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Phosphorus Soil Test Correlation to Sugarcane Grown on Histosols in the Everglades

G. H. Korndörfer, D. L. Anderson,* K. M. Portier, and E. A. Hanlon

ABSTRACT

Sugarcane (*Saccharum* spp.) in Florida is principally grown on Histosols in the Everglades Agricultural Area. Soil-test-based P fertilization recommendations have not been addressed since the 1970s. The objectives of this research were to evaluate the most acceptable soil test P extractant that best correlates to crop yield, and to define soil test P groupings associated with crop response to applied P. Results will be used in the future to recalibrate soil test data to yield and rate of P application. Phosphorus trials were conducted at four sites on organic soils between 1968 and 1972 and additionally at eight sites on organic soils between 1982 and 1990. Phosphorus applications ranging from 0 to 98 kg P ha^{-1} were broadcast or row-applied in combination with different cultivars, and/or K, Si, or S rates at 12 sites (multiple experiments used per site per crop). The effectiveness of water, acetic acid, and Mehlich-1 extractable soil P as yield response predictors was determined. Acetic acid extractable P was more highly correlated to sugar and cane yields (r = 0.72* and 0.63, respectively) than water-extractable P (r = 0.27** and 0.39**, respectively). Mehlich-1 extractable P was poorly correlated to sugar (r = 0.25*) and cane (r = 0.05^{ns}) yields. Acetic acid extractable P was selected as the best-suited extractant related to crop yield response to P fertilization. Soil test calibration curves (i.e., relative yield as a function of acetic acid extractable P) were determined from the choice of seven types of regression models, in which the reciprocal function was chosen with the highest coefficient of determination (R^2) and minimized residuals. Soil acetic acid extractable P criteria were developed to define soil test level groups associated with yield response conditions: low soil test levels ranged from 0 to 9 mg L^{-1}, medium from 9 to 39 mg L^{-1}, and high exceeded 39 mg P L^{-1}.**

SUGARCANE in Florida is grown on 171 000 ha of Histosols in the EAA. These Histosols are high in organic matter (40–95%) with water tables within 1 to 2 m of the surface. Under well-drained conditions, cultivated Histosols mineralize 17 to 39 kg P ha^{-1} yr^{-1} (Diaz et al., 1993; Anderson et al., 1994), which is plant available and may contaminate surface drainage waters. Although P is still recommended to optimize sugarcane yields, fertilization does not appear to elevate drainage water P concentrations above those of uncropped fallow fields (Coale et al., 1994). Under current environmental concerns for the Everglades (South Florida Water Management District, 1992) water managers advocate the use of nutrient recommendations from soil tests to avoid overfertilization, which may degrade surface water quality (Anderson and Flaig, 1995).

The Mehlich 1 extractant (Mehlich, 1953) has been used by the University of Florida Extension Soil Testing Laboratory, Gainesville, since the 1970s (Sartain, 1978). Soil test results from this extractant have been calibrated with vegetable and agronomic crops grown on sandy soils throughout Florida (Hanlon and Hochmuth, 1992). Originally, the Mehlich 1 extractant was developed for coarse-textured, sandy, acidic soils with CEC < 10 cmol kg^{-1} (Isaac, 1983a). Histosols within the EAA range from pH 4 to 8 (Anderson, 1990), sometimes contain appreciable quantities of free $CaCO_3$ (Lucas, 1982), and possess much higher CEC values than the upper limit assumed for the Mehlich 1 or Mehlich 3 extractants. Work with vegetables in the EAA on Histosols suggested that Mehlich 1 may not be suitable for these soil conditions in the EAA (Sanchez and Hanlon, 1990). However, Mehlich 1 extractant was included in this study during the 1980s due to its relevance to other Florida soils and current use.

In recent years, work with additional extractants has included a modification of an acetic acid extractant for P, first described for K, Ca, and Mg extraction by Forsee (1945, 1951). Specifically, this extractant showed promise in describing the P status of EAA Histosols relative to yield (Anderson, 1991; Anderson et al., 1990). This extractant, with its greater acidic buffer capacity, may be more suitable for Histosols with a wider range in soil pH, high pH buffer capacity, and high CEC. Mehlich extractions have been successfully used for crop calibration on low pH, low pH buffer capacity, and low CEC Histosols in North Carolina (Table 1; Lilly, 1981). A number of other extractants also have been used for organic soils worldwide (Table 1) to varying levels of success.

