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An Integrated Approach to Managing Nitrogen on Dairy Farms: Evaluating Farm Performance Using the Dairy Nitrogen Planner

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ABSTRACT

Nutrient flow in dairy farming involves animal and field components that are linked by transfers of crops and manure. Connections of the farm to the surrounding environment are created by inputs and outputs of feed, fertilizer, biological N_2 fixation, animals and animal products, and nutrient losses to air and water. Because of these linkages among farm components and connections to the environment, an integrated system-level approach would be useful to evaluate farm performance in terms of production efficiency and environmental protection goals. The purpose of this study was to evaluate dairy farm N flow and management by comparing farm performance data with reference values from the Dairy Nitrogen Planner (DNP), an integrated animal and field spreadsheet planning and evaluation tool. Performance data were from two Pennsylvania dairies: Farm 1, 109 lactating Holstein cows (*Bos taurus*), with forages produced on 92-ha crop land and supplemental feeds purchased as directed by nutritional services; Farm 2, 65 lactating cows, with nearly all feeds produced on the 111-ha crop land and no forage quality analysis or ration formulation assistance. Farm performances on Farm 1 and 2, respectively, were (with the difference relative to the DNP projection): annual N input, 17 450 kg (−5%) and 10 670 kg (−10%); milk-N output, 3880 kg (−8%) and 2790 kg (−0.4%); feed-N intake, 20 200 kg (−2%) and 18 820 kg (+1%); and manure N for application, 8550 kg (−14%) and 10 200 kg (+11%). The differences between farm performance and DNP projections identified overall farm organization and crop management opportunities for improved farm system performance on Farm 1. Animal ration balancing was identified as a priority area for enhancement on Farm 2, with subsequent action to adopt the services of a professional nutritionist increasing milk production by 20% and decreasing manure N by 10%.

Substantial efforts have gone into managing nutrients on dairy farms to maximize profits while reducing pollution potential to protect water resources (Lanyon, 1994a). Nitrogen has been a focus of these efforts because N is so essential to animal nutrition and crop production and its transformations often lead to considerable losses. The challenges of managing N on dairy farms are the interacting nature of N flows between animal and field components as well as the varying degree and multiple pathways of N transfers between the farm and its surrounding environment. The magnitudes of these transfers are determined both by the biological requirements and the management level and goals of the farmer. Overall N efficiency, as well as N loss, for dairy farms depends on the performance of individual components and the balance among these components. An N-conserving approach in one farm component typically will influence the performance of other components. For example, balancing a ration may reduce dietary N intake, resulting in less N excretion in manure while maintaining milk yield (Ferguson et al., 1992). This, in turn, would reduce manure N flow into other farm components, with the potential for improving overall N efficiency on the farm (Bacon et al., 1990). An approach that conserves NH_3 during manure handling and storage, on the other hand, would effectively conserve N within the farm only if the manure is applied in such a way as to prevent NH_3 volatilization after field application (Aarts et al., 1992). Clearly, when developing tactics to manage N for minimal environmental pollution while maintaining crop and animal production, all components of a farm system should be considered.

Farm management involves the setting of goals, development and implementation of plans, and the evaluation of the results so that in the next management iteration performance will more closely achieve the goals (Lan-

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Abbreviations: DM, dry matter; DNP, Dairy Nitrogen Planner.

Table 1. Characteristics of two Pennsylvania dairy farms from which performance information was collected.

Farm component	Farm 1	Farm 2
Herd		
Lactating cows (Holstein), no.	109	65
Dry cows and bred heifers, no.	29	15
Replacement heifers, no.	84	25
Beef steers, no.	—	20
Rolling herd average, kg cow^{-1} yr^{-1}	7382	6888
Manure		
Collection frequency	every other day	daily
Storage	in-ground concrete–earthen pit, 2100 m^3	aboveground tank, 1700 m^3
Storage duration	up to 1 yr	6 mo
Soil		
Productivity group†	predominantly low to medium	Predominantly high; some low
Crop		
Corn, ha	69 (as silage)	29 (as high-moisture grain)‡
alfalfa–grass mixture, cool-season grass, ha	23 (as hay or haylage)	71 (as hay or haylage)
Winter rye, ha§	33 (harvested as ryelage)	—
Sorghum–sudangrass, ha	—	11 (as haylage)

† Based on Penn State Agronomy Guide (Anonymous, 1995).
‡ Corn grain harvested at 250 to 350 g kg^{-1} moisture and ensiled before feeding.
§ Planted as a winter cover crop after corn harvest.

yon, 1994b). A series of computer-based decision-support programs are available for the crop-field planning component of nutrient management (Thompson et al., 1997). Effective evaluation tools are less common, however, especially those that integrate management of both crop fields and livestock. If dairy farm nutrient management is to move beyond the crop-field and manure planning conception to a performance-based total system approach (Reynnells, 1992), tools for farm performance evaluation, not just whole-farm planning, will be necessary.

We developed a computer worksheet, Dairy Nitrogen Planner (DNP), as an evaluation and planning tool for an integrated approach to whole-farm N management (Dou et al., 1996). This rule-based spreadsheet accounts for soil and crop management, manure production and allocation, and animal feeding, and monitors N flows through these components. The objective of the present work was to evaluate the management and performance of two Pennsylvania dairy farms using DNP projections as the reference.

MATERIALS AND METHODS

Farm Description

Farm 1

Data on this Dauphin County, Pennsylvania farm (Table 1) were collected in 1988. The dairy herd consisted of 109 lactating cows, 29 dry cows and large bred heifers, and 84 replacement heifers. Major crops included corn (*Zea mays* L.) silage (69 ha), alfalfa (*Medicago sativa* L.) and alfalfa–grass mixture (23 ha), plus rye (*Secale cereale* L.) (33 ha), planted as a winter cover crop after corn, as ryelage. Soils on this farm are predominantly shallow to moderately deep, with limited areas that are deep and well drained. Soil series were Klinesville (loamy-skeletal, mixed, mesic Lithic Dystrochrepts), Calvin (loamy-skeletal, mixed, mesic Typic Dystrochrepts), and Leck Kill (fine-loamy, mixed, mesic Typic Hapludults), corresponding to soil productivity Groups 3, 2, and 1 (estimated corn yield potential from 6350 to 7850 kg ha^{-1}; Anonymous, 1995). The 1988 growing season was dry, with monthly precipitation April through September of 44, 125, 44, 88, 80, and 86 mm (total 467 mm), as compared with a normal year for the area of 85, 88, 100, 94, 90, and 94 mm (total 551 mm) (Pa. Agric. Stat. Serv., 1989).

