APPLICATION OF THE CORNELL NET CARBOHYDRATE AND PROTEIN SYSTEM ON A PASTURE-BASED DAIRY FARM

P. E. Cerosaletti, D. G. Fox, L. E. Chase, A. N. Pell, and W. A. Knoblauch
Department of Animal Science
Cornell University

INTRODUCTION

Pasture-based dairy systems are receiving renewed interest in the United States. Many dairies have turned to pasture seeking economic and labor management benefits. Despite realizing advantages, many producers find it difficult to maintain high levels of production and animal body condition while utilizing pasture as a major component of their rations.

Pasture has also received attention from agencies and university groups studying ways to improve water quality (1). Pasture systems are often viewed as water quality best management practices based largely on the proven benefits of reducing soil erosion by having land in permanent vegetative cover (2, 3, 4). However, research has shown that soil and nutrient losses into water sources can be as great a concern in pasture-based animal production systems as in confinement-based systems (5, 6, 7, 8, 9).

To accomplish both animal productivity and water quality objectives, employing an animal model such as the Cornell Net Carbohydrate and Protein System (CNCPS; 10, 11, 12, 13), which allows for more detailed accounting of diet, animal, and environmental conditions and performance, would seem helpful.

The objectives of this study were to examine the field applicability of the CNCPS in evaluating diets for high-producing dairy cows on pasture, characterize the nutrient flows and excretions of a pasture-based diet using the CNCPS, and to explore using the CNCPS to balance pasture diets, thereby improving animal performance and reducing costs and nutrient excretions and imports.

PROCEDURES

The farm selected for study was a 45-cow dairy farm located in Bloomville, NY. This farm had been using an intensive grazing system for nine years at the time of the study in 1996. Animal productivity was high, averaging more than 19,800 lb milk sold per cow per year. In addition to pasture, lactating cows received concentrate and dry hay supplementation in the barn. Diets of the observed farm were first analyzed and then balanced using CNCPS v. 3.1 (14). This version of the model incorporates the ruminal and post-ruminal submodels of CNCPS v. 3.0 with a factorial mineral absorption and excretion submodel described in INRA (15). Rations analyzed corresponded with monthly DHIA sample days, beginning on May 17, 1996 and ending on October 12, 1996.

Feed Composition

Pastures were sampled for available dry matter yield before grazing and chemical composition approximately every two weeks beginning May 5, 1996. Mid-month sampling coincided with DHI test day. Pasture chemical composition samples were frozen in liquid nitrogen within 40 min of harvest to minimize chemical changes. Hay, concentrate, and pasture samples were analyzed for dry matter (DM), crude protein (CP), soluble protein, neutral detergent fiber crude protein (NDFCP, estimated from nitrogen insoluble in neutral detergent), acid detergent fiber crude protein (ADFCP, estimated from nitrogen insoluble in acid detergent), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin, ash, ether extract, and minerals.

Pasture samples were also analyzed by in vitro gas production methods (16, 17, 18) to determine carbohydrate fraction digestion rates. For the purposes of the study, carbohydrate digestion rates determined via in vitro gas production techniques (pasture forages) and CNCPS feed library carbohydrate rates (all other feeds) were used simultaneously in evaluating diets. Further research is underway at Cornell to determine how to best utilize new digestion rates in the CNCPS.

CNCPS feed library values were used for all components not analyzed for. The effective fiber (eNDF) values of the pasture forages in all diets were set at 50% of NDF, based on the CNCPS modeling study of pasture diets conducted by Kolver et al. (19). Cost of the concentrate mix was determined by amounts of individual ingredients in the feed formula and their respective prices. Ingredient prices were held constant across the season in both ration evaluation and balancing.

Environmental and Production Inputs

Temperature inputs in the CNCPS were calculated as the average of daily minimum and maximum temperatures recorded at the farm over the 30 days since the last test date. Body weights for each cow, estimated using a heart girth tape, and body condition scores (BCS; 1 to 5 scale as described by Sniffen and Ferguson (20)) were obtained within two days of DHIA sample date. For each test date, production information (milk, fat, and protein), previous test day BCS, current test day BCS, current test day body weight, and amount of concentrate fed for each cow were sorted and averaged by milk production level (<50 lb, 50-70 lb, 70-90 lb, and > 90 lb milk).

Ration Evaluation and Balancing

The DMI of pasture forage were not measured. To estimate this feed input, pasture intake was varied until the model predicted a body condition score change (expressed as days to gain or lose one BCS) which matched that observed for the given milk production group. To balance rations, only individual concentrate mix

ingredients typically available to the farm were used. Individual ingredient amounts were varied to achieve balanced ration objectives, with the total amount of concentrate fed remaining the same as the original ration in most cases. The amount of molasses fed through the concentrate was not varied for dust control and palatability reasons. The amount of urea fed was limited to 1.75% of the concentrate mix for palatability reasons. Hay or pasture DM intake was not varied from levels in the original ration.

