Evidence for excess dietary phosphorus on dairy farms with rotational grazing of tropical grasses[1,2]

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ABSTRACT

On-farm phosphorus (P) balances are of importance for identifying critical control points in P feeding and management. In this study, P mass balances were constructed on fourteen pasture-based dairy farms of Puerto Rico, using production and management data. The farms ranged in animal units (AU, 454.5 kg) density from 1.23 to 27.50, with a mean of 7.53 AU/ha. Dietary P concentrations ranged between 5.02 and 7.24 g P/kg dry matter intake (DMI), with a mean of 6.16 g P/kg. These dietary P concentrations averaged 87% higher than the National Research Council recommendation of 3.4 g P/kg DMI. High dietary P concentrations were not associated with higher milk yields (P > 0.05). Manure P concentration of 13.2 g/kg fecal dry matter was, unexpectedly, not related to dietary concentration or total P intake. Estimates of total annual P excreted per cow ranged from 23.9 to 36.9 with a mean of 30.3 kg. Phosphorus excretion levels were 55% higher than those recommended for maintenance and milk production. Soil test P (Olsen) levels showed that 87% of the paddocks receiving manure application exceed agronomic critical P levels of 35 mg/kg. The on-farm mass balance showed annual P surpluses that ranged from 15.0 to 472.9 with a mean of 156.2 kg/ha. Reducing the P concentration in the diet and in inorganic fertilizer applied to fields, and implementing best management practices, will have the greatest and most immediate impact on reducing the excess P present on dairy farms of Puerto Rico, and will contribute to the optimization of P use for eventual sustainable milk production and water quality maintenance.

Key words: dairy farm, P mass balance, manure P

RESUMEN

Evidencia de exceso de fósforo dietético en lecherías con pastoreo rotacional de gramíneas tropicales

El balance de fósforo (P) de la finca es de importancia para identificar los puntos críticos de control en la alimentación y manejo del P en las lecherías. En este estudio, los balances de masa de P en catorce lecherías se construyeron basándose en los datos de producción y manejo de cada finca

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evaluada. La carga animal fluctuó entre 1.2 y 27.5 unidades animal (UA, 454.5 kg), con una media de 7.5. La amplitud observada en la concentración de P dietético fue entre 5.02 y 7.24 g P/kg de materia seca consumida (MSC), con una media de 6.16. Estas concentraciones de P fueron 87% mayores que las recomendadas por el Consejo Nacional de Investigación (NRC), de 3.4 g P/kg MSC. Las altas concentraciones de P no fueron asociadas a una mayor producción de leche P > 0.05). La concentración de P en las heces fecales fue de 13.2 g/kg, un valor alto que, inesperadamente, no estuvo relacionado con la concentración dietética o con el consumo total de P. Los estimados de excreción anual total de P fluctuaron entre 23.9 y 36.9, con una media de 30.3 kg/vaca. Estos niveles de excreción fueron 55% mayores que los esperados basándose en las recomendaciones de P para mantenimiento y producción de leche. Los niveles de P en el suelo (Olsen) indican que 87% de los predios que recibieron aplicación de agua de charca de oxidación (desperdicios fecales) excedieron los niveles agronómicos críticos de 35 mg/kg. El balance de masa de P en la finca indicó excedentes anuales de P que fluctuaron entre 15.0 y 472.9 kg/ha, con una media de 156.2. Reducciones en la concentración de P en la dieta y en la cantidad de P aplicado en el fertilizante inorgánico y la implementación de mejores prácticas de manejo tendrán el mayor y más rápido efecto para controlar el exceso de P en las lecherías de Puerto Rico. Estas medidas contribuirán a la optimización del uso del P para lograr la producción sustentable de leche y mantener buena calidad de las aguas superficiales.

Palabras clave: balance de masa de P, P en heces, lecherías

INTRODUCTION

Milk production has been the leading agricultural commodity in Puerto Rico for the last four decades, accounting for 24.36% of the gross agricultural income of 775.6 million dollars (ORIL, 2004). A management system based on intensive feeding of concentrate feeds has evolved in local dairying because of the low nutritive value of tropical pastures and the high cost of land. Ample agricultural subsidies, high stocking rates (SR) and decreased land availability for pasture production have also led to intensified concentrate supplementation. All dairy farms have waste management systems in which the manure and urine voided in the milking parlor and other paved areas of animal confinement are directed to waste-holding lagoons. The organic sludge residues are then returned to soils thus sustaining pasture production via overhead irrigation systems.

Researchers in Europe (Valk et al., 2000), United States (Spears et al., 2003; Dou et al., 2003), and Latin America (Elizondo-Salazar, 2005) have documented positive phosphorus (P) imbalances in dairy production areas. Importation of feeds and fertilizers has resulted in P input exceeding output contained in animal products (milk and animals sold). Net on-farm accumulation of P has occurred from feed P concentrations in excess of animal dietary needs (Powell et al., 2001a), and subsequent application of manure to field areas in excess of crop P requirements. The P remaining within the farm and not utilized by pastures can either accumulate in soils or be lost via runoff and leaching.

