APPLICATION OF THE CORNELL NUTRIENT MANAGEMENT PLANNING SYSTEM: OPTIMIZING HERD NUTRITION

T.P. Tylutki and D.G. Fox
Cornell Cooperative Extension and Department of Animal Science
Cornell University

INTRODUCTION

Nutrient management and the importance of integrating the crop and animal enterprises has been discussed at this conference several times in recent years (1, 2, 3). A major hurdle to the integration process has been the large and cumbersome amount of data that must be analyzed to develop a realistic whole farm nutrient management plan for a particular farm. While individual components exist to develop feeding programs and crop plans, little has been done to integrate these systems.

The Cornell Nutrient Management Planning System (CNMPS) is a suite of Microsoft Excel® spreadsheets developed by faculty and staff in the Departments of Soils, Crops and Atmospheric Sciences, Animal Science, Agricultural and Biological Engineering, and Cornell Cooperative Extension. The goal of the software is to integrate soil fertility, crop management, crop rotations, animal nutrition, economic, and engineering considerations into a viable nutrient management plan (4). The software consists of four integrated components: 1) calculating a mass nutrient balance, 2) evaluating and improving the animal feeding program, 3) evaluating and modifying crop rotations, and 4) developing a crop nutrient management plan.

Testing of software is a multi-step process. Towards the end of development, alpha testing is started by the developers under real-world conditions to determine if the software performs as desired. After this step, the software is beta tested by every-day users of the end-product to evaluate and identify problems with the software before general release. For the CNMPS, the first version and alpha testing has been completed and beta testing is scheduled to begin in early November. This paper describes the modifications made to the Cornell Net Carbohydrate and Protein System (CNCPS) for the CNMPS and the alpha test conducted with McMahon's EZ-Acres, a 500 cow dairy in Homer, NY.

PREDICTING HERD FEED REQUIREMENTS

The first step in developing an integrated nutrient management plan is to accurately predict the annual herd feed requirements. To achieve these objectives, the Cornell Net Carbohydrate and Protein System (CNCPS) (5) was modified to calculate herd feed requirements on an annual basis. First, the actual rations being fed are used to evaluate the current feeding program. This result is then used by the crop rotation spreadsheet to evaluate the current rotation. Any changes made to the crop rotation then need to be re-evaluated from the herd nutrition standpoint.

Since this is an iterative process, the software needs to communicate between components.

The modified CNCPS allows data for up to 12 groups of cattle to be saved. Two assumptions are made in the initial phases of developing a nutrient management plan: 1) the herd is in a steady-state condition (neither expanding nor reducing herd numbers), and 2) the rations being fed are representative of the whole year. Additional inputs are required by the modified CNCPS. These include: group name, number of animals in the group, level of refusals targeted, and number of days to feed (365 is the default to represent steady-state). In addition to the importance of nutrient management planning, the feed budgets calculated by the modified CNCPS can be used for other purposes including plans for expansion and risk management programs for commodity purchases.

PREDICTING HERD NUTRIENT EXCRETION

Since the majority of nutrients enter the farm as imported feed (3), optimizing herd nutrition and minimizing nutrient excretion are key steps in achieving the goals of the CNMPS. This section describes a submodel added to the CNCPS to predict manure production, nitrogen excretion, mineral balances, and excretion of phosphorous and potassium.

Calculating Manure Production

Manure production is calculated as the sum of fecal and urinary production, using values predicted by the CNCPS. Fecal production (kg/d) is calculated as:

$$((TFDM + EN + FMF) / 1000) / FDM$$

where:

TFDM = total fecal dry matter from indigestible feed, gms/d;
EN = endogenous nitrogen, gms/d;
FMF = fecal mineral flow from feed, gms/d; and
FDM = % dry matter of feces as calculated by the following:

if milk production < = 45.4 kg/d
FDM = (-.102 x milk production (kg/d) + 21.487) / 100
else,
16.85%

Using the data of Mertens (6), Morse (7), and Stone (8), an equation to predict urine production (kg/d) was developed:

$$(3.55 + .16 \times DMIA + 6.73 \times CPIA - .35 \times MILKA) \times AU$$

where:

DMIA = dry matter intake per animal unit, kg/d;
CPIA = crude protein intake per animal unit, kg/d;
MILKA = milk production per animal unit, kg/d; and
AU = animal units (Body weight, kg / 454).

