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Nutrients in Dairy Manure Sludge in Puerto Rico: Management and Implications

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ABSTRACT.
Dairy manure sludge (DMS) application to grazed forage pastures is a widespread agronomic practice. Unfortunately, the quantitative benefits of DMS application to improved pastures still has not been shown in the Caribbean. On-going application of DMS based on estimated nitrogen (N) content is unsustainable, and in many areas presents a threat to water quality, because the excess phosphorus (P) in dairy sludge is usually not extracted by plants and remains in soil until removed in runoff. Application of DMS based on P content of the material may be a better alternative, but pastures may need to be supplemented with N. The nutrient concentration of DMS sludge in various farms of Puerto Rico was assessed. The mean (standard deviation in parenthesis) nutrient concentration of DMS (n=17) was 233 (120), 122 (77), 232 (123) mg/L for total N, total P, and total K, respectively. The economic benefit of DMS application, in terms of substitution for the price of nutrients in mineral fertilizer, could be from \$79 to \$158 per ha-cm (acre-in) of application, but the excess volume of DMS application from the improper application could offset potential agronomic and economic gains. Farmers applying DMS to fields should take every precaution to ensure that the infiltration rate of the soil is not exceeded and that during the application the volumes are kept to levels in which the nutrients applied do not exceed crop nutrient requirements. Further precautions include reducing the number of applications during the year and spreading the material to other areas of the farms. A case study demonstrated that there is an excess of nutrients generated on-farm which originate primarily from grazing animals, and is exacerbated by high animal densities, improper distribution of N and P from DMS and fertilizer. Excess nutrients generated result in unsustainable nutrient rates to fields which could result in a waste of resources and environmental degradation.

KEYWORDS: dairy manure sludge, forage production, nutrients in pastures

INTRODUCTION
Modern milk production facilities in Puerto Rico have grown increasingly dependent on feed-concentrate for the maintenance of milk production levels (Welch et al. 1997). Increased concentrate feeding with reduction in feed from grazing, high quality haylage or fresh-cut pasture results in higher production costs, greater on-farm nutrient input (especially phosphorus, P) and can compromise animal health (Vicente-Chandler et al. 1984; Torres, 2005). The dairy industry in Puerto Rico has benefited from the implementation of state programs that strengthen the infrastructure base, such as

dairy-waste-holding lagoons (DWHL) combined with irrigation systems for pasture. Farmers with DWHL are USDA-NRCS clients and follow their recommendations for dairy manures sludge (DMS) to fields which is based on an empirically-based model. There are concerns because DMS application is based on theoretical DMS nitrogen (N) and P concentration and plant nutrient extraction book values. There is no quantitative information to guide farmers as to how they should combine DMS application with commercial fertilizers for pasture production. Further, farmers spread DMS to fields without considering the nutrient value of the material. The objective of this work was to quantify nutrient inputs from DMS in four farms. One farm was selected as a case study to quantify nutrient inputs to fields from individual and combined sources (fertilizer, DMS, and direct excretion) at the dairy farm level.

MATERIALS AND METHODS

Four dairy producing facilities in Puerto Rico were selected (Table 1). Quantification of nutrients in DMS was performed by monitoring nutrients in the lagoon and in the fields during the farmers' regular application schedule during 2007 and 2008.

Table 1. General characteristics of farms used in the study.

Producer	Soil type	Mean slope	Number of lactating cows	Area available for grazing	Farm area that receives sludge
		%		-----------ha--------	
Isabela	Coto (Typic Eutrostox)	1 to 5	150	123	9
San Sebastian	Humatas (Typic Haplohumults)	15 to 45	96	39	4
Camuy	Bayamón (Typic hapludox), Almirante (Plinthic hapludox)	5 to 25	300	53	13
Hatillo	Espinoza (Typic Kandiudults)	5 to 25	750	81	32

The rates and form of application varied among the farms as these had varying irrigation spraying equipment, nominal working pressures, speed of sprayer movement, nozzle size, spraying distance and irrigator type among other factors. The DMS in the DWHL were sampled prior to its application to the fields using standard methods (Peters and Combs, 2003). A regular grid pattern was established within each field and 20-L buckets were placed to gather DMS applied. At the end of the DMS application, the volume within buckets was measured and a composite sample taken for analysis for total N and total P in a commercial laboratory. Information was gathered from two (Hatillo and Camuy) of the four farms, related to number and frequency of applications and annual nutrient inputs to fields were estimated. Soils were sampled (0-15 cm) from fields and analyzed for extractable P using Bray1 (soil pH <7.2) or Olsen (soil pH ≥ 7.3 procedures (Page et al., 1982).

