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Using a nutrition model to implement the NRCS Feed Management Standard to reduce the environmental impact of a concentrated cattle feeding operation

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Abstract

Environmental hurdles to sustainable livestock production

Livestock farms are under increasing pressure to reduce manure nutrient excretions and nutrient accumulation on agricultural land in order to meet environmental regulations. To date, nutrient management regulations in New York (NY) and other states in the US have addressed the Clean Water Act through implementation of the National Resource Conservation Service (NRCS) 590 standard for nutrient management on farms with concentrated animal feeding operations (CAFO). The NRCS 590 standard focuses on reducing risk to water quality as the result of over-application of fertilizer and manure, and prevention of direct manure losses to our streams and lakes; this is accomplished through the use of the phosphorus (P) runoff index, the nitrate leaching index, and land grant university crop nutrient guidelines.

Unfortunately, current nutrient management planning efforts do little to reduce importation and subsequent loading of nutrients onto farms and watersheds. Recently, the USDA-NRCS has identified the need to reduce manure nutrients through improved feed management on farms with animal feeding operations, and have developed a national standard (NRCS 592) to be used as part of the nutrient management planning process (NRCS USDA, 2003). The purpose of a feed management plan as described in the national NRCS 592 standard is: 1) to supply the quantity of available nutrients required by livestock while reducing the quantity of nutrients excreted, and 2) improve net farm income by feeding nutrients more efficiently.

Livestock feeding and management systems and environmental issues vary from state to state. In some states, the predominant livestock enterprises are commercial swine or poultry operations; in others it is commercial beef and/or dairy operations. In some regions, cattle are kept primarily in dirt lots; in others, they are completely confined to barns. Feed source ranges from all home grown with adequate land to re-cycle the nutrients to all purchased with the manure being spread on land in crop farms in the area. Environmental priorities range from protecting public drinking water sources to emission control. Therefore each state NRCS modifies the national 592 standard to address the specific issues in their state. The NY NRCS 592 Standard (NY NRCS USDA, 2005) was developed through collaboration between NY NRCS and faculty and staff at Cornell University to address our primary environmental concerns; the risks to air and water quality in our state due to the large positive N and P balances on NY dairy farms. Because most dairy farms in the Northeast import most of their concentrates, mass nutrient balances indicate more than two-thirds of the N, P and K imported each year as purchased feed and fertilizer are not exported off of the farm in saleable products (Klausner, 1993; Tylutki and Fox, 1997; Klausner et al., 1998; Cerosaletti et al., 2003). In an in depth study of nutrient flows on a NY dairy farm, 72% of the mass balance N (i.e. the surplus between imports through feed, fertilizer and N fixation and exports through milk and animals sold) was projected to escape into the off-farm environment (Hutson et al., 1998). About 12% of this excess N was predicted to leach into the groundwater and 64% was predicted to be lost through volatilization/denitrification. A water monitoring program on this farm indicated the concentration of N and P averaged 14.4 mg/L nitrate N and 0.4 mg/L of total P from early spring through fall (Hutson et al., 1998). These levels exceeded the federal water quality standard for groundwater (10 mg/L N and 0.10 mg/L). This data indicates nutrients can reach ground and surface water from the dairy farm through both surface runoff and leaching. On another NY dairy farm, where all concentrate feeds had been imported and milk production increased by 44% over a 15 year period, nitrate concentration in neighboring well water increased 54% and soil test P increased from 3 to 14 mg/kg (Wang et al., 1999). These increased losses were attributed to high mass balances of N and P and it was recognized that losses could be significantly reduced if fewer nutrients were imported onto the farm in the first place.

Thus, the NRCS 590 Nutrient Management Standard alone does not address the risk to water quality as the result of high mass balances of N and P on dairy farms in NY. In the past 20 years, soil test P levels of NY agricultural fields testing high or very high in P have increased from 26% to almost 50% falling into that category (Ketterings et al., 2005). In addition, new concerns about air emissions from livestock operations (NRC, 2003) and regulation of them indicate the excess N that is volatilized from our dairy farms must be addressed. Environmental policy to address these concerns and highly variable margins are requiring major changes on dairy farms, and is threatening their sustainability.

