SOIL FERTILITY

Sugarcane Response to Phosphorus Fertilizer in Relation to Soil Test Recommendations on Everglades Histosols

Barry Glaz,* Gerald Powell, Raul Perdomo, and Modesto F. Ulloa

ABSTRACT

To protect habitat in the Everglades, legislation mandates a reduction of at least 25% in the P content of water discharged from the Everglades Agricultural Area (EAA). Accurate P fertilizer recommendations for sugarcane (interspecific hybrids of *Saccharum* spp.), the major crop in the EAA, are needed to help achieve this P reduction. The objective of this study was to compare two soil-tests for basing P fertilizer recommendations for sugarcane grown on Histosols in the EAA. Three yield characteristics were measured at four field locations with no added P (P0), an often-recommended commercial rate of 24 kg P ha^{-1} (P1), and 48 kg P ha^{-1} (P2) for the plant-cane, first-ratoon, and, at three locations, the second-ratoon crop. One group of eight genotypes was planted at two locations, and two other groups of eight genotypes were each planted at one of two other locations. An acetic acid-extractable P (Pa) soil test predicted yields better than the water-extractable P (Pw) test. However, unexpected responses in sugar and cane yields occurred for both P extraction procedures. Further knowledge of the effects of soil pH, factors affecting P mineralization, and sugarcane genotype response to P may explain some of the unexpected results.

The EAA is a 280 000 ha agricultural basin of Histosols in southern Florida. About 144 000 ha of sugarcane are grown in the EAA (Glaz, 1998). Legislation mandates that the P content of water discharged from the EAA be reduced by at least 25% from the baseline mean calculated using 1978 through 1988 data (Whalen and Whalen, 1994). This is one of several measures aimed at sustaining much of the unique habitat characteristic of the predrained Everglades. In addition, about 16 000 ha in the EAA are being converted from agriculture to specially designed artificial wetlands to serve as Storm Water Treatment Areas (STAs) (Stone and Legg, 1992). Water released from the STAs must have its P concentration reduced to no more than 50 μg L^{-1} by 2002 (Walker, 1996). In addition, the legislation included options for further research to determine if levels lower than 50 μg P L^{-1} would be necessary to restore the ecologic health of the Everglades. Since then, research has documented changes in natural populations of Everglades flora and fauna at P concentrations greater than 10 μg P L^{-1} (McCormick et al. 1999).

Farmers in the EAA are successfully using an extensive BMP program to meet P-reduction requirements (Stone and Legg, 1992; Whalen and Whalen, 1994; Izuno and Capone, 1995). Stone and Legg (1992) estimated that the cost of BMP implementation was $153 ha^{-1} and annual operation and maintenance costs were about $9 ha^{-1}. A BMP approved for EAA farmers is to apply P fertilizers according to a calibrated soil test. Since the inception of this BMP, most EAA sugarcane farmers have complied by using a water soluble test for labile P (Pw) (Sanchez, 1990). The criteria for the P fertilizer recommendations from the Pw test were reported by Gascho and Freeman (1974) and Gascho and Kidder (1979). One major sugarcane grower chose the Bray 2 soil extractant (Bray and Kurtz, 1945) in 1958 because compared with Pw, it removed more of the acid-soluble and adsorbed P (Andreis and McCray, 1998).

Some EAA farmers have recently shown interest in Pa, a soil test that measures acetic acid-extractable P (Korndörfer et al., 1995). Due to its acid extraction, it is expected that Pa measures labile and reserve P. The Pw procedure often provides acceptable results for vegetable crops in the EAA that have a substantially shorter growing season than sugarcane. With the 8 to 14 mo growing season of sugarcane, several workers believe that a measure of reserve P such as the Bray 2 or Pa would provide better calibrations.

Korndörfer et al. (1995) reported that Pa predicted cane and sugar yield responses to P better than Pw. However, their analyses were based on what are now outdated or minor cultivars on EAA Histosols. Also, they did not report P responses by crop year (plant crop and ratoons) and they did not test responses of theoretical recoverable sugar. The objective of this study was to compare, for the plant and two ratoon crops, P fertilizer recommendations determined by Pw and Pa for major and promising sugarcane genotypes grown on Histosols in the EAA.

