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Long-term trends of nitrogen and phosphorus mass balances on New York State dairy farms

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ABSTRACT

The whole-farm nutrient mass balance (NMB) is an adaptive management tool that can be used to identify areas for improvement in nutrient management and to monitor progress over time. The objectives of this study were to (1) evaluate the trends of nitrogen and phosphorus mass balances of 27 New York State dairy farms over 6 to 10 yr, (2) identify specific management changes made by 4 case study farms that improved NMB over time by shifting NMB up or down depending on the initial NMB, and (3) evaluate the potential of key indicators to identify opportunities for improvement in NMB. During the study period, milk price fluctuated whereas costs associated with feed and fertilizer increased substantially. Of the 27 farms, 67 to 74% (depending on the nutrient) decreased NMB per hectare over time, whereas 63 to 67% decreased NMB per megagram of milk over time. In general, changes in NMB were directionally correct, with 43 to 56% of farms operating in the optimum operational zone (with both NMB per hectare and per megagram of milk below the feasible levels suggested for New York) toward the end of the study versus 22 to 26% in the first 2 yr of the assessments. The 4 case study farms improved their NMB, whole-farm nutrient use efficiencies, and feed nutrient use efficiencies while maintaining or increasing milk production per cow. The case study farmers made the largest changes in precision feed management, reducing protein and P in purchased feed by replacing concentrates with blends with lower nutrient concentrations. Total nutrient imports, feed imports, the percentage of homegrown feed and nutrients, the concentration of nutrients in the purchased feed, fertilizer imports, and overall crop yields were useful in identifying potential areas for improvement in NMB.

Key words: dairy farms, nutrient use efficiency, precision feeding, and precision management

INTRODUCTION

In 1999, under the Clean Water Act (USDA-EPA, 1999), New York State (**NY**) introduced its first concentrated animal-feeding operation (**CAFO**) permit for dairy and livestock farms that exceeded a population threshold. These facilities were defined as point sources of pollution by Environmental Protection Agency rules and the permit requires control of pollutants, including losses of nitrogen and phosphorus from livestock production areas and land under control of the operation that receives manure. In addition, state and federal programs were instituted to assist nonregulated farms to implement comprehensive nutrient management plans (**CNMP**). The implementation of CNMP and their associated best-management practices contributed to an improvement in NY statewide P balances over time (Ketterings and Czymmek, 2012). The plan-based CNMP approach takes a very important first step by ensuring enough land base is accessible to reasonably recycle nutrients, but it does not provide a mechanism for farms to measure and manage internal nutrient use efficiency as a way toward nutrient source reduction.

In 2011, the Natural Resources Conservation Service (**NRCS**) released a Technical Note entitled "Adaptive Nutrient Management" (NRCS, 2013), recognizing that no single nutrient management strategy exists that is optimal for all cropping scenarios. The adaptive management approach promotes adjustments in amount, source, timing, and placement (method of application) of fertilizer and manure to minimize nutrient losses and increase nutrient use efficiency over time. Adaptive management allows farms to set a performance base and then choose a range of practices and approaches to meet goals over time. This approach requires the use of tools and benchmarks to both determine a starting point (performance base) and to evaluate the effect of management changes on performance indicators over time.

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Various tools exist for evaluation of management practices at the field or cow level. However, an annual whole-farm nutrient mass balance (**NMB**) assessment is one of very few on-farm tools to aid in whole-farm performance. An NMB is the difference between the nutrients imported onto and those exported from farms, expressed as nutrients per tillable hectares or per megagram of milk production. Negative NMB are undesirable in the long term, whereas a large positive balance may indicate low nutrient use efficiency and high risk of nutrient loss. Although several studies assessed NMB on various agricultural operations in the United States (Anderson and Magdoff, 2000; Spears et al., 2003; Hristov et al., 2006), none included benchmarks or feasibility assessments. Two exceptions include studies in Belgium by Nevens et al. (2006) and in NY by Cela et al. (2014). The latter study characterized the distribution of NMB of 102 dairy farms in NY in a single year and proposed feasible balances at ≤118 kg of N/ha (excluding N_2 fixation; **N1**), ≤146 kg of N/ha (including N_2 fixation and assuming no manure application to legumes; **N2**), and ≤13 kg of P/ha, based on the NMB at or below which 75% of the farms operated in the study. Cela et al. (2014) also reported feasible balances per megagram of milk at ≤8.8 kg of N/Mg for N1, ≤11.8 kg of N/Mg for N2, and ≤1.1 kg of P/Mg based on what 50% of the farms achieved in that database. Farms that operate with NMB that are below the feasible balances per hectare and per megagram but above zero are defined as farms managed in the optimum operational zone. Farms in the optimum zone have low risk of losing nutrients to the environment as well as high nutrient use efficiencies.

