (DIP/(1 - 0.33)) \text{ or } IP33 = UIP/0.33$ where $IP33$ is equal to 0.33 for $UIPIP$ (proportion of UIP from the IP) in the unspecified diet; therefore, if UIP is excessive, $IP33 = UIP/0.33$; else, $IP33 = DIP/(1 - 0.33)$.
$CP = IP + 0.5 \times (IP33 - IP),$ which is the calculation of the proportional reduction in the CP requirement.
$CPDM = CP/1000 \text{ DM},$ which is the CP concentration in the DM as a proportion.

TABLE 6. Growth measurements of heifers fed for 0.6, 0.8, and 1.0 kg/d of BW gain. All values are presented as least squares means.

	Average daily gain												<i>P</i> ¹	
	0.6 kg				0.8 kg				1.0 kg					
	Plant protein		Animal protein		Plant protein		Animal protein		Plant protein		Animal protein		Energy	Protein
Heifers, no.	48		49		40		37		49		48			
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE		
Initial BW, kg	85	1.4	87	1.9	82	1.6	86	1.1	84	1.6	81	1.6	0.08	0.44
Final BW, kg	325	2.2	331	3.1	321	2.6	324	1.9	322	2.4	326	2.0	0.22	0.02
Growth rate, kg/d	0.68 0.01		0.68 0.01		0.84 0.01		0.83 0.01		0.93 0.01		0.95 0.01		0.05	0.36
Days on treatment	361	7.8	359	6.2	285	4.3	288	5.3	257	4.0	258	3.3	0.05	0.81
Final hip height, cm	128	0.4	128	0.4	127	0.5	127	0.5	125	0.4	126	0.4	0.05	0.05
Final wither height, cm	121	0.5	122	0.5	120	0.6	121	0.5	118	0.5	120	0.5	0.05	0.05
Mean BCS ²	3.0	0.03	3.0	0.02	3.1	0.03	3.2	0.03	3.4	0.03	3.3	0.03	0.05	0.16
Mean maximum BCS ³	3.2	0.04	3.2	0.04	3.6	0.04	3.4	0.04	4.0	0.05	3.8	0.04	0.05	0.10

¹No significant interactions of energy and protein.

²Body condition score (BCS) was measured on a five-point scale where 1 = thin to 5 = fat (12).

³Maximum BCS is the highest BCS observed for individual heifers during the treatment period and then averaged for the treatment.

ers. Two regressions were used to test the validity of the model. The first regression calculated the intercept and generated an R^2 . The second regression with a forced 0 intercept yielded an estimate of the bias of prediction. A comparison of the R^2 values of the two regressions indicated the loss of fit when the intercept was forced to 0. The second regression model tested the predicted versus the observed animal response. The regression through the origin yields a coefficient that is an estimate of the bias, and the standard deviation is an estimate of the precision of the predicted values when compared with the observed values.

Mean square prediction error (MSPE) terms (7, 43) were calculated to quantify the inaccuracy associated with the prediction of ADG. The MSPE was calculated as:

$$\text{MSPE} = n^{-1} (A - P)^2$$

where A = actual observed value, P = predicted value, and n = number of comparisons. The MSPE is the sum of the squared differences of each observed value, minus the predicted value, divided by the number of comparisons. The MSPE is comprised of three factors, bias, random error, and deviation from the slope, and can be used to identify quantitatively the mean overprediction or underprediction of the model tested. Bias (used as a measure of model inadequacy) was calculated as the squared difference of the actual mean minus predicted mean values: $(A - P)^2$. Random variation was the variation not accounted for in the model and was calculated as $S_a^2 \times (1 - r^2)$, where r = correlation coefficient between the actual and

predicted values and S_a^2 = variance of the actual values. The third component of MSPE is the deviation from the regression (or slope) and is calculated by $S_p^2 \times (1 - b)^2$ where b = slope of the regression of actual values on predicted values and S_p^2 = variance of the predicted values. The bias and deviation from the regression are used to determine systematic error in the prediction of the model.

RESULTS AND DISCUSSION

Two hundred seventy-three heifers completed the study; 6 heifers were culled because of health and injury reasons. Growth data for heifers on all treatments are summarized in Table 6. Growth rates were different ($P < 0.05$) among energy treatments. The ADG of heifers fed diets formulated for an ADG of 0.6 and 0.8 kg were higher than target growth rates by 0.082 and 0.036 kg, respectively. The ADG of heifers fed the diet formulated for an ADG of 1.0 kg was 0.061 kg less than the target growth rate. The DMI were different ($P < 0.05$) because growth rates were controlled primarily by changes in intake and not by the energy density of the diets.

Final hip and wither heights were different ($P < 0.05$) among energy treatments (Table 6). Heifers fed diets formulated for an ADG of 0.6 kg had a hip height that was 2.8 cm greater, wither height that was 3.1 cm greater, and spent 106 more d on the trial than did those fed diets formulated for an ADG of 1.0 kg. Although overall rates of growth were higher for heifers that consumed more energy, stature differ-

ences were less when measured at similar BW. This lower stature was attributed to age because days of treatment were significantly less for heifers fed diets formulated for an ADG of 1.0 kg ($P < 0.05$).

Data from slaughtered Holstein steers demonstrated that subcutaneous fat deposition increased as BW and ADG increased (2). Body composition at a particular BW is a function of stage of growth and rate of gain (32). Mean BCS of heifers fed diets formulated for an ADG of 1.0 kg were greater ($P < 0.05$) for heifers that consumed more energy (Table 6), which suggests that heifers grown at faster rates of ADG had a higher proportion of fat in the gain because BW were similar ($P > 0.05$). The mean maximum BCS of heifers on each of the treatments were 3.3 (ADG = 0.6 kg), 3.4 (ADG = 0.8 kg), and 3.9 (ADG = 1.0 kg). The mean maximum BCS were the highest recorded scores per heifer within a treatment and averaged by treatment. Mean BCS reported by Daccarett et al. (11) for heifers from 6 to 15 mo of age were similar to the mean BCS observed in this study for heifers fed diets formulated for an ADG of 0.6 and 0.8 kg, but less than the mean BCS observed for heifers fed diets formulated for an ADG of 1.0 kg.