Water-extractable soil P (P_w) is currently used to recommend P for sugarcane in the EAA. Recommendations range from 0 to 37 kg P ha^{-1} yr^{-1} (Gascho and Freeman, 1974). Phosphorus is not recommended for the plant crop when P_w exceeds 4.4 mg dm^{-3}. Regardless of the soil test P_w level, 20 kg P ha^{-1} yr^{-1} is recommended for subsequent ratoon crops (Gascho and Kidder, 1979). These recommendations were based on yield response to P fertilization for two experiments initiated in 1968 and 1971, but yields were not calibrated to soil test P_w. Revision of this recommendation is required because additional fertilization information and significant changes in cultivars, soils (soil subsidence of Histosols), production practices, and environmental concerns have occurred since recommendations were first developed in the 1970s (Gascho and Freeman, 1971; Gascho and Kidder, 1979).

The objectives of this research were to evaluate the most acceptable soil test P extractant that best predicts sugarcane crop yield and to define soil test P groupings

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Abbreviations: EAA, Everglades Agricultural Area; CEC, cation-exchange capacity; TCH, megagrams of cane per hectare; VCF, varietal correction factor; SPH, sugar yield; ANOVA, analysis of variance, *,**Significant at the 0.05 and 0.01 probability levels, respectively; ns, not significant.

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Table 1. Some P extractants that have been used for organic soils.

Name or place used	Extraction	Reference
Florida	0.5 *M* acetic acid, pH 4.8	Anderson, 1990
Florida, Indiana, the Netherlands	Water	Forsee, 1951; Houba et al., 1986; Larsen et al., 1958; Sanchez, 1990
Michigan	0.018 *M* acetic acid	Bigger et al., 1953; Spurway and Lawton, 1949
Michigan	0.135 *M* HCl	Bigger et al., 1953; Spurway and Lawton, 1949
Morgan	1.4 *M* NaOAc + acetic acid, pH 4.8	Morgan, 1951
North Carolina (Mehlich 1)	0.05 *M* HCl + 0.0125 *M* H_2SO_4	Daughtrey et al., 1973; Mehlich, 1953
North Carolina (Mehlich 3)	0.2 *M* acetic acid + 0.25 *M* NH_4-NO_3 + 0.015 *M* NH_4-F + 0.13 *M* $CHNO_3$ + 0.001 *M* EDTA†	Mehlich, 1984; Tucker, 1992
Poland	0.5 *M* HCl	Okruszko and Walczyna, 1970
England, Hungary	0.01 *M* $CaCl_2$	Jaszberneny et al., 1994; Williams and Sparling, 1984
Wisconsin, Michigan (Bray P_1)	0.025 *M* HCl + 0.03 *M* NH_4F	Bray and Kurtz, 1945; Lucas, 1982

† EDTA = ethylenediaminetetraacetic acid.

associated with crop response to P on Histosols in the EAA.

MATERIALS AND METHODS

Experiments in the EAA and adjacent areas were conducted on four experimental sites from 1968 through 1972 (Gascho, 1973; Gascho and Kidder, 1979), and eight additional sites from 1981 through 1990. Twenty-three unique P application experiments were defined based on differences in site, mode of P application (broadcast or band), cultivar, or interaction with rates of applied K (KCl), elemental S, or calcium silicate slag. Experiments were annually harvested for the plant crop and subsequent ratoons. Some sites had as many as two ratoon crops (total three crop-years). All total, test data were available from 73 field-year combinations.

The database is composed of experimental data (Table 2) from Histosols: Torry (euic, hyperthermic Typic Medisaprist); Lauderhill (euic, hyperthermic Lithic Medisaprist); Terra Ceia (euic, hyperthermic Typic Medisaprists); Pahokee (euic, hyperthermic Lithic Medisaprist); and Okeelanta (sandy, siliceous, euic, hyperthermic Terric Medisaprist). Full factorial and single-factor treatment arrangements in randomized complete-block designs were utilized to meet multiple experimental objectives at each site (Table 2).