The NY NRCS 592 Feed Management Standard (NY NRCS USDA, 2005) reflects results of our research in developing herd feed management plans that will help our livestock farms get over the environmental hurdle of excess farm nutrient accumulations while reducing feed costs. The objective of this paper is to use NY as a case study to describe how we envision nutrition models can be used to implement the NRCS 592 Feed Management Standard in a concentrated cattle feeding operation to reduce their environmental impact in a cost effective way. We decided the case study approach would make more of a contribution to the goals of this conference than a general discussion of modeling environmental impacts at the system scale, since it involves the linking together of key aspects of a system needed to make an impact on a statewide basis. Included are collaboration between NRCS and the land grant university to develop state feed management standards that will address their specific environmental issues in the most effective way, model development and modification to implement those standards, and on farm evaluation of its effectiveness.

The NY NRCS Feed Management Standard

The NY NRCS Feed Management Standard states that diets shall be developed in accordance with standards outlined in the most current National Research Council (NRC) or recommendations based on the land grant university (Cornell). Laboratory analysis shall be done on the feed ingredients used to formulate the diet according to NRC and Cornell recommendations, and on the formulated diet to determine the accuracy of feeding management to deliver the diet. Feed analysis shall be conducted as often as necessary to adjust the diets for changes in chemical composition of the feeds fed. Feed and manure analysis will be conducted by laboratories whose tests are accepted by Cornell. It further states that one or more of the following feed management practices and/or technologies shall be used to reduce N, P and other excreted nutrients while maintaining the health, well-being, and productivity of the animal (listed are those that apply to dairy and beef cattle):

- Formulate diets closer to animal requirements, complemented by feed management that results in grouping animals closer to requirements and consistent delivery of the formulated diets to the correct group of animals.
- Reduce protein in the diet by formulating diets to meet rumen nitrogen and animal amino acid requirements.
- Manipulate the crude protein and energy content of the diet to enhance the availability of amino acids.
- Reduce phosphorus in the diet to NRC recommendations by reducing supplemental phosphorus.
- Use selected enzymes or other products recommended by the land grant university to enhance feed digestibility or feed use efficiency.
- Use growth promotants recommended by the land grant university as allowed by law.
- Implement phase feeding.
- Use other feed management or diet manipulation technologies recommended by the land grant university that have demonstrated the ability to reduce manure nutrient content.
- Consider the potential impact of using different combinations of feed ingredients on the nutrient content of excreted manure.
- Consider the potential impact of feed management on the volume of manure excreted on manure storage requirements.
- Maximize use of feeds grown on the farm to minimize the quantity of nutrients imported to the farm, and to maximize the recycling of nutrients on the farm.

We define <u>precision feeding</u> as the implementation of the practices outlined above in the NRCS Feed Management Standard; precision feeding is a site-specific practice that involves accurate diet formulation and delivery to each group of animals in the herd, and evaluating and improving the feeding program on a specific farm on a daily basis. Starting with the initial evaluation of what the nutrient status of a herd is through implementation of a precision feeding program requires information specific to that farm, group, and animals. Examples of site-specific data include: average and range in animal body weight and production (milk or growth) in each group at different times of the year, feed requirements by each group and available to them at different times of the year, current detailed feed analysis on the carbohydrate and protein fractions in each feed ingredient and their variability, and environmental factors such as temperature and wind exposure, distance walked by the cattle, and breed type.

Model used for precision feeding in support of the NY NRCS Feed Management Standard

To implement all of the practices summarized in the NY NRCS Feed Management Standard, Cornell recommends the use of a nutrition model designed for precision feeding that can address all of these practices. The Cornell Net Carbohydrate Protein System (CNCPS) is a ruminant nutrition model we have developed over the past 25 years to accurately predict dairy, beef cattle and sheep requirements and nutrient supply based on animal, environmental, and feed compositional information in site specific production situations (Fox et al., 2004; Cannas et al., 2004). The CNCPS integrates NRC (2000, 2001) and other published animal requirement equations with sub-models to predict rumen fermentation, nutrient excretion and annual feed requirements for each group and for the herd. Predicted animal requirements account for different physiological states (lactation, pregnancy, and growth), body reserves and environmental effects. The CNCPS uses feed carbohydrate and protein degradation and passage rates to predict extent of ruminal fermentation, microbial protein production, post-ruminal absorption, and total supply of metabolizable energy and protein to the animal. In the decade of the 90's, we developed versions that could be used for precision feeding on a herd basis, including the formulation of rations for all groups of cattle on the farm in the same file to predict nutrient excretion and individual feed requirements for each group and the entire herd. The level of aggregation of equations were chosen based on the level of complexity that could be used effectively given the inputs available in most dairy and beef cattle production operations to drive the equations.