MATERIALS AND METHODS

Responses to three rates of P fertilizer were determined for 24 sugarcane genotypes. Eight genotypes were field tested at two locations, and two other groups of eight genotypes were each tested at one of two other field locations. All four locations were in Palm Beach County, FL. Location 1 was at the 20 Mile Bend Farm of Sugar Farm Cooperative, Eastern

B. Glaz, USDA-ARS Sugarcane Field Station, HCR Box 8, Canal Point, FL 33438; and G. Powell, R. Perdomo, and M.F. Ulloa, Florida Crystals, P.O. Box 86, South Bay, FL 33493. Received 15 June 1999. *Corresponding author (bglaz@ag.gov).

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Abbreviations: BMP, best management practice; EAA, Everglades Agricultural Area; P0, no P fertilizer; P1, 24 kg P ha^{-1}; P2, 48 kg P ha^{-1}; Pa, acetic acid-extractable P; Pw, water-extractable P; STAs, Storm Water Treatment Areas; TCH, metric tons of cane ha^{-1}; TRS, theoretical recoverable sugar measured as g sugar kg^{-1} cane; TSH, metric tons of sugar ha^{-1}.

Table 1. Dates of fertilizer application, stalk count, and stalk sampling for theoretical recoverable sugar (TRS) and stalk weight at four locations and three crop years.

Fertilizer application	Crop year		
Location	Plant cane	First ratoon	Second ratoon
1	December 1993	10 Apr. 1995	21 Mar. 1996
2	23 Nov. 1993	18 Apr. 1995	2 Apr. 1996
3	29 Dec. 1994	26 Mar. 1996	24 June 1997
4	22 Nov. 1995	24 June 1997	1 Apr. 1998
TRS and stalk weight			
Location			
1	7 Feb. 1995	28 Nov. 1995	10 Oct. 1996
2	10 Jan. 1995	22 Jan. 1996	
3	14 Dec. 1995	10 Dec. 1996	13 Oct. 1997
4	21 Jan. 1997	27 Dec. 1997	29 Oct. 1998
Stalk count			
Location			
1	25 May 1994	13 Oct. 1995	27 Aug. 1996
2	13 July 1994	6 Oct. 1995	
3	10 Aug. 1995	22 Aug. 1996	17 Sept. 1997
4	21 Aug. 1996	2 Sept. 1997	22 Sept. 1998

Division. This farm is in the eastern region of sugarcane production in the EAA, about 12 km west of West Palm Beach, FL. Locations 2, 3, and 4 were at the Okeelanta Corp., about 6 km north of the southern border of sugarcane production in Palm Beach County.

All four experiments were conducted on Histosols typical of the EAA. These soils often contain more than 85% organic matter (Zelazny and Carlisle, 1974) comprised primarily of decomposed sawgrass (*Cladium jamaicense* Crantz). The experiment at Location 1 was on a Terra Ceia muck (euic, hyperthermic Typic Medisaprist). The experiments at Locations 2, 3, and 4 were on Dania muck soils (euic, hyperthermic shallow Lithic Medisaprist). As described by McCollum et al. (1976), the distinguishing characteristic between a Dania and Terra Ceia muck is depth of soil over limestone rock. The thickness of the organic layer is >130 cm in a Terra Ceia muck and <51 cm in a Dania muck.

Treatments in all experiments were arranged in randomized complete-block designs with four replications. Each experiment had two factors, sugarcane genotypes and P fertilizer rates. Fertilizer rate zero, P0, was no P fertilizer; P1 was an often-recommended commercial rate of 24 kg P ha^{-1}; and P2 was 48 kg P ha^{-1}. These fertilizer treatments were applied in each crop year of each experiment; applications were made in the furrow at planting and topdressed in a band adjacent to each row in ratoon crops. All P was applied as triple superphosphate. Fertilizer application dates are shown in Table 1. These dates were similar to commercial fertilizer application dates for the fields containing each experiment.

All plots were fertilized with Cu, Mn, Zn, and B at commonly used commercial rates and with K at the rate of 186 kg ha^{-1}. The planting dates of the experiments were December 1993 (Location 1), 23 Nov. 1993 (Location 2), 29 Dec. 1994 (Location 3), and 22 Nov. 1995 (Location 4). Plots were four

Table 2. Soil pH, water-extractable P (Pw), and acid-extractable P (Pa) values from four locations.