Rations were balanced to maintain BCS change that was observed for a given production group and test day. This assumes that the BCS change observed was that desired by the farm operator. In cases where a CNCPS-balanced ration resulted in substantially more energy predicted from the diet, the amount of concentrate fed was reduced to maintain BCS score change equal to that observed. Other ration balancing guidelines followed were those outlined by Stone et al. (21) and Fox et al. (22) in performing ration diagnostics and fine tuning with the CNCPS. The most notable deviation is that predicted and actual DM intakes in this case cannot be compared, as pasture DMI was not measured. Additionally, no efforts were made to adjust eNDF levels when they were below 20% of ration DM, as additional dry hay in the diet may not have been possible due to inventories, logistics, and/or management goals of the farm operator.

Reduction of the excretion of phosphorus (P) was of interest in this study. To accomplish this in balancing the ration with the CNCPS, levels of P in the concentrate were adjusted so that P levels in the diet exceeded the net mineral requirements by 10%, allowing a safety factor to cover variations in DMI and feedstuff mineral composition.

RESULTS AND DISCUSSION

Pasture Chemical Composition

Pastures were of high, but variable quantity. Table 1 shows pasture DM available exceeded the 1000 lb acre^{-1} required to allow maximum pasture DMI as suggested by Rayburn (23). Variations in CP, NDFCP, soluble CP, NDF, and lignin had the greatest impact on predicted energy and protein derived from the diet. Measured B2 carbohydrate fraction digestion rates were higher than CNCPS feed library values for pasture forages (8.0-9.8% hr^{-1} vs. 4.5-6.0% hr^{-1}) and resulted in 2.3 and 3.4 lb more energy and protein allowable milk respectively.

The effect of using BCS change in estimating pasture DMI and the resulting relationship between energy status and apparent pasture DMI is evident in the months of July and September (Table 2). In July, where BCS loss was greatest for most groups, predicted pasture DMI was lowest. In September, positive changes in energy status as well as increased urea cost (due to high CP content of pasture) resulted in high predicted pasture DMI.

Table 1. Available herbage mass prior to grazing, chemical composition, and carbohydrate degradation rates of pasture forage by sample date, 1996[a].

		Sample date					
		5/17	6/15	7/16	8/16	9/13	10/12
Available herbage mass, lb acre^{-1}		1241	1332	1529	1461	1033	1087
DM	% as fed	20.9	16.2	15.5	15.1	17.6	26.3
CP	% DM	23.9	21.4	20.4	26.5	27.9	22.9
Sol P	% CP	28.0	25.0	23.0	26.0	16.0	26.0
NDFCP	% CP	32.2	32.2	39.7	38.9	58.1	33.6
ADFCP	% CP	2.5	6.1	6.4	2.6	7.2	6.1
NDF	% DM	42.7	43.0	34.0	43.1	51.9	43.9
eNDF	% NDF	50.0	50.0	50.0	50.0	50.0	50.0
ADF	% DM	20.1	26.6	28.3	22.1	24.8	23.4
Lignin	% NDF	12.4	9.1	11.2	4.9	12.0	8.9
Fat	% DM	4.1	3.9	4.0	4.7	4.6	3.8
Ash	% DM	8.4	9.5	8.8	8.8	8.5	9.0
Ca	% DM	0.56	1.01	0.88	1.05	0.76	1.42
P	% DM	0.37	0.42	0.50	0.42	0.42	0.34
Mg	% DM	0.20	0.34	0.37	0.40	0.34	0.34
K	% DM	2.78	3.05	3.17	2.49	2.80	1.83
A kd	% hr^{-1}	36	39	40	29	25	33
B1 kd	% hr^{-1}	19	31	19	25	19	21
B2 kd	% hr^{-1}	9.8	8.8	9.8	9.4	9.4	8.0

[a] CNCPS feed library values for NPN, starch, protein fraction (A, B1, B2, B3) degradation rates, amino acids, DIP, and UIP contents were used in all diet evaluations.

Using BCS change to estimate pasture DMI in this study may not have improved the accuracy of this estimation, as BCS change in this case represented a change over 30 days, yet the production parameters were measured for only one day. A secondary estimate of pasture DMI, such as by difference from total predicted DMI or measuring herbage allowed and consumed, may have improved accuracy of the estimate. Despite these challenges, using BCS change as a basis for adjusting pasture intake resulted in total DMIs usually within ±10% of the CNCPS predicted total DMI. These results are similar to those obtained in other studies which suggest that in pasture diets typical of the Northeast US, total DMI of grazed cows is similar to predicted DMI of ungrazed cows if forage availability is not limiting (24, 25, 26, 27).