Dietary formulas are presented in Table 2. The concentrate mixes were greater in CP than the formulated 17.5%, but both mixes were similar in CP content (20.3 and 20.7%), and the percentages of CP in AP and PP diets were similar within each category of ADG (Tables 2 and 3). The chemical composition of the diets (Table 3) represents the mean composition over the treatment period. The AP diets were formulated to supply 114, 228, and 340 g/d of AP for the three categories of ADG. Actual intake of AP for heifers fed the AP diet formulated for an ADG of 1.0 kg was 286 g/d, approximately 16% less than that originally formulated because of an overestimation of DMI. Intake of AP for the lower growth rates was not decreased because all of the diet was consumed. Soluble protein was 22.8% (ADG = 0.6 kg), 26.2% (ADG = 0.8 kg), and 28.0% (ADG = 1.0 kg) lower for AP diets than for PP diets (Table 3). However, when evaluated using the CNCPS, the ruminal submodel indicated a positive ruminally available nitrogen balance for all treatments (Table 7). A positive ruminal nitrogen balance indicates that for each unit of digestible carbohydrate, nitrogen was adequate to meet the predicted requirements of the bacteria for microbial CP (MCP) synthesis.

Calculated MP or absorbable protein balances using the CNCPS and NRC system indicated that protein supply met or exceeded requirements in four of five comparisons; NRC predicted that the PP in diets

formulated for an ADG of 1.0 kg was deficient by 19 g/d (Table 7). The PUN values for heifers fed the respective diets suggested that protein supply was adequate for the desired growth rate (Table 7). The PUN was greater ($P < 0.05$) in all heifers that received PP diets, which was consistent with the higher protein degradabilities and potential loss of ammonia across the ruminal wall. To verify the post-prandial PUN effect of the diets, blood was sampled from 6 heifers on each treatment during one replication (data not shown) over a 24-h period. The PUN

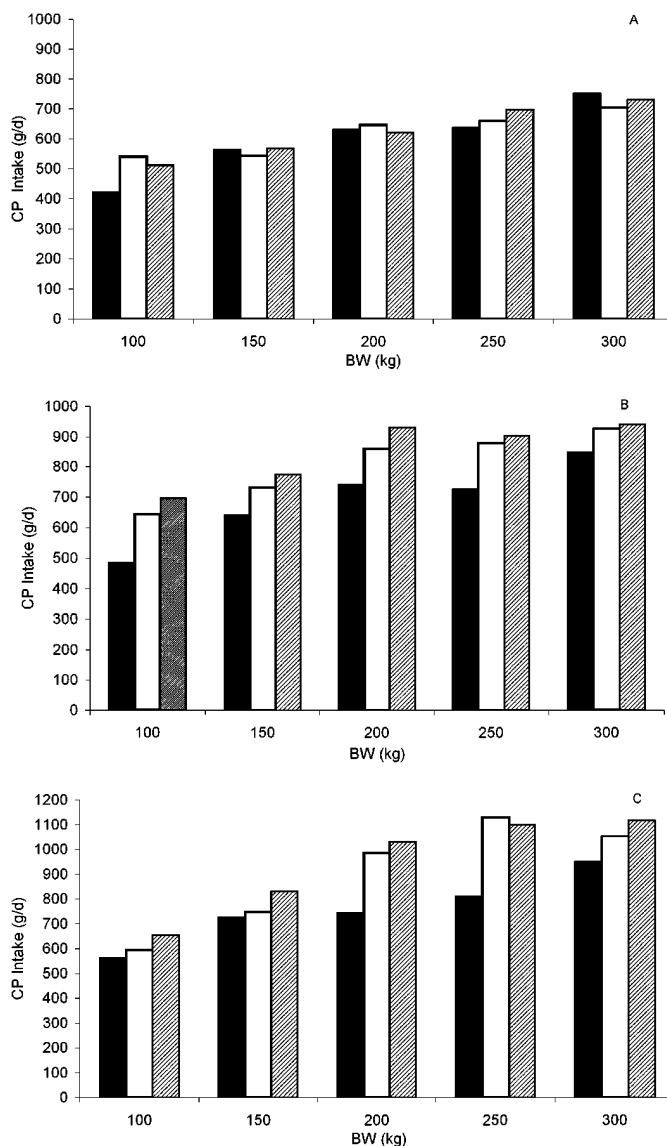


Figure 1. Crude protein intake by protein source and NRC (31) requirements for CP for heifers gaining A) 0.6, B) 0.8, and C) 1.0 kg/d of BW. Legend: NRC requirements (solid bar), plant protein diets (open bar), and animal protein diets (diagonal bar).

values were consistently higher for heifers fed the PP diets.

Heifers targeted for an ADG of 0.6 kg had 5% higher CP intakes during the growth period from 90 to 320 kg of BW than the CP intake recommended by the NRC (31) (Figure 1a). The CP intake of heifers targeted for an ADG of 0.8 kg exceeded NRC (31) recommendations by 21% (Figure 1b) over the entire growth period. Although there are no published CP requirements for heifers gaining 1.0 kg/d, NRC (31) equations used to generate a requirement suggested that heifers targeted for an ADG of 1.0 kg consumed 20% more protein than the calculated NRC requirement (Figure 1c). Calculated CP requirements using the NRC (31) equations for large frame heifers fed for an ADG of 1.0 kg/d were 11% greater than current requirements for 0.8 kg/d of LWG. Despite the higher CP intake, heifers fed these diets had PUN values that indicated that protein was not fed in excess, suggesting that the CP requirements for growing heifers published by the NRC (31) are too low.

Intakes of UIP were computed using the CNCPS and NRC (31) tabular values and were compared with NRC (31) requirements by treatment and BW from 90 to 320 kg (Figure 2, a, b, and c). The UIP values were used for comparison because the difference between UIP and CP intake is degradable intake protein (**DIP**). Predicted intake of UIP obtained from using NRC (31) tabular values yielded UIP intake values that were approximately 22 to 44% higher than those predicted by the CNCPS; however, neither system predicted a supply near the NRC (31) requirements (Figure 2, a, b, and c). The NRC (31) UIP values used for dietary ingredients indicated that UIP intake was increased 37% (ADG = 0.6 kg), 46% (ADG = 0.8 kg), and 48% (ADG = 1.0 kg), and the CNCPS predicted UIP intake was increased by 46% (ADG = 0.6 kg), 53% (ADG = 0.8 kg), and 53% (ADG = 1.0 kg), for AP diets compared with PP diets formulated for the same ADG. Although use of the tabular NRC (31) UIP values to calculate the content of UIP in the total diet suggested a higher UIP content compared with calculated values from the CNCPS (Table 7), both are in agreement with the proportional difference in UIP intake between PP and AP diets. The UIP intakes as a percentage of total protein were similar across treatments and ranged from approximately 20 to 45%. Differences in the prediction of UIP between the NRC and CNCPS were due to the integration of digestion and passage rates in the CNCPS versus a static value in the NRC system.

