Implementation of the *CuNMPS*: Development and Evaluation of Alternatives

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INTRODUCTION

Nutrient management has become increasingly important since concentrated animal feeding operation (CAFO) regulations have been implemented in New York State. Currently, CAFO nutrient management planning is focused on crop nutrient management and how to deal with manure as a waste/fertility product. Additional environmental regulations will continue to be developed and implemented in the United States. For example, the United States Department of Agriculture and the Environmental Protection Agency are beginning to pursue animal nutrition as a component of nutrient management. In several states, phytase must be included in rations of monogastric animals in an attempt to decrease phosphorus excretion. As we move towards control of air emissions from agriculture and the PM2.5 policy (particles greater than 2.5 microns in diameter—includes ammonia), cattle excretion and nutrition will have a larger emphasis (Sweeten et al., 2000). The result will be an increased need for integrated nutrient management planning.

In the last ten years, nutrient management and integrated nutrient management have been discussed many times at this conference (Bannon and Klausner, 1997; Kilcer, 1997; Klausner, 1993; Pell, 1992; Tylutki and Fox, 1997) with references being made to the Cornell University Nutrient Management Planning System (*CuNMPS*) (Tylutki and Fox, 1997; Tylutki and Klausner, 1995). The *CuNMPS* has evolved since 1995 to include two components: the Cornell Net Carbohydrate and Protein System version 5.0 (CNCPS) (Fox et al., 2000), and Cornell CropWare (Ketterings et al., 2001). The current versions of both tools represent large improvements in our understanding, and ability, to begin developing tools that can be used to develop integrated nutrient management plans on farms. They are based on the Excel spreadsheets presented in 1997 by Tylutki and Fox (1997) and Bannon and Klausner (1997), but have had numerous updates in both biology and field usability, based in part on experiences from applying them on case study farms.

Beginning in 1997, we initiated a study to evaluate the implementation of the *CuNMPS* on a dairy farm, and to identify changes needed to make these software tools more useful in nutrient management planning. The objectives of this paper are to 1) describe our case-study farm at the beginning of the case study in 1997 and after 5 years of implementing integrated nutrient management through the use of the *CuNMPS* models, 2) to highlight some of the changes that were implemented, 3) discuss the impact these changes have had on the farm, and 4) to provide a framework for others to use in implementing this process on other farms.

CASE-STUDY FARM DESCRIPTION

McMahon's EZ Acres is now (2002) a 625-cow dairy operation owned and managed by two brothers (Mike and Pete). In December 1995, the herd was moved to a new 500-cow free-stall operation. In 1997 the farm consisted of 1075 tillable acres of which 43% was in corn and 57% was in mixed alfalfa/grass hay crop species (Bannon and Klausner, 1997). The farm consists of a mix of level well-drained soils (gravel based valley-floor land) and moderately to poorly-drained sloping soils (acidic clay based hill land). The dairy complex is located on the valley floor above an aquifer that supplies the drinking water for approximately 50,000 people. Additionally, a naturally stocked brown trout stream runs the length of the valley floor and is monitored closely by the New York State Department of Environmental Conservation. The hill land has a low leaching potential but a higher run-off potential. Run-off from these soils can enter tributaries of the trout stream. Since 1997, additional land has been acquired (purchased and rented); the 2002 crop year consists of 435 acres of corn, 350 acres of grass, and 350 acres of alfalfa (1,135 acres total).