Soil test P (STP) levels have increased in some soils receiving manure to the extent that in environmentally sensitive areas runoff could serve as a pollution source to receiving waters (Martínez et al., 2001; Ortega-Achury, 2005). Enhanced nutrient content of surface waters can lead to increased primary productivity and subsequent eutrophication. Research in Puerto Rico has shown that many agricultural land areas receiving dairy manure have STP values much greater than agronomic critical levels (Martínez et al., 2001). Although direct linkage between animal production facilities and stream nutrient levels has not been established on the island, streams draining watersheds with existing animal production facilities have higher nutrient concentrations than watersheds with a combination of forest, cropland and suburban land uses (Sotomayor et al., 2003). High P concentrations in runoff have been documented from dairy farm plots receiving organic amendments (Ortega-Achury, 2005) or inorganic P fertilizer (Ramírez, 2005), runoff P concentrations being highest when intense frequent rainfall follows nutrient applications (Ortega-Achury, 2005; Sotomayor-Ramírez et al., 2004b). Also, higher P concentrations in runoff have been observed in soils amended with organic residues in comparison to soils with similar STP levels receiving inorganic fertilizers (Ramírez, 2005).

The potential for nutrient contamination of surface waters from dairy operations calls for the implementation of a nutrient management program at the farm level. Determination of a farm P mass balance is a valuable step toward identification of critical control points within the farm management structure. Farms with large P surpluses must take steps to reduce them via the implementation of best management practices (BMPs). Sotomayor-Ramírez et al. (2003) estimated that dairy farms in Puerto Rico have annual P surpluses of 17 to 19 kg P/animal unit (AU), or approximately 76 to 86 kg P/ha. These values were obtained from published information, as no quantitative empirical P mass balance data exist with which to corroborate such findings and to facilitate such a study of the relationships among feed P concentrations, manure P, and on-farm P balances under milk producing systems of Puerto Rico. It is hypothesized that increased feed P concentrations and higher stocking rates (SR) lead to higher manure P and greater P surpluses. Thus, the objectives of this study were to quantify dairy farm dynamics in Puerto Rico, and to describe some of the factors influencing the large positive P mass balances.

MATERIALS AND METHODS

Preliminary questionnaire

Fourteen pasture-based dairy farms were selected from the two principal milk-producing regions of the island. The selection criteria were to include a broad range of geographic locations and stocking rates, as well as to consider availability of records and willingness of farmers to cooperate. All of the farms selected do participate in the local DHIA and USDA-NRCS conservation management plans, and information obtained from those programs provided part of what was needed for the study. Surveyed farms are located in the municipalities of San Sebastián, Quebradillas, Camuy, Arecibo, Hatillo, Utuado, Juncos, Las Piedras, San Lorenzo and Humacao (Figure 1). The questionnaire requested information on general farm characteristics, land use, number of cows (lactating and dry), number of heifers and calves, milk production levels, grazing practices, and feeding practices (Torres-Meléndez, 2005). Assumed average bodyweight of 545 kg for lactating and dry cows, 227 kg for heifers, 127 kg for younger stock and 590 kg for bulls was used on all farms. The AU used to calculate stocking rates (SR) was designated as 454.5 kg of livestock bodyweight. Forage dry matter intake (DMI) was estimated by using an empirical equation developed by Ruiz (2004, unpublished) based on local data. The resulting DMI estimates obtained were slightly below those estimated with the NRC (2001) equation. Pasture intake was calculated by subtracting intake of concentrate and forage supplements from the total DMI estimates.

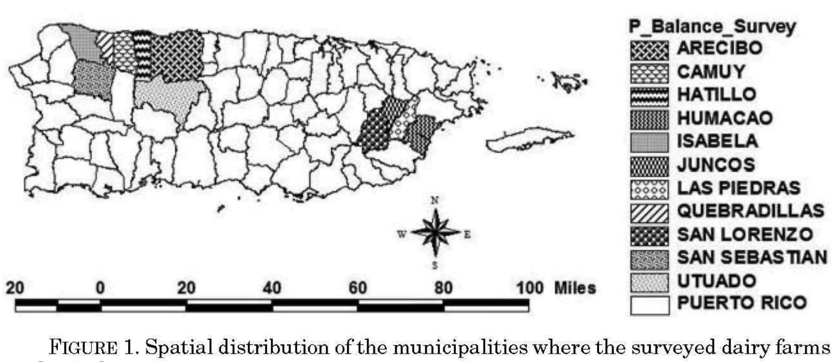

FIGURE 1. Spatial distribution of the municipalities where the surveyed dairy farms are located.