Table 2. Body condition score (BCS) change and measured and CNCPS-predicted feed intakes by production group and sample date.

	Sample date					
	5/17	6/15	7/16	8/16	9/13	10/13
< 50 lb milk						
	Fraction of a score per 30 d					
BCS change	0.25	-0.15	0.15	0.01	0.50	0.35
	lb d^{-1}					
Concentrate	8.0	12.5	13.5	9.8	13.4	14.3
Hay	20.0	5.1	5.5	5.7	5.8	10.9
Pasture	13.0	14.5	15.5	16.5	31.0	18.0
Total DMI	41.0	32.1	34.5	32.0	50.2	43.2
Predicted DMI	37.7	37.5	37.3	35.3	39.0	39.8
% of predicted	109%	86%	93%	91%	129%	108%
50 - 70 lb milk						
	Fraction of a score per 30 d					
BCS change	0.22	0.00	-0.24	-0.04	0.08	0.27
	lb d^{-1}					
Concentrate	17.0	18.7	17.1	17.0	19.7	20.5
Hay	18.5	4.8	6.2	5.4	4.9	9.7
Pasture	10.4	16.8	9.8	16.3	21.2	16.5
Total DMI	45.9	40.3	33.1	38.7	45.8	46.7
Predicted total	41.9	41.6	40.1	40.0	40.8	43.0
% of predicted	109%	97%	83%	97%	112%	109%
70 - 90 lb milk						
	Fraction of a score per 30 d					
BCS change	0.01	-0.11	-0.28	-0.08	-0.05	0.23
	lb d^{-1}					
Concentrate	25.0	23.2	22.6	23.1	23.3	24.1
Hay	16.9	5.7	5.6	5.1	5.7	10.6
Pasture	5.0	17.3	12.0	16.5	22.5	17.6
Total DMI	46.9	46.2	40.2	44.7	51.5	52.3
Predicted total	48.0	48.8	46.5	45.8	48.1	48.1
% of predicted	98%	95%	86%	98%	107%	109%
> 90 lb milk						
	Fraction of a score per 30 d					
BCS change	-0.05	-0.15	-0.60	-0.48	-0.11	0.25
	lb d^{-1}					
Concentrate	28.6	20.0	24.4	25.0	25.1	24.1
Hay	19.5	6.3	7.5	6.2	6.3	13.5
Pasture	8.3	23.8	16.3	15.0	27.4	26.5
Total DMI	56.4	50.1	48.2	46.2	58.8	64.1
Predicted total	56.0	49.8	54.4	51.0	51.1	53.4
% of predicted	101%	101%	88%	90%	115%	120%

Milk Production

Predicted amino acid (AA) allowable milk levels were lower than observed levels in the June, July, and August diets of the 70-90 lb and > 90 lb milk groups, as well as in the May diet of the > 90 lb milk group (data not shown). This suggests that assumptions regarding pasture eNDF, protein digestion rates, amino acid contents of feeds, or other factors affecting AA flows to the small intestine and subsequent absorption were not accurate for these months. As AA contents of feeds in this study were not measured (CNCPS feed library values were used instead), errors in AA contents may be likely. In all CNCPS-balanced diets, AA allowable milk was predicted above the observed milk production data (data not shown). Further studies of the AA adequacy of pasture-based diets with the CNCPS where AA content of the pasture herbage is known appear warranted.

Predicted Rumen Performance

Selected diet characteristics predicted by the CNCPS for the original diet and balanced diets across the season appear in Table 3. Predicted pH values of this

Table 3. Selected CNCPS output for original and CNCPS-balanced diets by production group across sample dates.

	Production group			
	< 50 lb	50-70 lb	70-90 lb	> 90 lb
Original				
Peptide balance, %[a]	194	170	163	163
Rumen N balance, %	144	139	139	138
Urea cost, mcal d^{-1}	1.50	1.14	1.03	1.05
eNDF, % of required[b]	124	104	94	100
Rumen pH, predicted	6.38	6.27	6.22	6.26
MP balance, %	31.4	18.2	10.5	8.0
MP from bacteria, %	49	48	47	46
Balanced				
Peptide balance, %[a]	150	126	119	125
Rumen N balance, %	119	117	119	121
Urea cost, mcal d^{-1}	1.04	0.70	0.59	0.72
eNDF, % of required[b]	121	103	92	99
Rumen pH, predicted	6.37	6.26	6.20	6.26
MP balance, %	31.2	17.9	10.8	11.5
MP from bacteria, %	57	58	56	53

[a] peptide balance calculations were based on CNCPS feed library values for NPN content of feeds, not measured values
[b] pasture eNDF value = 50% of NDF in all diets

study agree well with the upper range of values observed in other pasture studies (28, 29, 30, 31, 32). Diets which included more hay (May and October) had higher predicted rumen pH values. The CNCPS has been shown to overpredict rumen pH in pasture-based diets (19) and may have in this case as well. The eNDF value for pasture in this study (50% of NDF) was not derived by measurement, and may not have been correct. Further study to establish this value for pasture forages is warranted.