CHANGES IN CASE-STUDY FARM PRODUCTION AND NUTRIENTS 1997-2002

In 1997, implementation of the CuNMPS in developing whole farm nutrient management planning was initiated, including an analysis of logical alternatives for the farm, as described previously (Bannon and Klausner, 1997; Kilcer, 1997; Tylutki and Fox, 1997) . These results serve as the baseline data for this case study. At the time (June 1997 test date), the herd consisted of 922 animals with daily milk production averaging 72.1 lb/d. The diets were 46% homegrown with 74 and 77% of the nitrogen and phosphorus, respectively, purchased. Total feed cost was estimated to be $1,900 per day. The herd was projected by the CNCPS to excrete 202,023 lbs of N and 43,559 lbs of P in manure (feces plus urine) annually. Kilcer (1997) calculated that corn silage storage losses exceeded 35% of the total dry matter harvested. This high loss explained the corn and hay crop ratio discrepancy when he compared harvested (73.6 : 26.4% corn silage to hay crop harvested) and fed amounts (64.8 : 35.2% corn silage to hay crop fed). It was concluded by Bannon and Klausner (1997) and Kilcer (1997) that the crop production scheme did not adequately match the soil properties, resulting in less than desired yields. This was of utmost importance to the farm managers, who believed that they could not produce the herd forage needs with their land base (supported by the 46% of the diet being homegrown).

Herd and excretion parameters were re-calculated for the case-study farm using version 5 of the Cornell Net Carbohydrate and Protein System (CNCPSv5). Milk production was re-evaluated utilizing farm records (Pro-Dairy Milk production record book). As illustrated in Table 1, actual milk production averaged 68 pounds per cow throughout 1997. Additionally, herd size for the year was smaller than previously reported. These discrepancies can be explained by the high cull rate the herd was experiencing (44%) and analyzing the herd with annual data versus one test day. The farm purchased a 100-cow herd in 1997 in an attempt to increase herd size; however the purchase allowed them to only maintain herd size because of a high cull rate. The corrected values were used in CNCPSv5, providing slightly different values than reported in 1997 by Tylutki and Fox (1997). The corrected values show that only 42.9% of the diet was homegrown (Table 2) with 81% of the N and 78% of the P being purchased. Nutrient efficiency is calculated slightly differently in CNCPSv5 versus the spreadsheet utilized in 1997. Efficiency is currently calculated as Product / Total Nutrient Intake where product is a combination of milk, growth, reserves, and conceptus. Calculating efficiency in this way results in 19% N efficiency and 25% P efficiency (Table 2). Feed costs were predicted to be slightly higher ($2,200 daily) with purchased feed cost representing the majority of this ($1,813 daily) (Table 3). Manure nitrogen was predicted to be much higher (309,043 lbs N) using CNCPSv5, due to improvements made in the CNCPS model.

Table 1. Herd parameters and progress over a five-year period.

	Herd size	Milking No. hd	Dry No. hd	Heifers No. hd	Milk lb/d	Milk lb. shipped/d	Calving Interval	Age of first calving	Cull rate
1997	852	408	70	374	68	27,622	NA[a]	NA	44.0%
1998	891	426	70	395	65	27,848	13.0	22.6	42.2%
1999	883	454	59	370	67	30,213	13.2	21.5	33.9%
2000	960	495	69	397	67	33,399	13.2	22.1	34.8%
2001	1,007	507	81	419	71	35,861	13.4	22.3	31.6%
2002	1,077	544	83	452	74	40,167	12.8	21.5	23.3%
02 vs. 97	126%	133%	119%	121%	109%	145%			53%
02 vs. 98	120%	128%	118%	114%	113%	144%	98%	95%	55%
Slope	44.3	27.5	3.1	13.9	1.4	2,570	-0.0	-0.1	-3.8%
r-sq	93%	98%	43%	73%	67%	95%	3%	24%	91%

[a] NA indicates that data was not available. DairyComp 305 cowfiles began to be warehoused for this study starting in 1998.

Table 2. Improvements in proportion of diets home grown, and nitrogen and phosphorus purchases and efficiency of use (product / intake) over 5 years.

	Proportion of diet		Purchased		Efficiency	
	Homegrown	purchased	N	P	N	P
1997	42.9%	57.1%	81%	78%	19%	25%
1998[a]						
1999	48.9%	51.1%	64%	64%	26%	30%
2000	47.5%	52.5%	62%	64%	21%	27%
2001	55.0%	45.0%	61%	54%	24%	31%
2002	59.1%	40.9%	51%	47%	25%	35%
02 vs. 97	137.8%	71.6%	62.7%	60.3%	132.9%	141.0%
Slope	3.1%	-3.1%	-5.5%	-6.0%	0.9%	1.8%
r-sq	89%	89%	93%	97%	38%	75%

[a] 1998 diet information was not available.