Sample collection

Farms were visited from March through May 2004 and information included in the questionnaire was obtained. The day of the visit, representative samples of feeds used on-farm, such as concentrates, mineral supplements, and harvested forages (sorghum silage, tropical grass silage, alfalfa hay, and local grass hay), were collected. The paddock to be grazed next by the cows was identified and in it pasture biomass and availability were measured (Santillan et al., 1979). It was assumed that seasonal variation in STP and P plant tissue concentrations was insignificant, and thus a single determined value was representative of those occurring throughout the year and over the whole farm. Within each field, soil and plant tissue samples were collected by walking in a zig-zag pattern and evenly taking 10 to 15 subsamples, which were mixed together to form one sample. At each farm, freshly deposited feces of five lactating cows representative of early, mid and late lactation was collected in sterile 500-ml Whirl-Pak® bags. All soil, feed, and manure samples were transported on ice to the laboratory for storage and analysis.

Laboratory Analysis

Soil samples were air-dried prior to storage, whereas feed and manure samples were stored frozen until processing. Feed and plant tissue material was dried in a forced-air oven at 60° C for 48 h, then ground to pass a 1-mm sieve. Fecal samples were thawed, homogenized by hand and split into sub-samples. Fecal dry-matter was quantified after drying in a convection oven at 60° C. Dry forage and feed samples were analyzed at a commercial laboratory (Dairy One, Ithaca, NY)[6] for crude protein (CP), neutral (NDF) and acid detergent fiber (FDA), and minerals (N, K, Ca, Mg, S, Na). The concentration of P in feed, plant tissue, and manure samples was determined in the Animal Nutrition Laboratory at the University of Puerto Rico-Mayagüez Campus by dry-ashing at 490° C for 5 h in a muffle furnace and by quantification in a spectrophotometer at 470 nm, after color development with ammonium-vanadate and molybdate (Ryan et al., 2001). Water soluble P was extracted by shaking 0.3 g dry-manure with 30 ml of deionized water, for 1 h (Dou et al., 2002) and then filtering through Whatman 42 paper. Determination of P con-

[6]Company and trade names in this publication are used only to provide specific information. Mention of a company or trade name does not constitute a warranty of equipment or materials by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

centration in the filtrate was performed with the procedure of Murphy and Riley (1962). Soil test P was extracted by using the Olsen procedure and P was quantified colorimetrically (Olsen and Sommers, 1982).

Phosphorus mass balance

Beede and Davidson (1999) studied several models of P balance and P excretion and concluded that the model proposed by Van Horn et al. (1998) is the most appropriate, because it assumes that retention of P in the animal is constant. Tomlinson et al. (1996) concluded that a simple input-output model is as precise as other models which make use of complex equations derived from excretion data reported in the literature. Also, excretion estimates as calculated by animal P mass balance, simple input-output models, are more accurate than extrapolation from a simple equation based on weight of the animal (ASAE, 1990), because the latter does not take into account variations in dietary composition, consumption levels, and productive performance (Van Horn et al., 1996). Therefore, it was decided to use the simpler on-farm P mass balance model which is based on the difference between the mass of P input (kg P/farm) in feed and fertilizer and output in milk produced and animals sold as proposed by Beede and Davidson (1999) and Van Horn et al. (1998)

The animal P mass balance was calculated from the difference between feed P intake (concentrates, supplements, forages and minerals) and milk P output for each AU. This balance was applied to lactating cows to determine total P excretion and P concentration in feed that was in excess. For the other animals in the dairy (dry cows, heifers, yearling calves and bulls) P balance was taken as the P consumed minus the P retained by the animal for growth and maintenance. The P requirement for growth was calculated by using a factor of 7.4 g P/kg of weight gain by the animal (Kirchgebner, 1993, as cited by Satter and Wu, 1999). Assumed weight gains used were 0.74, 0.68 and 0.54 kg/day for bulls, calves, and heifers, respectively. For pregnant animals in their last trimester a requirement of 2.5 g P/day for growth of the fetus was used (Kirchgebner, 1993 as cited by Satter and Wu, 1999).

Statistical analyses

The data were expressed as means for each farm. Regression models were developed to evaluate the relationships among P concentrations in diets, P excretion levels, milk production levels and P mass balance using SAS v. 8.0 (SAS Institute, 2001).