Rumen peptide balances (feedstuff peptide available in rumen/peptide requirement of rumen bacteria * 100) predicted in this study are considerably greater than those obtained for high producing dairy cows in confinement housing (21). This is due to the very low NPN values of pasture forage in the CNCPS feed library (2.2-4.8% of soluble P). The feed library values for NPN were used in the absence of measured values in this study, and may not have been correct. Recent research at Cornell with pasture forage of similar quality has found NPN levels closer to 20-30% of soluble protein (R. Ruiz, personal communication)[1]. Lower NPN values result in a greater percentage of the forage soluble protein being rumen available true protein, and consequently rumen available peptide. Rumen nitrogen balances (rumen available nitrogen/rumen microbe N requirements * 100) and urea costs (energy associated with synthesis and excretion of urea) were not large, suggesting that rumen nitrogen losses were not excessive, as might be expected for high quality pasture (29). This is likely the result of having large quantities of rumen available carbohydrate in the supplemented concentrate. The percentage of metabolizable protein (MP) coming from bacterial flow in the higher producing groups meet the 45% guideline for early lactation cows (21), but lower producing groups fall short of the 55% goal for cows in late lactation.

Using the CNCPS to balance rations, peptide and rumen N balances were reduced on average 25% and 15% respectively. Greater utilization of rumen available N by bacteria reduced urea cost 36%. Microbial yield was greater in CNCPS-balanced diets, resulting in an 18% increase in percentage of MP coming from bacteria. It is evident from Table 3 that eNDF levels were not adjusted for. Predicted microbial production could have been improved in diets below pH 6.28 with additional eNDF. Another possibility would be to have used a non-forage fiber source such as soy hulls or beet pulp in place of corn meal. Such highly digestible, low nitrogen fiber sources provide rumen available carbohydrate to rumen bacteria so that they might utilize more of the ruminally available N. Additionally, the primary fermentation end products of these fibrous feeds are acids much weaker than lactic acid, the intermediary product of starch fermentation which causes lactic acidosis (33).

[1] Personal communication. R. Ruiz, Department of Animal Science, Cornell University, Ithaca, NY.

Nutrient Excretions and Balances

Predicted N excretion decreased on average nearly 10% in balanced diets (Table 4). Reduction in N excretion declined as milk production increased, a result of smaller reductions in N intake. Similar decreases in excreted N have been predicted where the CNCPS has been used to optimize rumen fermentation in a modeled diet (34).

Table 4. Predicted nitrogen and phosphorus intakes and excretion for original and CNCPS-balanced rations by production group across sample dates.

	Production group			
	<50 lb	50-70 lb	70-90 lb	>90 lb
N intake				
Original, g d^{-1}	583	618	696	800
Balanced, g d^{-1}	530	569	644	765
Reduction, g	53	49	52	35
Reduction, %	9.1	7.9	7.5	4.4
N excretion, fecal + urinary				
Original, g d^{-1}	380	408	463	529
Balanced, g d^{-1}	339	367	419	494
Reduction, g	41	41	44	34
Reduction, %	10.8	10.0	9.5	6.4
Efficiency, balanced (g excreted per kg milk)	18.9	13.7	11.7	10.8
P intake				
Original, g d^{-1}	89	105	123	137
Balanced, g d^{-1}	67	80	99	115
Reduction, g	22	25	25	22
Reduction, %	24.7	23.8	19.9	16.1
NRC requirements[a], g d^{-1}	50	70	91	114
P excretion, fecal + urinary				
Original, g d^{-1}	74	82	92	98
Balanced, g d^{-1}	53	58	70	80
Reduction, g	21	24	22	18
Reduction, %	28.4	29.3	23.9	18.4
Efficiency, balanced (g excreted per kg milk)	2.96	2.16	1.95	1.75

[a] NRC, 1989: 1300 lb body weight, 4.0% butterfat, 100% DMI, milk levels 40, 60, 80, and 100 lb