All diets for the dairy herd were formulated by a professional nutritionist based on feed analysis and recommendations of the National Research Council (NRC, 1989). Concentrates and some forages were purchased and fed to the animals, along with on-farm produced forages. Based on availability and quality of forages, different diets were formulated for groups of lactating cows, replacement heifers, and dry cows and bred heifers.

Manure from the lactating cows, along with bedding, was scraped every other day and stored in a concrete-lined earthen pit, while manure from the other groups was collected and stacked in the open feedlot. All the manure was applied to fields primarily in spring and fall. Spring manure applications, mainly in April and May, were surface-spread on corn fields, followed by same-day incorporation. Fall manure applications, mostly in October, were surface-spread on corn–rye fields. A few applications were made in other times of the year to alfalfa or alfalfa–grass fields. Additionally, a total of 7690 kg N from poultry (*Gallus* sp.) manure and 180 kg N from residential septage were also applied on the farm in the year.

Farm 2

Data on this Centre County, Pennsylvania farm (Table 1) were collected in 1993. There were 65 lactating cows, 15 dry cows, 25 replacement heifers, and 20 beef steers. There was a total of 111 ha cropland, comprising 29 ha managed as high-moisture corn grain, 11 ha as sorghum–sudangrass [*Sorghum bicolor* (L.) Moench interspecific hybrid] silage, and 71 ha as alfalfa or alfalfa–grass mixture. Soils are predominantly deep, with some shallow areas; are all well drained. Soil series include Hagerstown silt loam (fine, mixed, mesic Typic Hapludalfs), Murrill channery loam (fine-loamy, mixed, mesic Typic Hapludults), Hublersburg gravelly silt loam (clayey, illitic, mesic Typic Hapludults), and Opequon silty clay (clayey, mixed, mesic Lithic Hapludalfs). The Opequon series is soil productivity Group 4 (estimated corn yield potential of 6350 kg ha^{-1}; Anonymous, 1995); the other two soils are Group 1 (7850 kg ha^{-1}). Monthly precipitation April through September was 243, 48, 68, 107, 130, and 151 mm (total 747 mm), compared with the area's norm of 79, 99, 115, 104, 94, and 91 mm (total 582 mm) (Pa. Agric. Stat. Serv., 1993).

The farmers' management goals included minimizing purchases of off-farm feeds and fertilizer. Feeding was based on the farmers' experience and the crops produced rather than on forage analysis and ration formulation to balance nutrient intake and supply with potential cow performance. Legume-based hay and haylage were fed to all animal groups. High-moisture corn grain was provided to lactating cows and beef steers only; dry cows grazed on pasture for April through October and were fed hay and haylage during confinement. The aboveground manure tank was for manure from the lactating cows with the milkhouse wash water added, plus barn roof runoff and rainfall from a concrete barnyard (≈4500 m^2). Slurry from the manure tank was applied to fields twice a year (spring and fall). Spring applications made to corn fields to supply N were incorporated within one day. Fall applications were to alfalfa–grass fields to supply P and K. Manure from dry cows in confinement was accumulated as a dry bedded pack and spread twice a year. Manure from the heifers and steers was collected and applied to fields or pastures on a weekly basis. Additionally, a total of 650 Mg swine (*Sus* sp.) manure containing 1120 kg total N was imported, one-quarter of which was applied to a corn field and the rest to an alfalfa–grass field.

Observed Farm Performance

Farm performance information was obtained as part of whole-farm nutrient balance studies, following the protocol developed by Bacon et al. (1990). For each farm, the study included a complete record of field location, size, and crop management activities, including dates of planting and harvesting and dates and rates of manure application and fertilization. All material flows within the farms (harvest crops, manure applications), as well as import and export of forages and animal manure, were measured using drive-on mechanical or electronic scales. Almost every grain or forage wagon and randomly selected manure loads were weighed on each farm. Quantities of materials entering (purchased feeds, fertilizer, bedding material) or leaving (milk, animals) each farm were obtained from receipts of purchases and sales or information on exchanges with neighboring farmers. Composite samples of crops from each field, routine manure samples, and random samples from purchased feeds and bedding materials were collected to determine moisture and nutrient concentrations. Moisture content was determined by drying in forced-air or microwave ovens. Nitrogen concentrations in the crop samples were determined by the method of Isaac and Johnson (1976). Manure nutrient concentrations were determined by methods of Doty et al. (1982). The quantities of N in milk and livestock exported from the farms were determined by multiplying the amounts exported by concentration estimates based on the DNP or book values (NRC, 1989), respectively. Biological N_2 fixation by alfalfa was estimated by multiplying total herbage N by 0.6, which is an approximation to estimate the potential magnitude of this source (Heichel et al., 1984; Bacon et al., 1990; Klausner, 1993). The same coefficient was used to estimate biological N_2 fixation by alfalfa–grass mixtures, since analyses of these mixtures showed similar N concentration values as pure alfalfa samples. The data were managed using a field and farm information program (Lanyon and Meij, 1992).

Dairy Nitrogen Planner Description and Input Variables

The DNP is a computer worksheet (Dou et al., 1996) consisting of two separate spreadsheets: a ration spreadsheet and a whole-farm spreadsheet. The ration spreadsheet is the Quattro Pro version of the Cornell Net Carbohydrate and Protein System ver. 2 (CNCPS) (Fox et al., 1992; O'Connor et al., 1993; Russell et al., 1992; Sniffen et al., 1992) adapted at the University of Pennsylvania (CAHP2.12d) (W. Chalupa, personal communication, 1996). This single-animal, single-day model features ration formulation and predicts feed-N partitioning into milk, body weight change, and manure production, as well as N fractionation between feces and urine. The spreadsheet can be used to balance the nutrients for a specified as-fed diet to meet the predicted requirements of the cow based on forage type and forage analysis values from a laboratory sample or from the embedded electronic feed dictionary.