Predicting Nitrogen Excretion

Nitrogen excretion is predicted by partitioning N excretion from the predicted N balance into feces and urine.

Fecal nitrogen (gms/d) is calculated as:

$$(FFN + BFN + MFN)$$

where:

FFN = fecal nitrogen from indigestible feed;
BFN = bacterial fecal nitrogen, primarily bacterial cell wall; and
MFN = metabolic fecal nitrogen.

Urinary nitrogen (gms/d) is calculated as:

$$(BEN + BNA + NEU + TN)$$

where:

BEN = excess bacterial nitrogen;
BNA = bacterial nucleic acids;
NEU = metabolizable nitrogen supply – net nitrogen use (i.e., inefficiency of use); and
TN = degraded tissue nitrogen.

Although results from the nitrogen balance calculations agree well with published experiments, complete validation of this component is needed.

Determining Mineral Requirements And Excretion

Mineral requirements are determined using INRA (9) requirements for macro-minerals (calcium, phosphorous, potassium, magnesium, sodium, and chlorine) and NRC (10) requirements for micro-minerals and vitamins. The INRA system was chosen for macro-mineral calculations due to its factorial approach. This system describes net macro-mineral requirements by physiological function (maintenance, lactation, growth, and pregnancy). The maintenance requirements are further partitioned into endogenous fecal and urinary losses. Varying transfer coefficients (based upon body weight or physiological state) are then applied to the net requirements to calculate dietary requirements.

The mineral section of the modified CNCPS can be used to evaluate mineral balances, calculate macro-mineral excretion, and optimize mineral utilization within groups. At the herd level, the mineral section predicts herd phosphorous and potassium excretion, efficiency of mineral use (product/input), and a mass nutrient balance for the feeding program.

USING THE CNCPS TO MINIMIZE NUTRIENT IMPORTS AND EXCRETION

Case Study Farm Description

McMahon EZ-Acres is a family owned dairy operation (three brothers in partnership) located near Homer, NY. In December 1995, the herd was moved to a new 500 cow free-stall from four tie-stall operations. Design of the new facility emphasized cow comfort. Since the herd has been in the new facility, milk production has increased steadily to its July 1997 average of 32.7 kg/day. In April 1997, 100 cows were purchased to bring milking cow numbers up to 500. The herd is milked 2x with no rbST. Tables 1 and 2 list cattle numbers, milk production, and other parameters from the June 12, 1997 test day. The farm is situated over an aquifer that provides the Village of Homer and the City of Cortland their drinking water.

Mass Nutrient Balance

The mass nutrient balance (3) was calculated for the farm for July 1, 1996 through June 30, 1997 is shown in Table 3. Klausner (3) has reported similar percentages of nutrients remaining within the farm boundary for herds of all sizes (77.3% for N, 67.5% for P, and 64.7% for K). Typically, two-thirds of imported nutrients come from imported feed with the remaining third coming from fertilizer (3). This herd, however, only imports 9.1%, 12.7%, and 0% of their N, P, and K, respectively from fertilizer. These low levels are accomplished by proper use of manure as a crop nutrient source. The farm has been working with a field crops specialist with Cornell Cooperative Extension for several years in an effort to establish a crop nutrient management plan. As various phases of the nutrient management plan have been implemented, the farm dramatically reduced use of commercial fertilizer with no yield loss.