One of the farms (Camuy) was selected as a case study for the quantification of nutrient inputs from the individual and combined sources (i.e. fertilizer, liquid sludge, direct excretion) on a field by field basis. The farm has an area available for grazing of 53 ha of which 25 ha are used by milking cows and 28 ha are used by heifers and dry cows. The farm has had an average standing stock of approximately 300 milking cows, 2 bulls and 96 heifers and 85 dry cows. The daily mass of nutrients generated by animal excretion and total generation within the farm was computed (Table 2).

Table 2. Nutrient amounts generated by animal excretion and annual on an on-farm basis, in the selected dairy producing facility of Camuy.

	N [/1]	P_2O_5	K_2O	N	P_2O_5	K_2O	$N:P_2O_5$
	----------kg/animal/day--------			-----------kg/farm/yr------------			
Cows [1]	0.15	0.18	0.22	16923	19262	23891	0.88
Bulls [2]	0.08	0.08	0.15	60	55	106	1.09
Calves and heifers	0.05	0.02	0.06	1911	589	2230	3.24
Dry (fields only)	0.07	0.08	0.20	2115	2327	6064	0.91
Sum				21009	22233	32291	0.94

[1]Milking cow N production estimate is based on daily 17 kg feed intake with 18.6% protein; 18 kg milk with 2.9% protein. The P production estimate was obtained from C. Torres (2005) and feed intake data.

[2] Heifer estimate is based on 550 lb animal, 2% live-weight forage consumption of forage

The theoretical nutrient amounts combined from milking cows, bulls and heifers (allocation) (i) going into the lagoon, (ii) going as manure solids within the milking area and (iii) excreted directly by the animals to the field was calculated (Table 3).

Table 3. Allocation of nutrients that are potentially generated by milking cows, bulls and heifers, excluding dry cows in the selected dairy producing facility of Camuy.

	Lagoon	Manure solids	Excreted to fields	Total
	--------------------kg/yr------------------			
N[1]	5105	2482	11282	18868
P_2O_5	3533	3496	12841	19870
K_2O	5920	4336	15925	26181

[1]N amounts do not consider any losses by volatilization or denitrification.

We estimated that the animals as a group spend 13 hours (54%) of the day grazing and 11 hours (46%) of the day being milked or waiting to be milked (milking process). Of the 11 hours in the milking process, the average time that each cow actually spends in the milking parlor is about 8 hours. Of the total amount of manure generated by each animal, approximately 33% is generated in the milking parlor and 66% of the manure is excreted to the fields. We estimated that about 55% of the excreted manure in the milking parlor (or 18% of the total) is scraped in a semi-solid state and is eventually spread to fields.

All of the estimates of P and potassium (K) excreted by the animals is based on the above-mentioned proportions, but the N is partitioned differently based on the fact that 60% of the N that is excreted occurs through urine and 40% occurs through solid feces (Van Horn et al. 1991). It is estimated that all of the urine-N generated in the milking process is directed to the waste holding lagoon. Of the feces-N generated in the milking parlor, 20% goes to the waste-holding lagoon, with the remaining 80% is scraped in semi-solid state and handled as mentioned previously. As a check comparison, the N:P_2O_5 theoretical ratio of semi-solid manure based on this assumption is 0.71 and the value quantified was 0.76. Therefore, the amount of N that goes into the lagoon corresponds to that generated in the milking parlor and part of that from the waiting area. The theoretical annual nutrient distribution is shown in Table 3.

The farmer has kept a record of the rates and dates of fertilizer application to particular fields since 2002. He has also recorded dates and duration of DMS application to particular fields. The annual nutrient contribution from fertilizer to each field was quantified from the sum of the amounts of fertilizer with the formulation 15-5-10 (N-P_2O_5-K_2O) applied to each field.

To compute the nutrient contribution from DMS application, we assumed that 1.9 ha-cm (0.75 acre-inch) of DMS was applied each time. The nutrient concentration in the DMS sludge from the DWHL was quantified by us at various times throughout the year. The product of DMS volume, field area, and nutrient concentration in sludge was used to quantify nutrient inputs. The annual DMS nutrient contribution to each field was computed from the sum of the applications to each field, and the nutrient contribution to the farm was computed from the sum of all the applications to all of the fields during the year.