The whole-farm spreadsheet consists of several pages, each representing a farm management component (herd, manure, soil, crop, feed), plus a farm summary page. A macro program in the whole-farm spreadsheet retrieves information from the ration spreadsheet. These data are aggregated in the herd page for the annual requirements of the entire herd. The aggregated manure and N fractionation information is linked to the manure page, where N losses are estimated based on the type of manure handling and storage facilities as well as the time animals spend on pasture. Nitrogen additions from bedding are included in the manure page. Residual soil N that is expected to be available for the upcoming crops is estimated in the soil page based on field management (legume residue, manure history) (Dou et al., 1996). Crop N requirement based on crop type and expected yield, manure application and supplemental N fertilizer rates based on manure N availability, and residual soil N data imported from the relevant pages are estimated on the crop page. A feed inventory is maintained on the feed page by subtracting herd requirement and feed sales from on-farm production, inventory carryover, and purchases. Finally, N flows for animal and feeding, soil and crop, and the whole farm are summarized on the farm page.

For Farm 1, input parameters to DNP for the soil and crop component included management of eight groups of fields representing 81 individual fields, with each group having the same type of crop and similar soil management information. Expected crop yields were set at the farm averages from several preceding years (corn silage: 31 Mg ha^{-1}; alfalfa, alfalfa–grass, grass hay: 9 Mg ha^{-1}; ryelage: 9 Mg ha^{-1}, all at standard moisture content) (Anonymous, 1995). Rations were calculated for three groups of lactating cows, two groups of replacement heifers, and one group of dry cows and bred heifers. The quantities of manure spread and manure N exported, along with manure collection and storage information, were entered into the manure page. Actual concentrate and forage purchases were included in the feed page.

For Farm 2, since feeding practice was based on experience and the available crops instead of professional recommendations, rations were reconstructed for lactating cows, dry cows, small heifers, large heifers, and steers based on results from interviews with the farmer, recorded crop production, and purchased feeds. An estimate of the amount and N concentration of the hay or haylage mix described by the farmer was obtained by pooling the production of all species of hay or haylage and calculating a weighted crude protein concentration (181 g kg^{-1} for hay, 193 g kg^{-1} for haylage) based on the field samples. Since forage quality analyses were not conducted, additional feed quality parameters were estimated from the feed dictionary included in the ration spreadsheet and adjusted for storage changes (Rotz and Muck, 1994). Quantities of hay mix, haylage mix, and high-moisture corn were assigned to each animal group based on crop production from the farm records and animal performance. The rations reconstructed from these estimates and the farmers' descriptions, together with animal performance, were entered into the ration spreadsheet for evaluation. For the whole-farm spreadsheet, crops and fields were grouped into corn, sor-

Table 2. Crop yield, crop production, and feed purchases (DM) on Farm 1, compared with dry matter intake (DMI) projected by the Dairy Nitrogen Planner (DNP).

	Crop yield	Crop production	Feed purchase	Projected intake
	Mg DM ha^{-1}	— Mg DM yr^{-1}	—	Mg DMI yr^{-1}
On-farm produced				
Corn silage	4.6	320	—	257
Ryelage	3.3	93	—	129
Legume hay and haylage	4.3	86	—	69
Grass hay	5.3	16	—	84
Subtotal	—	515	—	539
Purchased				
Hay	—	—	89	—
Soybean meal	—	—	55	36
Ear and shelled corn	—	—	102	207
Corn distiller's grain	—	—	34	52
Cottonseed (whole)	—	—	42	82
Other†	—	—	—	2
Subtotal	—	—	322	379
Total	—	515	322	918

† Minerals, vitamins, molasses, etc.

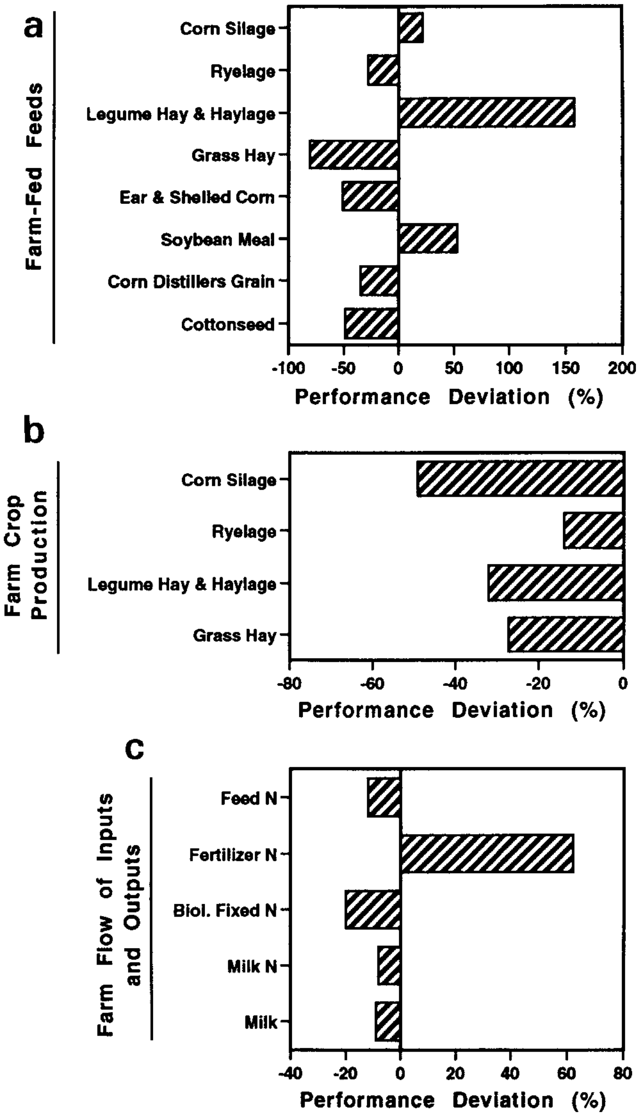

Fig. 1. Performance evaluation summaries for Farm 1. Performance deviation is [(Performance − DNP projection)/DNP projection] × 100. (a) Feeding program evaluation comparing farm-fed feeds with DNP projections. (b) Farm-grown crop yields as compared with DNP projections. (c) Selected comparisons of N input, milk-N output, and milk sold on Farm 1 with DNP projections.

ghum–sudangrass (silage), legume–grass (hay), and legume–grass (haylage). Expected crop yields for this farm were set at the estimates for each soil productivity group (Anonymous, 1995). Manure management information, along with manure import data, was entered into the manure page.