Table 3. Feed cost and nutrients (nitrogen and phosphorus) in manure over a five-year period.

		Purchased feed cost			Manure nutrient[a]			
	Total feed cost/d	daily	per cwt	Per animal	N lbs/yr	N Lbs/acre	P lbs/yr	P Lbs/acre
1997	$2,200	$1,813	$6.56	$2.13	309,043	287	43,435	40
1998								
1999	$1,982	$1,396	$4.62	$1.58	221,236		33,117	
2000	$2,517	$1,462	$4.38	$1.52				
2001	$2,514	$1,508	$4.21	$1.50				
2002	$2,467	$1,375	$3.42	$1.28	256,349	226	31,192	27
02 vs 97	112.1%	75.8%	52.1%	60.0%	82.9%	78.7%	71.8%	67.5%
Slope	$81	-$72	-$0.58	-$0.16	-8,783		-2,306	
r-sq	43%	61%	92%	90%	25%		78%	

[a] Loading rates were calculated only for 1997 and 2002 to highlight change in loading pre-and post-implementation. Manure N and P are reported only for 1997 (pre-implementation), 1999 (first year of CNCPS formulation on-farm), and 2002 (post-implementation).

IMPLEMENTATION OF WHOLE FARM PLANNING OVER 5 YEARS

The process of evaluating and implementing the *CuNMPS* on the case-study farm was evolutionary; Tylutki (2002) provides complete details of changes made, procedures followed, and results. What began as a simple evaluation to be conducted over time resulted in a complex whole farm systems analysis with intervention required in all systems. Due to the data requirements of CAFOs and the software and needs identified during this case study, we began integrating manufacturing quality control principles in the software and in training sessions for agri-industry and extension staff (Tylutki and Fox, 2000a; Tylutki and Fox, 2000, 2002). This integration led us to a new paradigm; precision farming. Precision farming consisted of precision feeding, crop management, animal management, and business management. As we worked with this case study, we learned that integrated whole-farm nutrient management using precision farming approaches can be regarded as an evaluation of the whole business (Tylutki and Fox, 2000b). Based on this finding, we outlined a whole-farm management scheme (Figure 1) based on quality management and Six Sigma (currently used in numerous other business sectors). This scheme focuses on root cause analysis, continuous improvement of the DMAIC approach to management (define, measure, analyze, implement, and control), and shifting managers thinking to a more holistic business management approach. Successful implementation required a thorough understanding of the farm as an integrated series of systems (Figure 1).