Initial Analysis

The initial analysis utilized the current herd data summarized in tables 1 and 2 collected on the June 12, 1997 test day. Rations are balanced on a regular basis and are evaluated with the CNCPS. The high cow ration is 46% forage, well within acceptable guidelines. Intakes typically are higher than predicted, likely due to the high level of feedbunk management and cow comfort. Rations had been relatively stable the previous several months. Hay crop quality and amounts available from the 1996 crop year was less than ideal due to weather conditions during the growing season. For this reason, rations included other sources of non-forage fiber substitutes. This analysis did not include the hutch calves and younger transition heifers since they are fed a complete calf feed until approximately 150 kg. Older heifers in the transition group were included in the open heifer analysis. While this results in a slightly higher estimate of herd feed requirements, the number of cattle represented in this group is small enough to not influence the results greatly. Fresh and hospital cows were grouped together as well since they are fed the same ration. Weighbacks (from the lactating cows) fed to the open heifers were assumed to be the same composition as corn silage.

Table 1. Herd parameters used in the analysis.

Group	Number of head	Age (mo)	Days Pregnant	DIM	Lact. Number	Milk (kg/d)	Fat (%)	Protein (%)	Bodyweight (kg)	Condition Score
Hutch calves	44	1							55	
Transition heifers	64	4							100	
Open heifers	160	11							363	
Bred heifers	106	22	172						454	
Dry cows	100	45	253		2.1				636	
Fresh cows/ hospital pen	96	50	70	62	2.6	34.3	4.7	3.0	587	2.55
1st calf heifers	93	36	150	182	1.2	31.8	3.7	3.1	572	2.92
High cows	216	60	123	183	3.0	36.5	3.7	3.0	677	2.83
Low cows	43	60	157	332	2.5	19.1	4.2	3.4	726	3.59
Average/totals	922	37	173	197	2.4	32.7	3.9	3.1	654[1]	2.95[1]

[1]Averages are representative of lactating cows only.

Table 2. Rations fed at the case-study farm as of June 12, 1997.

Ingredient	Open heifers[1]	Bred heifers	Dry cows	Fresh/hospital	1st calf heifers	High cows	Low cows
Corn silage		.36	2.95	9.03	9.08	9.25	6.21
MML haylage						1.36	
Grass hay 14%				.91		.91	
Grass hay 11%	1.99	6.24	4.72		2.03		4.68
Corn meal			.23	2.72	3.48	2.92	1.60
Gluten feed	1.77	2.66		2.98	4.00	5.27	3.68
Cottonseed				.32	1.11	1.42	
Protein mix[2]			.59	3.77	3.26	4.10	1.83
Canola meal		.03	1.36	2.36	.80		
Minerals	.12	.14	.13		.10		.16
Weighbacks	3.86						

[1]Units are kg dry matter per day.
[2]The protein mix is a custom mix that includes minerals.

Table 3. Mass nutrient balance for the case-study herd.

Nutrients		Nitrogen	Phosphorus	Potassium	Units
Entering the farm					
	Grains	81.9	13.0	13.3	Mt/yr
	Forages	6.4	.8	5.6	Mt/yr
	Fertilizer	9.9	2.1	0	Mt/yr
	N fixation by legumes	9.7	0	0	Mt/yr
	Animal purchases	1.4	.4	.1	Mt/yr
	Total	109.3	16.3	19.0	Mt/yr
Leaving the farm					
	Grains	0	0	0	Mt/yr
	Forages	0	0	0	Mt/yr
	Fertilizer	1.4	.4	.1	Mt/yr
	Milk sales	21.3	4.3	6.4	Mt/yr
	Animal sales	2.1	.6	.2	Mt/yr
	Total	24.8	5.3	6.7	Mt/yr
Remaining		84.5	11.0	12.3	Mt/yr
		77.3	67.5	64.7	%
Enter farm as					
	Feed	80.8	84.8	99.4	%
	Fertilizer	9.1	12.7	0	%
	Purchased animals	1.3	2.5	.6	%

Tables 4 and 5 summarize the evaluation of the current feeding program. Predicted total milk production for the year is 5,597,538 kg. The rations were 54% purchased feed, typical for many dairy farms. This level of purchased feeds results in a large percentage of nutrients imported (74% for N, 77% for P, and 50% for K). This is in close agreement with others (3). The largest expense typically is feed costs. This farm has feed costs of $1,900/day, including both home-raised and purchased feeds. Table 4 shows only 36% of the N, 30% of P, and 22% of K fed are exported as milk or cattle sold, similar to other NY dairy farms (11). Manure production was predicted to be 39,078 kg per day, agreeing well with the manure production estimated in the crop nutrient management planning program (12), when wash water from the milking system and bedding are added.

