Research Note

APPLICATION OF THE CARIBBEAN P INDEX TO SOILS RECEIVING ORGANIC AMENDMENTS[1]

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J. Agric. Univ. P. R. 86(3-4):145-154 (2002)

Many of the surface water bodies of Puerto Rico exceed the total phosphorus (P) concentration limit proposed by the United States Environmental Protection Agency (USEPA) for rivers (0.1 mg/L) and lakes (0.05 mg/L) (Sotomayor et al., 2001). Agricultural non-point sources are believed to be the leading cause of nutrient (primarily nitrogen and phosphorus) and sediment contamination of surface waters (Parry, 1998).

A joint effort between the College of Agricultural Sciences and the U.S. Natural Resource Conservation Service, Caribbean Area Office, is in progress to identify agricultural soils with high potential for excessive P runoff. Once identified, a comprehensive nutrient management program (CNMP) will be implemented at those sites to reduce their P contamination potential. Herein we present the results of the initial phase of this effort.

A study was conducted of 22 animal feeding operations (AFOs) owned by NRCS-sponsored farmers to ascertain the potential for excessive P losses from their fields (Table 1). Eleven of the farms were either applying poultry litter or had a history of poultry litter application. Those farms were located in the municipalities of Coamo, Salinas, Santa Isabel, Cayey, Barranquitas and Aibonito. The other 11 farms applied manure and wastewaters from dairy or beef cattle operations. These farms were located in the municipalities of Camuy, Arecibo, Isabela, Hatillo, San Sebastián, and Manatí. Several plots were selected within each farm for evaluation. Information on percentage and length of slope, percentage soil coverage, and distance to water bodies was obtained. Soil samples (0-8 cm) were collected and analyzed for extractable phosphorus by the Olsen, Bray and $CaCl_2$ methods (Pote et al., 1996; Mullins and Hajek, 1997). A sampling depth of 0-8 cm was used instead of the traditional 0-15 cm used in agronomic studies since the latter has proven more representative for environmental purposes (Sharpley et al., 1996). A modified version of the P index was used to rank the contaminant potential of the soils.

P Index

The Phosphorus Index (PI) is an assessment tool that may be used to assess the risk of P losses from a field and to identify management practices that can lead to an unfavorable impact on the environment. The initial version of the index was developed by a group of scientists sponsored by the U.S. Department of Agriculture (USDA) (Lemunyon

[1]Manuscript submitted to the Editorial Board 13 November 2001.

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TABLE 1.—*Description of the farms used in the study.*

Farm No.	Type of manure used	Municipality	Predominant soil order
1	Chicken	Coamo	Inceptisol
2	Chicken	Coamo	Inceptisol
3	Chicken	Salinas	Vertisol
4	Chicken	Coamo	Inceptisol
5	Chicken	Aibonito	Oxisol
6	Chicken	Aibonito	Ultisol
7	Chicken	Barranquitas	Ultisol
8	Chicken	Cayey	Inceptisol
9	Chicken	Cayey	Inceptisol
10	Chicken	Cayey	Inceptisol
11	Chicken	Corozal	Ultisol
12	Cattle	Camuy	Oxisol
13	Cattle	Camuy	Ultisol
14	Cattle	Camuy	Ultisol
15	Cattle	Hatillo	Ultisol
16	Cattle	Manatí	Mollisol
17	Cattle	Arecibo	Ultisol
18	Cattle	Arecibo	Ultisol
19	Cattle	Arecibo	Ultisol
20	Cattle	Isabela	Ultisol
21	Cattle	Isabela	Oxisol
22	Cattle	San Sebastián	Mollisol

and Gilbert, 1998). In a previous study, the original version of the P Index was used to evaluate the P status of several farms from the poultry region (Martínez et al., 1999).

Since its conception, scientists from different states of the United States have developed different versions of the index to make it more suitable to their specific conditions. In our case, a version more suitable to Caribbean conditions was developed by selecting a series of source and transport criteria that in our judgment were more relevant to our conditions, and attributing to them different weighting factors to describe their relative contribution to the observed P losses from a field. We have termed this version the Caribbean P Index.

