Phosphorus persistence in runoff from an Ultisol amended with dairy manure sludge

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Abstract
Five consecutive simulated rainfall events were performed over a 45-day period on an undisturbed soil (Typic Haplohumult) under forage (*Brachiaria decumbens*) production. The soils had Bray-1 soil test phosphorus (STP) in the "high" (range of 30 to 90 mg P/kg) and "very high" (range of 91 to 200 mg P/kg) categories and were amended with a low (15.5 kg N/ha and 5.6 kg P/ha) and a high (31 kg N/ha and 11.2 kg P/ha) application of fresh dairy manure sludge. The concentrations of dissolved P (DP), total P (TP) and suspended sediment (SS) concentrations in runoff were quantified. Runoff DP and TP concentrations were primarily influenced by the "very high" STP level and to a minor extent by the high manure application. Nutrient concentrations were higher on the first day after manure application and were highest in soils with "very high" STP levels. The concentrations of DP and TP in runoff 4, 8, 15 and 45 days after manure application decreased on average by 52, 40, 36, and 35%, respectively, relative to the first day. Manure management for agricultural soils should be guided by soil test P levels, manure dose applications and expected rainfall events.

Keywords
soil test phosphorus, nutrient in runoff, dairy manure sludge, water quality, tropical soils.

Introduction
Long-term application of dairy manure sludge based on crop N requirements leads to soil P accumulation in soils of the tropics (Torres *et al.* 2009). The runoff phosphorus (P) concentrations have been quantitatively related to agronomic soil tests for P such as: Olsen extractant, Bray-1, or Mehlich-3 (Sims and Wolf 1995). Increasing STP leads to higher runoff P concentrations as observed using linear, non-linear and split-line relationships (Sharpley 1995; Daverede *et al.* 2003; Kleinman *et al.* 2004). Although Ultisols having the oxidic and kaolinitic mineralogy of the tropics may have enhanced capacity to reduce soil solution P due to precipitation and adsorption reactions, it seems that there are similar trends in the relationships between STP and P concentrations in runoff between Ultisols and other soils of temperate areas.

Ramírez-Ávila *et al.* (2008) reported that the quantitative relations between STP and runoff P concentrations vary due to soil organic matter, ground cover, soil moisture and amendment applications. It is not clear what are the mechanisms explaining why there is less P in runoff in wet soils than in dry soils or in the second of two consecutive runoff events. Runoff P concentrations are highest immediately after P application and decrease with time (Edwards and Daniel 1993). Although sorption and precipitation processes have been documented to control soil solution P, other mechanisms such as leaching, increased dilution of transported P, losses of the most labile P fraction and increased soil P extractability in dry soils may contribute (Pote *et al.* 1999; Kleinman and Sharpley 2003). Evaluation of mechanisms controlling runoff P at the field scale is affected by weather fluctuations, landscape heterogeneity, spatial variability and animals. Indoor rainfall simulations using boxes are an alternative to evaluate patterns of runoff nutrient concentrations (Sharpley and Kleinman 2003; Guidry *et al.* 2006). We carried out rainfall simulations using intact soil cores to evaluate runoff nutrient concentrations as influenced by STP, manure application and time after manure application.

Methods
Two grazed pasture production fields, with and without dairy manure sludge application, from a commercial dairy production farm in Puerto Rico were selected. Within each field, areas having "high" and "very high" STP categorical levels (Sotomayor-Ramirez *et al.* 2004) were identified. Intact rectangular soil (Typic Haplohumults) cores (100 x 30 x 9 cm) were collected from each area, trimmed and placed in galvanized sheet metal runoff boxes with similar dimensions (100 x 20 x 7.5 cm). Soil samples taken from each collection area at a depth of 0 - 10 cm, air dried, sieved to pass a 2-mm mesh, and analyzed for STP using

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Bray-1 (Bray and Kurtz 1945). The runoff boxes were transferred to greenhouse facilities.

The experimental design was a 2 (high and very high STP categorical levels) × 3 (none, low and high dairy manure sludge levels) factorial with 5 replicates. The low and high manure dose achieved rates of 15.5 kg N/ha and 5.6 kg P/ha and 31 kg N/ha and 11.2 kg P/ha, respectively. Consecutive sequential (t) rainfall simulations were done for all treatments at 1, 4, 8, 15 and 45 days after manure application. A set of samples was left without rainfall simulations for 30 days and rainfall simulations were then performed at 30, 32, 38, 45 and 74 days after manure application.