RESULTS AND DISCUSSION

Farm 1

Animal Performance

The feed provided on the farm (837 Mg DM, including 515 Mg produced and 322 Mg purchased) and the DNP projection (918 Mg) were in close agreement (Table 2), considering storage losses and waste during feeding (Ishler et al., 1991). Nevertheless, within feed types there were substantial differences between farm observations and the expected values from DNP (Fig. 1a). Total DM of forages (515 Mg of home-grown and 89 Mg of purchases) was about 12% more than the DNP-projected DM intake (539 Mg). Almost 40% less supplemental feed was purchased for the period than expected by the DNP (233 vs. 379 Mg). Since the protein supplement, soybean meal, was overpurchased by more than 50%, the discrepancy was due to underpurchasing of the energy-supplement feeds (e.g., <50% of the DNP-projected corn grain was purchased). Because actual feed inventories were not monitored, we could not evaluate the effect of feed carryover from one year to the next on the difference between farm utilization and the DNP projection. Deviation of farm performance from the DNP could also be due to the formulated rations being implemented by the farmer with some flexibility. The farmer, for financial or other reasons, apparently underfed the animals concentrates relative to the professionally formulated diets and tended to overfeed forages produced on-farm or locally purchased.

Actual feed-N intake (20 200 kg) compared closely with the DNP projection of 20 610 kg. Feed N was partitioned by DNP into milk (4220 kg N), animal body gain (1370 kg N), and manure (14 970 kg N). Milk sales, 760 Mg, were about 9% less than the DNP-projected production of 836 Mg. Underfeeding of the energy-supplement feeds might have restricted cow performance, even though adequate N (protein) was provided. In practice, milk sales do not match milk production because milk in the first 3 d of lactation and milk from cows treated for mastitis must be excluded from sales. Also, the size of the milk tank was small compared with the potential herd production at the time; hence, excess milk was periodically excluded from sales. No information was available for this period to estimate the quantity of milk excluded from sales.

Field Performance

A total of 1760 Mg manure containing 8550 kg N was either applied on-farm or exported in the year. The DNP projection of 1410 Mg containing 9980 kg N, including the potential losses in the specific manure handling system, was closer than using book values such as the Pennsylvania Manure Management Manual (Beegle et al., 1995), which would project 3170 Mg of manure with 15 820 kg of N available for application. Monitoring of manure inventory carryover and comparisons of on-farm manure management with the DNP results over a period of several years could provide insight into the efficacy of the on-farm manure handling system and the reliability of the DNP protocol for estimating the manure available for application.

Forage harvest yields were less than projected by DNP (Fig. 1b). In the case of corn silage, the highest yield in the year was only two-thirds of the farm average, while most of the fields yielded only one-third. An intense dry period during the growing season (especially in June, when rainfall was less than one-half of the long-term average) inhibited crop growth and reduced yields, especially on the shallow to moderately deep soils. The empirically based DNP was not developed to account for weather dynamics in individual years. Low yields could also be attributed to deviations of farm crop management from agronomic recommendations. For example, in fields with extremely low silage yields (less than one-third of the farm average) corn planting was more than a month behind recommended dates and neither manure nor commercial fertilizer was applied.

Actual manure applications ranged from 0 to 1155 kg manure N ha^{-1}, while the DNP suggested a rather narrow range of application (180–250 kg manure N ha^{-1}). Nitrogen flows in the soil–crop unit on the farm averaged 193 kg N ha^{-1} yr^{-1} input (both managed inputs and biological N_2 fixation) and 85 kg N ha^{-1} yr^{-1} output (in harvested crop), compared with the DNP flows of 246 kg N ha^{-1} yr^{-1} input and 180 kg N ha^{-1} yr^{-1} output. In addition to the growing-season drought that inhibited crop growth and yield, departures from recommended practices (due to the constraints on time, equipment, and/or labor that often occur on many dairy farms) could account for reduced yields. Indeed, management can be one of the most important factors influencing nutrient flows and losses on dairy farms (Saporito and Lanyon, 1995). The difference between actual crop yields and the DNP performance reference could be the basis for future management attention, to avoid these problems in subsequent years (Lanyon, 1994a).

Farm Performance

Total N entering the farm in the year (17 450 kg) was only 5% less than the DNP projection of 18 440 kg N (Table 3). Of the total N entering the farm, more than two-thirds was from feed purchases (concentrates plus some forages); fertilizer N accounted for less than 20% of the input. Oversupply of N fertilizer and underpurchasing of feed N (Fig. 1c) suggest that improving both feed and crop management could enhance farm performance. Nevertheless, due to its magnitude, feed management may offer a special opportunity to reduce N input to a dairy farm (Kohn et al., 1997). Bacon et al. (1990) observed a 21% decrease in annual N input on a dairy farm when a 29% reduction in purchased feed N occurred, while fertilizer N purchase was actually increased by 6% and milk production was unchanged.

Table 3. Total N input, production output, and N reserves at the whole-farm level for Farm 1, compared with projections by the Dairy Nitrogen Planner (DNP).†

N budget	Farm performance	DNP projection
	kg N yr^{-1}	
Input		
Purchased feed	11 760	13 360
Purchased N fertilizer	3 280	2 030
Bedding	20	70
Biological fixation‡	2 390	2 980
Total	17 450	18 440
Production output		
Milk	3 880	4 220
Sold animal	570	1 420
Sold crop	110	110§
Manure exported	370	370§
Total	4 930	6 120
Input − output	12 520	12 320
Reserves¶		
In soil	—	2 060
In herd	—	−50
In crop	—	8 080

† Data rounded to the nearest 10.

‡ Biological fixation = Total N in harvested legumes or legume–grass mix × 0.60 (Heichel et al., 1984; Bacon et al., 1990; Klausner, 1993).