Caribbean P Index

The risk of P losses is a function of transport and source characteristics. The modified P Index, shown in Table 2, contains eight field features and management practices covering both transport and source characteristics (for detailed information the reader is referred to the NRCS-Caribbean Area Phosphorus Index Technical Note, 2001). The transport criteria are (1) soil erosion rate, (2) runoff class, (3) distance to surface water, and buffer strips. The source characteristics are (1) soil test P factor, (2) fertilizer P application rate, (3) fertilizer P application method and timing, (4) organic P application rate, and (5) organic P application method and timing. The following formula describes the procedure used to compute the PI rating.

$$PI = [(SE \times C1) \times (RC \times C2) \times (PSW \times C3)] \times \Sigma\,(\text{Source Characteristic Rating} \times C_i)$$

TABLE 2.— *Caribbean Area P Index.*

Caribbean Area P Index						
Characteristics		Value ratings				
Transport	WF[1]	Very Low (0.6 point)	Low (0.7 point)	Medium (0.8 point)	High (0.9 point)	Very High (1.0 point)
1. Soil erosion (tons/ha/yr)	1.0	<7	>7 ≤ 14	>14 ≤ 22	>22 ≤ 33	>33
2. Runoff class	1.0	Very low/negligible	Low	Medium	High	Very High
3. Distance to surface water; buffer strip width	1.0	>30 m of high stand cover (>91% cover); > 7 m of buffer strip	>30 m of good stand cover (81-90% cover); 3-6 m of buffer strip	>30 m of medium or better stand cover (>61% cover); no buffer strip	>30 m of low stand cover (<60% cover); no buffer strip	<30 m; no buffer strip
Characteristics		Value ratings				
Site source	WF	Very Low (0.1 point)	Low (1 point)	Medium (2 points)	High (4 points)	Very High (8 points)
4. Soil test P level (mg/kg)[2]	1.0	Very low	Low	Medium	High	Very high

[1]Weighting factors were assigned based on the professional judgment of the authors.
[2]Refer to Table 3 for specific values on each category for different soils.

TABLE 2.—*(Continued) Caribbean Area P Index.*

Characteristics		Caribbean Area P Index				
		Value ratings				
Site source	WF	Very Low (0.1 point)	Low (1 point)	Medium (2 points)	High (4 points)	Very High (8 points)
5. Fertilizer P application rate; FPR = annual P application rate/P crop uptake	0.5	≤1 time crop uptake	≤2 times crop uptake	≤4 times crop uptake	≤6 times crop uptake	>6 times crop uptake
6. Fertilizer P application method and timing	0.5	None applied	Incorporated <1 wk after applied	Incorporated <1 month after applied	Surface applied before rainy season	Surface applied during rainy season
7. Organic P application rate; OPR = annual P application rate/P crop uptake	0.75	≤1 time crop uptake	≤2 times crop uptake	≤4 times crop uptake	≤6 times crop uptake	>6 times crop uptake
8. Organic P application method and timing	1.0	None applied	Incorporated <1 wk after applied or sprinkler applied during dry season	Incorporated >1 month after applied, or when sprinkler applied with no runoff	Surface applied during low rain or when applied via irrigation excessive runoff occurs	Surface or sprinkler applied during rainy season

[1]Weighting factors were assigned based on the professional judgment of the authors.
[2]Refer to Table 3 for specific values on each category for different soils.

where:

SE refers to soil erosion rating; C1 refers to weighting coefficient for soil erosion;

RC refers to runoff class rating; C2 refers to weighting coefficient for runoff class;

PSW refers to distance to surface water/buffer strip rating; C3 refer to weighting coefficient for distance to surface water/buffer strips; and C_i refers to weighting coefficient for each source characteristic.

Contrary to the original version, this formula separately evaluates the transport and source characteristics of a site and combines them in a multiplicative manner. This procedure allows for a better representation of site vulnerability. A site could have a high source characteristics rating, but if the possibility of P reaching a water stream is minimal (i.e., low transport capacity or long distance to water bodies) the overall site vulnerability would be low. Each field site is assigned an overall category (i.e., Low, Medium, High or Very High). The final ranking identifies fields in terms of their relative risk of phosphorus movement and helps management planners to identify practices that could reduce the impact of manure applications on water quality.

