Research Note

PHOSPHORUS BALANCE ON DAIRY FARMS OF PUERTO RICO[1]

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A farm nutrient budget is a valuable step in the nutrient management planning process (Meisinger and Thompson, 1996; Van Horn et al., 2001; Powell et al., 2002a). One goal in nutrient management planning is to eliminate any surplus or deficit at the farm level, so that the amount of nutrients available to the crop roughly equals the crop requirement (Beegle et al., 2000). In this paper we use data obtained from published literature, published surveys, government statistics and unpublished information from Puerto Rico, to develop a phosphorus (P) budget for a typical dairy farm in Puerto Rico. The goal of the mass balance at the farm level was to determine whether feed and crop management practices are leading to excessive P accumulation that may result in losses to the environment.

Dairy cow feeding practices and management alternatives vary among dairy zones of Puerto Rico (Ramos-Santana and Randel, 1996). One important difference is in the quantity of dairy concentrate consumption, particularly the use of high fiber ("bulky") concentrate. The P mass balance for a dairy farm in this paper is presented by using two simplified scenarios which occur in Puerto Rico. In Scenario 1, the animals graze in the mornings and afternoons without bulky concentrate supplementation. There is less consumption of concentrate feed because the animals spend less time in the stable and consume only the amount provided in the milking parlor. In Scenario 2, the animals graze only in the afternoon and evenings and are fed bulky concentrate outside the milking parlor between the milkings. There is greater concentrate feed consumption because of the supplementation of bulky concentrate. In both instances we assumed that almost all the wastewater went to the temporary waste storage lagoon and then was evenly distributed to surrounding paddocks.

On the basis of National Research Council (NRC, 2001) recommendations for lactating dairy cows, the P concentration of the diet should be approximately 3.5 g P/kg feed on a dry matter (DM) basis. Given that the P concentration of tropical grasses is close to 3.0 g P/kg DM (Vicente-Chandler et al., 1983), depending on the stage of lactation and level of production of the cows, feed concentrate should contain between 4.0 and 4.5 g P/kg DM. This level is necessary to meet requirements for maintenance and lactation (NRC, 2001). The amount of basal or maintenance P excretion in saliva, intestinal cells and undigested ruminal microbes is equivalent to the maintenance requirement and could be considered another source of P input into the system. However, its effect is neutral since the same amount of P excreted is absorbed from dietary P and is accounted for

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as an output of P from the system. Maintenance requirement of P is necessary to replenish the P excreted in undigested microbial mass, epithelial cells of the intestinal tract and inefficiencies in the recycling of P in saliva. This requirement is expressed in terms of dry matter intake, 1.0 g P/kg DM being consumed. The requirement of absorbed P for milk production is 0.9 g P/kg of milk. Dietary requirements are determined by dividing the absorbed P requirements by the digestibility of P in the digestive tract of the cow (mean of 60% with a range of 50 to 75%).

The P content of commercial concentrate sampled from several dairy farms in Puerto Rico is on average 8.0 g P/kg feed (range of 5.4 to 9.8 g P/kg feed); concentrations of bulky concentrates range from 5.7 to 7.1 g P/kg feed, with an average value of 6.0 g P/kg feed (T. Ruiz, unpublished data). Forage pasture P concentrations of Stargrass (*Cynodon nlemfuensis* var. *nlemfuensis*), Pangola (*Digitaria erianta* Steud.), and Guinea [*Urochloa maxima* (Jacq.) Web.] (USDA-NRCS, 2001) taken at the Gurabo dairy farm of the UPR-AES and other private farms (T. Ruiz, unpublished data), where low to medium fertilizer rates are used, range from 1.1 to 4.5 g P/kg DM. This amount is in accordance with data published by Vicente-Chandler et al. (1983), which show that P concentrations rarely exceed 3 g P/kg DM even when fertilized at high P rates. It is estimated that P concentrations in forage of 3 g P/kg DM should meet the animal P requirements of dairy cows of low to medium milk production, as occurs for conditions in Puerto Rico (Powell et al., 2001).

The P budget on a unit lactating cow basis is shown in Table 1; Table 2 gives details and explanations used to construct the budget. The annual range in the amount of P excreted, 30 to 32 kg P/cow, found in this study (Table 1) is higher than the 19 to 35 kg P/cow reported by Powell et al. (2001) because of the greater P content in the diet for cows in Puerto Rico and lower milk production. The results show an estimated annual surplus of 17 and 19 kg P/cow/yr for scenarios 1 and 2, respectively. Erb (2002) showed average P accumulation of 23 kg/cow/yr on 13 dairy farms in Wisconsin ranging from 50 to 500 head. Given that a typical dairy farm in Puerto Rico contains on average 152 milking cows, a net positive balance of 4,586 and 4,913 kg P/farm is obtained, assuming that all the P generated and consumed is from lactating dairy cows.