Table 5 shows the predicted annual total herd feed requirements. The crop rotation evaluation by Kilcer (13) indicates this farm has not been able to produce all of the forage needs and much of the protein required by the cattle. Feeds such as corn gluten feed and canola meal are being used to substitute for high quality hay crops. As more feed is imported by a farm to meet protein requirements, phosphorous and potassium almost always are imported in quantities much higher than is required by the cows and crops (11). Management of this excess P and K is difficult given the limited land resources found on many farms (3). Accumulation of K in soils is linked with higher K concentrations in grass and legume crops, a concern for dry cow health.

Proposed feeding program

The goal of the re-analysis was to minimize purchased feeds to minimize nutrient imports. As shown in the evaluation of the current feeding program, this herd has been utilizing non-forage-fiber-substitutes to supplement marginal quality and quantities of hay crop silages. We concluded this farm has the potential to improve management of the hay crops to increase both yield and quality to allow for more home-grown forage to be fed while maintaining, or improving, milk production..

The proposed feeding program was designed to utilize high quality orchard-grass haylage. Table 6 shows the amounts of feed required for the herd with this new feeding program. Due to manure spreading in previous years, the production of a low K, high quality grass hay for dry cows is not feasible. It is assumed that dry cow hay will be purchased from a neighboring crop farm that has not had manure applications for many years (Table 6 column labeled Grass hay 14%). Only small changes were made in the amounts of corn silage, cottonseed, and protein mix fed to the herd. These minor changes were made to the lactating cow rations to balance ration protein levels. The amount of corn meal required for the new feeding program is 32% higher than the current one. Although an imported feed, its content of N, P, and K is much smaller than the high protein concentrates currently fed. The additional corn meal was required to improve energy balances in high cow and the bred heifer groups (to increase ADG to CNCPS predicted optimal levels). The new program completely eliminates corn gluten feed and canola meal. Ration cost was decreased $110 per day ($40,150 annually) by this change.

From a nutrient management point of view, this change has dramatic implications (Table 7). Milk production remained constant, however the percent of the ration that is home raised was increased to 78% from 46%. By decreasing the amount of feed purchased, the amounts of N, P, and K imported were also decreased dramatically, as shown in the average percent purchased line of tables 4 and 7. The average percent purchased N was decreased 55%, P was decreased 48%, and K was decreased 82%. Efficiencies of nutrient utilization were similar between the current and proposed feeding systems; the benefit is a higher degree of nutrient recycling within the farm boundary. Manure production was increased 10% due to the higher forage intake of the herd resulting in higher indigestible feed dry matter.

Table 4. Evaluation of the nutrient impact of the current feeding program.

Herd Analysis				
	Total milk production		5,597,538	kg per year
	Avg. milk production of lactating cattle		34.2	kg/cow/day
	Avg. gain of growing cattle		.36	kg per day
	Avg. wt of all cattle		526	Kg
Rations	Avg. percent raised		46%	
	Avg. percent purchased		54%	
	Avg. ration cost per cwt milk		$ 4.74	
	Avg. ration cost per kg Gain		$ 19.12	
	Total ration cost of herd		$1,900.46	/day
			$694,142	/year
Nutrients		N	P	K
Avg. percent purchased		74%	77%	50%
Excreted	kg/year	91,662	19,764	51,862
Urinary	kg/year	41,783	375	33,331
Fecal	kg/year	49,878	19,388	18,531
Product	kg/year	32,596	6,004	11,299
Efficiency of nutrient use		36%	30%	22%
Manure			Kg/day	
Predicted Total Manure		39,078		
Predicted Fecal		22,913		
Predicted Urine		16,164		

Table 5. Annual herd feed requirements with the current feeding program.