The weighting factors (WF) and value ratings shown in Table 2 were assigned on the basis of the working group's best professional judgment. The lowest weighting factor is assigned to the factor with the lowest relative contribution to P losses from a field. Multiplying the weighting factor by the value rating establishes the relative contribution of each factor to the global P Index rating.

In order for the P Index to be effective the potential environmental relevance of agronomic soil P test values in different soils must be established. This is particularly difficult in Puerto Rico because of the large pedologic and mineralogical diversity of our soils, all of which results in widely different P sorption—desorption patterns (Jones et al., 1982; Beinroth, 1982). We are currently evaluating several of the most prevalent soils of the island for their P sorption capacity and their susceptibility to dissolved P losses due to runoff. Table 3 shows a preliminary range of values that, according to our estimates, define different categories of the contaminant potential of our soils. Minor adjustments on these values could be expected as our research progresses (a detailed description of the determination of those values will be presented in a forthcoming paper).

TABLE 3.—*Soil test P interpretation categories by soil groups.*

		Soil test P interpretation				
Soil groups	Soil test (mg/kg)	Very low	Low	Moderate	High	Very high
Strongly acid high P sorption	Olsen or Bray	0-10	11-30	31-130	131-300	>300
Moderate and slightly acid low to medium P sorption	Bray	0-10	11-30	31-55	56-100	>100
	Olsen	0-20	21-40	41-90	91-200	>200
Non acid low to medium P sorption	Olsen or Bray	0-10	11-30	31-70	71-150	>150

Use of the P Index

The PI numerical value is interpreted in Table 4 and delineates whether the nutrient management plan should be based on nitrogen or phosphorus. Separate value ratings for both organic and inorganic, and organic or inorganic nutrient systems were set up to avoid underestimating P losses in systems where inorganic fertilizer is not applied.

As an example of the application of the P Index, consider a site where animal manure constitutes the only source of nutrients. On this site manure is applied to the surface exclusively during low rain periods at a rate of four times the P crop needs. The soil is moderately acidic with an Olsen P level of 150 mg/kg. In addition, the soil belongs to a high runoff class and loses approximately 25 t of sediments per hectare per year. Finally, there is a stream less than 30 m from the site.

The determination of the P Index would be as follows:

$$PI = [(1 \times 0.9) \times (1 \times 0.9) \times (1 \times 1)] \times [(1 \times 4) + (0.75 \times 2) + (1 \times 4)]$$

$$PI = 7.70$$

This site would be ranked as having a high potential for excessive P losses and would be considered a threat to the sustainability of the surrounding body of water (Table 4). Reviewing each individual site classification will help identify whether the cause and severity of the risk warrants management attention. In a field with a Low or Medium vul-

TABLE 4.—*Interpretation of the P Index.*

P index value		
Organic and inorganic fertilizer	Organic or inorganic fertilizer	Generalized interpretation of P Index for the site
≤3.7	≤2.7	**LOW** potential for P movement from the site. If farming practices are maintained at current level there is a low probability of an adverse impact on water bodies. Apply nutrient source on a nitrogen base.
>3.7 ≤ 7.7	>2.7 ≤ 5.5	**MEDIUM** potential for P movement from the site. The chance for an adverse impact on water bodies exists. Soil and water conservation practices should be taken to lessen the risk of P movement and potential water quality degradation. Apply nutrient source on a nitrogen base.
>7.7 ≤ 15	>5.5 ≤ 11	**HIGH** potential for P movement from the site. The chance of organic material and nutrients reaching surrounding water bodies is likely unless remedial action is taken. Soil and water conservation practices are necessary to reduce the risk of P movement and water quality degradation. Apply nutrient source on a phosphorus base (1 to 2 times P crop uptake.)
>15	>11	**VERY HIGH** potential for P movement from the site and an adverse impact on water bodies. All necessary soil and water conservation practices, plus a P management plan must be implemented to avoid the potential for water quality degradation. Do not apply P or apply nutrient source on a P base (<1 times P crop uptake) after implementation of recommended best management practices.

nerability rating, it may be possible to base manure applications on a nitrogen budget. On sites with a High or Very High rating, animal manure management should be based on a phosphorus budget. In those cases, manure application rates should not exceed the amount of phosphorus removed by harvested plant biomass during the growing season.