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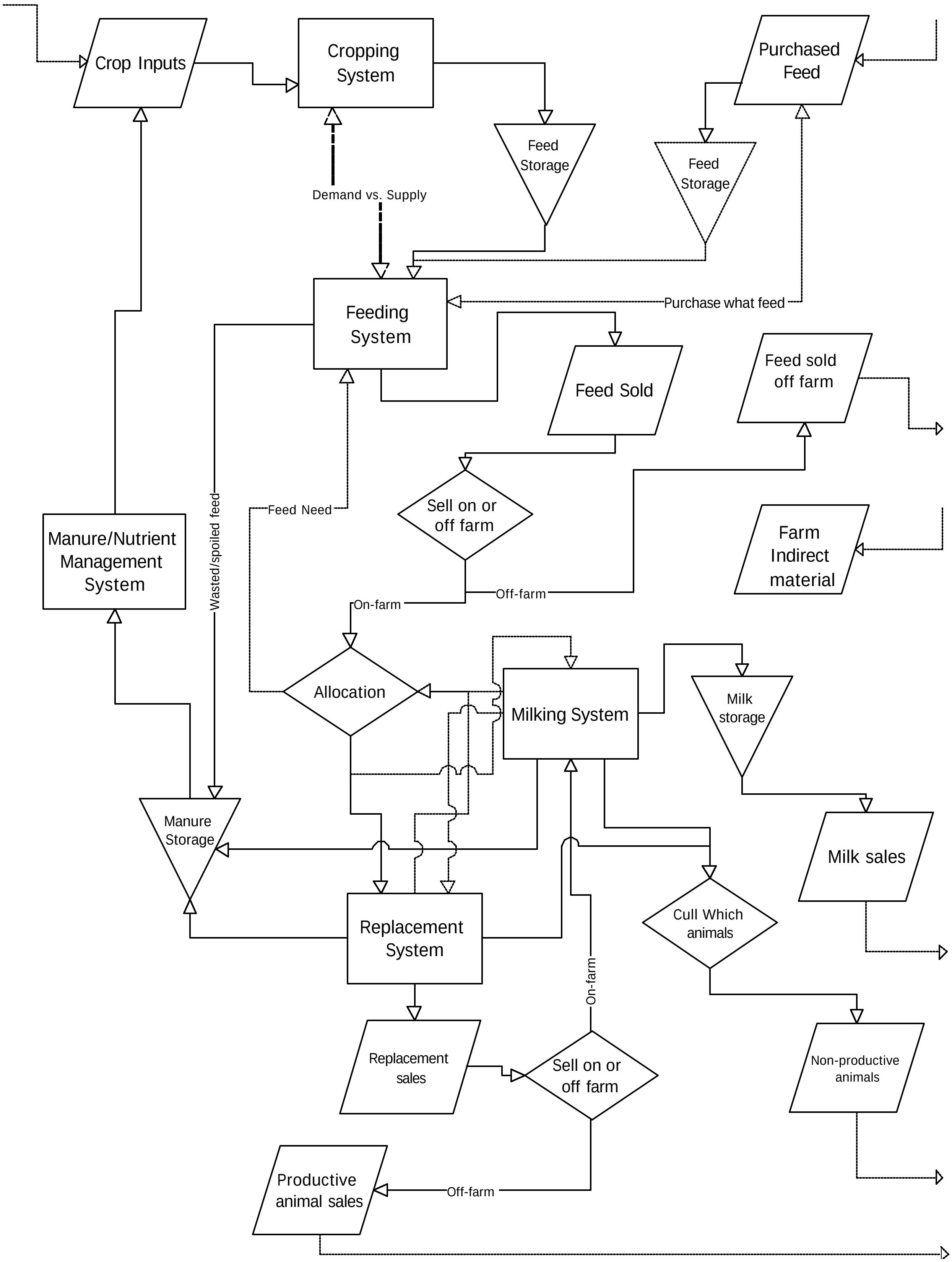

Figure 1. Systems flow diagram of the case-study farm.

While many farms will be able to implement components successfully, radical management change is required to maximize returns on an optimized system. Implementing such a business model in production agriculture requires the manager to become a teacher, leader, believer in continuous improvement, and a critical thinker. These roles were the backbone of precision farming in this case study. The concept of precision feeding was put forth by Paul Cerosoletti in a phosphorus reduction program for dairy cattle feeding in the New York City Watershed Cannonsville Reservoir basin. The objective of precision feeding is to accurately predict animal requirements and feed biological values on each farm so that rations can be formulated with less safety factor, with associated production risks being managed as described by Tylutki (2002). Precision feeding relies on good management practices (GMPs) to ensure that the ration consumed by the cow is as close as possible to the formulated ration. Precision crop management integrates traditional crop nutrient management planning with additional data required from the nutritionist (to identify forage quantity and quality goals) and the agronomist (to ensure that forage quantity and quality goals are met). Precision animal management focuses on cow health, comfort, and productivity to ensure that production, quality and cow longevity goals are met. All of these required improved management in this case study; thus we turned to Six Sigma for a proven management model (Tylutki and Fox, 2000b).

Table 4 lists the primary changes that occurred over the five-year period. In addition to changes listed in table 4, numerous other changes occurred primarily consisting of general management, herd management, crop management, communication, employee and management (and consultant) training, and data analysis. The farm has evolved following a continuous improvement paradigm with simple statistics and root cause analysis assisting management in decision making.