Simulated rainfall with an intensity of 70 mm/hr was applied to each set of plots with a duration corresponding to 30-min of runoff (USDA-NRCS 2001). A 500 ml subsample was obtained from the cumulative volume of runoff collected. Samples were analyzed for total P (TP) after digestion, and dissolved P (DP) after filtration (Pote and Daniel 2009; Pote *et al.* 2009). The degree of P saturation (DPS) was quantified as described by Schoumans (2009). An ANOVA was performed on nutrient concentrations in runoff using PROC GLM of SAS (SAS Institute, Carey NC) using STP, and manure levels as fixed effects and time as repeated measures; mean separation was estimated by Tukey's test (P<0.05).

Results and Discussion

The mean soil organic matter was 88.0 g/kg (coefficient of variation, CV = 19%). The soil had a mean pH of 4.54 (CV = 6.69%), and had parasesquic mineralogy; conditions which promote P fixation. Exchangeable cations (Ca, Mg, K, Na) and soil electrical conductivity tended to be higher in soils with a dairy manure sludge application history. In general, as soil moisture decreases there occurs lower runoff volumes, higher time to runoff initiation, and lower runoff/ratio. In our experiment, we observed these trends only in the "very high" STP and high manure treatment. These same treatments also had higher DP and TP concentrations, throughout the consecutive rainfall events.

Runoff DP and TP concentrations, averaged across the five rainfall simulations over a 45-d period, were significantly greater (P<0.01) in soils with "very high" than "high" STP level, regardless of whether the soil was amended or not with manure (Figure 1). In general, runoff DP concentrations were 30, 37 and 48% higher in soils with "very high" STP than soils with "high" STP in unamended, low, and high manure application levels, respectively. The high manure application treatment increased DP and TP concentrations relative to low manure application treatment and unamended soil. Suspended sediment concentrations in runoff tended to be greater in soils with manure application than without manure application, although these were not statistically different (P<0.05).The DP/TP ratio in soils with "very high" STP was 90% and 81% in soils with "high" STP level. The proportion of P in runoff as particulate material was nearly 50% lower in soils with "very high" STP than in soils with "high" STP. The data suggests that at the field scale, as STP increases a greater proportion of the total P in runoff will be in dissolved form, but there will also be more P in particulate form.

In the first rainfall simulation after manure application (day 1), runoff DP and TP concentrations in soils with "very high" STP were significantly greater than for soils with "high" STP for both unamended and amended soils except for the treatment with high STP levels and high manure application (Figure 2). The DP and TP concentrations were reduced by 36 and 35%, respectively, on all other days (4, 8, 15 and 45) relative to day 1. The data clearly indicate that the most important determinant on DP and TP concentrations in the first rainfall event of a soil can be both the "very high" STP condition as well as a high manure amendment level. Runoff DP and TP concentrations were always lowest for soils with "high" STP without manure application and with low manure application level.

The major P losses in runoff will occur on the first day after dairy manure applications and after the first simulation, the DP concentrations in runoff were similar to rainfall simulations at 4, 8, 15 and 45 days (Figure 3). The relationship between DP and time can be modeled for the "very high" STP level [1] and for the "high" STP level [2], averaged across manure application, as:

$$DP = 0.6765\ (day)^{-0.289};\ r^2 = 0.93 \quad [1]$$
$$DP = 1.2346\ (day)^{-0.14};\ r^2 = 0.95 \quad [2]$$

A set of soils did not receive rainfall simulations for a 30-day period, after which simulations were performed at days 32, 38, 45 and 74 days. Runoff concentrations of DP and TP were similar for days 32, 38, 45 and 74 of simulation (data not shown). Runoff DP concentrations in soils with “very high” STP after 45 days of consecutive rainfall simulations (five events) were similar to those which had not received simulated rainfall simulations.