Experimental plots contained four rows of sugarcane planted on 1.5-m spacings and 6.1 to 10 m in length. Broadcast fertilizer treatments were applied and incorporated (0–15 cm) by rotavation before furrowing. Row-placed fertilizer treatments were placed in the bottom of the opened furrow. Three to seven rates of P, applied as triple superphosphate above or below the recommended P fertilization rate, were chosen at each site (Table 2). Phosphorus was only applied, as triple superphosphate, at planting for the 1981 through 1990 experiments and for each crop from 1968 through 1972 (Gascho and Kidder, 1979). Fertilizer nutrients other than P were applied as recommended from soil test (data not shown; Anderson, 1989; Sanchez, 1990). Nitrogen was not added in any experiment, following University of Florida recommendations for sugarcane production on Histosols. Potassium chloride was used in combination with potassium-magnesium sulfate, if Mg was recommended at 11 kg ha^{-1}. Boron, Cu, Mn, and Zn were applied once in the furrow before planting, at rates of 0.23, 0.90, 2.26, 2.26 kg ha^{-1}, respectively. Double rows of sugarcane stalks (46-cm lengths) were placed in the furrows and covered. Cultural practices were the same as those maintained in commercial fields (Bowen and Anderson, 1992).

The varieties for each experiment were chosen from the top five cultivars used by the Florida sugarcane industry at the time of planting. Sugarcane from the experimental sites was grown for 40- to 68-wk crop intervals. Annual rainfalls, as recorded 1968 through 1990 by the Everglades Research and Education Center Weather Station, Belle Glade, FL, ranged from 947 to 1927 mm (1334 mm 22-yr mean).

Sugarcane was planted in late September through mid-January during 1981 through 1987 and harvested for each crop, mid-October through mid-March from 1983 through 1990 (Sites 1–8). Planting, burning, harvesting, and other cultural practices used at Sites 9 through 12 (1968–1972) are described by Gascho and Kidder (1979). Excess leaves and

Table 2. Soils, treatments, cultivars, and experimental designs of the study sites.

Site†	Soil series‡	Soil pH	Applied P rates	Applied K	Applied S	Applied Si slag	Broadcast (b) or row (r)	Cultivar	Treatment design§
			kg ha^{-1}						
					1981 to 1990 data				
1	Lauderhill	7.3	0, 15, 29, 44, 88	186	0	0	r	CP70-133;CP72-1210	FF
2	Terra Ceia	5.7	0, 10, 19, 39, 58	186	0	0	b/r	CP70-1133	FF
3	Pahokee	4.9	0, 7, 15, 29, 44	112	0	0	b/r	CP70-1133	FF
4	Okeelanta	4.1	0, 10, 20, 39, 59	186	0	0, 1121	b/r	CP70-1133	FF
5	Torry	6.7	0, 10, 20, 39, 59	186	0, 560	0	b/r	CP72-1210	FF
6	Pahokee	4.8	0, 8, 16, 31, 47	112	0	0	b	CP68-1026	SF
7	Torry	7.7	0, 7, 15, 22, 29, 44, 59	186	0	0	r	CL61-620	SF
8	Pahokee	4.9	0, 7, 15, 22, 29, 44, 59	186	0	0	r	CP74-2005	SF
					1968 to 1972 data				
9	Pahokee	6.6	0, 49, 98	0, 205, 411	0	0	b	CL41-223	FF
10	Torry	5.5	0, 29, 59	112	0	0	b	CL41-233	SF
11	Pahokee	6.0	0, 20, 39, 59	0, 93, 187, 280	0	0	r	CP63-588	FF
12	Okeelanta	5.7	0, 15, 29, 44, 59	0, 224, 336, 448	0	0	b	CP63-588	FF

† Multiple experiments at Sites 5, 7, 9, and 11.

‡ Okeelanta series is a sandy muck characterized with an organic epipedon (40–127 cm) over a sandy substratum (C horizon).

§ FF = full factorial; SF = single factor.

trash were removed by burning prior to harvesting. Whole stalks were cut by hand at the soil surface, and tops were removed by cutting at the top hard internode and discarded. Whole-plot weights of millable cane stalks were measured with an industrial weighing load cell mounted on a tractor with a hydraulically controlled lift. Biomass yields were calculated as megagrams of cane per hectare (TCH).