Changes in the feeding and cropping systems resulted in large nutrient management impacts. Feeding system changes included: using bags to store forage in excess of bunk capacity while planning a new bunk silo, improved bunk face management, covering the bunk adequately (including type of plastic and switching to tire sidewalls), routine dry matter determination of silages (minimum frequency of three times weekly), improved communication between feeders and management, stated goals for feeder deviations, development and implementation of a feeder checklist, control chart use by feeders, and routine maintenance schedules for feeding equipment. Additionally, a major shift in hay crop storage philosophy occurred. In 1997, hay crop was stored by all 1st and 3rd cut hay silage stored in one bunk and 2nd and 4th in another bunk, regardless of species or maturity. This was changed in 1999 when hay crop storage was segregated by species (grass in one bunk, alfalfa in another bunk). To accomplish this, a concrete apron had to be poured on the back end of the bunk to allow feeding fermented feeds while filling (no bunk end-walls). The feeding flexibility gained by this is tremendous as it is now possible to feed four different hay crop silages simultaneously and allows the corn silage bunk to be packed differently (gentle slope on each end versus steep slope on back end). These changes have made temporal allocation of forages possible that was important in meeting one of the primary objectives: decreased nutrient importations as a result of increased homegrown feed quantity and quality.

Table 4. A listing of changes that have occurred over a five-year period on the case-study farm.

Year	Changes	
1997	Base data year	Began intensifying grass management
	Purchased 100 cows	
1998	Began processing corn silage	New mixer truck
	Hire young-stock manager	One partner leaves farm
	New harvester	Started to store hay crops by type vs. cutting
1999	Added more fans	Began charting:
	Began bagging forages in excess of bunk capacity	Parlor performance
	Began sprinkling cows in holding area	Weekly milk components
	Began temporal forage planning and allocation	Feeder deviations
	Began weekly group sampling for components	Forage dry matter
	Intensified grass management	Cull rate
	Many ration changes (CNCPS based)	Regrouped herd
	More bags used (hay crop in addition to corn silage)	Started to see impact of intensive grass: shorter alfalfa/corn rotations on valley fields
	Began storing hay crop by type (alfalfa vs. grass) versus by cutting	
2000	Began developing Quality Manual	Began reviewing farm via systems thinking
	Began developing SOPs	New dry cow facility
	Began discussing Stretch Goals	Full implementation of CNCPS target growth system for replacement heifers.
2001	Began using Hispanic labor	Replaced EZ-Feed with FeedWatch
	Harvested 100 acres as dry corn	Updated truck fleet
	Initiated budget planning (with stretch goals) followed by quarterly reviews.	Ripple: needed larger corn head
	New pull behind tank spreader (larger allowing for less trips)	Utilized custom harvester to help with corn harvest
2002	Altered hay crop harvest process to reduce soluble protein	Planning started for next free-stall barn
	Began planning for methane digester/manure storage	Renovated hospital barn stalls
	CAFO plan developed	Started using activity for heat detection
	Growing forages specifically for transition cows	Two new used tractors
	New corn silage bunk (no more bags)	

Crop system changes included different species selection, changes to the crop rotations, and harvest strategy. Crop rotations are continuing to evolve due to the persistency in stands and yields of the intensively managed grass. Several fields are currently in their 7th or longer year and continue to yield extremely well with supplemental nitrogen. However, this has produced a ripple; less acres in rotation resulting in shorter rotations of the corn and alfalfa crops, which, from a soil erosion and soil health viewpoint, is desirable. Decisions relating to when to rotate out of alfalfa into corn are now based on the NDF levels of samples collected at first cutting (greater than 50% NDF indicating a high grass content) versus perception (it still looks like alfalfa) with most alfalfa rotating into corn after four years. Quality of the forages has become the driving force behind harvest strategy with attempts in 2002 focusing on decreasing hay crop soluble protein while increasing the dry matter content ensiled. This will take a few more years to finalize given the dry summer central New York has experienced this year.

Throughout the process, the McMahon families involved have proven to be outstanding cooperators, and their willingness to change, improve, and question the status quo serves as a model for managers of other farms (and businesses) for achieving environmental and economic sustainability.