§ Measured farm data were entered into DNP.

¶ Including manure organic N that would be available for crops in the following 3 yr, N gained or lost due to body weight change of the herd, and N in crops of carryover.

Farm output of N in managed products (4930 kg) was 28% of the total input (Table 3). The production output was mainly milk, with a small amount of N in animals and crops sold plus some exported manure. Farm output projected by the DNP was 6120 kg or 33% of the input. Bouldin et al. (1984) reported 30% of N input to be converted into production output for a typical New York dairy farm. Lanyon and Beegle (1989) recorded about 15% for a Pennsylvania dairy farm and Bacon et al. (1990) recorded 30 to 32% for another Pennsylvania dairy operation in a 2-yr study. The DNP spreadsheet accounted for changes in N reserves on the farm, including the organic fraction of the N in manure applied that is expected to be available in the following seasons, net change of N in the herd, and N that would be in carryover crops. These estimates could be used to further evaluate farm performance when additional comparable actual farm information is available.

Farm 2

Animal Performance

Total feed provided on this farm was about 748 Mg (682 Mg produced plus 66 Mg purchased, DM basis). The DNP-projected DM intake was 674 Mg, based on the reconstructed rations (Table 4). The milk sales of 551 Mg corresponded closely to the DNP-projected 569 Mg. The close correspondence between the fed and DNP rations and between the milk produced and the DNP results illustrates the ability of the DNP to utilize farmer-based feeding information to formulate a performance standard.

Because the farmer-fed rations were not professionally balanced, the DNP was used to make new rations balanced for projected animal requirements using on-farm produced feeds plus off-farm concentrates. Comparing the farmer-fed rations for lactating cows with the

Table 4. Crop yield, production and feed purchases (DM) on Farm 2, compared with dry matter intake (DMI) projected by the Dairy Nitrogen Planner (DNP)

Component	Crop yield	Crop production	Feed purchase	Projected intake
	Mg DM ha^{-1}	—— Mg DM yr^{-1}	——	Mg DMI yr^{-1}
High-moisture shelled corn	5.7	167	61	208
Forage hay†	6.5	460	5	37
Forage haylage†	—	—	—	429
Sorghum–sudangrass hay	5.2	55	—	—
Total	—	682	66	674

† Forages could not be separated by species due to storage and feeding techniques.

Table 5. Ration comparison for the lactating cows on Farm 2, based on availabilities of farm-grown feeds plus supplements and projected animal performance.

	Farmer-fed†	Recommended
Ration composition, kg DM cow^{-1} d^{-1}		
High-moisture shelled corn	7.7	7.7
Hay mix	1.2	1.0
Haylage mix	14.3	6.5
Supplements‡	0	4.5
Ration evaluation		
Concentrations		
Ration crude protein, %	15.9	15.8
Bypass protein, % of crude protein	23.7	32.2
Balances		
Metabolizable energy, Mcal§	6.0	0.6
Metabolizable protein, g	−26.8	54.2
Peptide, % requirement	148	105
NH_3, % requirement	178	106
Rumen excess N, g	97.5	−34
Target milk, kg cow^{-1} d^{-1}	24.0	30.0
N balance, g N d^{-1}		
Intake	599	508
Milk	118	147
Feces	251	230
Urine	227	128
Other¶	3	3

† Reconstructed rations based on farm data of feed availability and animal performance.

‡ Supplemental feeds: 0.50 kg soybean meal, 0.45 kg Prolak, 0.03 kg wheat middling, and 3.50 kg dry corn grain, all on a dry matter (DM) basis.

§ The respective values for metabolizable energy in joules are 2.5×10^7 and 2.5×10^6.

¶ Other N = N intake − (milk N + manure N). This includes N in scurf and body weight change.

DNP rations suggests that the farmer supplied adequate crude protein but inadequate bypass protein and undersupplied metabolizable protein (Table 5). While the undersupply of metabolizable protein might be limiting milk production, other indicators of N status (peptide, NH_3, and rumen excess N) exceeded the DNP reference values (Fig. 2b), suggesting higher N losses in manure than would be expected with a balanced feed program. The lack of balance in the farmer-fed ration resulted in inefficient N utilization (20%) compared with the DNP (29%), which is also a more commonly recognized efficiency for well-fed dairy cows (Bulley and Holbek, 1982; NRC, 1989). The almost exclusive use of alfalfa hay and haylage without balancing the rations and the nature of the proteins and other nutritional fractions required by the lactating cows led to these discrepancies. New diets corresponding more closely to the DNP projections would reduce feed-N intake by 15% and reduce manure N excretion by 25% while increasing milk yield by 25%. Better balancing feed supplies of energy and rumen vs. by-pass proteins has shown substantial impact on improving animal efficiency and reducing rumen losses (Tamminga, 1992; Baker et al., 1995; Satter, 1986).

Field Performance

The DNP partitioned total feed-N intake of 18 580 kg into milk (2800 kg), body weight gain (410 kg), and manure (15 380 kg). A comparable manure production estimate using engineering standards (ASAE, 1993) would be 8510 kg N in fresh manure. Apparently, the ASAE standards, although widely used by engineers to design waste management systems, do not account for variations of dietary intake and feeding management that occur across farms (Morse et al., 1994; van Horn et al., 1994).

For the nonlactating groups from which manure was hauled and applied to fields on a weekly basis, farm records of 280 Mg manure with 2370 kg N closely matched the DNP projection of 280 Mg fresh manure containing 2840 kg N. For manure from the lactating group, the farm records showed a total of 12 140 kg N contained in 5050 Mg cow slurry applied in the year, which was more than 30% higher than the DNP projections and 90% higher than estimates based on Pennsylvania Manure Management Manual (Beegle et al., 1995). Although there were no manure inventory data available to estimate possible carry-over at the beginning and left-over at the end of the year, records of slurry applications in adjacent years on the farm averaged 16% less than the study year. Adjusting for a manure carryover of 16% would result in 4200 Mg slurry with 10 200 kg N accounted for in the study year. These adjusted estimates are within 15 and 11%, respectively, of the DNP-projected 3630 Mg slurry and 9150 kg N. The disagreement of the farm data with the estimates based on the Pennsylvania Manure Management Manual (Beegle et al., 1995) may be due in part to the dilution effect caused by barnyard and roof runoff on the farm.