Phosphorus excretion was reduced on average 25% in the CNCPS-balanced diets. This is a result of two actions: reduction of proteinaceous feeds (which

tend to have higher P content) in the concentrate supplement and reduction of mineral P supplements in the concentrate as a result of balancing for phosphorus supplied in the diet. The reduction in mineral P supplements in the concentrate accounted for 75% of the decrease in excreted P. The intake of P in original diets averaged 46% over NRC requirements (35), while CNCPS-balanced diets averaged only 14% over the same requirements. In both original and CNCPS-balanced diets, intake of P above requirements, as well as P excretion, decreased with increasing milk level. Absolute reductions in P excretion followed reductions in intake closely, but on a percentage basis excretions declined more than intake. Morse et al. (36) found a 27% reduction in P intake (22 g d^{-1}) resulted in a 22% reduction (12 g d^{-1}) of P excreted in feces and urine and a 0.55 g d^{-1} reduction in fecal P for every 1 g reduction in P intake. Klausner et al. (37) observed a 40% reduction in excreted P over a nine-month period in a case study where diets were adjusted using the CNCPS. All of the reduction in that study came from reductions in proteinaceous feeds in the ration. It is emphasized that all excretions were predicted using the CNCPS and based on pasture intake required to support the observed milk production.

Supplemented Concentrate

Substantially more corn meal and less byproduct feeds were used in the CNCPS-balanced rations to increase intake of ruminally available carbohydrate (Table 5). More urea was used in CNCPS-balanced rations as a result of high peptide balances predicted in the original rations, and urea levels of the concentrate may pose palatability problems. Higher NPN values for pasture forage would result in lower urea usage. Savings in concentrate costs for all cows averaged $0.30 per cow per day or $50 per cow over the entire grazing season.

As milk production increases, a greater amount of undegraded feed protein was required, which was met with whole roasted soybeans. Crude protein levels of the required balanced diet concentrates were similar, except for the < 50 lb group, which was significantly lower. Crude protein levels in the concentrate could have been further reduced if eNDF levels of the diet had been increased, thus allowing for increased microbial yield. Feeding the highly digestible fiber sources discussed previously, which would not depress the rumen pH and microbial yield as much higher starch concentrates would, could also aid in reducing supplemented protein needs. Given that predicted rumen pH limited microbial yield in most diets, these supplements would seem appropriate. Required P density of the mineral mix in balanced rations increased dramatically with milk production level, but was similar in the two highest production groups.

Analysis of CP and P concentrations in required concentrates in the balanced diets, as well as choice of concentrates used in the required mixes, suggest that two supplements might be formulated given this level of concentrate supplementation. One distinct possibility would be a separate mix for cows producing <50 lb,

Table 5. Composition of concentrate mixes in original diets and those required for each production group in CNCPS-balanced diets.

	Original	CNCPS-Balanced			
		< 50 lb	50-70 lb	70-90 lb	> 90 lb
Ingredients, % DM					
Corn meal	42.00	81.74	77.39	74.28	71.50
Soybean meal 48	6.25	1.91	4.36	3.77	3.17
Roasted soybean	7.50	0.00	0.97	4.59	8.29
Urea	0.50	1.32	1.73	1.66	1.65
Tallow	1.25	0.53	0.96	0.77	0.14
Molasses	7.50	7.76	7.68	7.62	7.57
Mineral mix	7.28	6.75	6.92	7.32	7.68
Distillers grains	17.50				
Hominy	7.50				
Linseed meal	2.50				
Monosodium phosphate	0.25				
% P in mineral mix[a]	4.29	1.63	2.83	3.42	3.48

	Original[b]	CNCPS-balanced			
		< 50 lb	50-70 lb	70-90 lb	> 90 lb
Chemical composition					
DM, % as fed	89.4	87.8	88.0	88.1	88.1
CP, % DM	20.3	14.3	17.0	17.7	18.6
Sol P, % CP	24.5	41.7	44.4	41.3	38.9
NPN, % Sol P	83.6	94.3	94.1	94.4	94.9
NDFCP, % CP	15.7	9.0	8.2	9.6	10.9
ADFCP, % CP	7.9	3.0	2.8	3.2	3.5
NSC, % DM	46.4	67.8	64.5	63.0	61.6
Starch, % NSC	77.0	75.5	74.5	74.5	74.8
NDF, % DM	15.6	7.7	7.6	7.8	8.0
Lignin, % NDF	14.1	2.2	2.3	2.8	3.3
Fat, % DM	8.0	4.2	4.7	5.0	4.9
Ash, % DM	9.6	6.0	6.2	6.6	6.9
Ca, % DM	1.2	1.1	1.2	1.2	1.3
P, % DM	0.8	0.4	0.5	0.6	0.6
Mg, % DM	0.6	0.3	0.3	0.4	0.4
K, % DM	1.2	0.7	0.8	0.8	0.9

[a] Mineral mix, % of DM: Ca 14.8, P 4.3, Mg 2.9, K 1.2

[b] Original grain chemical composition is the average of chemical analyses

and another concentrate for cows >50 lb, which would likely resemble the mix for higher producing cows. Another breakpoint for a two-concentrate mix might be 70 lb milk cow^{-1} d^{-1}. Multiple concentrate mixes based on differing requirement levels have been suggested elsewhere as a strategy to reduce nutrient excretion (38).