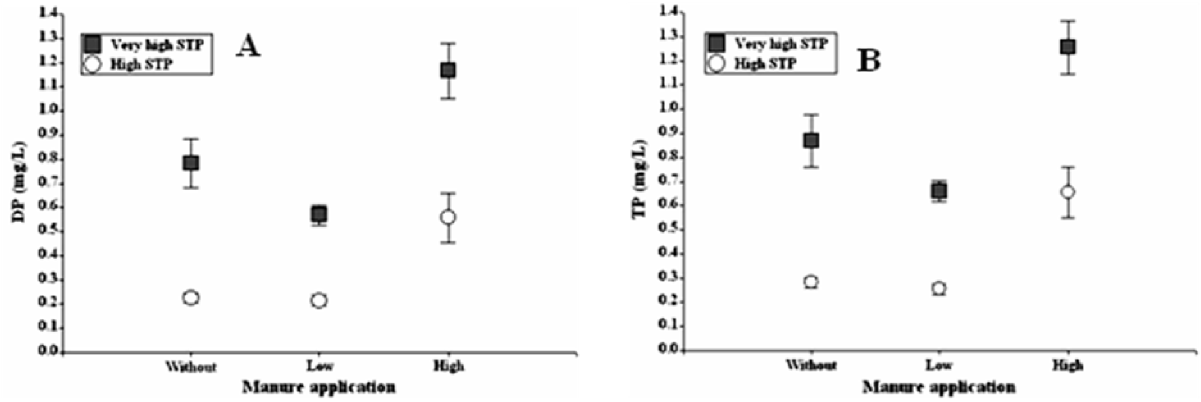

Figure 1. Effect of manure application level and soil test phosphorus (STP) on (A) dissolved P and and (B) total P concentrations in runoff from Ultisols.

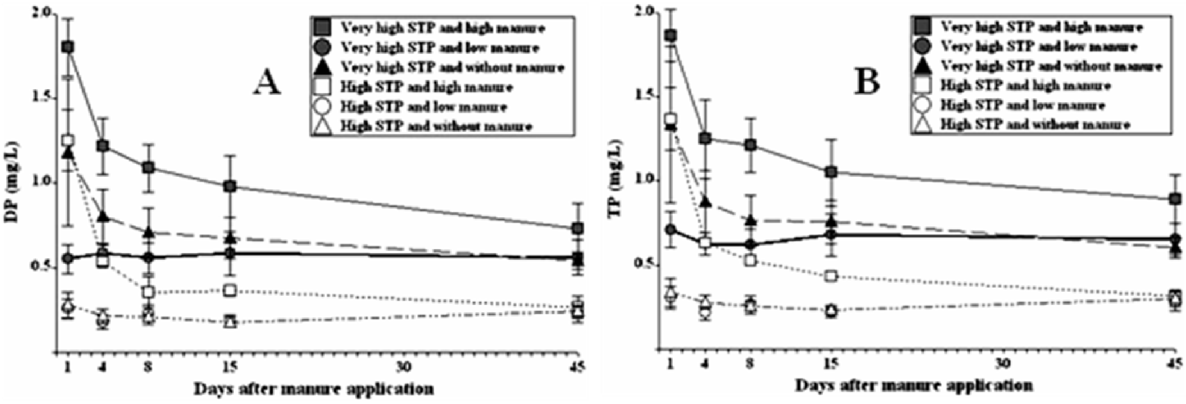

Figure 2. Temporal trends in dissolved P and total P as influenced by soil test P and manure application level for Ultisols.

The data indicate that by day 30 of the incubation, enough P was fixed in the soil so that P concentrations in runoff were reduced in soils that did not have runoff, relative to those soils in which P was being lost from soil solution by sorption and precipitation reactions as well as the P lost via surface transport in runoff. Runoff P concentrations were reduced primarily by P sorption and precipitation reactions (occurring from day 1 onwards after experiment initiation) and to a minor extent by the losses of the most labile forms of P.

Increasing amounts of P were being fixed in the soils during the incubation period (Table 1). Increasing STP from “high” to “very high” and manure application, increased the degree of P saturation. Soils with “very high” STP level had a 27% increase in the degree of P saturation relative to those with “high” STP. Soils receiving manure had an 8% increase in the degree of P saturation relative to unamended soil. These observations indicate that the soil test P was a more important determinant of the degree of P saturation than the manure application.

Conclusions

Runoff concentrations of DP and TP were influenced by the main effects of STP and manure application. The soil test P value was a more important determinant influencing the nutrient concentrations in runoff than the manure application level. The reduction in DP and TP concentrations in runoff during consecutive rainfall events was primarily due to sorption and precipitation reactions and to a minor extent the losses of the most labile P fractions. Lack of rainfall for 30 days after manure application may be the most important management factor for reducing the P concentration in runoff.