Estimated intakes of DIP and UIP were remarkably different than NRC (31) recommendations, which implies that the formulation of a ration to meet those

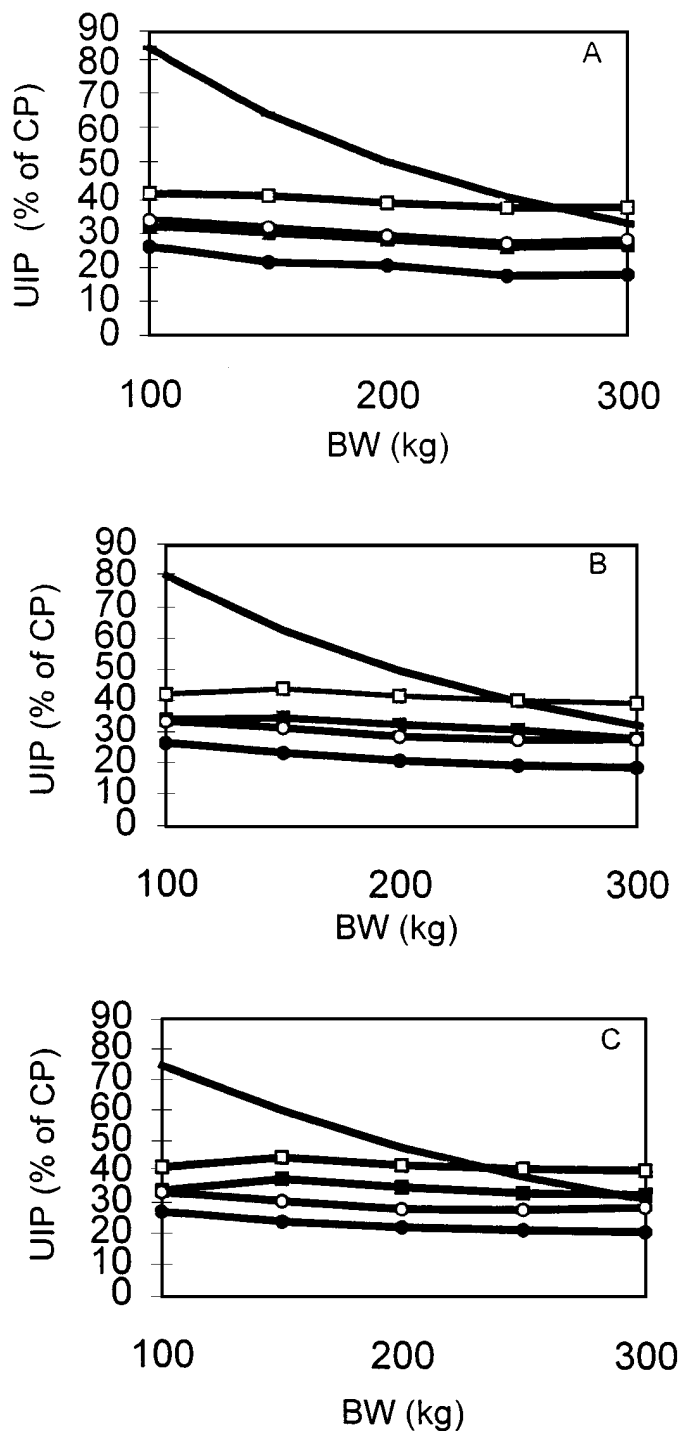


Figure 2. Requirements of the NRC (32) for undegradable intake protein (UIP) versus the predicted supply of UIP as calculated by the Cornell Net Carbohydrate and Protein System (CNCPS) and the NRC for Holstein heifers gaining A) 0.6, B) 0.8, and C) 1.0 kg/d of BW. Legend: predicted supply of UIP for the diets supplemented with plant protein as calculated by the NRC (○), predicted supply of UIP for the diets supplemented with animal protein as calculated by the NRC (□), predicted supply of UIP for diets supplemented with plant protein as calculated by the CNCPS (●), and predicted supply of UIP for diets supplemented with animal protein as calculated by the CNCPS (■).

requirements may be unrealistic (Figure 2, a, b, and c). Reduced growth rates have been observed when high concentrations of UIP have been fed, which might be due to insufficient ruminally available nitrogen that limits microbial fermentation and DM digestibility (33, 42). The calculated protein balances (Table 7) from the CNCPS indicated that protein requirements calculated by the CNCPS were met and that protein intake was not excessive. The CNCPS predicted higher MP balances than did the NRC, which is consistent with the prediction of higher MCP yield. The PUN values (Table 7) for heifers fed all diets supported the MP balance data, which suggested that dietary protein supply was adequate but not excessive. The PUN values of heifers fed the diet formulated for an ADG of 1.0 kg were less than those reported for heifers at similar rates of LWG (6). The PUN data did not agree with the calculated CP intakes relative to NRC (31) requirements. The CP intakes of heifers fed diets formulated for ADG of 0.8

and 1.0 kg were calculated to be 20 to 21% in excess of NRC (31) tabular requirements for heifers growing at 0.8 and 1.0 kg. However, the PUN data suggested that protein intake was not excessive (Table 7) and that dietary protein requirements may be higher than NRC (31) recommendations. Also, relatively low PUN values suggested that ruminal nitrogen and carbohydrates might have been balanced, reducing ammonia loss.

Analysis of growth data by protein treatment, independent of energy treatment, indicated that protein source and increased UIP had no effect on ADG, day of treatment, final BW, and BCS ($P > 0.05$) (Table 6). Supplementation of diets with AP resulted in a small but significant increase in both hip (0.7 cm) and wither (1.3 cm) height, indicating a minor benefit of increased supply or potentially improved AA profile for skeletal growth. Heifers fed diets formulated for an ADG of 1.0 kg including AP were 2.1 cm taller at the wither ($P < 0.05$), which is in con-

TABLE 7. Calculated DMI, protein fractions, and balances with equations from the NRC (31) and Cornell Net Carbohydrate and Protein System.