From a theoretical standpoint, the information generated from Table 1 can be used to construct a field-by-field P budget or a total farm budget on an area basis. A field-by-field budget can be constructed if the planner, for example, has specific information related to actual activity in each field, i.e., forage pasture, green chopped forage, or haylage, and whether the dairy waste (either from the temporary waste storage lagoon or from animal excretion) is spread on particular fields. If limited information is available, a whole farm budget can be constructed. With increasing amounts of information available, there is greater accuracy in the P budget.

We chose a dairy farm from the Arecibo municipality of Puerto Rico (Zone North III, according to Ramos-Santana and Randel, 1996), which has approximately 18.9 ha (48 acres) available for forage pasture production and grazing, and on an average annual basis, has 120 lactating dairy cows. All fields within the farm are grazed rotationally. We could not obtain specific animal distribution in this operation, so we assumed that all the animals on the farm were lactating cows. We assumed that removal of DM and P from the field is much greater when the forage is harvested for hay or silage than when it is grazed.

Lactating dairy cows under production systems in Puerto Rico consume an estimated 2,000 kg DM/cow/yr, and 1,500 kg DM/cow/yr under scenarios 1 and 2, respectively. At a carrying capacity of 6.35 animals per hectare (2.5 animals per acre), forage harvested or grazed is between 12,700 and 9,525 kg/ha. With an average P concentration of 3.0 g/kg DM, average annual P removal is 38 and 29 kg P/ha for scenario 1 and scenario 2, respectively. We can estimate the P inputs from fecal excretion to the fields if we assume that the entire P surplus generated on the farm is returned to the field

TABLE 1.—*Mean annual P budget for a dairy farm in Puerto Rico.*

	Item	P content	
		Scenario 1	Scenario 2
		---------- g/cow/d ----------	
Farm inputs	Commercial concentrate	80.00	76.00
	Bulky	0	15.00
	Grass forage	17.05	12.40
	Water	0.01	0.01
Subtotal[1]		97.05	103.41
Farm outputs	Milk	14.40	14.85
	Maintenance	15.50	16.00
Subtotal[2] (required)		29.90	30.85
Subtotal $\text{required}_{(60\%\ \text{efficiency})}$		49.83	51.42
P excretion[3]	Manure (feces + urine)	82.66	88.56
P surplus [4]		32.83	37.14
		--------- kg/cow/yr ---------	
P excretion	Manure (feces + urine)	30.17	32.32

[1]Total farm input is the sum of commercial concentrate, bulky feed, grass forage, and water.

[2]The amount of P required is based on all farm outputs (milk production and maintenance requirement), adjusted for a 60% efficiency.

[3]P excretion is the net difference between inputs and P removed off-farm as milk. This includes the amount used for maintenance (15.50 g/cow/d) and the remainder is excess P excretion.

[4]P surplus is the amount of P that is excreted minus the dietary requirement.

by either direct excretion of the animals, or by irrigation from the wastewater lagoon, and that no P is added in the form of inorganic fertilizer. Annual P inputs to the fields within the farm are estimated at 3,620 (192 kg P/ha) and 3,878 kg P/farm/yr (205 kg P/ha) for scenario 1 and scenario 2, respectively. Thus, P surplus (P in excess of that needed for milk production and maintenance requirement) is estimated at 76 and 86 kg P/ha/yr, for scenario 1 and scenario 2, respectively.

The values obtained in this study are considerably higher than the 17 kg P/ha/yr for dairy farms in Wisconsin (Erb, 2002) and 31 kg P/ha/yr for farms in the Netherlands (Valk et al., 2000), in part probably because of the smaller farm land area and higher P content in the diet which occurs in Puerto Rico. The net P balance at the field level can decrease if more land area is used for animal grazing, in addition to increases in the proportion of animals that are grazing, such as dry cows, and heifers ranging from one to two years old, all of which can increase the amount of forage dry matter removed.

According to data from USDA-NRCS (1992), a 455-kg lactating dairy cow of moderate to high milk production produces 36 kg fresh manure/d. At 87.5% moisture it is 4.5 kg dry manure/cow/d. If the P content of the manure is 7 g P/kg manure (3.18×10^{-2} kg P/cow/d) the annual production amounts to 11.60 kg P/cow/yr. With the herd and farm size as in the above example, the total amounts to 1,392 kg P/farm/yr or 74 kg P/ha/yr. This value is lower than values obtained using actual data from Puerto Rico. This difference may be due to very high P concentration in the dairy feed concentrates used on the island.