Table 1. Degree of phosphorus saturation as influenced by the duration of the experiment, soil test P, and manure application.

	Soil test P [1]		Manure application	
	"high"	"very high"	unamended	amended
Time (days)	Degree of P saturation (%)			
1	29.7a	51.3 c	41.2 a	50.5 ab
45	36.4ab	63.9 c	45.4 a	55.7 b
75 [2]	44.3 b	64.6 c	47.8 ab	57.7 b

1 Soils with different letter within soil test P or manure application groups are significantly different (P<0.05).

2 The evaluation at 75 days was performed on soils that received manure, were not irrigated for 30 days and then received rainfall simulations at days 30, 32, 38, 45 and 74 days after manure application.

References

Bray RH, Kurtz LT (1945) Determination of total, organic and available forms of phosphorus in soils. *Soil Science* **59**, 39-45.

Daverede IC, Kravehenko AN, Goeft RG, Natziger ED, Bullock DG, Warren JJ, Gonzini LC (2003) Phosphorus runoff: Effect of tillage and soil phosphorus levels. *Journal of Environmental Quality* **32,** 1436–1444.

Edwards DR, Daniel TC (1993) Drying interval effects on runoff from fescue plots receiving swine manure. *Transactions of the American Society of Agricultural Engineers* **36**, 1673–1678.

Guidry AR, Schindler FV, German DR, Gelderman RH, Gerwing JR (2006) Using simulated rainfall to evaluate field and indoor surface runoff phosphorus relationships. *Journal of Environmental Quality* **35**, 2236-2243.

Kleinman PJA, Sharpley AN (2003) Effect of broadcast manure on runoff P concentrations over successive rainfall events. *Journal of Environmental Quality* **32**, 1072-1081.

Kleinman, PJA, Sharpley AN, Veith TL, Maguire RO, Vadas PA (2004) Evaluation of phosphorus transport in surface runoff from packed soil boxes. *Journal of Environmental Quality* **33**, 1413–1423.

Pote DH, Daniel TC (2009) Dissolved phosphorus in water samples. In 'Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters'. (Eds Kovar, Pierzynski) pp. 109-111. (SERA-IEG 17). Available at http://www.sera17.ext.vt.edu/Documents/P_Methods2ndEdition2009.pdf

Pote DH, Daniel TC, DeLaune PB (2009) Total phosphorus and total dissolved phosphorus in water samples. In 'Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters'. (Eds Kovar, Pierzynski) pp. 112-116. (SERA-IEG 17). Available at http://www.sera17.ext.vt.edu/Documents/P_Methods2ndEdition2009.pdf

Pote DH, Daniel TC, Nichols DJ, Moore Jr. PA, Miller DM, Edwards DR (1999) Seasonal and soil-drying effects on runoff P relationships. *Soil Science Society of America Journal* **63**, 1006-1012.

Ramírez-Ávila JJ, Sotomayor-Ramírez D, Martínez GA, Pérez LR (2008) Phosphorus relationship for tropical Ultisol under pasture. *Journal of Agriculture of the University of Puerto Rico* (In review).

Sharpley AN (1995) Dependence of runoff phosphorus on extractable soil phosphorus. *Journal of Environmental Quality* **24,** 920-926.

Sharpley AN, Kleinman PJA (2003) Effect of rainfall simulator and plot scale on overland flow and phosphorus transport. *Journal of Environmental Quality* **32**, 2172–2179.

Sims JT, Wolf AM (1995) Recommended soil testing procedures for the northeastern United States. Northeastern regional publication No. 493 (revised). University of Delaware Agric. Exp. Stat., Newark, DE.

Schoumans OF, (2009) Determination of the degree of phosphate saturation in noncalcareous soils p. 109-111 In (Kovar and Pierzynski Eds) Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters. (ed.) SERA-IEG 17. Available at http://www.sera17.ext.vt.edu/Documents/P_Methods2ndEdition2009.pdf

Torres CR, Martínez GA, Sotomayor-Ramírez D (2009) Evidence for excess dietary phosphorus on dairy farms with rotational grazing of tropical grasses. *Journal of Agriculture of the University of Puerto Rico* **93**, 23-40.