An important part of choosing a model for precision feeding is to determine how well it has been evaluated with both experimental and on farm data collected under conditions where it will be applied. Our evaluations of the CNCPS model were summarized by Fox et al. (2004). In an evaluation with individually fed growing cattle, the CNCPS accounted for 89% of the variation in ADG with a 7.4% underprediction bias. When the CNCPS was evaluated with data from individual dairy cows where the appropriate inputs were measured and changes in energy reserves were accounted for, the CNCPS accounted for 90% of the variation in actual milk production of individual dairy cows with a 1.3 % bias. Over the past 15 years, the CNCPS has been used successfully on beef and dairy cattle farms to evaluate and formulate site-specific rations and herd nutrient excretion and feed requirements. The nutrient excretion predictions are used to evaluate alternative herd feeding programs that can minimize N and P losses. The feed requirements are used in allocating home grown feed inventories across the groups in the herd for best use of the nutrients they contain. In case studies on dairy farms in NY, implementation of precision feeding with the CNCPS has reduced N and P excreted about 1/3, while reducing feed costs $50 to $150/lactating cow/year. Feeding consultants using the CNCPS report that with accurate inputs, the CNCPS can predict actual daily milk produced to within 1 to 2 lb., and typically report 2 to 4 lb. more milk produced/cow/ day. This gives us confidence to proceed more aggressively with recommending that it be used to implement the NY NRCS 592 Feed Management Standard.

To meet the need for site-specific diet formulation, the CNCPS model predicts the following:

Prediction of animal energy and amino acid requirements and energy reserves fluxes based upon site-specific information (e.g. environment, activity, level of production, stage of production, body condition scores).

1. Prediction of forage level in the diet that can be fed while meeting the target production level as well as provide the fiber intake needed in the diet to maintain an optimum rumen pH. Feed specific values are used for this prediction, including the percentage of neutral detergent fiber (NDF), degree of lignification of the NDF, and particle size. This NDF value is called physically effective NDF (peNDF), and represents the percentage of the NDF in the feed that is effective in stimulating chewing and rumination.
2. Prediction of energy feeds needed along with the forage to meet target growth rates or milk production levels.
3. Prediction of microbial protein synthesized as the result of fermenting the sugars, starch, and fiber in each feed in the diet to meet the energy and fiber requirements.
4. Prediction of the N in the form of ammonia and amino acids that are required and will be available for microbial growth on feed carbohydrates.
5. Prediction of the amino acids in feed protein that will escape degradation in the rumen but will be digested in the small intestine.
6. Prediction of feeds high in N sources needed to meet deficiencies in (a) degradable "protein" (urea or natural protein) and (b) amino acid requirements of the animal that are not met by the microbial protein and protein in the energy feeds that is digested in the small intestine.

To make these predictions, feed content of carbohydrate (starch, sugars, NDF, lignin) and protein fractions (total, soluble, and unavailable, amino acid profile) and their digestion rates along with fat and ash content must be determined.

Example applications of the CNCPS model to reduce the environmental impact of concentrated cattle operations

Precision feed management to reduce whole farm nutrient balances. A case study was conducted on a 500 cow commercial dairy farm with 1075 acres of tillable land over a 5 yr period to evaluate the impact of developing and implementing a feed management plan designed to improve environmental and economic sustainability (Tylutki et al., 2004). This farm was chosen as a case study because it is located on a valley floor above an aquifer that supplies the drinking water for approximately 500 people. Additionally, a naturally stocked brown trout stream runs the length of the valley floor and is closely monitored by the New York State Department of Environmental Conservation. Specific goals included the development of a system for precision feed management to reduce mass farm N and P balances while improving farm profitability. Critical components were the development and implementation of plans for herd nutrient management (CNCPS model) and crop, soil, and manure nutrient management (Cornell Cropware). Implementation of precision feed and herd management resulted in increases in animal numbers (26%), milk per cow (9%), and total milk sold daily (45%) and decreases in purchased feed cost (48%), feed cost/lb of milk sold (52%), total manure nitrogen (17%) and phosphorus (28%) excretion and loading rates/acre. These results were attributed to improvements in forage production, quality, and storage (38% increase in proportion of diets homegrown), and precision feeding of high forage diets designed and monitored with the CNCPS. Details are in Tylutki et al. (2004).