IMPACT

As tables 1-3 show, the systems modifications outlined in table 4 have resulted in large impacts on the farm. Total herd size has increased 26% in five years; most of this growth has been due to decreased cull rates. Numerous changes impacted the cull rate with most relating to changes in management and nutrition of far-off dry and transition cows. While milk per cow has trended higher, late 1998 and early 1999 was a difficult time period. The herd was exhibiting clinical acidosis in mid-1998 as a result of low ration NDF levels prior to implementation of the CNCPS; for nine months following this, milk per cow declined in a linear fashion to a low of 59.6 pounds per cow. Since that low point, milk production has continued to increase with milk per cow reaching farm record highs in 2002 (76 pounds per cow until reduced by heat stress). The trend in herd growth is 44 more animals annually (slope listed in Table 1). The integration of increased cow numbers and higher milk per cow resulted in 45% more milk shipped daily in 2002 versus 1997. Additionally, there were improvements in calving interval (continuing to decline), and age at first calving. The CNCPS target growth rates and breeding weights were used to set strict goals for heifer management, which includes a minimum breeding weight of 55% of mature weight (830 pounds) at a moderate body condition score. Animal scales were installed to track heifer body weights, including bred heifers pre-calving with a goal of 1,300 pounds five weeks pre-calving to achieve 82% of mature weight post-calving. Heifer growth is tracked as carefully as milk production in order to maximize returns over investment in the replacement heifer system.

Changes to the cropping and feed storage systems have resulted in increased yields post-storage. Yields post-storage integrate storage losses with crop production. Bunk silo storage losses have been reduced to 18 to 20% versus 25 to 35% in 1997. A large component of storage losses was due to utilizing bags for excess forage. Losses in bags ranged from 5 to 80% with many large sections of bags lost due to spoilage from micro- and macro-holes. Even with best management practices, rodents entered greater than 75% of bags. These losses did not offset the gains observed overall from having the additional feed to store. Changes to crop rotations, fertility practices, and harvest strategy allowed harvested yields to continue to trend upwards (with exceptions for weather and army worms). These changes resulted in the proportion of the diets from homegrown forage being 38% higher in 2002 than in 1997. This difference would be greater if additional land were available to increase inventory, as the current diets average 0.85% of bodyweight as forage NDF with a goal of 1% of bodyweight to be achieved in the next two to three years. This farm grows forage only, thus the proportion of the diet being homegrown is a direct function of forage yield and quality. Quality goals for forage are discussed on a regular basis and are: <52% NDF grass silage, <40% NDF alfalfa silage, and 37-42% NDF corn silage. Dry matter goals are 28-35% DM for grass silage, 37-45% for alfalfa, and 32-40% for corn silage. These goals are used for crop planning purposes as we continue to strive towards the 1% bodyweight from forage NDF goal. As more feed is homegrown, nitrogen and phosphorus imports have continued to decline. A large improvement was made in P imports by removing all inorganic P from the rations. This herd has been on diets with a 0.25-0.37% P for over three years while herd performance has increased, with no ill effects observed. As Table 2 shows, decreasing N and P levels in the diets has resulted in efficiency improvements. Nitrogen efficiency can be improved further (>30% goal) whereas P is most likely going to remain in the 35% range. Gains in N efficiency require changes in the crop harvest system to reduce the soluble protein levels of forages and then carefully matching RUP sources with microbial protein. Large gains have been made in this area; however further improvements can be made. Phosphorus efficiency in lactating cows generally varies between 37 and 42% with growing and dry animals varying between 15 and 35%; thus, a whole herd averaging 35% is well within the acceptable range.

An added benefit of higher forage levels across the herd is a reduction in purchased feed cost (Table 3). Forage quality and quantity, coupled with safety factor reduction, have allowed the farm to capture a 50% reduction in purchased feed cost per hundredweight. The reliance on more forage and reductions in ration safety factors come with risk, however. Small shifts in forage quality, failure to determine dry matters routinely, poor feeding management, and poor feedbunk management result in increased production variability (Tylutki, 2002). This was observed in 2001 when the farm was switching from EZ Feed to FeedWatch. For several weeks, the feeders were forced to feed from sheets and while they were learning new software. During this time, dry matters were being entered incorrectly, resulting in the forages not being corrected for dry matter. Analysis of the daily milk production charts showed that milk per cow had a four pound range over a two week period when less than a two pound range is normal for this herd. It was also observed during this time period that MUNs varied more (12-17 mg/dl) compared to typical ranges of 11-14 mg/dl.