Group	Corn silage	Grass 14%	hay Grass 11%	hay Cottonseed	Corn meal	Protein mix	Minerals	Canola meal	MML haylage	Gluten feed	Grand Total
Open heifers	316[1]	0	163	0	0	0	9.6	0	0	143	632
Bred heifers	14	0	242	0	0	0	5.4	1	0	102	364
Dry cows	108	0	172	0	0	21	12.4	48	0	0	362
Fresh/hospital cows	317	32	0	11	96	131	.0	80	0	103	770
1st calf heifers	308	0	69	36	120	109	3.1	26	0	134	807
High cows	730	72	0	108	233	319	.0	0	99	411	1972
Low cows	98	74	0	0	25	28	2.4	0	0	57	284
Grand Total	1890	177	646	155	475	609	33.0	156	99	951	5190

[1]Units are metric tons DM/yr.

Table 6. Whole herd feed requirements for the proposed feeding program.

Group	Corn silage	Grass 14%	hay Cottonseed	Corn meal	Protein mix	Minerals	Intensive Grass	Grand Total
Open heifers	316[1]	0	0	0	0	9.6	308	633
Bred heifers	184	0	0	0	0	5.4	176	365
Dry cows	108	109	0	50	87	12.4	0	366
Fresh/hospital cows	317	0	11	129	143	.0	175	774
1st calf heifers	308	0	36	120	109	3.1	232	809
High cows	730	0	108	306	249	.0	595	1987
Low cows	98	0	0	25	28	2.4	131	285
Grand Total	2060	109	155	630	615	33.0	1617	5219

[1]Units are metric tons DM/yr.

Table 7. Evaluation of the nutrient impact of the proposed feeding program.

Herd Analysis			
	Total milk production	5,597,538	kg per year
	Avg. milk production of lactating cattle	34.2	kg/cow/day
	Avg. gain of growing cattle	.39	kg per day
	Avg. wt of all cattle	526	Kg
Rations	Avg. percent raised	78%	
	Avg. percent purchased	22%	
	Avg. ration cost per cwt milk	$ 4.33	
	Avg. ration cost per kg. gain	$ 17.15	
	Total ration cost of herd	$1,790.22	/day
		$653,877	/year
Nutrient	N	P	K
Avg. percent purchased	33%	40%	9%
Excreted kg/year	94,249	15,507	74,026
Urinary kg/year	37,037	352	51,059
Fecal kg/year	57,212	15,155	22,967
Product kg/year	32,791	6,068	11,314
Efficiency of nutrient use	35%	39%	15%
Manure	Kg/day		
Predicted Total Manure	42,999		
Predicted Fecal	25,650		
Predicted Urine	17,349		

Table 8 summarizes the effects of ration changes for the high cow production group. Overall, the amount of ration protein was decreased but more protein is being derived from microbial sources. Following the decrease in protein intake, predicted MUN decreased 20%. Amino acid allowable milk is increased, primarily due to the increased microbial protein supply. The current ration is high in corn protein and the first limiting amino acid is lysine. The proposed ration is lower in corn protein and the first limiting amino acid is now methionine. Cost was reduced nearly $.80 per 45.4 kg milk. The proposed ration is 66% forage, higher than most at this level of milk production. We believe that with the excellent feedbunk management on this farm, this ration will support the same level of milk production.

We conclude that the CNCPS is a vital component of the CNMPS and both the modified CNCPS and the CNMPS require further testing on herds throughout New York. The whole herd CNCPS can be used to evaluate the herd from a nutrition and nutrient management standpoint. A thorough understanding of ruminant nutrition and the CNCPS is required. Errors in dry matter intake or ration formulas entered for each group of cattle will invalidate the annualized whole herd analysis. However, we have shown that it is possible to decrease the amount of purchased feed and thus nutrient imports using the CNCPS (14) and all of the recommendations for using the CNCPS with a herd are still relevant.

The proposed analysis requires a major change to the cropping system and management of this operation. In order to determine if such a change is feasible,

the other components of the CNMPS need to be used as described by Bannon and Klausner (12) and Kilcer (13). If it is determined that such a change is not feasible, other ration alternatives need to be evaluated.

Table 8. Summary of ration characteristics for the current and proposed ration (balanced for 36.3 kg milk per day at current DMI).