Identifying approaches for reducing P loads in the watershed of a major water source for New York City. In the New York City Watershed, phosphorus has been identified as a major pollutant of concern in the Cannonsville Reservoir Basin, due to its impact on water quality and the subsequent economic challenges of addressing phosphorus issues (Cerosaletti et al., 2003). The reservoir, located in Delaware County, NY, is identified at the state and federal levels as impaired, due to high levels of phosphorus, and is subject to a TMDL for phosphorus. TMDL regulations place severe limitations on economic development in the Cannonsville basin, an area containing several of Delaware County's largest industries. Cerosaletti et al. (2004) used the CNCPS model to investigate and implement dietary strategies in commercial dairy herds in the Cannonsville Basin to reduce dietary P intake in lactating dairy cattle, reduce imported feed P, and reduce manure P. Cerosaletti et al. (2003) reported achieving a 28% reduction in feed P imports, a 33% reduction in manure P content, and a 50% reduction in the amount of P remaining on the farms. Mass P balance (amount of P remaining on the farm as % of P imports) was reduced from 60% to 42%. They concluded that if a 20% reduction in purchased feed P intake was achieved on every mature cow in the Cannonsville Reservoir Basin, this could reduce the amount of feed P imports into the basin between 141,120 and 160,965 lb annually. Manure P excretion would be reduced by a similar amount. The magnitude of these reductions is substantial when compared to the total annual average TMDL allowed P load to the Cannonsville Reservoir of 110,000 lb. Presently, Delaware County is implementing a precision feeding program on dairy farms in both the New York City and Susquehanna River Basin watersheds in the county. This program integrates the use of the CNCPS model in evaluating diets, developing alternative ration strategies, and predicting manure nutrient excretions and feed nutrient import reductions. These are critical steps in quantifying the impact of precision feeding as a best management practice. The CNCPS is integrated in this program as part of a comprehensive feed management planning and implementation process that seeks to reduce nutrient accumulations on dairy farms, manure nutrient excretions, as well as improve farm economic viability through improved homegrown feed production and formulation and delivery of precision rations.

Predicting ammonia emissions from dairy herds. Concerns about ammonia losses to the atmosphere are increasing (NRC, 2003). Therefore, we can expect to see increased emphasis in nutrient management planning on reducing nitrogen losses to the atmosphere from livestock operations. Hutson et al. (1998) found that large amounts of N were volatilized on a dairy farm, and occurred at many points between excretion and land application.

A website (www.dairyn.cornell.edu) was developed in collaboration with USDA ARS Beltsville to provide guidelines for reducing N balances and losses to water and air on dairy farms. A simple model based on CNCPS equations is provided to estimate herd N excretion and volatilization losses with number of different cattle in each of lactating, dry, and replacement heifer groups, diets fed, and different levels of milk production. The CNCPS was used to predict nitrogen excretion values and ammonia losses under different combinations of diet protein levels, herd structure, and milk production.

Table 1 shows CNCPS model predictions of N excretion from data collected in 46 dairy herds in NY, using nitrogen content of feeds, dry matter intake, body weight, and milk production and milk protein content.

Table 1. Estimated average nitrogen excretion for lactating cows in 46 commercial dairy herds in New York[1]

Item	Average	Minimum	Maximum
Milk, lb/day	85.5	54	118
DMI, lb/day	50.3	38	63.4
Ration CP	17.9	15.3	20.5
N intake, g/day	653	496	897
Milk N, g/day	188	119	260
N intake converted to milk N, %	*28.8*	*21.4*	*35.8*
Total N excreted, g[2]	460	336	624
N excretion, % of N intake	*70.4*	*63.5*	*82*
Fecal N, g[2]	252	183	320
Urinary N, g[2]	207	150	304
Urinary N, % of total	*45*	*37*	*50*

[1]L. E. Chase. 2004 (personal communication).
[2]Predicted with the CNCPS model.

This table indicates that total N excreted and urinary N is highly variable between farms. The CNCPS model predicted that on average, 28.8% of the N consumed is converted to Milk N by lactating dairy cows in these herds, which agrees with milk N efficiencies measured in nitrogen balance trials summarized by Jonker et al. (1998; 28%) and by Chase (2003; 27%). Thus we believe the CNCPS can predict total N excretion with an acceptable accuracy in these herds, indicating we can use it to make site-specific predictions of nitrogen excretion. This table shows the Milk N efficiency ranged from 21 to 35% across these herds. The amount of N excreted varied with the level of milk production, because N intake increases as the demand for nutrients increase when milk production increases, yet the efficiency of total N utilization increases due to the dilution of non-productive uses (maintenance). About 37 to 50% of the N excreted by lactating dairy cows is in the urine (table 1). A high proportion of the urinary N is in the form of urea, which can be degraded to ammonia by the urease enzyme in the manure on the barn floor, and thus is the primary source of N emissions from a dairy barn. The % of the total N that is excreted in the urine will increase as protein intake in excess of requirements increase, because most of the excess N is converted to urea during metabolism and is excreted in the kidneys.