To calculate the nutrient contribution from direct excretion to each field, we estimated that the cows are rotated into each pasture every 21 days and thus enter each field about 15 to 19 days of the year (depending on climatic conditions and on whether the field receives DMS or not). The animals spend about 16 hours of the day in the field (55% of the time). The grazing time within each field depends on the size of the field. For example, a field of 2.4 ha, the animals spend about 2 days grazing, whereas in a field of 0.81 ha, the animals spend 1 day grazing (our best professional judgment was used for consideration of the time that animals spend within each field). Animal annual nutrient excreta allocation was calculated from the product of the number of animals, days spent in the field, fraction of time spend in the field, daily animal nutrient excretion and number of days per year the field is used.

RESULTS AND DISCUSSION

The mean (standard deviation in parenthesis) nutrient concentration of DMS was 233 (120), 122 (77), 232 (123) mg/L for total N, total P, and total K, respectively. The mean N:P_2O_5 ratio was 1.2 (0.66). The four farms evaluated differed in terms of the quantity and quality of animal feed, dilution of the lagoon due to rainfall or excess wash, and frequency of emptying or application, and thus represent the wide range of possible conditions found in Puerto Rico. The values presented are lower than those presented for other sites in Minnesota and Wisconsin (Peters and Combs, 2003) and in Arkansas (Daniels et al. undated) yet N:P_2O_5 ratios were similar. The values presented could be used as book-values for Puerto Rico and other areas with similar herd management practices in the absence of site-specific information. Typical forage crops extract from 2.5 to 4 times more N than P_2O_5 (Vicente-Chandler et al. 1983), which demonstrates that long-term N addition of DMS based on solely on N content, will lead to P buildup in soil. Soil testing for P should be a regular management practice in manure application areas to avoid excess P accumulation in soil which can increase P concentrations in runoff and negatively impact surrounding water bodies (Sharpley et al. 2000).

USDA-NRCS suggests that up to 70% of the N in the nutrient holding lagoon is denitrified or volatilized prior to plant uptake (USDA-NRCS, 2001). It was not possible for us to ascertain at what stage of the N transformation processes the lagoons were when sampled. Also, P concentrations have been shown in some instances to be greater when the lagoon is stirred because particulate P is suspended in the water column (Dou et al. 2001), but not in others (Torres, 2005). In the lagoons studied (n=17), we did not observe differences in P concentrations between stirred and un-stirred samples. The potential economic value of DMS in relation to fertilizer was estimated in the four farms studied assuming between 30 and 100% availability for N and between 70 and 80% availability for P of the quantified nutrient concentrations in the DWHL, and a substituting the costs of urea ($0.88/lb N), triple-superphoshate ($1.26/lb P_2O_5) and muriate of potash ($0.71/lb K_2O) during 2005 for N, P_2O_5, and K_2O, in the DMS, respectively. Estimates range between $113 to $162 per ha-cm (0.97 acre-in) of application, and with a typical annual application of 50 ha-cm (49 acre-in) could range between $5,500 to $8,000/farm/yr.

Table 4. Dairy manure sludge nutrient application rates.

Field	Time of application	Irrigation depth median	Nutrient application rate			N/P_2O_5
		cm	----------------kg/ha---------------			
Isabela (static irrigator)						
	min		N	P_2O_5	K_2O	
1	45	0.5	13.9	16.9	18.7	0.82
2	50	0.8	16.4	15.3	25.6	1.06
San Sebastian (static irrigator)						
3	75	1.4	21.8	17.9	27.2	1.22
4	75	0.72	8.9	7.2	11.5	1.20
Camuy (movable irrigator)						
5	NA	0.42	20.9	7.1	25.5	2.9
6	NA	1.41	69.6	23.6	85.0	2.9
7	NA	1.91	94.0	31.8	114.7	2.9
Hatillo (movable irrigator)						
8	NA	4.5	162	85.6	190.2	1.9
9	NA	3.2	114.6	60.5	134.5	1.9
10	NA	3.75	135.0	71.3	158.4	1.9

Nutrient loads based on measured concentrations and volumes of DMS applied to different fields are shown in Table 4. The data demonstrate the wide range of values with a 15-fold range for N and a 12-fold range for P. For example, N application rates ranged from 8.9 kg N/ha in San Sebastián to 135 kg N/ha in Hatillo. The biggest determinant influencing nutrient loads to fields was the depth of application. The mean nutrient rates for each site were used to extrapolate annual nutrient application rates (Table 5).