Eighty-percent (80%) of the field plots evaluated in this study exceeded the critical agronomic soil P level of 35 mg/kg P determined by the Olsen method (Muñiz-Torres, 1986). This value defines a level beyond which further additions of P are not recommended from an agronomic standpoint. The average soil P values (150 mg/kg) of farms receiving broiler manure were higher than that of those receiving cattle manure (93 mg/kg) although the difference was not statistically significant (Figure 1).

Because of their steep topography and the difficulties that this factor imposes on the use of manure spreading equipment, poultry farms in Puerto Rico exhibit a large vari-

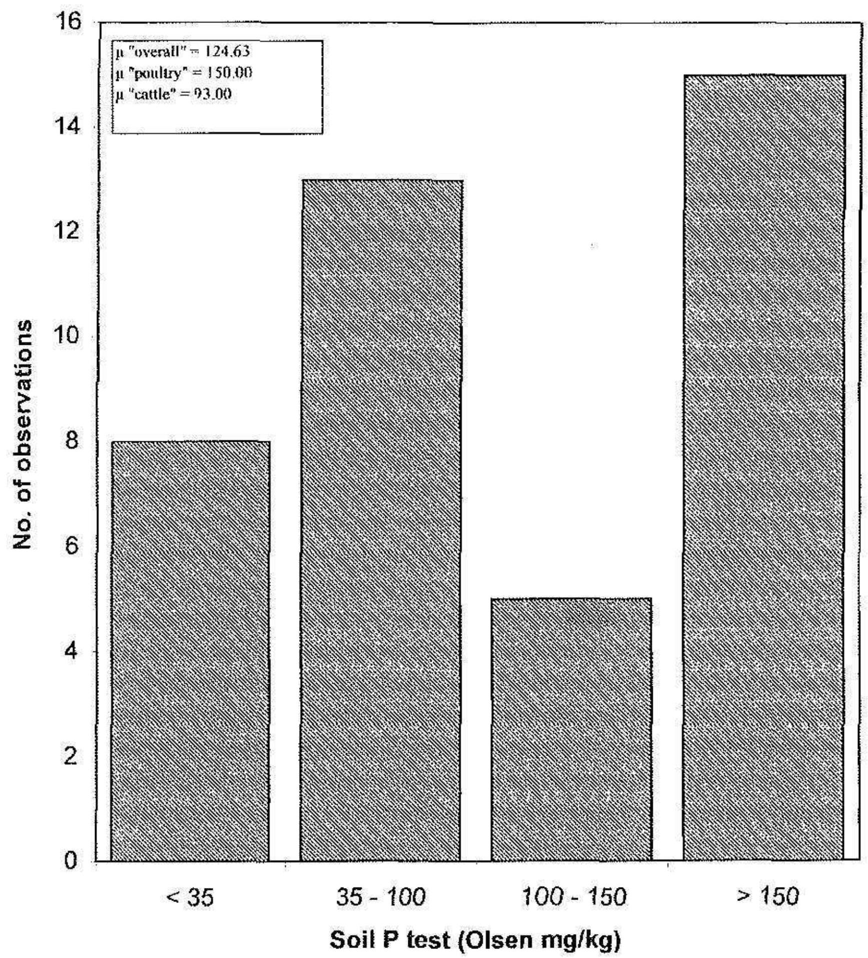

FIGURE 1. Soil phosphorus distribution in poultry and cattle operations in Puerto Rico.

TABLE 5.—*Soil P distribution across a poultry farm field site.*

Location of sampling site within landscape	Soil P value (mg/kg)—Olsen
Top of slope	183.99
Back slope	38.43
Toe slope	7.54

ability in soil P levels even within individual field plots. On a particular field plot, higher soil P levels are generally obtained at the top of the slope where manure-spreading equipment has easier access than on the toe slope (Table 5). Although this difference in soil P content may actually help to ameliorate water contamination by providing a contaminant-free zone between field plots with elevated P levels and surrounding water bodies, the effects of such practice need to be established.