In addition to herd size, the nitrogen excreted by a dairy herd is a function of several factors, including: 1) the level of milk production of the herd, 2) the proportion of the total dairy cattle in the herd that are dry cows and heifers, 3) the amount of excess protein in the rations, and 4) the balance between carbohydrates and proteins fed. Table 2 shows the effect of each of these variables on N excreted for a 100 lactating cow dairy herd, based on projections with the CNCPS model, using data from the Tylutki et al. (2004) case study described previously.

Table 2. Total N produced (lb/year) by a 100 lactating cow dairy herd[1]

	Balanced ration protein[2]							
	Total N		Fecal N		Urinary N		N efficiency[3]	
Lb. milk/cow milked/day	25% cull rate	50% cull rate	25% cull rate	50% cull rate	25% cull rate	50% cull rate	25% cull rate	50% cull rate
60	47150	51279	29250	31882	17900	19396	22	21
80	50864	60293	31156	37071	19707	23222	25	23
100	55663	65092	33213	39128	22449	25964	27	25
	Excess ration protein[4]							
60	54540	63969	29257	35171	25283	28798	19	18
80	57676	67106	31163	37077	26514	30029	23	21
100	60260	69690	33218	39133	27042	30557	25	24

1Based on the case study of Tylutki et al., (2004). On an average day, for each 100 cows milking, the herd was assumed to have 20 cows dry, and 60 heifers if the cull rate is 25% and 120 heifers if the cull rate is 50%. The cows were assumed to have a mature body weight of 1500 lb. and the milk contained 3.3% protein and 4% fat. Four groups of heifers were maintained (pre-puberty, breeding age, early bred and late bred) and rations were formulated to meet target growth rates to calve at 22-24 months of age and meet a target pre-calving weight of 85% of mature weight. All diets were based on feeds commonly utilized on Northeast dairy farms, including corn silage, alfalfa silage, corn meal, soybean meal, treated soybean meal, whole cottonseed and corn gluten meal.

[2]Balanced ration protein: diets for all groups in the herd were computed with the CNCPS model (Fox et al., 2004) in which rumen N and peptides, metabolizable protein, lysine and methionine requirements were met, with only small positive balances.

[3]Efficiency is the percentage of intake N for the herd that is synthesized into animal products (milk N + fetal N + growth N).

[4]Excess ration protein: 3 x the SD for CP (2.61 percentage units) reported by Chase (2004) for 46 dairy herds in New York was added as soluble protein to the balanced rations. This can occur due to several factors, including excessively high soluble protein in the forage or adding a high CP safety factor to account for large variations in feed composition or requirements of animals in a group.

The following conclusions can be made from the information shown in table 2.

1. Nitrogen excretion increases as milk production increases. However, the efficiency goes up also because more milk N is produced relative to the fixed costs of maintaining the herd.
2. Nitrogen excretion per 100 milking cows increases as more heifers have to be raised when cull rate increases.
3. Excess protein in the ration adds to the nitrogen excretion, and usually adds to cost of the ration. Managing the feeding program to reduce solubility of the protein in the silages, grouping cattle according to requirements, and reducing variability in the protein content of the feeds fed will allow less protein to be fed.

As indicated previously, a growing concern by regulatory agencies is the amount of the N excreted that is volatilized in concentrated cattle feeding operations. Factors that affect % of N in manure that is volatilized in the barn and lost as ammonia include temperature, ammonia concentration, pH, wind speed and depth of manure on the barn floor (T.H. Misselbrook, personal communication and Hutson et al., 1998). The estimates in table 3 were made based on data collected on a dairy farm in central NY by Hutson et al. (1998), which account for the primary factors of scrape interval and temperature. This table shows that the longer the manure lays on the barn floor and the higher the temperature, the greater is the % that will be volatilized.

Table 3. Estimates of % of N in dairy manure that is volatilized on the barn floor[1].

	Barn temperature, degrees F			
Scrape interval, hr	68	Annual average	50	40
6	10	4	1	0
12	19	8	2	1
24	35	16	5	2
48	38	20	10	5
72	39	22	14	6

[1]Hutson et al., 1998.

These percentages applied to the values in table 2 divided by 365 give an estimate of N lost as volatilized ammonia daily per 100 lactating cow dairy herd (table 4). For example, table 4 gives an estimate for the annual average temperature with an average scrape interval of 12 hr.; these values would be halved or doubled for a scrape interval of 6 or 24 hr., respectively.