Breakpoints for separate mixes will depend on the amount of concentrate fed in each herd.

The CNCPS can prove useful when evaluating suitability of feeds as pasture supplements, due to its ability to predict microbial yield (and microbial protein), which allows for a more accurate accounting of protein derived from a feed. This is particularly true of highly digestible low N content feeds, which are typically used as pasture supplements. The CNCPS also allows for economic quantification of the effects of environmental and management factors on animal performance, a feature useful in making management decisions such as how far paddocks can be from the barn without negatively impacting profitability, or how hot it could get before provision of shade is profitable.

The greatest cost associated with using the CNCPS to balance pasture diets is likely to be labor. This includes time and effort necessary to gather and enter inputs, as well as balancing the ration by trial and error, as there is no optimizer in CNCPS v. 3.1 to assist in balancing rations. However, CPM Dairy does have an optimizer for balancing rations with the CNCPS. The other major cost associated with using the CNCPS is the cost of forage analyses needed to obtain necessary composition inputs, some of which are not included in standard commercial analysis packages or are available at greater cost.

Mass Nutrient Balance

The mass nutrient balance of the dairy farm before and after balancing rations with the CNCPS appears in Table 6. The methodology of determining the

Table 6. Mass nutrient balance before and after balancing of rations with the CNCPS.

	N	P	K
	(ton yr^{-1})[a]		
Original			
Inputs	8.62	1.34	2.29
Outputs	3.92 (2.48)	0.80 (0.51)	2.04 (0.69)
Remaining on farm	4.70 (6.14)	0.54 (0.83)	0.23 (1.60)
% remaining on farm	55 (71)	40 (62)	11 (70)
Balanced			
Inputs	8.32	1.20	2.08
Outputs	3.92 (2.48)	0.80 (0.51)	2.04 (0.69)
Remaining on farm	4.40 (5.84)	0.40 (0.69)	0.04 (1.39)
% remaining on farm	53 (70)	33 (57)	2 (66)

[a] values in parentheses include nutrients from 275 tons of manure exported off the farm

mass nutrient balance is described by Klausner (39). In mass nutrient balance studies of New York dairy farms, the percentages of N, P, and K which remained on farms of various sizes ranged from 64-76%, 68-81%, and 67-89% respectively (39). Mass balances for N, P, and K on this pasture-based dairy (71, 62, and 70% retained respectively) fit in these ranges reported for confinement-based dairies. Using the CNCPS to balance rations resulted in predicted reductions in N and P remaining on the farm of 5% and 18% respectively.

CONCLUSIONS

The CNCPS can be used to evaluate pasture diets and identify ways to optimize rumen fermentation, reduce nutrient excretions, and lower feed costs. The following approach is suggested to use the CNCPS in this manner:

1) Collect feed input information, including weights of barn-fed feeds and feed analyses. Feeds should be reanalyzed upon changes. Pastures should be sampled at least once monthly or upon changes in pasture type (native grass vs. improved grass-legume pastures). Forage analysis should include CP, NDF, soluble P, fat, starch, NPN, NDFCP, ADFCP, ash, and lignin.

2) Collect necessary animal and environmental information, including body condition scores. Body condition scoring should be performed monthly on a representative number of animals in each production/stage of lactation group.

3) Pasture availability and allowance should be assessed to determine if animals have enough pasture forage to maximize pasture DMI. Pasture availability (forage mass before grazing) should be evaluated relative to the 1000 lb $acre^{-1}$ threshold suggested by Rayburn (23) below which pasture DMI is restricted. Pastures with forage availabilities of more than 1500 lb $acre^{-1}$ will generally allow for maximum pasture DMI if pasture allowance is 20% greater than the allowance needed for the animals (23).

4) The CNCPS should be used to predict current animal performance before adjustments to diets are evaluated in order to help determine and validate inputs (such as feed intakes and environmental inputs). For this purpose predictions of average herd performance may be useful as average herd measurements such as intake of barn-fed feeds, pasture DMI and milk production may be more readily available.