RESULTS AND DISCUSSION

General dairy farm and feeding management practices

All farms reported a rotational grazing system supplemented with concentrate feed. Mean land area of the farm, total number of animals, and number of lactating cows were 72.6 ha, 361 AU, and 198 AU, respectively (Table 1). The observed values encompass the general range typically found in Puerto Rico (Ramos-Santana and Randel, 1996). Recent tendencies since 1996 point to decreasing land areas together with increases in the number of AU and SR (USDA-NASS, 2002). The predominant breed observed on the farms was Holstein, with nine farms reporting 100% Holstein herds, whereas three reported between 4 and 10% of the total herd as Brown Swiss. Only two dairy farms reported that all of the animals present were lactating cows, whereas on the remaining farms about 43% of the animals were replacement heifers, dry cows, calves and bulls. Eleven farms reported that concentrate feed was provided in the milking parlor only, whereas seven reported additional supplementation outside the parlor, with the combination of dairy concentrate and high-fiber concentrate. Six farms reported supplementation with conserved forages (hay, sorghum silage and grass silage) at a low level (1.8 kg DM/cow). Eight farms reported that all of the grazed paddocks received inorganic fertilizer P, whereas four did not use inorganic fertilizer P. All farms regularly applied effluent from the manure lagoons to their pastures; however, not all paddocks used by the lactating cows received it.

Pasture biomass production (BM) was on average 2,697 kg DM/ha, with a range of 1,313 to 4,068 kg. Mean daily dry matter pasture availability or pasture allowance (PA) was 23.95 kg/cow, with a range of 7.55 to 59.95 kg. Values from 25 to 40 kg DM/cow are considered adequate for voluntary pasture consumption by animals without the need for concentrate feeding (Bargo et al., 2002).

TABLE 1.—*Herd composition, milk production, and stocking rates of dairy herds surveyed in Puerto Rico.*

	Average	s.d.	Median	Minimum	Maximum
Total land area (ha)	72.6	78.5	56	7.2	310
Total animals	361	335	209	135	1,289
Lactating cows	198	125	148.5	55	482
Stocking rates (SR) (AU/ha)	7.5	6.8	4.8	1.2	27.5
Milk Production (kg/cow/day)	18.4	3.5	18.92	14.1	25.91

Dietary P

The mean P concentration of feeds fed on the surveyed farms is shown in Table 2. The P concentration in the "bulky" concentrate was greater than that in the "dairy" concentrate because of the high proportion of by-product feeds present in the former, feeds which tend to have high P concentrations (NRC, 2001). The mean P concentration in the tropical pasture was 4.2 g P/kg DM, whereas that of grass hays was 2.0 g P/kg DM. The P concentrations of pastures quantified in this study are greater than the values reported by Vicente-Chandler et al. (1983) for tropical pasture P concentrations that rarely exceed 3 g P/kg DM even with annual inorganic fertilizer application rates greater than 100 kg P/ha. However, the present results are in accord with P concentrations reported by Cerosaletti et al. (2004), which ranged from 3.8 to 4.0 g P/kg DM of grass pasture. These authors attributed the high P concentration in grasses to the fact that only immature pasture herbage was being consumed, and to the high soil P concentrations. Existing tabular data utilized in the present study to formulate rations might have limited applicability to tropical pastures receiving organic amendments and inorganic fertilizer P because of systematic underestimation of P additions. Thus, leaf P analysis of herbage grown on-farm should be performed to provide data needed to improve the ration balance, to lower the levels of P supplementation used, and to optimize on-farm P recycling.

Average daily intake by lactating cows was estimated at 16.4 kg DM and 102.5 g P, respectively. It was observed that between 45 and 71% (mean of 59%) of the DM consumed came from supplemented concentrate, as did from 50 to 90% (mean of 72%) of the total P intake. The remaining P was provided by on-farm grown pasture and other forages consumed. The dietary P concentration for lactating cows ranged from

TABLE 2.—*Phosphorus concentration (DM basis) of feeds on the surveyed dairy farms.*

Feed	N	Average	s.d.	Minimum	Maximum
	g P/kg				
Concentrate (for milking cows)	11	7.5	0.60	6.5	8.4
High fiber concentrate (bulky)	8	8.5	0.70	7.5	9.4
Pasture	12	4.2	0.99	2.4	6.2
Hay (tropical grass)	2	2.0	0.42	1.7	2.3
Sorghum silage	2	2.2	0.21	2.0	2.3
Alfalfa hay	1	3.2	0.00	3.2	3.2
Fresh pasture (chopped)	1	0.9	0.00	0.9	0.9
Silage (grass)	1	2.7	0.00	2.7	2.7
Mineral mix	2	7.8	1.74	5.3	9.3

5.02 to 7.24 with a mean value of 6.16 g P/kg DM. According to the dietary P recommendations of NRC (2001) for the level of milk production observed on the surveyed farms, P concentration should have ranged from 3.1 to 4.0 (mean 3.3 P/kg DM) (Figure 2). Thus, average P overfeeding to lactating dairy cows was 87% above the NRC guidelines with a range from 52 to 119%.