Table 4. Estimated daily N volatilization losses (lb/day) on the barn floor per 100 lactating cow dairy herd.[1].

	Balanced ration protein			
	25% cull rate		50% cull rate	
Milk, lb./day	Total N excreted, lb./day	N volatilized, lb.	Total N excreted	N volatilized, lb.
60	129	10.3	140	11.2
80	139	11.1	165	13.2
100	153	12.2	178	14.3
	Excess ration protein			
60	149	12.0	175	14.0
80	158	12.6	184	14.7
100	165	13.2	191	15.3

[1]Based on the assumptions and total N excretion values in table 2 and a scrape interval of 12 hr. (8% volatilized) shown in table 2.

Summary of recommendations for herd feed management plans for concentrated cattle feeding operations to reduce N and P losses to the environment

We have learned from our experiences with implementing the CNCPS model on farms that the use of appropriate nutrition models as part of a feed management plan can have a large impact on reducing nutrients in manure. We recognize all components in our approach to feed management will not apply to all situations in all states with concentrated cattle feeding operations. However, we believe that most effective feed management plans should have three components;

- Precision diet formulation to reduce purchased nutrients, manure nutrients, and volatilization losses of N,

- Improved homegrown feed production storage (minimize wasted/loss inventory) and feeding management, and
- Improved formulation to more closely match herd requirements with feeds grown on land where the manure nutrients can be re-cycled.

Implementation of a herd CNMP must be done so that milk production, growth, reproduction, and animal health are not compromised. These methods revolve around two areas: 1) decreasing nutrients brought on the farm by more accurately formulating rations based on farm specific animal requirements and feed content of carbohydrates, protein fractions and P, and 2) improving the efficiency of nutrient utilization through improved feed and crop management strategies that aim to increase nutrient recycling (utilization) within the farm boundary.

Short-Term Strategies

1. *Formulate farm and group specific rations*. Tylutki (2002) demonstrated the impact of inaccurate ration formulation and quality control on variation in milk production and income. Based on these and other studies, we believe nutrition models such as the CNCPS will be utilized in the future to accurately predict farm specific animal nutrient requirements, absorbed nutrients from each feedstuff available to meet requirements, and nutrient excretion that can be used for manure nutrient management planning. Of particular importance are models that result in optimizing the rumen to maximize forage utilization and microbial protein production. Data and feed analysis required by models must be farm specific (housed on-farm) and accurate.
2. *Appropriate feed analysis schedule and protocol to accurately represent the feeds being fed.* To accomplish this, a farm specific feed analysis protocol needs to be followed resulting in a farm specific feed database that includes forages and concentrates. Tylutki (2002) simulated the impact of NDF and dry matter variation in corn silage using the average values and standard deviations as sampled on a 500-cow farm. The impact of improper forage analysis, and lack of control over the dry matters at feeding, resulted in a large annual variation in nutrient excretion (242 pounds N excretion and 64 pounds of P excretion), feed inventory required (61 tons of corn silage), and income over feed costs ($21,792) per 100 cows annually. Their recommendations include determining dry matters of all forages at least twice weekly (more often if wide fluctuations in intakes are observed) and then adjust diet formulations as needed.
3. *Improve feeding accuracy*. Most farms assume that what is being mixed and fed is what is supposed to be fed. In many cases, this is not a valid assumption (Predgen and Chase, 2002). Tylutki (2002) evaluated the impact of varying feeding accuracy ± 3%. The addition of feeding error increased annual variation in P excretion (18 pounds), corn silage inventory (9 tons), and income over feed costs ($19,148) per 100 cows annually. Feeding accuracy needs to be tracked to identify sources of variation, as well as to manage inventory. Commercial software and hardware is available that can be linked to the mixer scales to track this information.
4. *Monitor dry matter intake to improve accuracy of ration formulation and animal performance*. Proper ration formulation relies on many inputs from the farm, including animal body weight, feed inventory, and actual dry matter intakes. To decrease nutrient

excretion per unit of milk produced, actual dry matter intakes must be known in order to ensure adequate grams of each nutrient are provided to support animal requirements. The data can also be used as a diagnostic tool.