Subsamples of 15 to 20 cane stalks per plot were randomly collected from each plot, weighed, and passed through a three-roller sample mill for juice extraction. The crusher juice was analyzed for Brix (soluble solids) with a refractometer (Bausch & Lomb, Rochester, NY). After clarifying the juice with lead subacetate (Meade and Chen, 1977, p. 541), the Pol (juice sucrose concentration) was determined with a saccharimeter (Rudolph Research, Flanders, NJ). The percentage of sucrose in juice was estimated with a formula developed from sucrose tables (Meade and Chen, 1977, p. 882–885) and temperature Brix correction tables (Meade and Chen, 1977, p. 861–962):

$$\% \text{ Sucrose} = (\text{Pol} \times 26)/\{105.811 + [(\text{Brix} - 15)0.44]\} \qquad [1]$$

where the 20°C temperature correction for Brix is

$$\text{Brix} = \text{Brix} + (\text{temperature} - 20)0.075 \qquad [2]$$

Recoverable 96°C sugar (kg sugar Mg^{-1} cane) was calculated with the Winter–Carp–Geerligs formula modified by Arceneaux (1935) and the varietal correction factor (VCF) described by Rice and Hebert (1972):

$$96^{\circ}\text{C Sugar} = [(\text{Sucrose} \times 21.058) - (\text{CBrix} \times 6.15)]\text{VCF} \qquad [3]$$

where CBrix is corrected Brix. The sugar yield (SPH, Mg sugar ha^{-1}) was calculated from TCH and the theoretical recoverable 96°C sugar.

Soil Test Procedures

Soil samples were taken from the Ap horizon of each plot prior to application of fertilizer treatments. Soils were sampled as a repeated measure from each site and treatment plot within 1 mo after planting and harvest (before fertilization).

Water-extractable P was determined with 4 cm^3 of air-dried soil volumetrically sampled and placed into a screw-cap tube of 50 mL of distilled water. The contents were allowed to stand for 12 h (25°C) and mixed on an end-over-end shaker (30 rpm) for 1 h. Suspensions were filtered (≥ 2.5 μm, ashless), and the filtrate was collected (≈ 20 mL). Soluble reactive P was determined colorimetrically (Murphy and Riley, 1962) at 880 μm. Acetic acid extractable P (P_a) was determined as above, with 0.5 M acetic acid instead of distilled water. Mehlich 1 extractable P (P_{MI}) was extracted by mixing 4 cm^3 of soil with 20 mL of 0.05 M HCl + 0.025 M H_2SO_4 (Isaac, 1983a,b), agitating on a mechanical shaker for 5 min, and filtering (≥ 2.5 μm, ashless). Solutions were analyzed for P in an inductively coupled argon plasma spectrophotometer. Results are reported as milligrams P per liter.

Criteria for Determining Response, Relative Yield, and Soil Test Calibration

Simple correlation (r) between yield (TCH and SPH) and soil test P (P_w, P_a, and P_{MI}) was determined (SAS Institute, 1990), and the results were plotted as scatter plots. The relationship of TCH to applied P was determined from the ANOVA; ($P \leq 0.10$; SAS Institute, 1990) determined for each crop (plant crop, first ratoon, second ratoon) with the respective experimental design (Table 2) at each site and unique P application trial. Thus, the metadatabase analysis considered a total of 73 field–year crop P application experiments across 22 yr on 12 sites.

After determining significant TCH response to applied P experiments from the ANOVA, general linear model regression and nonlinear regression procedures (SAS Institute, 1990) were used to determine appropriate fit to seven models for each experimental condition indicating a yield response to P application:

Linear model $Y = \beta_0 + \beta_1 X$ [4]
Quadratic model $Y = \beta_0 + \beta_1 X + \beta_2 X^2$ [5]
Square root model $Y = \beta_0 + \beta_1 X + \beta_2 X^{0.5}$ [6]
Reciprocal $Y = \beta_0 + \beta_1 X + \beta_2 X^{-1}$ [7]
Negative exponential $Y = M[1 - \exp^{-\beta 2(X + \beta 1)}]$ [8]
Linear-plateau model $Y = \beta_0 + \beta_1 X$, if $X \leq C$, and $Y = \rho$, if $X > C$ [9]
Quadratic-plateau model $Y = \beta_0 + \beta_1 X + \beta_2 X^2$, if $X \leq C$, and $Y = \rho$, if $X > C$ [10]

where Y is the cane yield (Mg ha^{-1}); X is the rate of P fertilization (kg ha^{-1}); β_0 is the model intercept; β_1 and β_2 are model constants; M is the maximum yield attainable (negative exponential model); C is the critical rate of fertilization, occurring at the intersection of the linear–quadratic response and plateau lines; and ρ is the plateau yield constant. The linear-plateau and quadratic-plateau models, defined by Eq. [7] to [10], were obtained by fitting linear or quadratic models to the point of intersection with the plateau, ρ (Cerrato and Blackmer, 1990). The best model was selected from the highest significant ($P \leq 0.10$) R^2 and minimization of residuals associated with each model. The maximum predicted yield ($\hat{Y}_{max}$) was determined from the model derivative or plateau. When the best-fit model was linear, the highest P application rate used was associated with the maximum predicted yield at that rate (Table 3).