5) Pasture DMI can be estimated by fixing DMI of barn-fed feeds and then varying pasture DMI to meet total predicted DMI and/or until the CNCPS predicts measured BCS change. As trends in measured BCS may not reflect energy adequacy of the diet on any given day, the latter method should not be solely relied upon to predict pasture DMI. Where practical, estimations of pasture DM disappearance (pasture DM allowed minus residual pasture DM) might be used to predict herd average pasture DMI.

6) Once current animal performance has been predicted, it is advisable to divide the herd into at least two production groups to evaluate adjustments to the ration. Evaluating adjustments to diets should follow the steps outlined by Fox et al. (22).

REFERENCES

1. Fox, D. G. 1996. Science for Whole Farm Planning: Cornell University Phase II Task Summary Report. Task 3: Pasture assessment and grasslands management. Cornell Univ., Ithaca, NY.
2. Gard, L. E., R. F. Fuelleman, C. A. Van Doren, and W. G. Kammlade. 1943. Runoff from pasture land as affected by soil treatment and grazing management and its relationship to botanical and chemical composition and sheep production. J. Amer. Soc. Agron. 35:332-347.
3. Haynes, J. L. and O. R. Neal. 1943. The effect of certain pasture practices on runoff and production of protective cover. J. Amer. Soc. Agron. 35:205-211.
4. Sharpley, A. 1995. Identifying sites vulnerable to phosphorus loss in agricultural runoff. J. Environ. Qual. 24:947-951.
5. Steele, K. W., M. J. Judd, and P. W. Shannon. 1984. Leaching of nitrate and other nutrients from a grazed pasture. N. Z. Jl. Agric. Res. 27:5-11.
6. Lambert, M. G., B. P. Devantier, P. Nes, and P. E. Penny. 1985. Losses of nitrogen, phosphorus, and sediment in runoff from hill country under different fertiliser and grazing management regimes. N. Z. Jl. Agric. Res. 28:371-379.
7. Cooper, A. B., C. M. Smith, and A. B. Bottcher. 1992. Predicting runoff of water, sediment, and nutrients from a New Zealand grazed pasture using CREAMS. Trans. ASAE 35(1):105-112.
8. Johnson, T. R., K. D. Johnson, M. J. Cecava, J. M. Jones, and C. E. Baker. 1995. Quality of surface and subsurface water draining intensively grazed pastures and adjoining cropland on three dairy farms in Indiana. Page 85 *in* Proc. 1995 American Forage and Grassland Council, Georgetown, TX.
9. Nelson, P. N., E. Cotsaris, and J. M. Oades. 1996. Nitrogen, phosphorus, and organic carbon in streams draining two grazed catchments. J. Environ. Qual. 25:1221-1229.
10. Fox, D. G., C. J. Sniffen, J. D. O'Connor, J. B. Russell, and P. J. Van Soest. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578-3596.
11. Russell, J. B., J. D. O'Connor, D. G. Fox, P. J. Van Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70:3551-3561.
12. Sniffen, C. J., J. D. O'Connor, P. J. Van Soest, D. G. Fox, and J. B. Russell. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci. 70:3562-3577.
13. O'Connor, J. D., C. J. Sniffen, D. G. Fox, and W. Chalupa. 1993. A net carbohydrate and protein system for evaluating cattle diets: IV. Predicting amino acid adequacy. J. Anim. Sci. 71:1298-1311.