Location	pH	Pw	Pa
		kg ha^{-1}	
1	5.4	10.9	17.9
2	6.7	3.2	31.6
3	6.3	2.2	22.5
4	6.6	1.0	25.0

rows, 10.7-m long with 1.5 m between rows. The experiments at Locations 1, 3, and 4 were conducted for three crop years, the plant-cane, first-ratoon, and second-ratoon crops. The experiment at Location 2 was conducted for two crop years, the plant-cane and first-ratoon crops.

Soil samples from the top 20 cm of soil were collected soon after planting in each replication from two plots that were not fertilized with P at Locations 1, 2, and 3. At Location 4, soil samples were collected before planting from the 24-ha field that contained the experiment. The samples were analyzed for pH (Sanchez, 1990), Pw (Sanchez, 1990), and Pa (Korndörfer et al. 1995) by the University of Florida/Institute of Food and Agricultural Sciences, Everglades Research and Education Center Soil Testing Laboratory, Belle Glade.

The eight genotypes at Locations 1 and 2 were 'CL 72-321', 'CL 61-620', 'CP 72-2086', 'CP 73-1547', 'CP 80-1827', 'CP 81-1254', 'CP 85-1308', and 'CP 85-1382'. The eight genotypes planted at Location 3 were 'CL 73-239', 'CP 70-1133', 'CP 72-1210', 'CP 78-1628', 'CP 80-1743', 'CP 84-1198', 'CP 85-1432', and 'CP 85-1491'. At Location 4, the eight genotypes were 'CP 88-1508', 'CP 88-1762', CP 90-1113, CP 90-1428, CP 90-1464, CP 90-1535, CP 90-1549, and CP 92-1435.

The most important yield characteristic of sugarcane is t sugar ha^{-1} (TSH). There are two major components of TSH. One component is theoretical recoverable sugar (TRS), measured as g sucrose kg^{-1} of cane. The other component of TSH is t cane ha^{-1} (TCH). The product of TRS and TCH divided by 1000 equals TSH. To calculate TRS, samples consisting of 10 stalks were collected from each plot. Dates of these samples are listed in Table 1. To choose stalks, a starting point was selected from one of the middle two rows of each plot, and from that starting point, the next 10 mature stalks were collected. Since sugarcane grows in large stools of primary, secondary, tertiary, etc. stalks, this sampling procedure helps collect a representative mixture of stalks.

TRS was calculated from the Brix and pol of each sample using a previously described procedure (Legendre, 1992). As described by Meade (1963, p. 625), Brix represents the apparent solids in a sugar solution and is measured as a percentage. It was measured with a refractometer that automatically corrected for temperature. Pol, as described by Meade (1963, p. 625), was the value obtained from polarization of the sugar solution in a saccharimeter. No units were given for pol by Meade (1963, p. 625). TCH was calculated by multiplying stalk number by stalk weight. Stalk weight was measured from the same sample of 10 stalks used to calculate TRS. Dates on which stalk counts were conducted are shown in Table 1.

Analyses of variance were calculated by using PROC GLM of SAS (SAS Inst., 1985). The analyses were calculated as split plots in time (crop years) arranged in randomized complete-block designs with two factors (genotypes and P fertilizer rates). The REPEATED statement (SAS Inst., 1985) was used to calculate the repeated observations by crop. Genotypes and P fertilizer rates were evaluated as fixed effects. Preplanned single degree of freedom comparisons were used to evaluate linear and quadratic responses to P fertilizer rates for each crop year. These comparisons were calculated as described by Steel and Torrie (1980). The error mean square was used as the best estimate of pooled error to test significance of these preplanned comparisons. Significant *F* values were sought at $P \leq 0.05$.

RESULTS AND DISCUSSION

Responses to P fertilizer rates are combined across genotypes. Interactions of genotypes and P were discussed separately (unpublished data, 1999). The soil at Location 1 had a lower pH than the soils at the other

Table 3. Mean theoretical recoverable sugar (TRS), metric tons of cane ha^{-1} (TCH), and metric tons of sugar ha^{-1} (TSH) for three crop years and three P fertilizer rates at Location 1.