	Average daily gain					
	0.6 kg		0.8 kg		1.0 kg	
	Plant protein	Animal protein	Plant protein	Animal protein	Plant protein	Animal protein
DMI, kg/d ($\bar{X} \pm SE$)	3.9 ^c \pm 0.1	3.9 ^c \pm 0.1	4.8 ^b \pm 0.1	4.9 ^b \pm 0.1	5.9 ^a \pm 0.1	5.8 ^a \pm 0.2
CP, g/d	593	610	781	819	903	919
CNCPS DIP, ¹ g/d	470	430	603	545	695	599
CNCPS UIP, ¹ g/d	123	180	178	274	208	320
CNCPS DIP, % of CP	79.3	70.6	77.2	66.5	76.9	65.1
CNCPS UIP, % of CP	20.7	29.4	22.8	33.5	23.1	34.8
NRC DIP, ² g/d	417	367	546	474	640	528
NRC UIP, ² g/d	177	243	235	345	264	391
NRC DIP, % of CP	70.3	60.2	69.9	57.8	70.8	57.5
NRC UIP, % of CP	29.7	39.8	30.1	42.1	29.2	42.5
CNCPS Metabolizable protein balance, g/d	38	66	60	114	56	143
NRC Absorbable protein balance, g/d	7.5	52	0	83	-19	94
Plasma urea nitrogen, mg/dl ($\bar{X} \pm SE$)	10.7 ^a \pm 0.2	9.7 ^b \pm 0.1	11.5 ^a \pm 0.3	10.7 ^b \pm 0.1	12.7 ^a \pm 0.2	10.4 ^b \pm 0.2
CNCPS Ruminant ammonia balance, g/d	14.8	8.6	20.3	12.5	21.9	9.5
Metabolizable energy intake, ³ Mcal/d	9.6	9.7	11.9	12.1	14.4	14.3
TDN, ⁴ % of DM	68.3	68.3	68.5	68.4	67.7	67.9

^{a,b,c}Means in the same row with unlike superscripts differ ($P < 0.05$).

¹CNCPS DIP = Degradable intake protein as calculated by the Cornell Net Carbohydrate and Protein System (CNCPS), which integrates degradability and passage rate; CNCPS UIP = undegradable intake protein as calculated by the CNCPS.

²NRC DIP = Degradable intake protein as calculated by the NRC (32); NRC UIP = undegradable intake protein as calculated by the NRC (31).

³Calculated as [TDN (kilograms) \times 4.409] \times 0.82.

⁴Calculated from the CNCPS.

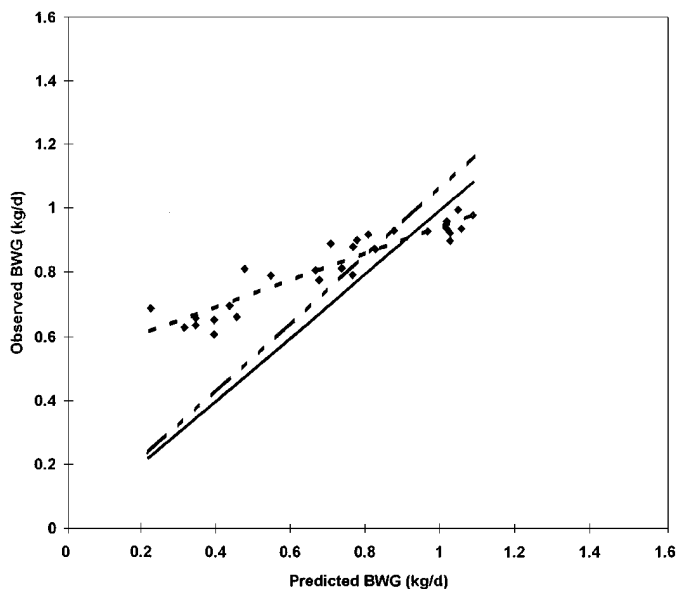


Figure 3. Body weight gain (BWG) allowed by the energy in the diet as calculated by the NRC (31) versus observed BWG for Holstein heifers. Observations represent mean BWG by pen over the treatment period. The regression equation is $Y = 0.42X + 0.53$; $R^2 = 0.87$. The standard deviation of observed BWG versus predicted BWG is $Y = 1.08X$. Legend: regression line (---), $Y = X$ (—), and regression bias (— · —).

trast to previous studies (6, 9, 17) in which protein source did not influence skeletal growth.

Bagg et al. (6) suggested that skeletal growth should be a consideration along with ADG when assessing growth of replacement heifers. A recent study (18) resulted in proposed standards for BW, height, and age of Holstein replacements. With heights of heifers on this study were in agreement with other data (11) and met or exceeded the recommended standards (18). However, heifers fed diets formulated for an ADG of 1.0 kg including PP were approximately 2.4 cm shorter than the standard defined for their age (18).

Evaluation of the NRC and CNCPS Models to Predict Requirements and Performance of Heifers

The NRC equations accounted for 87% of the variation in net energy allowable ADG with a standard error of observed versus predicted gain of 0.044 kg/d and a bias of -7.7% (Figure 3). The MSPE was 0.04 kg²/d, 49% of which was composed of a bias of 0.014 kg²/d (Table 8) and 48.5% was composed of deviation from the slope (0.024 kg²/d). The bias and deviation represented systematic prediction errors in the NRC

(31) equations and accounted for 97.5% of the variation in prediction.

The CNCPS system accounted for 86% of the variation in ME allowable gain with a standard error of observed versus predicted gain of 0.046 kg/d and a bias of -5.7% (Figure 4). The MSPE for ME allowable gain was 0.04 kg²/d of which 27.5% was explained by the bias of the prediction (Table 8). Deviation from the regression accounted for 67.5% (0.027 kg²/d) of the variation associated with the prediction of ME allowable gain. Possible explanations for the systematic errors in prediction are changes in efficiency of energy usage at various energy intakes, inaccurate prediction of body composition, and changes in passage rate and digestibility of diets in heifers on limited DMI (treatments 1 and 2). The variation accounted for and systematic error associated with the prediction of gain were similar for both systems. By combining the predictions of energy and protein allowable gain, both systems predicted energy to be first-limiting, which agrees with the original dietary formulations (Figures 5 and 6).

Studies (9, 42) have shown a benefit of high concentrations of UIP in the diets of heifers. The results of this study indicated that PP sources met both the

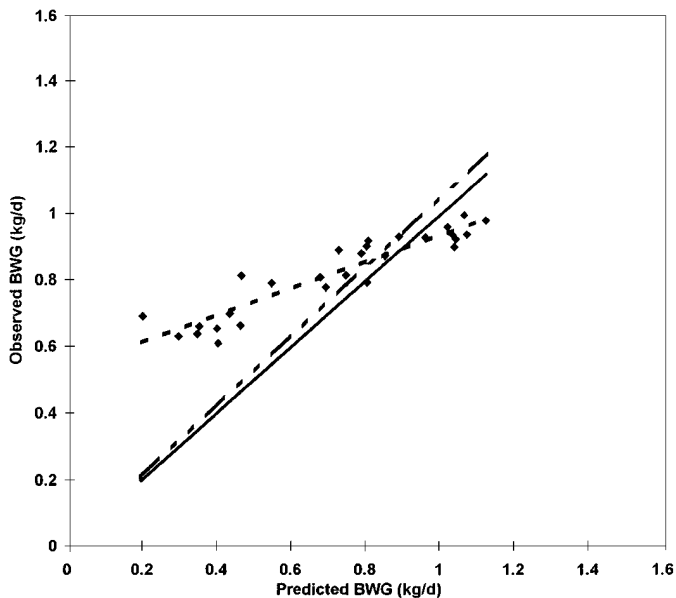


Figure 4. Body weight gain (BWG) allowed by the metabolizable energy in the diet as calculated by the Cornell Net Carbohydrate and Protein System versus observed BWG for Holstein heifers. Observations represent mean BWG by pen over the treatment period. The regression equation is $Y = 0.41X + 0.53$; $R^2 = 0.86$. The standard deviation of observed BWG versus predicted BWG is $Y = 1.06X$. Legend: regression line (---), $Y = X$ (—), and regression bias (— · —).