Total manure nutrients have also been reduced (Table 3) compared with 1997 values. Manure N has been reduced less than manure P; however as more forage is fed, maintenance protein requirements increase and forage N digestibility is generally lower than concentrates. From a nutrient management perspective, this shift also impacts the type of N excreted with more being organic N which is more stable in the environment versus ammonia N (from urine) that will be volatilized. The net effect, however of higher homegrown forage diets was a 22% lower N loading rate (lbs/acre) in 2002 vs 1997. Phosphorus loading has decreased 33% and is a direct result of decreased dietary P levels but also due to less purchased feed, primarily protein sources. High protein feeds such as soybean meal also tend to be high in P, thus improving forage quality and quantity fed results in lower P importations as well. While the reduction in loading is impressive, one must remember that these values represent total N and P excretion versus purchased N and P excretion. As total homegrown feed levels have increased, and total N and P purchases decreased, the amount of N and P being recycled within the farm is increasing. As an example, if alfalfa silage averaged 0.30% P and yielded four tons DM/acre, this removes 24 pounds of P annually and the farm is currently applying an average of 27 pounds per acre from manure. This means that the farm is accumulating P at a rate of 3 pounds per acre in 2002 versus 16 pounds per acre in 1997, an 81% reduction.

Nitrogen efficiency at the farm level continues to be addressed. A methane digester and long term manure storage are being planned to be constructed in 2003. This should allow for less commercial fertilizer application on the grass, thereby improving whole farm N efficiency. Annual forage inventory levels still need to be increased but this requires additional land and the next expansion step is planned for 2004 (requiring even more land). Farm systems such as this one are continuously changing and require monitoring and updating of plans to take into account the ripples introduced by expansion or other changes. This challenging environment requires management and agri-industry to continue to ask each other “why” and “how”.

CONCLUSIONS

The process utilized on this farm has taken five years to evolve and is based on systems thinking and quality control. Table 5 is a management checklist used by the farm. As nutrient management and environmental policy become stricter and engrained in our industry, farms must be willing to change how the systems shown in Figure 1 function to improve their efficiency so that farm gate requirements can be met. It is our estimation that full implementation of such plans requires five to seven years to complete; however partial implementation can result in large economic and environmental gains. Management and supporting professionals must be willing to accept and embrace change, just as Mike and Pete McMahon have done.

Table 5. Farm management checklist.

Upper Management level discussions

- Review the general farm information annually
- Review labor force quarterly
- Establish the farm goals, including where the farm wants to be in 5 and 10 years
- Flow chart the farm
- Review Farm logistics
- Identify the technical team on the farm
- How does general management think and work
- Communicate with management monthly
- Are control charts being updated monthly
- Are control charts being updated
- Analyze charts for trends
- Review hay harvest number (after each cutting)
    - Review current cutting
    - Was urea put on?
    - Plan where to put next harvest
- Corn harvest
    - Is chopper ready for corn?
    - Determine corn field harvest order
    - Check packing of corn
    - Check particle size of corn
    - Watch packing height of corn
- Review corn harvest
- Review hay crop overall including yields
- Plan commodity purchases
- Begin next years planning
    - Herd size projections for next 12 months
    - Will we have enough storage
    - Begin inventory allocation planning
    - How much forage should we feed for next 12 months
    - Anything storage-wise we need to change for next year
    - How many acres would be needed

Middle Management and other employees and other topics.

- Talk with feeder monthly including
    - Review dry matter intakes by group
    - Review silo management
    - Are DMs done as scheduled
    - Review feeder SOPs quarterly
- Review lactating herd performance monthly
- Review replacement herd performance monthly
- Review dry cow program monthly
- Talk with herds people to get their view on current status monthly
- Check mixer for weight accuracy and operation
- Check mixer via mixer test quarterly
- Talk with hoof trimmer quarterly
- Listen to what vet has to say quarterly
- Check inventory of forages and contracts quarterly at a minimum
- Temporal allocation of forages
- Fall equipment issues
    - Is the equipment ready for winter
    - What equipment maintenance is needed
    - Equipment purchase planning
- Spring equipment issues
    - Is tillage equipment ready
    - Was N applied to grass in early spring
    - Have plastic on hand to cover hay crops?
    - Is hay equipment ready
- .next years planning continued:
    - How much corn do we want
    - How much hay crop do we want
    - What kind of corn do we want
    - Corn seed ordered?