Measurements of corn and alfalfa–grass yields were about 11 to 16% less than the DNP results, and sorghum–sudangrass silage yields were >60% less (Fig. 2c). Using expected crop yields from the crop library in the model based on soil productivity group was reasonable for corn and alfalfa–grass on this farm with a well-managed crop production component in a year when the weather conditions were not extreme. Sorghum–sudangrass was an experimental crop not routinely grown on the farm, so some other production variables might have limited crop growth and the final yield or the expected crop yield may be too high for this location.

Farm records of manure applications on nonlegume crops, 250 to 400 kg N ha^{-1} yr^{-1}, were close to the DNP range of 280 to 380 kg N ha^{-1} yr^{-1}. Observed N flows in the soil–crop unit were 161 kg N ha^{-1} yr^{-1} input and 159 kg N ha^{-1} yr^{-1} crop output, compared with the DNP flows of 126 kg N ha^{-1} yr^{-1} input and 123 kg N ha^{-1} yr^{-1} output.

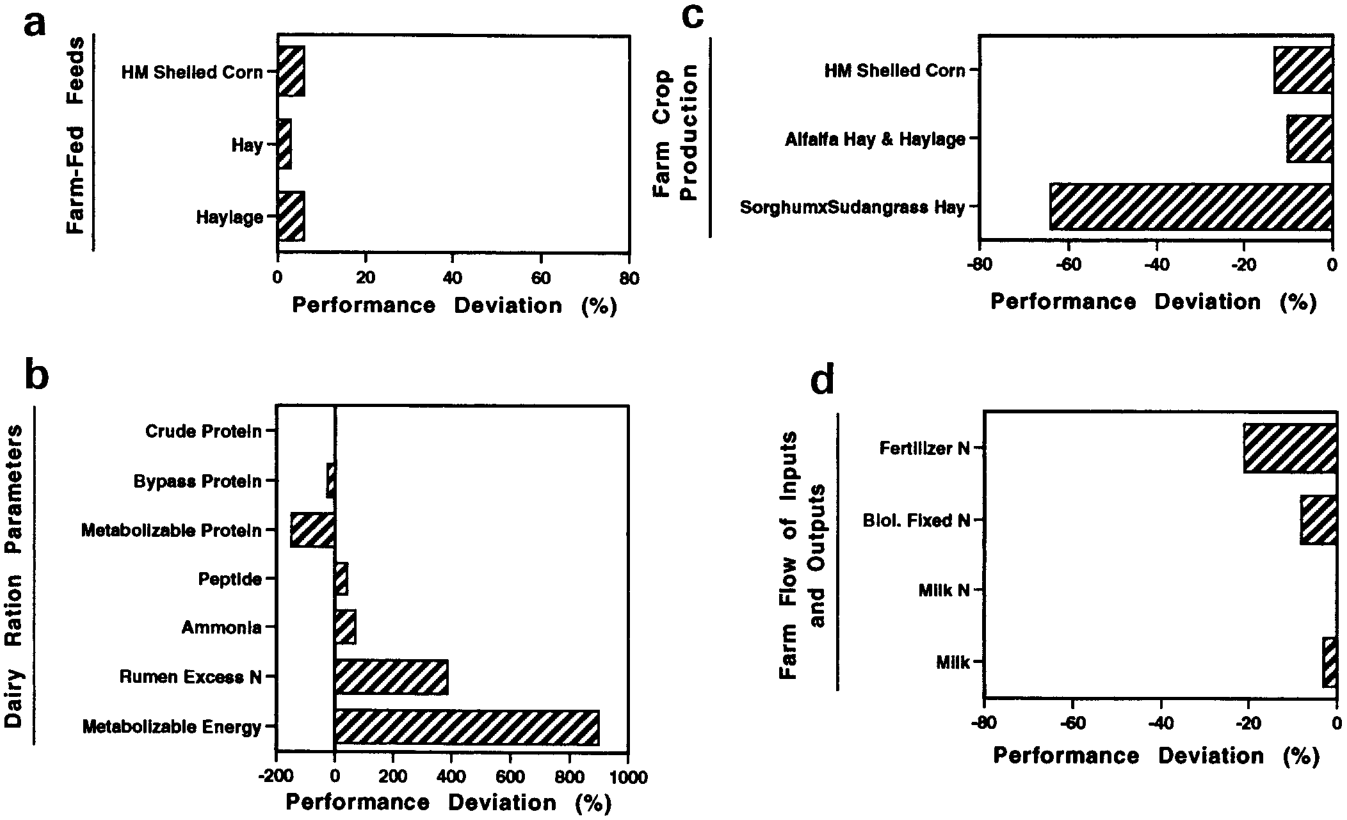

Fig. 2. Performance evaluation summaries for Farm 2. Performance deviation is [(Performance − DNP projection)/DNP projection] × 100. (a) Feeding program evaluation comparing farm-fed feeds with DNP projections based on reconstructed rations. (b) Lactating cow ration evaluation comparing farm-fed ration with DNP projections of a balanced ration. (c) Farm-grown crop yields as compared with DNP projections. (d) Selected comparisons of N input, milk-N output, and milk sold on Farm 2 with DNP projections.

Farm Performance

A total of 10 670 kg N entered the farm in the year, of which 73% was attributed to legume fixation and 12% to fertilizer purchases. The corresponding DNP flow was 11 860 kg N, with 71% through legume fixation and 14% through fertilizer purchases (Table 6). The only purchases in the year were 61 Mg corn grain, 5 Mg alfalfa–grass hay, and 1280 kg N fertilizer. Although the inputs and outputs are in close agreement, there is a substantial opportunity to improve milk production (Fig. 2d).

Implications

The strength of an integrated systems approach to performance evaluation using rule-based reference values is that opportunities specific to individual farms can be identified. Both animal and crop management options can be incorporated into whole-farm management responses. With this approach, changes to reconcile livestock production with water quality protection are not limited to prescriptions of the most likely solutions or adoption of narrowly focused recommendations from experts.