TABLE 8. Mean square prediction error (MSPE) and components of predicted versus observed growth.

	Actual gain	Predicted gain	MSPE	Bias	Random error	Deviation from slope	R ²
	(kg/d)		(kg ² /d)				
Metabolizable energy							
Predicted by CNCPS ¹	0.819	0.711	0.040	0.011	0.002	0.027	0.86
Predicted by NRC	0.819	0.700	0.040	0.014	0.002	0.024	0.87
Metabolizable protein							
Predicted by CNCPS	0.819	1.100	0.110	0.08	0.003	0.027	0.76
Predicted by NRC	0.819	0.830	0.053	0.001	0.005	0.047	0.68
Most limiting prediction							
CNCPS	0.819	0.711	0.040	0.011	0.027	0.027	0.86
NRC	0.819	0.684	0.041	0.018	0.021	0.021	0.85

¹Cornell Net Carbohydrate and Protein System.

DIP and UIP requirements for ADG. Protein must be first-limiting to evaluate the variation accounted for and bias in predicting protein allowable ADG; both systems predicted energy to be first-limiting, which agrees with the original dietary formulations. However, regressing protein allowable ADG on actual ADG allows comparison of the two systems. The NRC accounted for 68% of the variation with a standard error of observed gain versus predicted gain of 0.07

kg/d and a bias of 10% (Figure 7). The MSPE for the protein allowable ADG predicted by the NRC was 0.06 kg²/d or 0.24 kg/d. The bias associated with the MSPE was 0.001 kg²/d or 1.8% of the MSPE (Table 8). The bias indicated an excess protein supply that permitted protein allowable gain to exceed observed ADG by 0.032 kg. The CNCPS prediction of MP allowable gain accounted for 76% of the variation with a standard error of observed versus predicted gain of

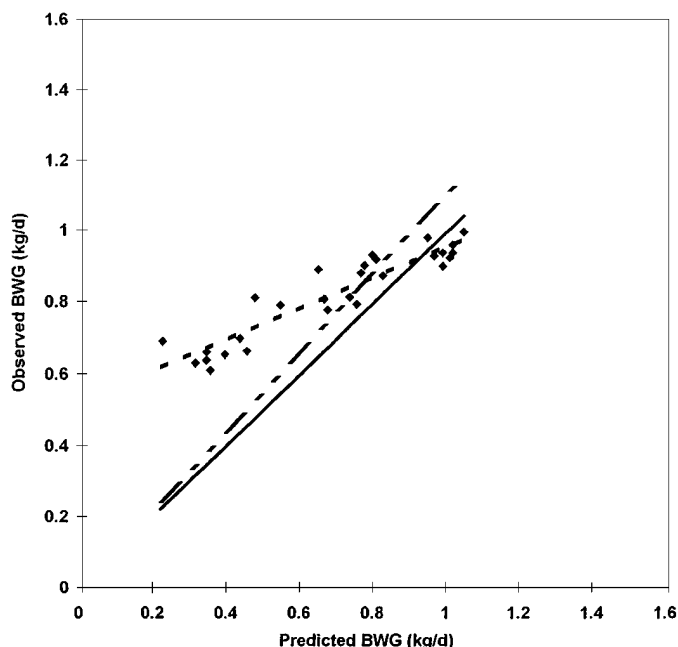


Figure 5. Most limiting BW gain (BWG) as calculated by the NRC (31) versus observed BWG for Holstein heifers. Observations represent mean BWG over the treatment period. The regression equation is $Y = 0.44X + 0.52$; $R^2 = 0.87$. The standard deviation of observed BWG versus predicted BWG is $Y = 1.11X$. Legend: regression line (---), $Y = X$ (—), and regression bias (· · ·).

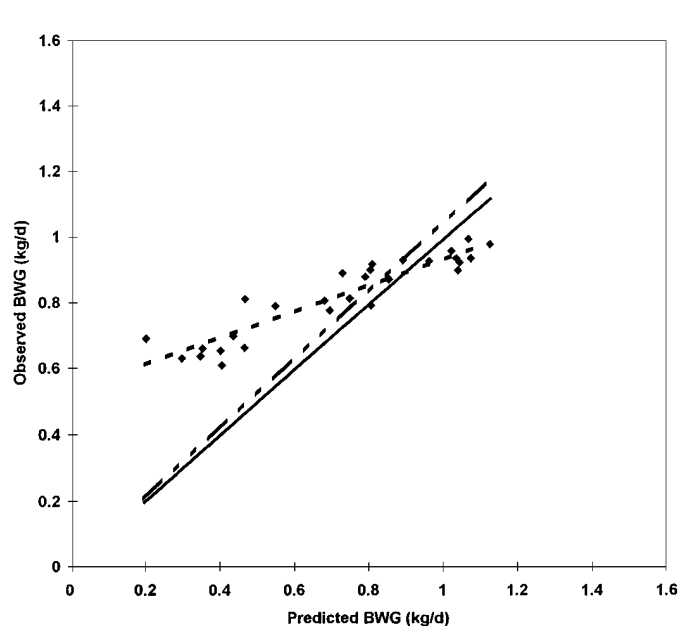


Figure 6. Most limiting BW gain (BWG) as calculated by the Cornell Net Carbohydrate and Protein System versus observed BWG for Holstein heifers. Observations represent mean BWG by pen over the treatment period. The regression equation is $Y = 0.41X + 0.53$; $R^2 = 0.86$. The standard deviation of observed BWG versus predicted BWG is $Y = 1.06X$. Legend: regression line (---), $Y = X$ (—), and regression bias (· · ·).

0.060 kg/d and an overprediction bias of 28% (Figure 8). The MSPE for MP allowable ADG predicted by the CNCPS was 0.110 kg²/d or 0.33 kg/d. The bias of that prediction was 0.08 kg²/d, which accounted for 72% of the error of prediction (Table 8). The bias indicated an excess protein supply that permitted MP allowable ADG to exceed observed ADG by 0.28 kg. Predicted MCP yield was used in the evaluation of protein allowable ADG for each system, and calculated MCP yields for each treatment are summarized in Figure 9 (a, b, and c). The mean difference in predicted MCP yield between the NRC and CNCPS equations was 0.24 kg/d, which was consistent across all treatments and periods.

