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Characterization of nitrogen, phosphorus, and potassium mass balances of dairy farms in New York State

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ABSTRACT

A whole-farm nutrient mass balance (NMB) is a useful measure of the nutrient status of a dairy farm. Research is needed to define and determine a feasible NMB range for dairy farm systems in New York State (NY). The objectives of this study were to (1) document the distribution of N, P, and K mass balances of 102 NY dairy farms (including 75 small, 15 medium, and 12 large farms); (2) establish initial NMB benchmarks based on what 75% of the farms achieved; (3) determine the maximum animal density that allows an example NY dairy farm to balance cow P excretions and crop P removal without exporting crops or manure; and (4) identify opportunities to improve NMB over time. Nutrient mass balances of the 102 farms ranged from −39 to 237 kg of N/ha for N without including N_2 fixation (N1), from −14 to 259 kg of N/ha when N_2 fixation was included (N2), from −7 to 51 kg of P/ha, and from −46 to 148 kg of K/ha. Seventy-five percent of the farms were operating at NMB less than 118 kg of N/ha for N1, 146 kg of N/ha for N2, 13 kg of P/ha, and 41 kg of K/ha (75% benchmarks). Farms with the highest nutrient use efficiencies (lowest NMB per unit of milk produced) operated with less than 8.8 kg of N/Mg of milk for N1, 11.8 kg of N/Mg of milk for N2, 1.1 kg of P/Mg of milk, and 3.0 kg of K/Mg of milk. The biggest contributor to the NMB was the amount of imported nutrients, primarily feed purchases. The example farm assessment (assuming no export of crops or manure) suggested that, when 70% of the feed is produced on the farm and P in feed rations does not exceed 4 g of P/kg of DM, cow P excretion and crop P removal were balanced at a maximum animal density of 2.4 animal units (AU)/ha (~0.97 AU/acre). Dairy farms operating with animal densities <2.4 AU/ha typically had NMB below the 75% benchmark, whereas most dairies with more than 2.4 AU/ha needed to export manure or crops to meet the 75% benchmark. Opportunities to reduce NMB on many farms, independent of size and without changes in animal density, are possible by more tightly managing fertilizer and feed imports, increasing the percentage of farm-produced nutrients, implementing precision feeding, and exporting crops or manure.

Key words: nutrient mass balance, dairy farm, animal density, milk production, nutrient use efficiency

INTRODUCTION

The long-term sustainability of dairy farms depends upon their ability to be profitable while limiting their environmental footprint. Over time, a general trend toward intensification of dairy farming has occurred (Gourley et al., 2007, 2012; USDA-NASS, 2010). Intensification (an increase in animal density) has the potential to increase nutrient imbalances and the risk of nutrient losses to the environment. However, appropriate resource management, including the export of crops or manure, can offset the risk. The development and implementation of tools and policies that address nutrient imbalances before they become extreme are essential to the long-term sustainability of dairy farming.

In New York State (**NY**), dairy farming is the largest agricultural industry (USDA-NASS, 2009). In 1999, NY introduced its first concentrated animal-feeding operation (**CAFO**) permit, developed under the Clean Water Act (USDA-EPA, 1999). The permit designated 2 regulated groups: "medium" (200 to 699 cows) and "large" farms (>700 cows). For purposes of our study, we used this delineation to create 3 dairy size categories consisting of small (<200 cows), medium (200–699 cows), and large (700 or more cows). The 2007 USDA census shows 5,683 dairy farms in NY, including 5,092 small farms (90%) and 591 farms (10%) with more than 200 cows. Though USDA dairy cattle census categories do not follow the CAFO thresholds, a significant majority of dairy farms in NY fall into the small farm category used in the current study.

Under the NY CAFO permit, all regulated dairy and livestock farms are required to develop and annually update a comprehensive nutrient-management plan (**CNMP**). Much of the CNMP is based on static and uniform guidelines and practices applied across all operations. The CNMP is presumed to be protective

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and compliance is achieved mainly by following the plan. Deviation from the plan is considered noncompliance even if no environmental harm was observed. More recently, the Natural Resources Conservation Service (**NRCS**) has begun to explore outcome-based approaches to incentivize and achieve improvements in whole-farm nutrient management over time through the introduction of the adaptive management concept (Ketterings, 2013; NRCS, 2013). Adaptive management allows farms to set a performance base and then choose the range of practices and approaches to meet goals over time. Performance is evaluated based upon measured results.