REFERENCES

Bannon, C. D. and S. D. Klausner. 1997. Application of the Cornell Nutrient Management Planning System: Predicting Crop Requirements and Optimum Manure Management. Pages 36-45 *in* Proceedings of the 1993 Cornell Nutrition Conference for Feed Manufacturers, Rochester, NY.

Fox, D. G., T. P. Tylutki, M. E. Van Amburgh, L. E. Chase, A. N. Pell, T. R. Overton, L. O. Tedeschi, C. N. Rasmussen, and V. M. Durbal. 2000. The net carbohydrate and protein system for evaluating herd nutrition and nutrient excretion (AnSci Mimeo 213 Ed.). Animal Science Department, Cornell University, Ithaca, NY.

Cornell Cropware. Ketterings, Q., G. A. Albrecht, K. Czymmek, C. N. Rasmussen, and V. M. Durbal. Ithaca, NY

Kilcer, T. 1997. Application of the Cornell Nutrient Management Planning System: Optimizing Crop Rotations. Pages 45-53 *in* Proceedings of the 1993 Cornell Nutrition Conference for Feed Manufacturers, Rochester, NY.

Klausner, S. D. 1993. Mass nutrient balances on dairy farms. Page 126 *in* Proceedings of the 1993 Cornell Nutrition Conference for Feed Manufacturers, Rochester, NY.

Pell, A. N. 1992. Does ration balancing affect nutrient management. Page 23 *in* Proceedings of the 1992 Cornell Nutrition Conference for Feed Manufacturers, Rochester, NY.

Sweeten, J. M., L. Erickson, P. Woodford, C. B. Parnell, K. Thu, T. Coleman, C. Reeder, J. R. Master, W. Hambleton, G. Bluhm, and D. Tristao. 2000. Air Quality Research and Technology Transfer White Paper and Recommendations for Concentrated Animal Feeding Operations. USDA Agricultural Air Quality Task Force, Washington D.C.

Tylutki, T. P. 2002. Improving herd nutrient management on dairy farms: 1) individual cow milk production variance. 2) developing a quality management program on a commercial dairy farm: a six sigma approach. 3) variation in nutrient content of feeds on a commercial dairy farm. 4) predicting phosphorus excretion by dairy cattle. 5) incorporating risk in managing dairy cattle nutrition. PhD Dissertation. Cornell University, Ithaca, NY.

Tylutki, T. P. and D. G. Fox. 1997. Application, of the Cornell Nutrient Management Planning System: optimizing herd nutrition. Pages p. 54-65 *in* Proceedings of the 1997 Cornell Nutrition Conference for Feed Manufacturers, Rochester, NY.

Tylutki, T. P. and D. G. Fox. 2000a. An integrated cattle and crop production model to develop whole-farm nutrient management plans. Page 432 *in* J. P. McNamara (Ed.) Modeling Nutrient Utilization in Farm Animals. CABI Publishing, New York.

Tylutki, T. P. and D. G. Fox. 2000b. Managing the Dairy Feeding System to Minimize Manure Nutrients. Pages 209-226 *in* Managing Nutrients and Pathogens from Animal Agriculture, Camp Hill, PA.

Tylutki, T. P. and D. G. Fox. 2000,. Quality control in herd nutrient management. Pages p. 130-143 *in* Proceedings of the 2000 Cornell Nutrition Conference for Feed Manufacturers, Rochester, NY.

Tylutki, T. P. and D. G. Fox. 2002. Mooving Towards Six Sigma. Quality Prog. February:34-41.

Tylutki, T. P. and S. D. Klausner. 1995. The Cornell Nutrient Management Planning System. Agronomy Abstracts. 1995:258.