The dietary P concentrations found in the present study are also higher than the mean values of 5.7 g P/kg DM reported in Wisconsin (Shaver and Howard, 1995), and 6.0 g P/kg DM reported for south Florida dairy farms (Morse et al., 1994). Bertrand et al. (1999) found that P was overfed by 21% on 27 commercial dairy farms in South Carolina, whereas Sansinena et al. (1999) reported a 30% overfeeding on dairy farms of the southeastern USA. Recent reports by Powell et al. (2002) indicate P concentrations in the diet of lactating dairy cows of 4.0 g P/kg DM in Wisconsin, and reports by Dou et al. (2003) show 4.4 g P/kg DM in Maryland and Virginia. Even so, the cited authors indicated that P was being supplied in excess by 33% of the nutritional requirements according to NRC (2001). The higher dietary P concentrations used on dairy farms of Puerto Rico are due to greater P content in the concentrate portion of the diet. It is apparent that decreasing the P content in concentrates and reducing the use of supplemental minerals containing P would significantly reduce P input on the farms, P intake by the animals and, indirectly, P retained on the farm.

Relationships between dietary P and milk production levels and fecal P excretion

Among the evaluated farms higher dietary P concentrations were not (P > 0.05) associated with increased milk yield (P > 0.05). The re-

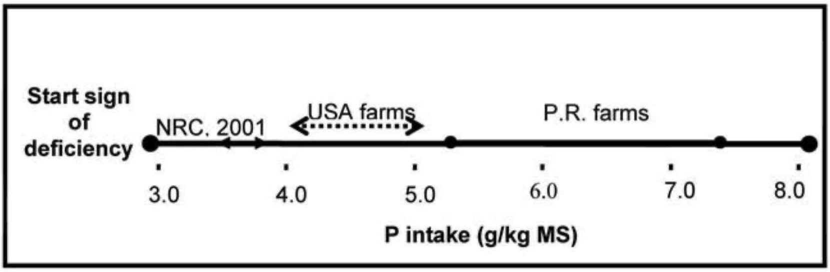

FIGURE 2. Dietary P intake requirements established by NRC (↔) (NRC, 2001), values published in the literature for USA commercial dairy farms (<- - ->) (Satter et al., 2002) and range of P concentration obtained on the surveyed dairy farms in Puerto Rico (•—•).

sults of this study and those found in the literature (Dou et al., 2003) demonstrate that increased concentrations of dietary P beyond critical levels is not associated with enhanced milk production but is highly related to increased fecal excretion of P (the principal excretory route) (Morse et al., 1992). There was a strong relationship between dietary P intake per cow or P concentration in the diet and estimated P excreted in urine and feces (Figures 3A and 3B). The respective regressions indicate that for each additional 1.0 g of P ingested daily the excretion increases 0.90 g P/AU, and that for each g P/kg DM consumed, total daily P excretion increases by 14.2 g P/cow. Morse et al. (1992) reported a corresponding increase of 0.88 g P/cow for each increase of 1.0 g in P ingested. On the basis of production and maintenance requirements of lactating cows on the dairy farms surveyed, between 40.3 and 76.8 g P/d were fed in excess of requirements. A fraction of the increased P excretion is returned to the soil, which can lead to increased STP in the long term.

The mean total P concentration in feces was 13.5 g P/kg DM with a range from 8.90 to 18.50 g. Corresponding figures for soluble P in feces were 4.03 and 1.10 to 7.10 g P/kg. The data show higher fecal P concentrations than those reported in the literature, concentrations which range from 6.8 to 9.0 g P/kg (Tomlinson et al., 1996), 6.7 to 9.3 g P/kg (Wu and Slatter, 2000), and 5.84 to 12.84 g P/kg (Chapuis et al., 2004). All these studies demonstrated a direct relationship between high consumption of P by the animals and high levels of P excretion via feces. Dou et al. (2003) reported a linear relationship between increased P

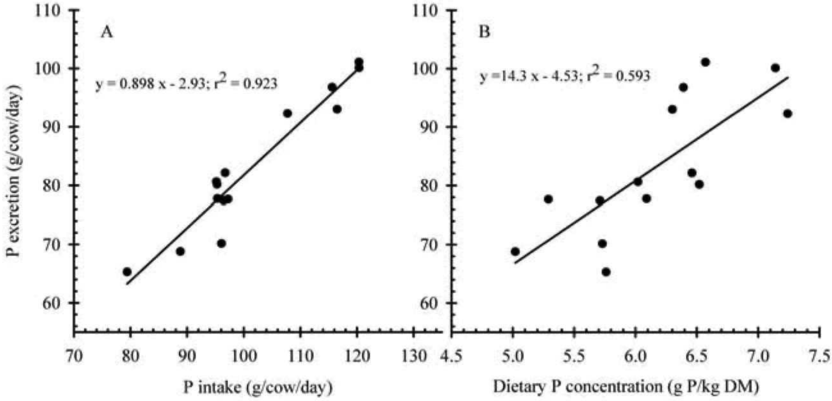

FIGURE 3. Relationships between P intake (A) and dietary P concentration (B) and fecal P excretion on dairy farms of Puerto Rico.

level in the diet and increase in the concentration of soluble P fraction in the feces.