5. *Make ration changes as needed to improve accuracy and minimize safety factor in the ration*. By increasing the dry matter intake 5%, ration nutrient concentrations can be lowered. Chase (1999) calculated that by increasing intake 5%, it is possible to decrease diet crude protein about one percentage unit to achieve the same pounds of protein intake. This allows higher inclusion rates of homegrown feeds, thus decreasing purchased nutrients. Safety factor reduction, while very effective in reducing excretion, requires a high management level, thus management and feeders need additional training to minimize potential performance variation (Tylutki, 2002).
6. *Improve feed-bunk management to increase intake and consistency of animal performance*. This includes daily cleaning, pushing feed up several times daily, and all other bunk management practices. More consistent performance, and feed intake, allows for more accurate ration formulation for any production level.
7. *Control the level of refusals*. Most farms' feed refusals from the lactating herd are fed to replacement heifers. From a nutrient excretion viewpoint, this is an expensive practice. Mineral and protein levels that are adequate for lactating cows do not fit most replacement heifer groups. The amount of refusals must be at a level that is consistent with farm management to achieve maximum dry matter intake; however extremely high levels need to be avoided and are indicative of poor management.
8. *Use the proper 'tools' to track the impact of changes in ration formulation and feeding management*. These 'tools' fall into two categories: short-term (milk production, milk components, and milk urea nitrogen) and long-term (body condition score, replacement heifer growth, lactation persistency, and reproduction). Both sets of tools are required to accurately evaluate a herd.
9. *Obtain and evaluate manure analysis*. Manure needs to be analyzed two ways: visual observation to determine what is not being digested by the cow, and the second is a manure nutrient analysis at time of land application. If large fiber particles or corn grain is evident in visual observation, rations and feeding management need to be addressed. As dietary N and P levels are decreased, manure nutrient concentrations will be decreased.

Long-Term Strategies

1. *Develop a crop and manure nutrient management plan*. Most states have computer programs available that can be used to meet CAFO requirements while matching manure and commercial fertilizer nutrients with crop requirements to produce crop yields up to soil potential (and management level) on each farm.
2. *Improve silo management*. Silo capacity and management can play a significant role in decreasing nutrient excretion. Most dairy and beef farms have varying soil types that are best suited for different crops from a crop production and environmental management standpoint. The storage system must be able to handle each crop type individually (e.g., corn silage, grass silage, alfalfa silage, and different qualities of each).

This allows the nutritionist to better match protein and carbohydrate sources with specific animal groups.

3. *Manage forage inventory to avoid feed shortages*. Proper ration planning, and inventory management, decrease farm nutrient loading. This is because a forage deficiency requires additional purchased feed and automatically increases purchased feed excretion. A nutrition model should predict requirements for each ration ingredient (by group and the entire herd), for allocating, and managing, forage inventory.
4. *Match cows/crops/soils*. Alfalfa and corn are not always the best choices for dairy producers due to soil constraints. The farm's manager(s), nutritionist, and field crops consultant must work together to determine the best mix of crops to grow, and how they can be fed, allowing for production goals (crop and animal) to be met while minimizing nutrient excretion. Accurate nutrition models should be used to predict the best match of herd requirements with alternative crop rotations and management to minimize farm-gate imported nutrients and the spreadable acres. For example, Wang et al. (2000) demonstrated on a dairy farm with 300 cows on 1062 acres that improving the match of crops grown with the model predicted cattle requirements could reduce mass balance of N and K by 19 and 29%, respectively while reducing feed cost by $ 39,000; improving yields to the potential for the farm could reduce farm mass balance of N, P and K by 29, 50, and 100%, respectively while reducing feed costs by $70,000.
5. *Increase the amount of homegrown feeds in the ration*. Increasing the amount of homegrown feeds in the ration decreases the amount of purchased nutrients. To accomplish this, homegrown feeds must be high quality to maintain (or improve) production and animal health, and stemming from optimal rumen fermentation.
    a. *Impact of Forage quality*. To increase the amount of forages in the rations, forage quality must be high. Maximum intake from forages can be expected when alfalfa is <40% NDF, grasses are <55%, and corn silage is 40-45% (Tylutki, 2002). A cow is limited in forage NDF intake to 1 to 1.1% of bodyweight (Mertens, 1994). As an example, a 1400 pound cow at 1.1% NDF capacity can consume 28 pounds of dry matter from grass at 55% NDF but only 24 pounds at 65% NDF. This four pound difference results in either increased purchased feeds and/or lower performance. In either case, purchased nutrient efficiency is lower.
    b. *Impact of Grains*. Homegrown grains and protein sources decrease the amount of purchased nutrients. Many dairy farms do not have an adequate land base to produce their own grain; therefore, they should maximize homegrown forage quality and quantity and choose purchased concentrates that accurately supplement their forages.