In a nutrient management context, the process of adaptive management involves characterizing, planning, evaluating, and adjusting management strategies over time (Ketterings, 2013; NRCS, 2013). This requires the use of tools to both determine a starting point (current status or base) and to evaluate the effects of management changes over time. An annual whole-farm nutrient mass balance (**NMB**) assessment is one of very few on-farm tools that facilitate the adaptive management approach at the whole-farm level (Ketterings, 2013; Soberon et al., 2013). Whole-farm NMB data are often relatively easy to collect and the assessment results in a summary of large amounts of data in easy-to-understand input-output diagrams (Oenema et al., 2003).

Several NMB calculators have been reported in the literature. The NMB calculator developed at Cornell University was used in our study; it determines the difference between the amount of nutrients imported onto the farm (in the form of feed, fertilizer, N_2 fixation, animals, and bedding) and the amount of nutrients exported from the farm (as milk, animals, crops and manure, hereafter referred to as managed exports; Klausner et al., 1998; Spears et al., 2003a,b; Soberon et al., 2013). The results are expressed per tillable hectare, per animal unit (**AU**), and per megagram of milk production. All 3 outcome measures can be monitored over time through annual assessments.

Though nutrient losses occur in every type of farming system, positive (surplus) NMB that result when nutrient imports exceed managed exports can be indicators of potential nutrient loss to the environment (Koelsch and Lesoing, 1999; Oenema et al., 2003; Gourley et al., 2007). Excess N can reflect additional ammonia volatilization to the atmosphere, nitrate leaching to ground water, or denitrification and greenhouse gas emissions (annual losses). Excess P can build up in the soil and, over time, contribute to P runoff, P leaching, and eutrophication of surface waters (Spears et al., 2003b). Excess K can also build up in the soil and lead to elevated K concentrations in forages, potentially affecting herd nutrition programs (Fisher et al., 1994; Cherney et al., 1998). In the case of N, negative (deficient) balances resulting when managed exports exceed imports can have a negative effect on crop yield. In the case of P and K, negative balances can result in declining soil P and K levels over time (soil mining) and reduced crop yield when soil P and K become deficient. However, negative P and K balances can be desirable for a period of time when initial soil P and K contents are very high (Oenema et al., 2003). A negative whole-farm NMB reduces but does not eliminate the risk of nutrient losses to the environment, as the distribution of nutrients within a farm can be unbalanced, with some areas having high net surpluses and others having net deficits (Gourley et al., 2012). Timing and method of manure or fertilizer applications, even when well distributed, can result in undesirable losses as well.

Whereas surplus NMB are inevitable in modern dairy farming systems due to unavoidable inefficiencies in crop and animal metabolisms, very few reference levels or benchmark NMB have been identified against which nutrient balances for dairy farms under a certain set of climate and soil conditions may be evaluated (Oenema et al., 2003; Nielsen and Kristensen, 2005). In the Netherlands, the Mineral Accounting System established permissible N and P surpluses at 300 kg of N/ha for grassland and 175 kg of N/ha for arable land (without including N_2 fixation as an input) and 17.6 kg of P/ha (40 kg of P_2O_5) in 1998 to 1999. A stepwise adjustment was implemented to reduce the permissible surpluses over time to 140 to 180 kg of N/ha per year for grassland, to 60 to 100 kg of N/ha per year for arable land, and to 8.8 kg of P/ha (20 kg of P_2O_5) in 2003 (Wright and Mallia, 2008). The Mineral Accounting System was designed as a tool that assessed N and P from fertilizer and manure combined, and that could provide an incentive for good nutrient management at the whole-farm level (Oenema and Berentsen, 2005). This system was discontinued because it was not in accordance with the mandatory requirements of the European Union (**EU**) Nitrates Directive (Wright and Mallia, 2008). The EU Nitrates Directive currently limits the amount of N from organic sources that can be applied to land to 170 kg of N/ha per year (European Union, 1991). National governments can ask for derogation and permit higher organic N application rates under certain conditions if they demonstrate no adverse effect on water quality (Van der Straeten et al., 2012). Although there is no European directive regarding P application in agriculture, some European countries and regions restrict P fertilization via national or regional legislation (Amery and Schoumans, 2014). For instance, in Northern Ireland, dairy farms can increase their organic N loading limit to 250 kg of N/ha, but they must have a P balance (feed P + fertilizer P −