Contrary to expected results, in the present study no relationship (P > 0.05) was found between the P concentration in the diet and total P and dissolved P concentrations in the feces. This finding could be due to the fact that all the dietary P concentrations exceeded those recommended by NRC; thus an adequate range of data did not exist for testing this relationship.

Animal P mass balance

Annual excreted P values were high when expressed either on an AU or an areal basis (Table 3), with ranges of 23.8 to 26.9 kg/cow and 16.1 to 546 kg /ha. Considering the amount of P excreted by all animals on the farm, the amount of P excreted annually per unit of area in pasture is increased on average to 171.15 kg, with a range of 25.15 to 546.21 kg/ha. The annual excreted P values per cow determined for Puerto Rico are in the upper limit of the 19 to 35 kg range reported by Powell and Van Horn (2001), above the 18- to 32-kg range given by Van Horn et al. (1994), and far above the 10.7-kg mean reported by Spears et al. (2003). Annual fecal excretion of P by high-producing cows (28 kg milk/day) fed a recommended amount of P should be approximately 21 kg per head (Wu and Satter, 2000; Powell et al., 2001), and for the milk production levels of Puerto Rico it should be 13.95 kg. The difference between the theoretical optimum P excretion levels and those reported in this study can be largely attributed to excessive P content in milking cow diets, and to lower milk production levels on the evaluated dairy farms of Puerto Rico relative to those of the farms in the continental United States.

TABLE 3.—*Phosphorus intake, excretion and P mass balance on surveyed dairy farms.*

Variable	N	Average	s.d.	Minimum	Maximum
Total P intake (kg/cow/yr)	14	36.98	4.46	28.98	43.93
Total P excretion (kg/cow/yr)[1]	14	30.33	4.27	23.83	36.90
Excess P excretion (kg/cow/yr)[2]	14	16.86	5.02	10.16	28.35
% P in excess	14	54.63	9.45	40.29	76.83
Total P excretion (kg/ha/yr)[3]	14	138.04	158.07	16.14	546.21
Total P excretion in the farm (kg/ha/yr)[4]	12	171.15	161.89	25.15	546.21
P Balance (kg/ha/yr)[5]	12	156.15	153.17	15.02	472.85

[1]Annual total P excretion by lactating cows.
[2]Excess P excretion = excess of P above dietary requirement.
[3]Annual total P excretion by lactating cows expressed on a real basis.
[4]Annual total P excretion by all the animals on the farm expressed on a real basis.
[5]P Balance (P input in feeds and fertilizers)—output (milk, animals for meat).

On-farm P mass balance

The on-farm P mass balance was calculated from the sum of all input including the P in feeds and inorganic fertilizers. The output included the P in milk, culled cows and yearling calves sold, according to the procedure used previously. The results indicate that the annual on-farm P retention on the surveyed farms was between 15.0 and 472 kg/ha with a mean value of 156.2 kg. Retention of more than 17 kg/ha is considered to be in the "high" category for Pennsylvania, where in 2002 about 30% of the cropland area was in this category (Lanyon et al., 2006). The excess P fed to animals results in increased amounts of fecal P which is eventually returned to pastures, either directly from grazing animals or through existing irrigation systems. The large amounts of P returned to fields result in P accumulation in soil, which can enhance runoff P concentrations, detrimental to downstream water quality.

Stocking rates and P balance

A wide range of SR was found in the surveyed dairy farms (Table 1). Six farms had SR of fewer than 5 AU/ha (low); two had values between 5 and 10 AU/ha (medium) and four had more than 10 AU/ha (high). These values are typical for the areas where the studied farms are located. Average SR for all dairies in Puerto Rico is 6.4 AU/ha (ORIL, 2004). Stocking rate is an important factor in the P mass balance because in the majority of cases those farms with greater SR rely on a greater proportion of P input originating from imported concentrates and supplements (Powell et al., 2002). In this study, the four farms with high SR imported annually a mean total of 8,201 kg P (315.82 kg P/ha), whereas farms with fewer than 10 AU/ha imported a total of 4,500 kg P (65.21 kg P/ha) in the form of concentrate feeds and supplements. Nutrients voided in feces are returned to fields with limited areas, thus leading to accumulation of P in soils and possible losses in runoff. Dairy cow feeding practices vary among geographic zones of Puerto Rico with increasing dependence on imported feed in direct proportion to the SR (Ramos-Santana and Randel, 1996).