Both the NRC and CNCPS models suggested that protein supply was in excess of that required to support the energy allowable ADG because both biases were greater than those predicting energy allowable ADG. The NRC predicted a lower net tissue requirement for protein and a lower supply of microbial protein, and the CNCPS predicted a higher tissue requirement and microbial protein supply. The CNCPS accounted for more variation; however, the bias was much larger (10% vs. 28%), indicating a greater predicted MP balance. Much of the difference was due to the difference in the predicted MCP supply

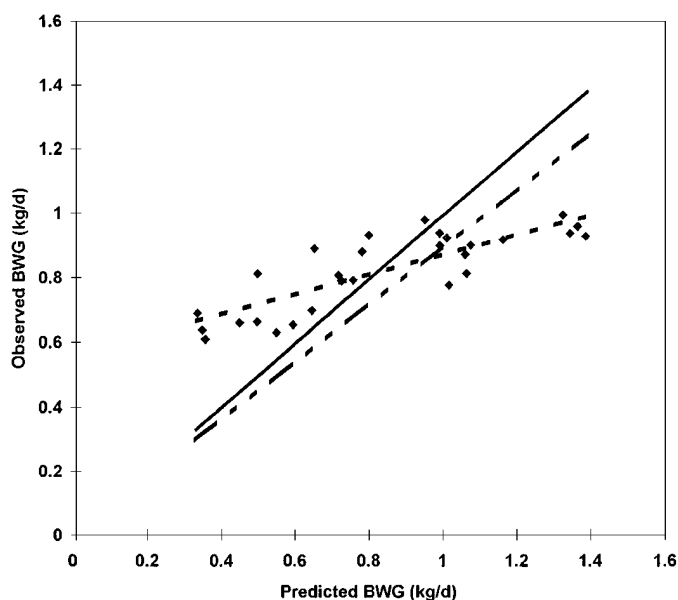


Figure 7. Body weight gain (BWG) allowed by the protein in the diet as calculated by the NRC (31) versus observed BWG for Holstein heifers. Observations represent mean BWG by pen over the treatment period. The regression equation is $Y = 0.31X + 0.56$; $R^2 = 0.68$. The standard deviation of observed BWG versus predicted BWG is $Y = 0.9X$. Legend: regression line (---), $Y = X$ (—), and regression bias (- - -).

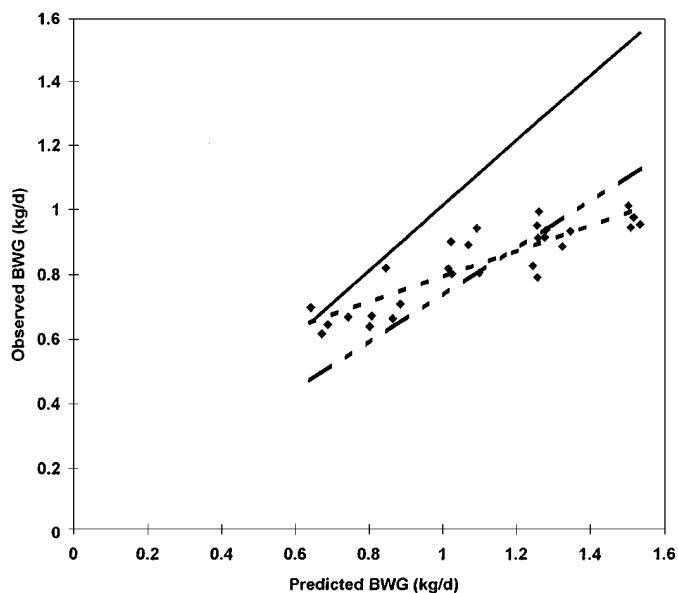


Figure 8. Body weight gain (BWG) allowed by the metabolizable protein in the diet as calculated by the Cornell Net Carbohydrate and Protein System versus observed BWG for Holstein heifers. Observations represent mean BWG by pen over the treatment period. The regression equation is $Y = 0.39X + 0.39$; $R^2 = 0.77$. The standard deviation of observed BWG versus predicted BWG is $Y = 0.72X$. Legend: regression line (---), $Y = X$ (—), and regression bias (- - -).

and the variable efficiency of the use of protein relative to stage of maturity used in the CNCPS (3).

The NRC and CNCPS predicted ADG relative to energy supply were not different, but the CNCPS predicted ADG with less overall bias. Prediction of energy allowable ADG by both systems was a function of the predicted NE_G required for the heifers. The base energy equation used in the NRC (31) calculation was a modification of the 1984 NRC (29) equation for large frame heifers. The coefficients of the equation were changed to allow energy predicted ADG to match the energy requirements for growth of the 1978 NRC (28) publication. The predicted energy requirements of the 1978 NRC (28) were based on the data of Lofgreen and Garrett (25), which was used to develop the 1984 NRC (29) equations. The maximum energy content of 1 kg of gain was limited to 4500 kcal/kg for growing heifers because it was assumed that dairy heifers never reached the degree of fatness of beef cattle. The equation was further complicated by the addition of daily LWG to the prediction of energy gain which implied that the energy contained in a unit of gain could be represented on a one-to-one relationship at all stages of growth and across all rates of LWG.

The CNCPS uses the 1984 NRC (29) equation for medium frame steers to compute requirements at a

particular stage of growth for all growing cattle. A size scaling procedure is used to determine stage of growth. Expected heifer mature weight is divided into a standard reference weight of 467 kg to obtain a ratio to apply to actual BW, which yielded a weight equivalent to the medium frame steer (16, 44). The use of the standard reference weight allows for the energy content of the gain to be adjusted for stage of growth relative to mature size. The current energy equations for the CNCPS, when adjusted for potential mature size, adequately predicted the energy content of the gain for widely varying cattle types (44). In an evaluation with slaughter data, which included Holstein heifers, the CNCPS accounted for 93% of the variation in retained energy of heifers with an overprediction bias of 2% (44). An example of the difference between the NRC (31) and the CNCPS in predicted energy content of the gain is shown in Figure 10. The example used is a 200-kg heifer that is gaining 0.8 kg/d. The NRC (31) stated that the mature size for large frame breeds is 800 kg. Figure 10 demonstrates that, to approach an equal energy content of the gain between the two systems, the input for mature size in the CNCPS must be 500 kg, which is substantially less than the 800 kg stated by the NRC (31). The NRC (31) equation does not allow for adjustment of the energy content of the gain for mature size. In this example, the requirement was a constant 2.25 Mcal/d for a range of mature sizes from 500 to 800 kg. The potential overestimation of energy requirement by the NRC (31) approaches 45% in an animal with a mature size of 800 kg (Figure 10), which implies that the NRC (31) equation likely overpredicts the energy content of gain in growing dairy heifers of large mature size, which in turn underpredicts the protein content of the gain. This evaluation reinforces the need for slaughter balance or calorimetry data that describe the energy and protein requirements for growing Holstein heifers over a wide range of growth rates.