To remove location-to-location variability in the data due to factors other than P (i.e., soil type, climate, season, crop), yield data was converted from a unit per area to percentage of relative yield of cane. Relative yield ($R\hat{Y}$) was calculated for each experiment indicating P response:

$$R\hat{Y}_0\% = (Y_0/\hat{Y}_{max})100\% \qquad [11]$$

where Y_0 = check yield with no applied P, and $\hat{Y}_{max}$ = maximum predicted yield derived from the mathematical model. For linear equations, the maximum predicted yield at the highest P application rate was used to calculate $R\hat{Y}_0\%$.

Soil test (P_a) calibration to $R\hat{Y}_0\%$ was accomplished with the best-fit procedures for the seven models given above Eq. [4] to [10], but where Y is the relative yield ($R\hat{Y}_0\%$) and X is the P_a soil level (mg L^{-3}). Criteria were used to define low, medium, and high soil test levels associated with yield response conditions in the reciprocal model selected for the calibration curve (Table 4). The boundary between low and medium soil test levels is determined at the point where there is a diminishing yield response to an increase of soil test level, obtained by the model first derivative, $dy/dx = 1$. The boundary between the medium and high soil test levels is where no further yield response to applied P fertilization is observed, i.e., all experiments with more than that level of P soil test showed no yield response to P fertilization.

Table 3. Pre-crop P soil test and cane yields for only the significant ($P \leq 0.1$) response experiments.

Site	Experimental conditions	Pre-crop soil test P_w		P_{MI}	$\hat{Y}_0$†	$\hat{Y}_{max}$‡	RŶ§
		P_w	P_a	P_{MI}			
		mg P dm^{-3}			Mg ha^{-1}		%
		Plant crop					
3	broadcast P	3	5	18	83	104	80
5	S = 560 kg ha^{-1}, row P	3	32	13	145	159	91
7	row P	1	39	22	83	90	92
		First Ratoon					
2	broadcast P	2	17	1	88	103	85
2	row P	1	18	5	90	104	87
3	broadcast P	3	7	22	70	95	74
3	row P	2	6	17	77	97	79
4	Si = 0 kg ha^{-1}, broadcast P	7	11	3	94	100	94
4	Si = 0 kg ha^{-1}, row P	5	10	2	90	101	89
5	S = 0 kg ha^{-1}, broadcast P	3	29	10	117	135	87
5	S = 0 kg ha^{-1}, row P	2	30	11	117	131	89
5	S = 560 kg ha^{-1}, row P	2	34	11	126	134	94
9	K = 0 kg ha^{-1}	1	–	–	59	88	67
9	K = 205 kg ha^{-1}	0	–	–	58	92	63
9	K = 411 kg ha^{-1}	0	–	–	62	94	66
12	K = 336 kg ha^{-1}	1	–	–	79	98	81
12	K = 448 kg ha^{-1}	1	–	–	78	108	72
		Secon Ratoon					
3	broadcast P	3	9	1	77	98	79
3	row P	2	8	2	79	100	79
5	S = 560 kg ha^{-1}, broadcast P	2	27	23	92	107	86
5	S = 560 kg ha^{-1}, row P	2	28	24	98	115	85
9	K = 205 kg ha^{-1}	1	–	–	57	80	71
9	K = 411 kg ha^{-1}	1	–	–	65	84	77
12	K = 0 kg ha^{-1}	0	–	–	61	91	67
12	K = 112 kg ha^{-1}	0	–	–	56	101	55
12	K = 224 kg ha^{-1}	0	–	–	65	90	72
12	K = 336 kg ha^{-1}	0	–	–	60	92	65
12	K = 448 kg ha^{-1}	0	–	–	74	101	73
Average ($\bar{x}$)		2.7¶	19.4	11.6			

† Check cane yield treatment without aplication of P.
‡ Maximum cane yield with all factors at adequate but not excessive levels.
§ Predicted relative cane yield (RŶ) to achieve maximum yield ($\hat{Y}_{max}$).
¶ Average corresponding with P_a and P_{MI} data (n = 16).