Nutrient mass balances can vary from year to year as they can be influenced by weather conditions, feed and milk prices, and so on. Therefore, to truly evaluate the effect of management changes on NMB, long-term trends need to be analyzed. A study by Soberon et al. (2015) analyzed NMB on 54 NY dairies over 4 to 6 yr and showed that 63 to 76% of the NMB decreased over time (depending on the nutrient), and >50% of the farms did so while increasing milk production per cow. Improvements in balances were primarily due to changes in feed imports. Soberon et al. (2015) identified total nutrient imports, feed nutrient imports, animal density, percentage of homegrown feed, homegrown nutrients fed, and feed nutrient use efficiency as key indicators to identify areas for improvement in NMB. However, the study did not assess specific management changes made at the farm level. Such an assessment will require additional assessment years. The objectives of the current study were to (1) evaluate the evolution of N and P mass balances of 27 dairy farms over 6 to 10 yr; (2) identify specific management changes made by 4 case study farms, each with at least 8 yr of data, that improved NMB over time while maintaining or increasing milk productions; and (3) evaluate efficiency indicators for their ability to identify opportunities for improvement in NMB.

MATERIALS AND METHODS

Participating Farms and Selection of Case Study Farms

Dairy farmers were selected based on their interest in participating and the availability of records to complete the NMB (Cela et al., 2014). In our study, we analyzed 27 NY dairy farms that assessed NMB for 6 to 10 yr between 2003 and 2013 (not all of them in consecutive years), resulting in a total of 193 annual NMB. Farms were located in 9 NY watersheds. The size and management practices varied widely across farms: 20 to 5,003 cows, 36 to 2,703 tillable hectares, 0.5 to 5.1 animal units (**AU**)/ha, 4.2 to 13.6 Mg of milk/cow per year, 1.6 to 28.1 Mg of milk/ha, and 33 to 98% of homegrown feed. Eighteen farms were classified as animal feeding operations (**AFO**; <200 mature dairy cows) and 9 were CAFO (>200 mature dairy cows, USDA-EPA, 1999). Therefore, this database is skewed toward medium and large farms compared with the distribution of all dairy farms in NY (Cela et al., 2014).

From this database, 4 farms with 8 to 10 yr of NMB records (35 NMB) were further evaluated for specific management changes that affected their farm's NMB. The 4 selected farms (1) operated in the last 4 yr with NMB per hectare and per megagram of milk below the feasible NMB ±10%, (2) had high-performing herds (>10.3 Mg of milk/cow per year) compared with the average of NY dairies in the 2003 to 2010 period (8.7 Mg/cow per year; USDA-NASS, 2014), (3) maintained or increased total milk produced per farm and per cow over the study period, (4) represented all size-categories (AFO, medium and large CAFO), and (5) illustrated the different NMB trends observed in the larger database (increases, decreases, fluctuations over time).

Characteristics of Case Study Farms

Farm 1. Farm 1 is a medium CAFO. On average, over the first 2 yr of assessments, it had 630 mature Holstein cows (0.68 heifer-to-cow ratio), 497 tillable ha (74% of which received manure), produced 10.5 Mg of milk/cow per year (Figure 1), had an overall crop yield of 10.7 Mg of DM/ha, and did not export crops or manure. The typical rotation of the farm was an alfalfa-grass or grass to corn rotation with, within any typical year, 23 to 31% of the land in alfalfa-grass, 20 to