14. Tylutki, T. P. and D. G. Fox. 1997. Application of the Cornell Nutrient Management Planning System: optimizing herd nutrition. Pages 54-65 *in* Proc. Cornell Nutr. Conf. Feed Manufacturers, Ithaca, NY.
15. INRA. 1989. Ruminant Nutrition. John Libbey Eurotext, Montrouge, France.
16. Pell, A. N. and P. Schofield. 1993. Computerized monitoring of gas production to measure forage digestion in vitro. J. Dairy Sci. 76:1063-1073.
17. Schofield, P. and A. N. Pell. 1995. Measurement and kinetic analysis of the neutral detergent-soluble carbohydrate fraction of legumes and grasses. J. Anim. Sci. 73:3455-3463.
18. Schofield, P. and A. N. Pell. 1995. Validity of using accumulated gas pressure readings to measure forage digestion in vitro: a comparison involving three forages. J. Dairy Sci. 78:2230-2238.
19. Kolver, E. S., M. C. Barry, J. W. Penno, and L. D. Muller. 1996. Evaluation and application of the Cornell Net Carbohydrate and Protein System for dairy cows fed pasture-based diets. Proc. N. Z. Soc. Anim. Prod. 56:251-254.
20. Sniffen, C. J. and J. Ferguson. 1993. Body Condition Scoring Guide. Church & Dwight Co., Inc., Princeton, NJ.
21. Stone, W. C., L. E. Chase, and C. J. Sniffen. 1992. Field application of the Cornell Net Carbohydrate and Protein System Model in a progressive dairy herd. Pages 168-179 *in* Proc. Cornell Nutr. Conf. Feed Manufacturers, Ithaca, NY.
22. Fox., D. G., M. C. Barry, R. E. Pitt, D. K. Roseler, and W. C. Stone. 1995. Application of the Cornell Net Carbohydrate and Protein Model for cattle consuming forages. J. Anim. Sci. 73:267-277.
23. Rayburn, E. B. 1994. Nutritional attributes and deficiencies of pastures. *In* Proc. Pasture Use in Modern Livestock Operations. Amer. Assoc. Bovine Practitioners, Rome, GA.
24. Holden, L. A., L. D. Muller, and S. L. Fales. 1994. Estimation of intake in high producing Holstein cows grazing grass pasture. J. Dairy Sci. 77:2332-2340.
25. Holden, L. A., L. D. Muller, T. Lykos, and T. W. Cassidy. 1995. Effect of corn silage supplementation on intake and milk production in cows grazing grass pasture. J. Dairy Sci. 78:154-160.
26. Muller, L. D., E. S. Kolver, and L. A. Holden. 1995. Nutritional needs of high producing cows on pasture. Pages 106-120 *in* Proc. Cornell Nutr. Conf. Feed Manufacturers, Ithaca, NY.
27. Muller, L. D., L. A. Holden, D. G. Fox, K. Hoffman, and L. E. Chase. 1998. Nutrition of grazing dairy cattle. Pages 51-74 *in* Proc. Grazing in the northeast: assessing current technologies, research directions, and education needs. NRAES-113, Cooperative Extension, Ithaca, NY.
28. Van Vuuren, A. M., C. J. van der Koelen, and J. Vroons-de Bruin. 1986. Influence of level and composition of concentrate supplements on rumen fermentation patterns of grazing dairy cows. Neth. J. Agric. Sci. 34:457-467.
29. Van Vuuren, A. M., F. Krol-Kramer, R. A. van der Lee, and H. Corbijn. 1992. Protein digestion and intestinal amino acids in dairy cows fed fresh *Lolium perenne* with different nitrogen contents. J. Dairy Sci. 75:2215-2225.

30. Holden, L. A., L. D. Muller, G. A. Varga, and P. J. Hillard. 1994. Ruminal digestion and duodenal nutrient flows in dairy cows consuming grass as pasture, hay, or silage. J. Dairy Sci. 77:3034-3042.
31. Olson, K. C., J. S. Caton, D. R. Kirby, and P. L. Norton. 1994. Influence of yeast culture supplementation and advancing season on steers grazing mixed-grass prairie in the Northern Great Plains: II. Ruminal fermentation, site of digestion, and microbial efficiency. J. Anim. Sci. 72:2158-2170.
32. Stockdale, C. R. 1994. Persian clover and maize silage. III. Rumen fermentation and balance of nutrients when clover and silage are fed to lactating dairy cows. Aust. J. Agric. Res. 45:1783-98.
33. Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant (2nd ed.). Cornell University Press, Ithaca, NY.
34. Fox, D. G., S. D. Klausner, T. P. Tylutki, and J. J. Hanshar. 1994. Cows, crops, and cash: making dairy farms sustainable. Pages 47-55 *in* Proc. Cornell Nutr. Conf. Feed Manufacturers, Ithaca, NY.
35. NRC. 1989. Nutrient Requirements of Dairy Cattle (6th Ed.). National Academy Press, Washington, DC.
36. Morse, D., H. H. Head, C. J. Wilcox, H. H. Van Horn, C. D. Hissem, and B. Harris, Jr. 1992. Effects of concentration of dietary phosphorus on amount and route of excretion. J. Anim. Sci. 75:3039-3049.
37. Klausner, S. D., D. G. Fox, T. P. Tylutki, W. C. Stone, L. E. Chase, and R. E. Pitt. 1996. Integrating knowledge to improve dairy farm sustainability – part II: Plant and animal nutrient management. Pages 23-45 *in* Dairy farm sustainability final report. Cornell Univ. Animal Science Mimeograph Series 188; ABEN Staff Report No. 96-1; ARME Research Bulletin 96-07; and SCAS Research Series 96-4, Ithaca, NY.
38. Chase, L. E. 1994. Environmental considerations in developing dairy rations. Pages 56-62 *in* Proc. Cornell Nutr. Conf. Feed Manufacturers, Ithaca, NY.
39. Klausner, S. D. 1993. Mass nutrient balances on dairy farms. Pages 126-129 *in* Proc. Cornell Nutr. Conf. Feed Manufacturers, Ithaca, NY.