RESULTS AND DISCUSSION

Soil Test Phosphorus Extraction

The average amount of P extracted by P_w, P_a, and P_{MI} was 2.7, 19.4, and 11.6 mg L^{-1}, respectively (Table 3). Soil P_a was seven times greater than P_w and 1.7 times greater than P_{MI}; acetic acid is a stronger extraction for P than the other methods. The range of P_w is narrow, 0 to 8 mg P L^{-1}, where most of the P_w data was between 0 and 3 mg P L^{-1} (Fig. 1). Since P_w extraction is in a narrow and low concentration range, it is difficult to distinguish soils with different abilities to release P to sugarcane. The data range for P_a (6–39 mg P L^{-1}) or P_{MI} (1–24 mg P L^{-1}) was much broader than for P_w. The extraction ability of P_w and P_{MI} may be affected by the presence of $CaCO_3$ and high soil pH buffer capacity. Many Florida Histosols contain significant amounts of free $CaCO_3$, present as shell and limestone bedrock (Lucas, 1982). Soil P_a appears less affected by the high buffer capacity and presence of free $CaCO_3$ than either the P_{MI} or P_w. For interpretation of any single soil test P criteria, a broad range of extraction should be one important consideration (Evans, 1987).

Table 4. Regression model fits (R^2) describing the relationship of RY and acetic acid extractable soil test P (x).

Regression models	R^2	Equations
Reciprocal	0.52**	$R\hat{Y} = 91.8 - 77.35x^{-1}$
Negative exponential	0.52†	$R\hat{Y} = 63.0 + 36.56\,[1 - \exp(0.153x)]$
Square root	0.49**	$R\hat{Y} = 72.9 + 3.03x^{0.5}$
Quadratic-plateau	0.48†	$R\hat{Y} = 76.73 + 0.64 - 0.007x^2$, if $x < 45.0$
Linear	0.47**	$R\hat{Y} = 78.81 + 0.35x$
Linear-plateau	0.47†	$R\hat{Y} = 75.28 + 0.75x$, if $x < 18.4$
Quadratic	ns	$R\hat{Y} = 76.73 + 0.64x - 0.007x^2$

*, **, † Significant at $P \leq 0.05$, 0.01, and 0.10, respectively; ns = not significant.

An essential consideration for acceptability of a soil test extraction is its correlation to crop and sugar yield. When the metadatabase, including all sites (i.e., with and without P response), was assessed under no P fertilization, P_a was more highly correlated to TCH and SPH (r = 0.63** and 0.72**, respectively) than P_w (r = 0.39** and 0.27**, respectively) or P_{MI} (r = 0.05 ns and 0.25*, respectively). Although the regression between P_w and TCH or SPH was significant, the coefficient of determination (r) is low. Soil P_w is a better predictor of vegetable yield than other extractants (P_a and P_{MI}) on muck soils of the EAA (Hochmuth et al., 1994; Sanchez and Burdine, 1988; Sanchez et al., 1989). Because vegetable crops are more highly fertilized than sugarcane (Sanchez, 1990), ranges in P_w are also greater. The water-soluble P fraction also affects short-term (4–12 d) growth stages of vegetables, reflected in changes in the