The integrated systems approach can also be used to explore potential changes when differences between farm performance and the rule-based reference are identified. For instance, sustaining corn silage yield at the average level on Farm 1 would allow 40% of the area currently managed as corn silage to be converted to corn grain while still producing adequate silage, as

Table 6. Total N input, production output, and N reserves at the whole-farm level for Farm 2, compared with projections by the Dairy Nitrogen Planner (DNP).†

N budget	Farm performance	DNP projection
	kg N yr^{-1}	
Input		
Purchased feed	240	240‡
Purchased N fertilizer	1 280	1 630
Bedding	180	420
Imported manure	1 120	1 120‡
Biological fixation§	7 800	8 450
Total	10 670	11 860
Production output		
Milk	2 790	2 800
Sold animal	440	700
Total	3 230	3 500
Input − output	7 440	8 360
Reserves¶		
In soil	—	1 500
In herd	—	−290
In crop	—	5 520

† Data rounded to the nearest 10.

‡ Actual farm data were entered into DNP.

§ Biological fixation = Total N in harvested legumes and legume–grass mix × 0.60 (Heichel et al., 1984; Bacon et al., 1990; Klausner, 1993).

¶ Including manure organic N that would be available for crops in the following 3 yr, N gained or lost due to body weight change of the herd, and N in crops of carryover.

projected by the DNP. This would create the opportunity to allow nearly one-half of the corn grain formulated for the herd to be produced on the farm, which, in turn, would reduce feed-N input to the farm. The reallocation of land resources and improved management would also help the field N balance, because the N applied would be better utilized by crops that are approaching the yield goal for which the N is supplied. Since herd performance would remain constant or improve under the revised management conditions, reduced feed purchases could translate into reduced N losses, as total N input minus production N output would decrease by 1910 kg. Of course, improving crop management requires additional inputs of money, time, and management skills. Although the current version of the DNP worksheet is unable to perform a complete economic analysis, potential savings in reduced feed purchases could help offset some of the increased expenses.

Inaccurately balanced rations on Farm 2 led to low feed-N capture and low milk-N efficiency. The result on this farm suggests that a self-sufficient management style in dairy farming is not always an efficient way to manage nutrients for each component or total farm resources. This management approach cannot take advantage of off-farm inputs to balance animal requirements with farm crop production. As long as animal manure is managed with water quality protection as a goal, importing supplemental feeds to compensate for the nutrient imbalance of on-farm forages and to balance nutrient supply and intake against animal requirements for realistic high performance appears to be a tactic that is economically viable and environmentally sound (Kohn et al., 1997). Purchasing feeds without adequate incentives to manage the nutrients in an environmentally sensitive way does create the potential for off-farm water quality impacts, since the economic incentives are often substantial (Westphal et al., 1989). On this farm, milk yield increased nearly 20% when a nutrition service was adopted and supplemental feed purchases to balance the diets were initiated. Preliminary results also showed a 10% decrease of manure N. Since animal number is fixed on this farm, the existing crop area could be reallocated to better meet the diet requirements in the future. Decreasing alfalfa area may be an important step toward increasing corn production or producing alternative forage crops with lower protein contents. Additional feed storage structures could be built to enable the production and feeding of corn silage. Not only can the inadequacies of the existing farm management be identified using the DNP as a benchmark, but alternatives for future changes can be evaluated.

That fertilizer input accounted for only a small portion of total N input to the dairies is not surprising given the attributes of N cycling on dairy farms. In general, a large quantity of N enters a dairy with purchased feeds or by legume fixation, and 70% or more of the feed N is excreted in manure which can be applied to crops. Consequently, the requirement for commercial fertilizer is reduced. The credit of manure nutrients, however, may not be fully appreciated or accounted for on farms when crop fertilization decisions are made (Young et al., 1985). Farm 1, for example, apparently applied more fertilizer N to the rye and some of the corn fields than was needed according to model calculations, which resulted in higher fertilizer N purchases than necessary (Table 3).

Different from conventional agronomic studies that focus on particular aspects of a farm component such as fertilizer rate experiments or forage species screening trials, system research features a macro examination and analysis of the whole farm that helps recognize the critical control points for nutrient flows and efficiency as well as farm performance. A rule-based tool such as the Dairy Nitrogen Planner can facilitate integrated farming systems evaluations. The examples illustrate how the DNP can be used to evaluate farm performance, identify potential management points for improvement, and after adjustments are made, to evaluate the new set of management options. This evaluation tool facilitates the implementation of an iterative, adaptive management process (Lanyon and Beegle, 1989). In addition, comprehensive, reliable on-farm information is essential to farm performance evaluation using the DNP. These benchmark data for establishing initial performance comparisons and for use in extrapolating to future options enhance the utility of the evaluation tool. With these data, a truly integrated approach for comparing actual conditions of the whole set of farm components with rules embedded in the tool can be achieved (Lanyon, 1994b, 1995).

REFERENCES

Aarts, H.F.M., E.E. Biewinga, and H. van Keulen. 1992. Dairy farming systems based on efficient nutrient management. Neth. J. Agric. Sci. 40:285–299.

American Society of Agricultural Engineers. 1993. Manure production characteristics. Engineering Practice Subcommittee, ASAE Agric. Sanit. Waste Manage. Comm. ASAE Standard D384.1. ASAE, St. Joseph, MI.

Anonymous. 1995. Agronomy Guide. Coll. Agric. Sci., Coop. Ext., Penn. State Univ., University Park.

Bacon, S.C., L.E. Lanyon, and R.M. Schlauder, Jr. 1990. Plant nutrient flow in the managed pathways of an intensive dairy farm. Agron. J. 82:755–761.

Baker, L.D., J.D. Ferguson, and W. Chalupa. 1995. Responses in urea and true protein of milk to different protein feeding schemes for dairy cows. J. Dairy Sci. 78:2424–2434.

Beegle, D.B., L.E. Lanyon, and J.C. Myers. 1995. Manure management for environmental protection: Utilization of manure. A supplement to manure management for environmental protection. Coll. Agric. Sci., Coop. Ext., Penn. State Univ., University Park.