The CNCPS uses the base equation from the 1984 NRC (29) equations to predict net protein in the gain, which is a function of energy concentration in the gain. The NRC (31) used the same base equation, except the intercept was lowered 15%, assuming that empty LWG is 85% of LWG. However, this adjustment may be invalid, because the relationship between empty BW and live BW is not the same as the relationship between empty BW gain and live BWG. The 1984 NRC (29) equations calculate empty BW to be 89.1% of live shrunk BW and predicts empty LWG to be 95.6% of LWG. Using the data of Abdalla (1) from Holstein steers less than 400 kg of BW, empty BW was 89% of live shrunk BW, and empty LWG was

95.7% of shrunk live BW, which are nearly identical to those used by the NRC in 1984 (30). Thus, the 15% decrease in the intercept suggests that the composition of gain predicted by the current NRC (31) protein equation may be underpredicting the protein content of the gain by approximately 18%. Again,

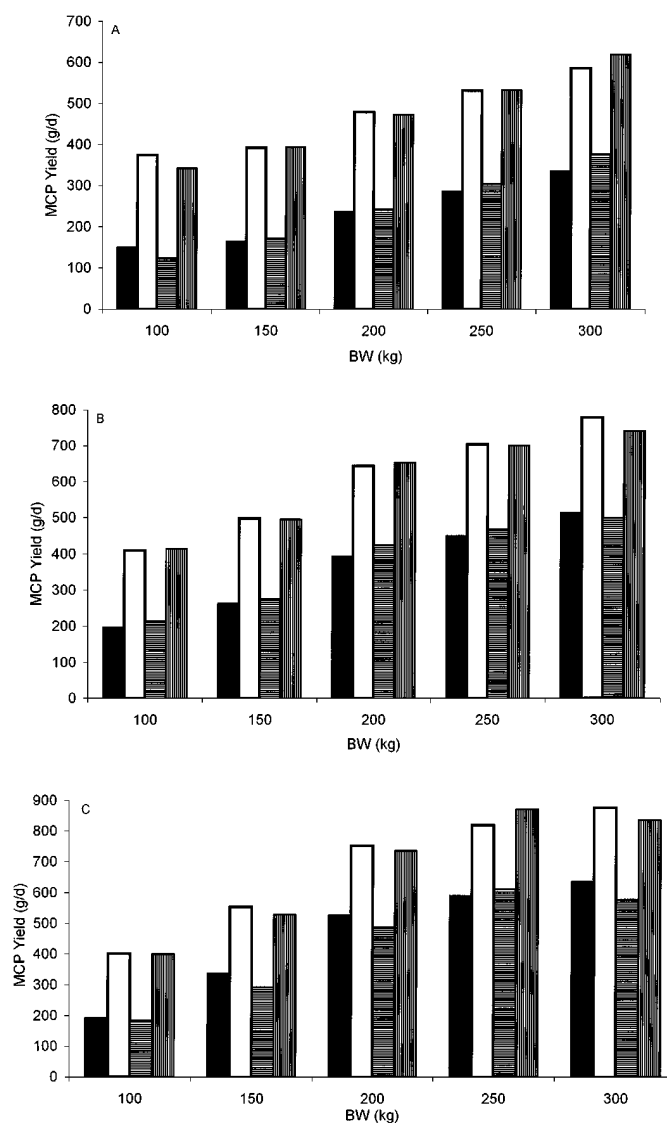


Figure 9. Calculated microbial CP (MCP) yield for Holstein heifers gaining A) 0.6, B) 0.8, and C) 1.0 kg/d of BW. Legend: predicted MCP yield by heifers fed the diets supplemented with plant protein as calculated by the NRC (31) (solid), predicted MCP yield by heifers fed the diets supplemented with animal protein as calculated by the NRC (31) (horizontal lines), predicted MCP yield by heifers fed the diets supplemented with plant protein as calculated by the Cornell Net Carbohydrate and Protein System (open), and predicted MCP yield by heifers fed the diets supplemented with animal protein as calculated by the Cornell Net Carbohydrate and Protein System (vertical lines).

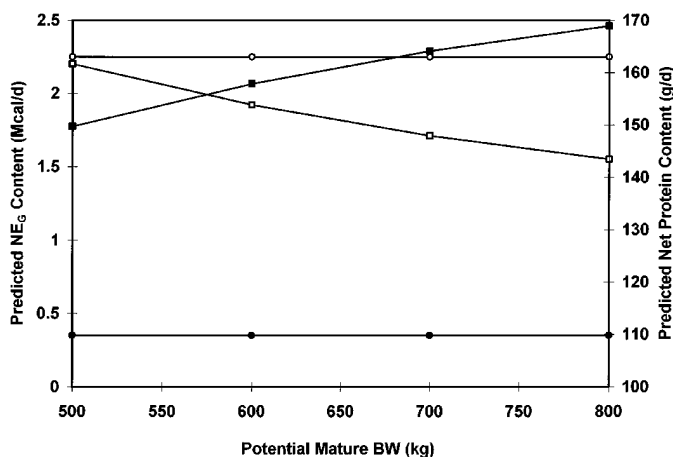


Figure 10. Predicted net energy for gain (NE_G) and predicted net protein content calculated according to equations from the Cornell Net Carbohydrate and Protein System (CNCPS) and the NRC (31) for a 200-kg large frame Holstein heifer gaining 0.8 kg/d. Legend: NE_G as calculated by the NRC (\circ), NE_G as calculated by the CNCPS (\bullet), net protein content as calculated by the NRC (\square), and net protein content as calculated by the CNCPS (\blacksquare).

using the 200-kg heifer growing at 0.8 kg as an example, the calculated net protein requirement using NRC (31) equations for an animal with a mature size of 800 kg is 110 g or 13.7% protein in the empty LWG.

For comparison, the CNCPS predicted a net protein requirement of 169 g or 21.1% protein in the gain. Data from three body composition studies (1, 3, 38) indicated that, for a light Holstein heifer, protein in the empty LWG averaged 19% on an empty BW basis. Because the 1989 NRC (31) energy equation does not adjust for potential mature size, the protein content of the gain is predicted at a constant rate (Figure 10). The 1989 NRC (31) prediction of lower protein in the gain is offset by applying a fixed efficiency of use of 0.5 for the conversion from absorbed to net protein. The CNCPS uses a variable efficiency of use of absorbed protein relative to stage of growth (3) and predicted an efficiency of use of MP of 67% in a 200-kg heifer fed for an ADG of 0.8 kg/d. By using these efficiency factors to calculate the MP requirement for the 200-kg heifer, a difference in MP requirement of 21 g/d existed between the two systems; the NRC (31) predicted the lower requirement.