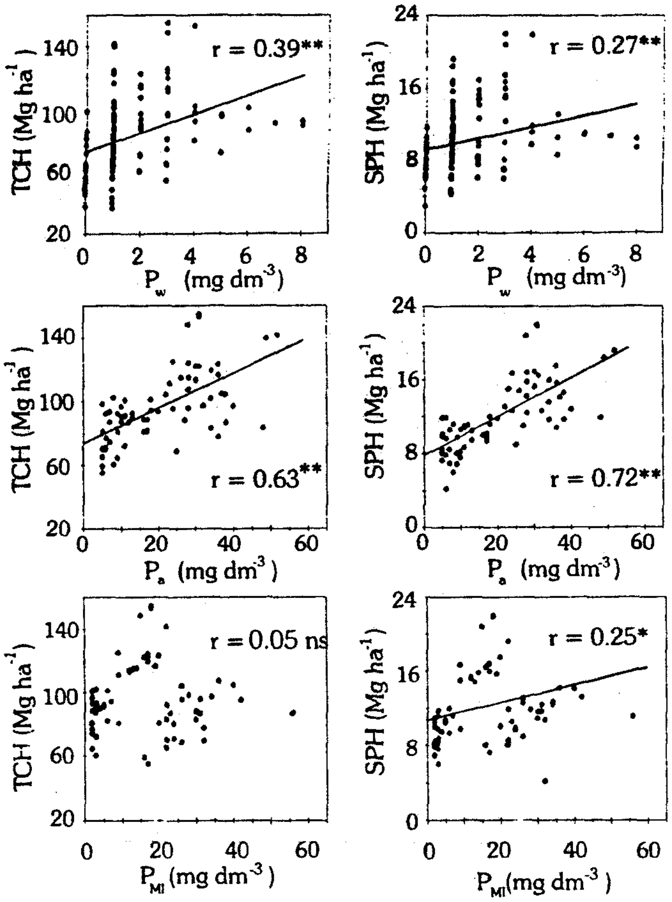

Fig. 1. Linear relationships between cane (TCH) and sugar yield (SPH) and extractable P (P_w, P_a, and P_{MI}). All data plotted when P applied = 0 regardless of response conditions.

marketable yield (Nagata et al., 1992; Sanchez and Burdine, 1988). Sugarcane growth stages affecting biomass or sucrose accumulation are 1 to 4 mo in duration (van Dillewijn, 1952) and are thus affected by long-term soil P reserves, as well as water-soluble or readily available P (Clements, 1980). Soil P_a appears to be more appropriate than either P_w or P_{MI} for assessing sugarcane crop yield.

Soil Test Acetic Acid Extractable Phosphorus Calibration to Relative Yield

Yield responses to applied P fertilization were observed among 38% of the tests on Histosols, based on ANOVA determinations, i.e., 28 of 73 experiments. From the P response group of experiments, the predicted maximum yield ($\hat{Y}_{max}$) was calculated from the appropriate yield response to P fertilization model for each site, experiment, and crop (Table 3). The $\hat{Y}_{max}$ (TCH) ranged from 80 to 135 Mg ha^{-1}. High variation in $\hat{Y}_{max}$ is a result of edaphic, climatic, crop (i.e., plant or ratoon), cultivar, or cultural practice variations normally associated with production (Jones et al., 1991). Therefore, R$\hat{Y}$ is frequently used to normalize data and minimize site influences (Evans, 1987). However, there are various reasons why the use of R$\hat{Y}$ should be avoided (Colwell et al., 1988). For example, relative yield should only be calculated from experiments with significant ($P \leq 0.1$) response models. Consequently, databases can only be evaluated when there are response conditions. This process omits data from broader edaphic conditions but where responses are not observed. To change this approach, it would be necessary to evaluate actual yields as a function of many factors, including the rate of fertilization. This requirement for response is a weakness of evaluating a single-factor soil test level (i.e., P_a) in relation to yield and response to applied nutrients.

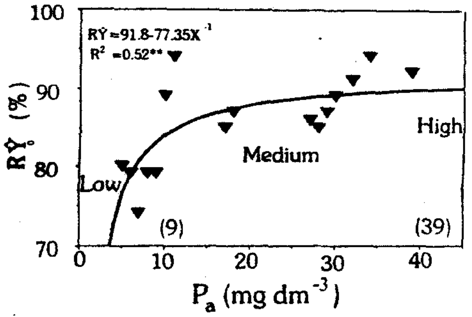

Fig. 2. Calibration of soil test P_a to relative cane yield (TCH, R$\hat{Y}_0$ %) for Histosols of the Everglades Agricultural Area.

Soil P_a was the single best soil test parameter correlated to crop yield in this study. Of the seven different mathematical models tested, the relationship between P_a and R$\hat{Y}$ (Table 4), the reciprocal (inverse linear) model provided the best data fit (Table 4, Fig. 2). Under the criteria defining soil test P groupings associated with crop response to P, three classes of P_a adequacy were established: low soil test concentration ranging from 0 to 9 mg P L^{-1}; medium concentration, 9 to 39 mg P L^{-1}, and high concentration exceeding 39 mg P L^{-1}. At high soil test P_a concentration, 90% R$\hat{Y}$ values were approached or exceeded and no yield responses to P fertilization were observed.