Annual application of N and P exceeded crop nutrient requirements by 4.1 and 5.7 times, respectively, of those extracted by forage in Hatillo and 0.34 and 0.44 times in Camuy. Soil test P (Bray1) was on average 341 ppm in Hatillo and 235 ppm in Camuy, which are in the extremely high environmental category (Sotomayor et al. 2004) and well in excess of values considered sustainable. Therefore, farmers applying DMS to fields should take every precaution to ensure that the infiltration rate of the soil is not exceeded and that during the application the volumes are kept to levels in which the nutrients applied do not exceed crop nutrient requirements. Further precautions include reducing the number of applications during the year and spreading the material to other areas of the farms.

Table 5. Annual nutrient loading to fields in Hatillo and Camuy farms from dairy manure sludge and annual estimation based on documented farmers' practices.

	Nutrients per application	Nutrients per year	Application / extraction ratio [1]
	------------------kg/ha----------------		
------------------------Hatillo--------------------			
N	162	1616	4.1
P_2O_5	85	853	5.7
K_2O	190	1897	3.4
------------------------Camuy----------------------			
N	66	132	0.34
P2O5	33	65	0.44
K2O	110	220	0.39

[1]Assuming crop extraction values of 350, 133, and 500 lbs/acre of N, P_2O_5, and K_2O, respectively.

Nutrient inputs to fields from individual and combined sources (fertilizer, DMS, and direct excretion) at the dairy farm level were quantified for the farm in Camuy. The mean nutrient rates from the individual sources (i.e. fertilizer, liquid sludge and direct excretion) demonstrate that the biggest source is direct excretion by the animals (Table 6). The data demonstrate that about one-third of the N and about one-fifth of the P that is excreted by animals is applied via fertilization or from DMS application. The high standard deviation observed demonstrates the high spatial variability to different fields in the application of the nutrients from the varying sources.

Table 6. Nutrient contribution from individual sources in the dairy producing facility in Camuy.

Contribution from:	N		P_2O_5		K_2O	
	mean	sd	mean	sd	mean	sd
	--------------------------------kg/ha/yr-----------------------------					
Fertilizer	109	74	36	25	73	49
Liquid sludge	121	88	60	45	202	148
Direct excretion	341	290	376	343	482	408

A large portion of the farm was grazed with lactating cows and received regular nutrient inputs via direct excretion. The fields that received direct animal excreta were also supplemented with complete fertilizer (15-5-10), DMS, or both. Nutrient loads from combined sources of direct excretion with fertilizer, sludge or both ranged from 423 to 733 kg N/ha and from 386 to 629 kg P_2O_5/ha (Table 7). Clearly the biggest nutrient contribution originates from direct excretion due to grazing animals.

Table 7. Nutrient contribution from combined sources in the dairy producing facility in Camuy.

Areas that received:	N		P_2O_5		K_2O	
	mean	sd	mean	sd	mean	sd
	-----------------------------kg/ha/yr-----------------------------					
Fertilizer + sludge	269	146	111	62	271	197
Fertilizer + excretion	428	381	385	399	529	513
Sludge + excretion	590	354	588	392	874	495
Fertilizer + sludge + excretion	731	480	627	475	970	615

Key knowledge gaps related to nutrient management of manures include: (i) how much of the N and P added to fields via DMS and animal excretion is actually available to crops, (ii) how much of the N and P going into lagoon stays within or is lost via other microbial and chemical transformation processes, and (iii) how much N and P is needed to achieve maximum forage yield and quality during grazing conditions. Vicente-Chandler et al. (1983) suggested that that forage under grazed conditions could receive up to 375, 125, and 250 kg/ha of N, P_2O_5 and K_2O as a complete fertilizer 15-5-10. But, the conclusions were not based on plant response to individual nutrient sources, but rather based on animal weight gain. Further work should be centered towards quantification of forage response (biomass and quality) to individual nutrient sources under grazing conditions.

CONCLUSIONS

The DMS generated in dairy producing facilities is an important commodity that can provide generous nutrient amounts when properly applied to grazed forage pastures. There is an excess of nutrients generated on-farm which originate primarily from grazing animals, and is exacerbated by high animal densities, improper distribution of N and P from DMS and fertilizer. As observed in the case study, some farms fertilize with complete fertilizer formulation of 15-5-10 whereas a large proportion of P and K requirements can be provided by direct excretion and DMS. Soil and plant tissue testing should be used to guide when only N need be applied to supplement nutrient from animal sources. Better spatial distribution of manure should help distribute nutrients to specific fields which are not grazed as intensively.

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