Component	Base analysis	Proposed analysis	Units
DMI	25.4	25.4	kg/d
Forage in ration	11.5	16.8	kg/d
ME balance	12.0	10.0	Mcal/d
MP balance	811	591	gms/d
ME allowable milk	46.8	46.8	kg/d
MP allowable milk	53.9	49.1	kg/d
AA allowable milk	35.3	38.5	kg/d
MP from bacteria	1469	1573	gms/d
MP from UIP	1899	1590	gms/d
Predicted MUN	25	20	mg %
Urea cost	2.09	1.07	Mcal/d
Diet CP	19.8	17.9	% DM
DIP	56	58	% CP
SIP	36	35	% CP
NFC	36	38	% DM
NEl	1.78	1.72	Mcal/kg
Rumen pH	6.32	6.46	
Cost	4.88	4.19	$/45.4 kg milk

Link Moore's negative UFL to this

IMPLICATIONS

The Cornell Nutrient Management Planning System is a integrated suite of software to assist in whole-farm nutrient management planning. It is our first attempt to develop field usable software that integrates the animal with the cropping system. A team of consultants must work together as each component requires a high degree of competency by the user This modified version of the CNCPS is a critical part of the system. The modified version of the model allows for groups of cattle to be evaluated independently and then whole herd parameters evaluated. As we move further into the whole farm nutrient management arena, tools such as this will be required to assist farm consultants.

REFERENCES

1. Pell, A.N. 1992. Does Ration Balancing Affect Nutrient Management. Proc. Cornell Nutr. Conf. p. 23.
2. Pell, A.N. 1993. Environmentally Friendly Rations. Proc. 1993 Feed Dealer Seminars. p. 9.
3. Klausner, S.D. 1993. Mass Nutrient Balances on Dairy Farms. Proc. Cornell Nutr. Conf. p. 126.
4. Tylutki, T.P. and S.D. Klausner. 1995. The Cornell Nutrient Management Planning System. 1995 Agronomy Abstracts. p. 258.

5. Fox, D.G. and M.C. Barry. 1994. Using Whole Animal Models to Evaluate and Refine Cattle Diets Under Widely Varying Conditions. Proc. of IVth Inter. Workshop on Modelling Nut. Util. in Farm Animals. p. 143.
6. Mertens, D.R., V.A. Wilkerson, and D.P. Casper. 1994. Nirogen Excretion of Holstein Cattle. J. Dairy Sci (abs.) 72:353.
7. Morse, D. 1994. Manure Production from Primiparous and Multiparous Lactating Holstein Cattle. J. Dairy Sci. (abs.) 72:151.
8. Stone, W.C. 1996. Applied topics in dairy cattle nutrition: 1) Soyhulls as either a forage or concentrate replacement in early lactation Holstein dairy cattle, 2) Evauluation of the Cornell Net Carbohydrate and Protein Sstem's metabolizable protein requirement and supply in Holstein dairy cattle, 3) in vitro effects of lipids on fermentatin systems. PhD Thesis, Cornell Univ.
9. Institut National de la Recherche Agronomique. 1989. Ruminant Nutrition. John Libbey Erurtext, Montrouge, France.
10. National Research Council. 1989. Nutrient Requirements of Dairy Cattle, 6th revised edition. National Academy Press, Washington DC.
11. Tamminga, S. 1992. Nutrition management of dairy cows as a contribution to pollution control. J. Dairy Sci. 75:345.
12. Bannon, C.D. and S.D. Klausner. 1997. Application of the Cornell Nutrient Management Planning System: Predicting Crop Requirements and Optimum Manure Management. Proc. Cornell Nut. Conf.
13. Kilcer, T.F. 1997. Application of the Cornell Nutrient Management Planning System: Optimizing Crop Rotations. Proc. Cornell Nut. Conf.
14. Stone, W.C., L.E. Chase, and D.G. Fox. 1992. Field Application of the Cornell Net Carbohydrate and Protein System Model in a Progressive Dairy Herd. Proc. Cornell Nutr. Conf. p. 168.