Bouldin, D.R., S.D. Klausner, and W.S. Reid. 1984. Use of nitrogen from manure. p. 221–245. *In* R.D. Hauck et al. (ed.) Nitrogen in crop production. ASA, CSSA, and SSSA, Madison, WI.

Bulley, N.R., and N. Holbek. 1982. Nitrogen mass balances for dairy farms from feed to field. Can. Agric. Eng. 24:19–23.

Doty, W.T., M. Amacher, and D.E. Baker. 1982. Manual of methods: Soil and environmental chemistry laboratory. Information Rep. 121. Dep. of Agronomy, Penn. State Univ., University Park.

Dou, Z., R.A. Kohn, J.D. Ferguson, R.C. Boston, J.D. Newbold, and W. Chalupa. 1996. Managing nitrogen on dairy farms: An integrated approach: I. model description. J. Dairy Sci. 79:2071–2080.

Ferguson, J.D., W. Chalupa, C.J. Sniffen, D.G. Fox, and P.J. Van Soest. 1992. A model to predict nitrogen excretion by lactating cows. J. Dairy Sci. 75(Suppl. 1):175. (Abstr.).

Fox, D.G., C.J. Sniffen, J.D. O'Connor, J.B. Russell, and P.J. Van Soest. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578–3597.

Heichel, G.H., D.K. Barnes, C.P. Vance, and K.I. Henjum. 1984. N_2 fixation, and N and dry matter partitioning during a 4-year alfalfa stand. Crop Sci. 24:811–815.

Isaac, R.A., and W.C. Johnson. 1976. Determination of total nitrogen in plant tissue using a block digestor. J. Assoc. Off. Anal. Chem. 59:98–100.

Ishler, V.A., A.J. Heinrichs, D.R. Buckmaster, R.S. Adams, and R.E. Graves. 1991. Harvesting and utilizing silage. Ext. Circ. 396, Penn. State Coop. Ext., Penn. State Univ., University Park.

Klausner, S.D. 1993. Mass nutrient balances on dairy farms. *In* Proc. Cornell Nutrition Conf. for Feed Manufacturers, Rochester, NY. 19–21 Oct. 1993. Cornell Univ., Ithaca, NY.

Kohn, R.A., Z. Dou, J.D. Ferguson, and R.C. Boston. 1997. A sensitivity analysis of nitrogen losses from dairy farms. J. Environ. Manage. 50:417–428.

Lanyon, L.E., 1994a. Dairy manure and plant nutrient management issues affecting water quality and the dairy industry. J. Dairy Sci. 77:1999–2007.

Lanyon, L.E. 1994b. Participatory assistance: An alternative to transfer of technology for promoting change on farms. Am. J. Altern. Agric. 9:136–142.

Lanyon, L.E. 1995. A nutrient management approach for Pennsylvania: Exploring performance criteria. Agronomy Facts 38-D. Coll. Agric. Sci., Coop. Ext., Penn. State Univ., University Park.

Lanyon, L.E., and D.B. Beegle. 1989. The role of on-farm nutrient balance assessments in an integrated approach to nutrient management. J. Soil Water Conserv. 44:164–168.

Lanyon, L.E., and H.K. Meij. 1992. FINFO: A field and farm technical information management program. J. Prod. Agric. 5:88–94.

Morse, D., R.A., Nordstedt, H.H. Head, and H.H. Van Horn. 1994. Production and characteristics of manure from lactating dairy cows in Florida. Trans. ASAE 37:275–279.

National Research Council (NRC). 1989. Nutrient requirement of dairy cattle. 6th rev. ed. Natl. Acad. Sci. Press, Washington, DC.

O'Connor, J.D., C.J. Sniffen, D.G. Fox, and W. Chalupa. 1993. A net carbohydrate and protein system for evaluating cattle diets: IV. Predicting amino acid adequacy. J. Anim. Sci. 71:1298–1308.

Pennsylvania Agricultural Statistics Service. 1989. Statistical summary and annual report, 1988–1989. PASS-102. Penn. Dep. of Agric., Harrisburg.

Pennsylvania Agricultural Statistics Service. 1993. Statistical summary and annual report, 1992–1993. PASS-102. Penn. Dep. of Agric., Harrisburg.

Reynnells, R. 1992. Animal agriculture: Priority nominations. p. 327–335. *In* J. Blake et al. (ed.) Proc. Natl. Livestock, Poultry and Aquaculture Waste Management Workshop, Kansas City, MO. July 29–31 1991. ASAE, St. Joseph, MI.

Rotz, C.A., and R.E. Muck. 1994. Changes in forage quality during harvest and storage. p. 828. *In* M. Collins et al. (ed.) Forage quality, evaluation, and utilization. ASA, CSSA, and SSSA, Madison, WI.

Russell, J.B., J.D. O'Connor, D.G. Fox, P.J. Van Soest, and C.J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70:3551–3561.

Saporito, L.S., and L.E. Lanyon. 1995. Evaluating the spatial and temporal dynamics of field nitrogen balances on a mixed crop and livestock farm. p. 342. *In* Agronomy abstracts. ASA, Madison, WI.

Satter, L.D. 1986. Protein supply from undegraded dietary protein. J. Dairy Sci. 69:2734.

Sniffen, C.J., J.D. O'Connor, P.J. Van Soest, D.G. Fox, and J.B. Russell. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci. 70:3562–3577.

Tamminga, S. 1992. Nutrition management of dairy cows as a contribution to pollution control. J. Dairy Sci. 75:345–357.

Thompson, R.B., D. Morse, K. Kelling, and L.E. Lanyon. 1997. Computer programs that calculate manure application rates. J. Prod. Agric. 10:58–69.

van Horn, H.H. A.C. Wilkie, W.J. Powers, and R.A. Nordstedt. 1994. Components of dairy manure management systems. J. Dairy Sci. 77:2008–2030.

Westphal, P.J., L.E. Lanyon, and E.J. Partenheimer. 1989. Plant nutrient management strategy implications for optimal herd size and performance of a simulated dairy farm. Agric. Syst. 31:381–394.

Young, C.E., B.M. Crowder, J.S. Shortle, and J.R. Alwang. 1985. Nutrient management on dairy farm in southeastern Pennsylvania. J. Soil Water Conserv. 40:443–335.