A large fraction of the phosphorus present in a soil is in a mineral or particulate form. This fraction is in equilibrium with a soluble fraction that is largely labile for the aquatic biota and can contribute to eutrophication. Although still a matter of research, there is some consensus that the 0.01N $CaCl_2$ soil extractable phosphorus fraction is indicative of the bioavailable fraction (Torrent and Delgado, 2001). That is, this fraction represents the amount of dissolved phosphorus leaving a particular field in runoff upon a rainfall event. The USEPA established a value of 1 mg/L dissolved P as a discharge limit for point sources of contamination (e.g., waste treatment plants) to protect the integrity of rivers and lakes. That value is also being used as an index of high risk of contamination from agricultural fields. Estimates of the amount of soluble P (0.01M $CaCl_2$) in our samples revealed that 46% of the field plots examined would exceed the 1 mg/L dissolved P value in their runoff (Figure 2). Once again poultry farms exhibited a higher risk of contamination, with 57% of their field plots exceeding the limit, relative to

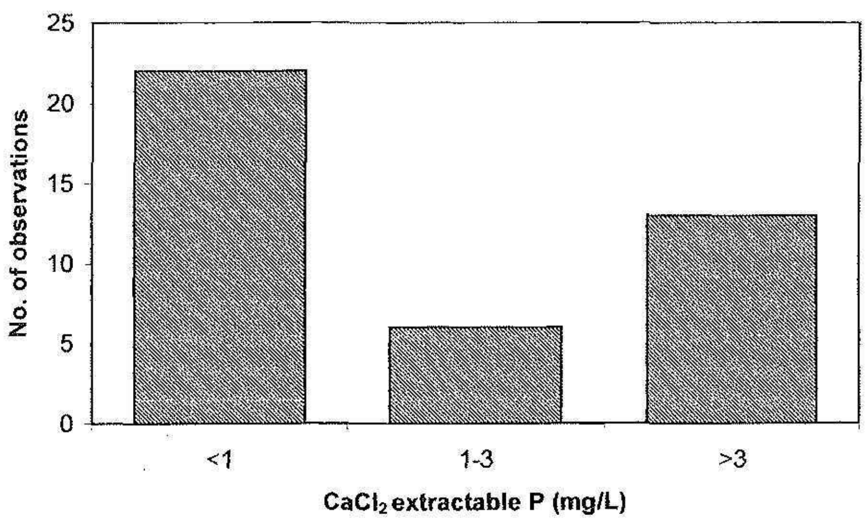

FIGURE 2. Estimates of $CaCl_2$ extractable phosphorus in soils receiving animal manure applications.

TABLE 6.—*P Index rank of the contaminant potential of different field plots in animal farm operations in Puerto Rico.*

Farm type	High or Very High	Medium	Low
All farms	20%	58%	23%
Broiler farms	37%	41%	23%
Cattle farms	0%	78%	22%

TABLE 7.—*P Index transport criteria results of animal farm operations in Puerto Rico.*

Farm type	Plots with >80% soil coverage	Plots with >12% slope
Broiler farms	72%	75%
Cattle farms	82%	12%

that of cattle farms (33%). In this case the mean values for the two organic materials were different at the 95% confidence level [$t_{39} = 2.02$; $P(T \leq t) = 0.025$].

The Caribbean P Index was applied to rank the potential contaminant impact of the different farms. A significant difference was observed between the contaminant potential of broiler farms and cattle farms (Table 6). The higher contaminant potential of broiler farms was not due exclusively to higher soil P levels but also due the more favorable transport conditions induced by their much steeper soils (Table 7).

Because of a combination of elevated soil P levels and steep topography, the poultry industry represents a higher water contamination threat among animal farm operations in Puerto Rico. Current estimates indicate that almost all poultry farms on the Island have areas from which runoff-soluble P may exceed proposed environmental critical levels.

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