High SR on the studied farms constituted a determining factor in the amounts of P excreted and the P balance; in both instances there was a significant ($P < 0.01$) positive curvilinear relationship (Figures 4A and 4B). The quantitative trends show that increased SR has a positive impact on the on-farm P mass balance. However, increased SR resulted in increased STP levels only for paddocks receiving manure sludge ($P < 0.05$) ($R^2 = 0.93$) but not for those that did not receive manure (Figure 5). Similarly, Lanyon (1992) and Knowlton and Herbein

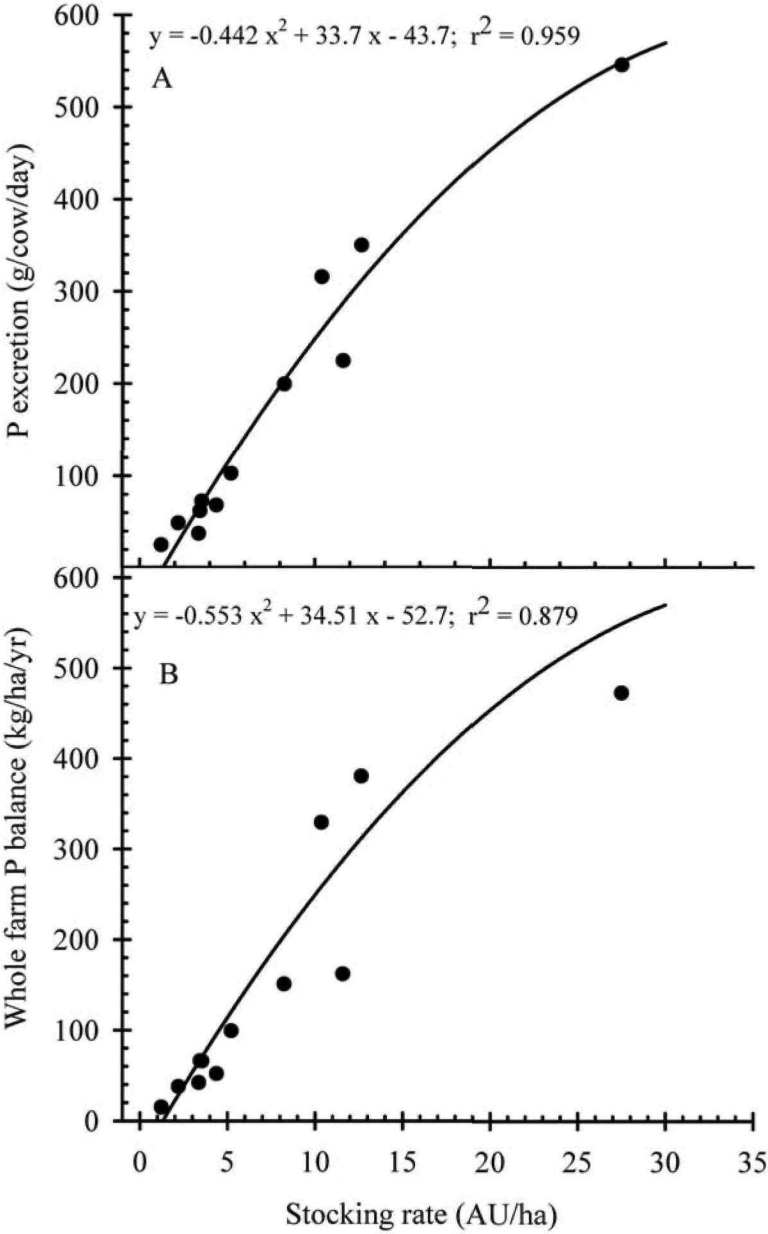

FIGURE 4. Relationship between stocking rate and P excretion (A) and whole farm P mass balance (B) on the surveyed farms.

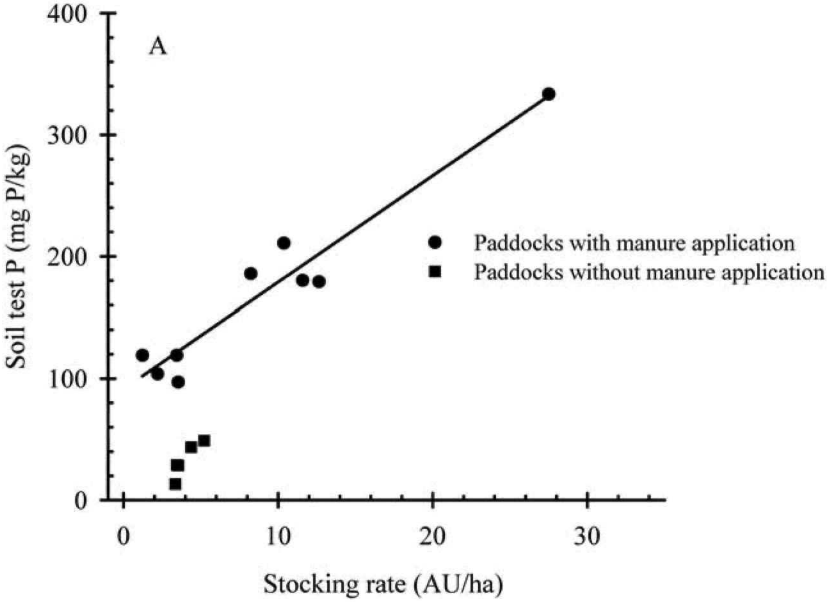

FIGURE 5. Relationship between stocking rate and P concentration in soil in paddocks with and without manure application.