The largest discrepancy between the two systems appeared to be in the prediction of MCP yield. Predicted MCP yields are shown in Figure 9 (a, b, and c) by growth rate and protein treatment from 100 to 300 kg of BW. On average, the difference in predicted MCP yield was 240 g/d. This difference in

MCP was 32 to 100% of the NRC prediction of MCP yield. The equation for MCP used by the NRC (31) was adopted from the 1985 NRC (30) and was based primarily on heavier weight cattle with higher TDN intakes (30). Thus, at the lower TDN intakes observed with growing but light replacement heifers, the NRC (30) equation underpredicts MCP yield because of the influence of the negative intercept at low TDN intakes. Using the NRC (31) tabular values for TDN intake, the MCP yield predicted for a 200-kg heifer with a TDN intake of 3.34 kg is 350 g/d, which is equivalent to 10.4% of TDN, similar to Burroughs et al. (8). For comparison, the Institute National de la Recherche Agronomique (20) nutrient requirement system uses 14.5% of fermentable OM, which is equal to TDN adjusted for fat content (14.3%). The 1996 NRC (32) uses 13% of TDN intake, which is equivalent to approximately 14% fat-free TDN. At 14.5% of TDN, MCP yield of the heifers would be 484 g/d, a difference of 134 g/d. In this study, the apparent TDN intake for 200-kg heifers fed at an ADG of 0.8 kg was approximately 3.77 kg/d. Using the NRC (31) equation to calculate MCP yield indicated a yield of 400 g/d, but the CNCPS predicted 640 g/d, which is 16.9% of TDN. Multiple runs of the intake data from this study using the CNCPS resulted in a predicted MCP yield of 17% of apparent TDN, a 63% increase over the NRC (31) equations. These data suggest that the NRC (31) equation might be underpredicting MCP yield by 20%, and the CNCPS may be overpredicting MCP yield in this heifer by 40 to 50%. The difference in the predicted MCP yield by the CNCPS may explain the large bias (28%) observed in the evaluation of protein allowable ADG.

The prediction of MCP yield is critical because it is used in the calculation of DIP and UIP needed to meet protein requirements of the heifer and is the basis for the high UIP requirements recommended by the NRC (31) for light growing heifers. The UIP requirement is calculated as the difference between the predicted MCP yield and the absorbed protein requirement divided by a digestion coefficient. The ruminally required protein (bacterial CP/0.9) and UIP are added and adjusted for recycled protein by dividing the sum by 1.15. The resulting value is considered the intake protein requirement. The intake protein is then multiplied by 0.15 (the coefficient for recycled protein), which leads to the ruminal influx protein. The ruminal influx protein is subtracted from the ruminally available protein, which results in the DIP requirement. Thus, the actual reduction in DIP is much higher than 15% because the initial reduction in calculated intake protein required is then multi-

plied by the same factor and subtracted from the ruminally available protein. The result is a potential decrease of up to 35% in the apparent degradable protein intake, and results in DIP and UIP values that are nonadditive with respect to CP intake. The NRC (31) equation assumes that recycled protein is an integral component of the DIP. For example, from the tabular requirement tables, the sum of the DIP (0.295 kg) and UIP (0.294 kg) requirements for a 200-kg heifer fed for an ADG of 0.8 kg/d is 0.59 kg. The CP intake requirement is 0.74 kg/d (20.5% more than DIP plus UIP). For comparison, Van Soest (45) recently proposed an equation for recycled protein that integrates feed intake above maintenance, actual DMI, and microbial capture and digestibility. Applying this equation to a heifer fed for an ADG of 0.8 kg/d and weighing 200 kg indicates that recycled protein is equivalent to 6.25% of the dietary CP, which is less than 50% of the coefficient used in the NRC (31) equation. The lower recycled protein value calculated from the Van Soest (45) equation is a result of the amount of CP intake and DMI above maintenance that reduces the potential contribution of recycled CP to the system.

The NRC system uses an adjustment factor that adjusts the intake protein based on which compartment has a higher requirement, the rumen or the animal tissues (Table 5). If the rumen has a higher requirement, then the DIP is not discounted; however, if the tissues have a higher requirement then the UIP is increased to meet tissue protein demands. Crude protein in the ration DM is limited to 16% for growing heifers, based on the recommendations by the 1978 NRC (28).

The net result of the prediction of the MCP yield and the current usage of the recycled protein equation is a potential underestimation of the DIP requirement and an overestimation of the UIP requirement. When the current DIP and UIP requirements are plotted, they intersect between 200 and 250 kg of BW, which implies that with a BW of less than 250 kg, there is insufficient MCP yield to meet tissue protein requirements, and this deficiency should be met by undegradable feed protein. The calculated intakes of DIP and UIP for heifers targeted for an ADG of 1.0 kg/d and fed PP suggest that DIP and UIP percentages of 70 and 30% of the CP intake were adequate to achieve gains greater than 0.9 kg/d.

Results of the current study suggest (based on the calculated intake of DIP and UIP and observed growth performance) that MCP yield was not deficient in these heifers and that the current recommendations overemphasize the need for UIP when the CP intake is adequate.

CONCLUSIONS

Supplementation of diets with AP as an added source of UIP did not significantly enhance growth or development of Holstein heifers when dietary protein supply was predicted by the CNCPS to be adequate to meet both ruminal and tissue requirements. Undegraded intake protein concentrations less than 40% of the dietary CP were adequate to achieve recommended growth rates for Holstein replacement heifers. In addition, the CNCPS equations may be overpredicting MCP. The NRC (31) recommendations appear to underestimate DIP and overestimate UIP requirements. Further work is necessary to quantify microbial protein yield in the light weight heifer. Evaluation of growth responses to dietary treatments with both the NRC (31) and the CNCPS suggests that NRC (31) recommendations need refinement. The NRC equations for predicting energy and protein requirements do not adequately reflect the biology of growth in dairy replacement heifers and require refinement.

ACKNOWLEDGMENTS

The authors thank Dave Harlan and Dennis Mul-lane at Taylor By-Products (Wyalusing, PA) for their generosity in supplying the AP for this study. We also thank Elizabeth Dayton, Tom Muscato, Jennifer Pierce, Gladys Birdsall, Mike Barry, and the T & R Dairy staff for all of their assistance.

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