TABLE 2.—*Details of the items used to construct the P budget for a dairy farm in Puerto Rico using actual production data from Puerto Rico.*

Item	Scenario 1	Scenario 2
Total dry matter (D.M.) consumption	Consumption is estimated at 15.5 kg DM/cow/d. This amount is that included in commercial feed and forage.	Consumption is estimated at 16 kg DM /cow/d. This amount is that included in commercial feed and forage.
Commercial feed concentrate	Consumption is estimated at 10 kg/cow/d with an average P concentration of 8 g/kg.	Consumption is estimated at 9.5 kg/cow/d with an average P concentration of 8 g/kg.
Bulky concentrate (high-fiber)	No consumption.	Consumption is estimated at 2.5 kg/cow/d with an average P concentration of 6 g/kg.
Grass forage	Average pasture consumption is based on 5.5 kg DM/cow/d. Average P concentration is estimated at 3.0 g/kg.	Average pasture consumption is based on 4 kg DM/cow/d. Average P concentration is estimated at 3.0g/kg.
Milk production (NRC, 2000)	Average annual milk production is approximately 16 kg/cow/d. Actual values will vary cyclically throughout the year due to seasonal fluctuations in temperature, birthing cycles, and duration of lactation period. Average milk P concentration is estimated at 0.90 g/kg.	Average annual milk production is approximately 16.5 kg/cow/d. Actual values will vary cyclically throughout the year due to seasonal fluctuations in temperature, birthing cycles, and duration of lactation period. Average milk P concentration is estimated at 0.90 g/kg.
Water (NRC, 2000)	Animal water consumption is estimated at 106-115 L/cow/d with a maximum P concentration in water of 0.05 mg/L.	Animal water consumption is estimated at 106-115 L/cow/d with a maximum P concentration in water of 0.05 mg/L.
Maintenance requirements (absorbed P)	Estimated at 1 g/kg DM consumed.	Estimated at 1 g/kg DM consumed.
Required	The amount of P needed is based on the sum of farm outputs, assuming an efficiency of 65% (digestibility).	The amount of P needed is based on the sum of farm outputs, assuming an efficiency of 65% (digestibility).

The results demonstrate that there is a large P surplus on the dairy farm described. The excreted P presented for the scenarios in Puerto Rico are nearly four and three times the P surplus generated on commercial dairy farms of the United Kingdom and the Netherlands, respectively (Valk et al., 2000). If the numbers that were used in this analysis are typical for situations encountered in Puerto Rico, it can be hypothesized that excess P is being generated on farms on the island. Given that the major portion of excreted P is either returned to soils via irrigation of waste-water from temporary waste storage lagoons, or directly by the animal, excess P is being added to soils, with a concomitant increase in soil-test P levels (Higgs et al., 2000).

In a recent survey, 75% of evaluated soils that were actively receiving dairy waste from temporary waste storage lagoons were in excess of suggested agronomic critical levels (Martínez et al., 2001), and 35% of the soils tested were close to suggested environmental soil test critical levels (Sotomayor et al., 2001). Research has shown that the concentration of P in runoff increases as the P concentration in topsoil increases. Thus watersheds with large areas of soils with high soil test P could exhibit higher P levels in their drainage systems that could contribute to eutrophication of surface waters (Sims et al., 2000). It must be kept in mind that the amount of actual P loss from the farm will vary with site hydrological conditions, soil type, soil test level, and management; therefore, the estimate must be seen solely as an estimate for P loss.

Suggested P input requirements for lactating dairy in the United Kingdom are 1 g P/kg DM consumed, and in the Netherlands 3 g P/kg DM consumed (Valk et al., 2000). Studies in Wisconsin show that greater dietary P intake resulted in greater fecal P excretion (Powell et al., 2002b) and greater losses due to runoff (Ebeling et al., 2002). In Puerto Rico, the actual consumption is 6.3 and 6.5 g P/kg DM, respectively, under the two scenarios previously discussed. It has been a common practice to increase the P content of the diet because dairy cattle lack the phytase enzyme in their digestive systems to degrade phytate-P (which is a major component of the major feed ingredients). The most obvious way to reduce the environmental threat of surplus P excreted and generated on farm is to reduce P levels in the diet, yet it is difficult to formulate low P diets by selecting low P ingredients (Sutton et al., 2001). Many in the local dairy industry apparently are unaware that adequate animal performance can be achieved with even lower levels of dietary P (NRC, 2001; Powell et al., 2002a). Other management practice alternatives could be reduction of fertilizer P addition, growing a greater proportion of feed-stuff on the farm (Erb, 2002), using plant genotypes that contain lower levels of phytate-P, and adding the enzyme phytase to the diet (Sutton et al., 2001).

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