Research needs to improve applications nutrition models for use in precision feeding

It was beyond the scope of this paper to review all available nutrition models that could be used for precision feeding on livestock farms to reduce their impact on the environment. However, since we have integrated the NRC recommendations into the CNCPS model and many of the CNCPS components are in the NRC models (2000, 2001), we use our experience with implementing and improving the CNCPS to identify research needs for improving their accuracy in site specific development of feed management plans.

Modeling is an ongoing process at Cornell in which we integrate new research and field experience into the CNCPS model to continually improve its accuracy and usefulness in implementing the NY 592 Feed Management Standard on dairy and beef cattle farms in our state. New research on specific aspects of the biology in our model that are critical in predicting nutrient balances, excretion and ammonia losses will allow it to better reflect a specific biological function and improve its accuracy and utility for site-specific application. Other research needs are related to its application in precision feeding of specific groups and a herd.

Specific aspects of the biology in the CNCPS model. Fox et al. (2002, 2004) summarized research needs to refine specific aspects of the biology in the CNCPS model. Because they allow us to more accurately predict microbial protein production and forage utilization in precision feeding applications, methodologies are needed to determine feed digestion rates for site-specific application. For example, alternatives for improving accuracy in predicting site-specific NDF digestion rate of forages are being evaluated (Van Amburgh et al., 2003, 2004). Because of ruminal pH effects on fiber digestibility and microbial protein production and therefore homegrown forage utilization, a dynamic ruminal sub-model to account for the effects of ruminal VFA production, absorption, and fluid dilution rate on ruminal pH is needed. The development of a dynamic VFA-pH sub model will allow us to select better ration ingredients and feeding strategies to minimize CH_4 production and improve predictions of N utilization in the rumen. Because of the need to accurately predict N requirements, dietary N utilization, and the route (fecal or urinary) and form (e.g. potentially volatile ammonia) of N excretion, elements of the N model for the CNCPS need to be revised. Currently, the CNCPS predicts total N excretion at acceptable levels; however, route of excretion should be evaluated and refined based on results of evaluations with research data. Van Amburgh et al. (2005) indicated there is much potential for formulating diets that contain less protein with the CNCPS model, and further refinements can enhance its ability to reduce N excretion. Because a metabolic model depends on the rumen model for its substrates, our first priority has been to develop a robust rumen model that can accurately predict quantities of end products of fermentation that are available for absorption. However, further research is needed to improve specific post rumen aspects of the predictions of amino acid utilization, including intestinal availability, and efficiency of use of absorbed amino acids for different physiological functions.

Evaluation and improvement of the prediction of ammonia losses by a herd. As shown in table 4, daily N volatilization losses can very widely between herds, due to differences in level of milk production, protein levels fed, replacement heifers kept, and manure management in the barn. Thus we believe nutrition models can be used to predict these losses for each farm better than using estimates collected on a few farms to regulate all. Further research is needed to evaluate the accuracy of predicting ammonia losses with our model, and to use that information to improve those predictions.

Accounting for within group and feed composition variation. Currently our CNCPS model does not account for variation in feed composition in predicting supply of nutrients. The process developed by Tylutki (2002; summarized in the previous section) for determining the variation in nutrient composition in feeds used on a specific farm, and how to account for it in adjusting average feed composition values needs to be built into our model.

Model user-friendliness. Several problems have being identified that restrict the use of decision support models, including their complexity and the number of inputs and information needed to execute them (McCown, 2002). Data requirements for the CNCPS are already high, and future versions of the CNCPS will require additional inputs. These inputs are needed to more accurately determine carbohydrate and protein fraction digestibility in order to improve prediction accuracy of ruminal and post-ruminal N accounting (including rumen and whole tract recycled N), and absorbed amino acids derived from dietary and microbial sources. However, to offset the challenges of high data requirements and entry, we have developed an input structure that was designed to reduce and streamline inputs for whole herd application, including feed analysis, animal inputs, and environmental inputs (Tylutki and Fox, 2005).

Despite limitations in utilizing models at the farm level, there is still optimism about its future because computational modeling is used in everyday life and provides a cost-effective (and attractive) way to describe and predict biological relationships (Newman et al., 2000). Furthermore, environmental regulations demand that producers make more accurate decisions regarding their production systems prior to implementing changes. Therefore, there is opportunity for use of models on farms, but care must be taken to build models that are user friendly, easy to understand, useful on the farm (how well it enhances decision-making), and are based on sound science.

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