(2002) reported high P concentrations in soils and risk of P losses in areas with high animal density.

Soil test P

Organic residues from the holding lagoon were applied to 33 of the 38 fields in which STP was evaluated. In general, fields where organic residues were applied had higher STP values than fields that received inorganic fertilizer P only. Also, fields that received organic residues had Olsen STP levels above the suggested agronomic critical level of 35 mg/kg (Muñiz-Torres, 1992). Addition of P above agronomic critical levels is not expected to enhance forage production. Extractable Olsen STP levels between 35 and 123, 124 and 179, and >179 mg P/kg are categorized as “high”, “very high”, and “extremely high”, respectively (Sotomayor-Ramírez et al., 2004a). Mean STP in soils that received organic residues was 109.3 mg/kg with a range from 13.2 to 402.1 mg P/kg of soil. This average value exceeded the 93 mg/kg reported by Martínez et al. (2001) on selected dairy farms of Puerto Rico. Of the analyzed soil samples, 47% were in the “high”, 18% were in the “very high” and 18% in the “extremely high” category in susceptibility to loss of P

(Figure 6). These results are similar to those of Martínez et al. (2001) who observed that 75% of the analyzed samples of soils to which dairy manure was applied exceeded the agronomic critical level of 35 mg/kg (Olsen).

CONCLUSIONS

The P concentration in the diets of dairy cows on farms surveyed in Puerto Rico exceed by 87% the recommended levels of P (NRC, 2001) for corresponding milk production levels. Use of imported concentrates was the primary factor contributing to the high animal P intake. High intake resulted in enhanced excretion of P. All the surveyed dairy operations presented positive P balances in the diet of the animals and on-

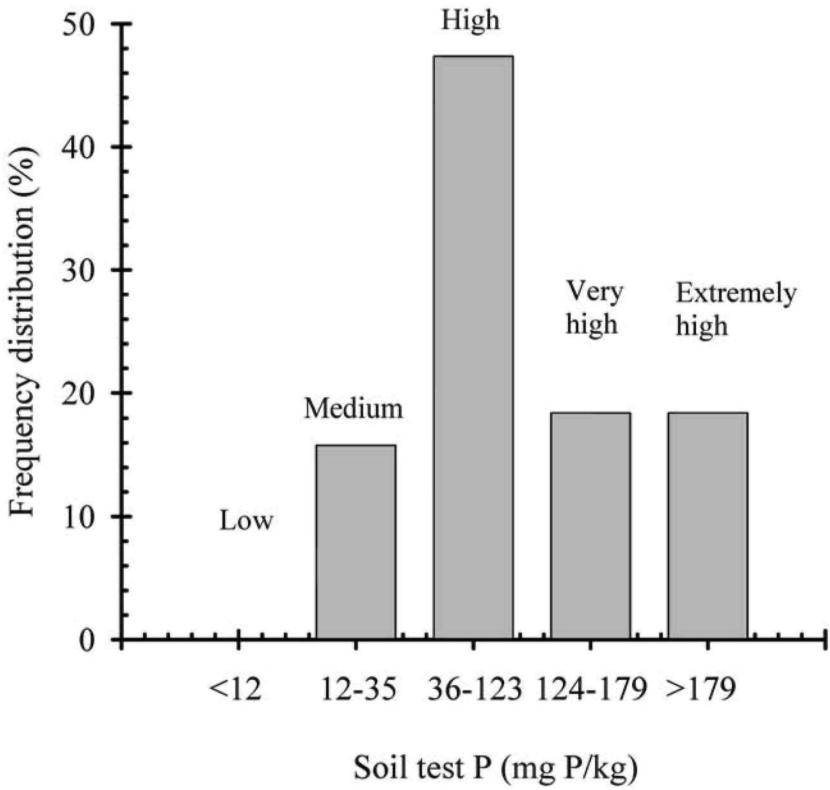

FIGURE 6. Soil test P distribution on the surveyed dairy farms grouped in the "Low", "Medium", "High", "Very high", and "Extremely high" classification as suggested by Sotomayor-Ramírez et al. (2004a).

farm soils. High SR had a positive impact on animal P excretion, STP levels and P mass balance. Soil test P analyses demonstrated that about 36% of the soils need reduced P application in order to lessen the possible environmental risk of water quality degradation. Reduction of P concentration in the diets, as well as in the application of P as inorganic fertilizer in areas with high concentrations of P, is the most practical alternative and will have the greatest impact on reducing P excretion and thus the potential for environmental P contamination caused by dairy farms in Puerto Rico.

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