To develop P nutrient recommendations, the entire metadatabase should be utilized, whereby actual yield becomes a function of soil test level and rate of fertilization. Traditionally, fertilization recommendations are devised from calibration of relative crop yield to a single-factor soil test extraction and fertilizer applied. However, frequently a single-factor soil test level will not appropriately relate to yield under a broad range of growing conditions. There are edaphic conditions where yield is unassociated with both P fertilization response and soil test P. The soil test P level can be low but unrelated to yield. In these cases, other factors may be more significant than any single factor, and edaphic conditions should be defined within a fertilization recommendation system. To determine the point of excessive fertilization that may have environmental consequences, describing when to fertilize is as important as determining when fertilization has no effect on yield. Environmental concerns further emphasize the importance of how soil test calibrations for fertilization are accomplished. These statements will serve as a basis for future metadatabase analyses to determine P fertilization requirements to obtain sugarcane yield goals under readily obtained pre-crop edaphic conditions.

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Impact of Fertilizer Placement and Tillage System on Phosphorus Distribution in Soil

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ABSTRACT

Repeated use of band applications, both surface and subsurface, of immobile nutrients applicable to a variety of tillage systems raises concerns about the collection of soil samples used for making fertilizer recommendations. This study was conducted to measure the effect of tillage system and fertilizer placement on soil test P in a major part of the root zone. Soil samples were collected from control treatments and from treatments where phosphate fertilizer supplying 29 kg P ha^{-1} yr^{-1} had been broadcast, applied as a surface band, or applied in a subsurface band for three consecutive years in a corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.] rotation. These placements were used in both a chisel and a ridge-till planting system. Soil samples were collected from depths of 0 to 7.5, 7.5 to 15.0, 15.0 to 22.5, 22.5 to 30.0, and 30.0 to 45.0 cm at distances of 0, 7.5, 15.0, 22.5, 30.0, and 37.5 cm from the row. Soil test P, to a depth of 15 cm at each position from the row, was significantly affected by fertilizer placement. Placement also had a significant effect on soil test P to a depth of 30 to 45 cm at a distance of 30 cm from the row. Tillage system had a significant effect on measured soil test P at sampling positions near the row. These results indicate that both tillage system and fertilizer placement could have a major effect on soil test values. If band locations are known, they should be avoided, if possible, during sample collection.

USE OF CONSERVATION TILLAGE SYSTEMS for crop production in the northern Corn Belt has been stimulated by several factors, but less intensive tillage provides only limited opportunity for incorporation of fertilizers that are broadcast on the soil surface. This restraint has altered thinking about fertilizer management in conservation tillage production systems. Repeated use of banded fertilizer, both surface and subsurface, has raised concerns about the collection of soil samples used for making fertilizer recommendations for conservation tillage production systems.

For several years, researchers have measured the effects of repeated use of conservation tillage systems on various soil properties. These research projects were dominated by comparisons between no-till and some form of conventional tillage such as moldboard plow or chisel plow.

Soil pH near the surface has been changed substantially (Letaw et al., 1984; Eckert, 1985). Repeated use of no-till planting systems produced a stratification of organic C and N (Dick, 1983). Tillage-induced changes in the distribution of K, Ca, and Mg were reported by Blevins et al. (1983).

Many studies have documented the stratification of broadcast P and K with repeated use of some form of conservation tillage production system. The stratification of P and K is very obvious when no-till planting systems are compared with some form of conventional system (Fink and Wesley, 1974; Karathansis and Wells, 1990; Ketcheson, 1980; Kunishi et al., 1982; Weil et al., 1988). The impact of several conservation tillage production systems on distribution of P and K has been reported by Cruse et al. (1983), Robbins and Voss (1991), and Walker et al. (1970). In general, distribution of these nutrients in ridge-till planting systems is similar to that found in no-till systems. Similar results have been reported in Minnesota trials (Randall and Swan, 1991).

The recognition of nutrient stratification has raised questions about changes that might be needed in the collection of soil samples when conservation tillage practices are used. This is especially true if phosphate and potash are banded instead of broadcast. A limited number of research projects have addressed this concern. Tyler and Howard (1991) concluded that random sampling appears to be the most reasonable system to avoid overestimating the effect of banded fertilizer. Kitchen et al. (1990), however, suggested that a portion of the sample taken should be collected from the band itself. The degree to which the banded area is represented is dependent on the spacing of the fertilizer bands.

There is evidence to document the stratification of

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