	TRS			TCH			TSH		
P level	Plant cane	First ratoon	Second ratoon	Plant cane	First ratoon	Second ratoon	Plant cane	First ratoon	Second ratoon
kg ha^{-1}		g kg^{-1}				t ha^{-1}			
0	125.0	125.8	121.8	85.66	48.87	26.40	10.727	6.206	3.232
24	125.1	130.6	123.6	93.63	86.04	52.05	11.710	11.284	6.401
48	124.7	130.5	120.7	98.65	91.43	57.23	12.308	11.928	6.896
SE†		2.1			3.48			0.474	
Contrasts (*F* values)									
P linear	0.02	4.05	0.25	11.81	126.82	66.55	9.33	122.14	50.09
P quadratic	0.01	1.56	1.37	0.20	23.57	9.78	0.18	24.45	8.89
$P > F$									
P linear	NS	0.05	NS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P quadratic	NS	0.21	0.24	NS	<0.01	<0.01	NS	<0.01	<0.01

† SE of the difference between means of two fertilizer rates at the same crop year or different crop years.

three locations which had similar pH values (Table 2). Also, Pw at Location 1 was substantially higher than at Locations 2, 3, and 4. The lower Pw values at Locations 2, 3, and 4 may be directly related to their higher pH values because the solubility of P in water decreases as pH increases. Location 1 had a lower Pa than locations 2, 3, and 4, but the magnitude of the difference was not as great as for Pw. Locations 2, 3, and 4 were similar in Pw, and Locations 3 and 4 had moderately lower Pa values than Location 2 (Table 2).

At Location 1, increasing rates of P resulted in linear increases in TCH and TSH in each crop year (Table 3). The quadratic responses to P for TCH and TSH also were significant in the ratoon crops. In each case, the significant quadratic responses were due to yield increases that were greater from P0 to P1 than from P1 to P2 (Table 3). The positive TSH response from P0 to P1 was particularly strong in the first-ratoon crop at Location 1 due to the positive linear response of TRS to P in that crop year. There were no other significant TRS responses to P at Location 1.

Glaz and Ulloa (1994) verified earlier work of Lucas (1982) when they reported that for a soil similar to the Terra Ceia muck at Location 1 with a pH at the low end of the 4.9 to 7.5 range, less P fertilizer was necessary due to an increase in soluble, available P expected at the low pH. In addition, P fertilizer was recommended only for the ratoon crops on the soil at Location 1, based on its labile soil P (Pw) of 10.9 kg ha^{-1} (Table 2 and Sanchez, 1990). Thus, the consistent, positive response to increasing P from P0 to P2 was not expected at Location 1 based on the Pw and pH soil-test results.

Korndörfer et al. (1995) classified the Pa of 17.9 kg ha^{-1} at Location 1 (Table 2) at the low end of the medium group. For this Pa classification, they predicted that a positive yield response to moderate rates of P fertilizer would be likely. Since a positive yield response occurred from P0 to P2, Pa was more useful than Pw for predicting response to P fertilizer at Location 1.

The same genotypes were planted at Locations 1 and 2. A positive yield response to increasing rates of P fertilizer was expected at Location 2 based on the higher pH and the lower labile soil P (Pw) at Location 2 compared with Location 1 (Table 2). However, at Location 2 there were no significant responses to P fertilizer for TRS, TCH, and TSH (Table 4). Of the four locations in this study, the soil at Location 2 had the highest Pa (Table 2) and was classified at the high range of the medium group described by Korndörfer et al. (1995). At this classification, a yield response was predicted by Korndörfer et al. (1995), but not with as much certainty as for lower Pa values. Thus, neither Pw nor Pa predicted the lack of response to P fertilizer at Location 2.

For the eight genotypes at Locations 1 and 2, the Pa

Table 4. Mean theoretical recoverable sugar (TRS), metric tons of cane ha^{-1} (TCH), and metric tons of sugar ha^{-1} (TSH) TRS, TCH, and TSH for two crop years and three P fertilizer rates at Location 2.

	TRS		TCH		TSH	
P level	Plant cane	First ratoon	Plant cane	First ratoon	Plant cane	First ratoon
kg ha^{-1}	g kg^{-1}			t ha^{-1}		
0	129.4	129.5	87.99	70.10	11.405	9.055
24	129.6	128.0	91.51	69.15	11.851	8.830
48	127.8	129.3	92.54	72.78	11.834	9.415
SE†	1.3		2.65		0.357	
Contrasts (*F* values)						
P linear	1.23	0.02	2.70	0.94	1.27	0.90
P quadratic	0.56	1.11	0.27	0.91	0.49	1.51
$P > F$						
P linear	0.27	NS	0.10	NS	0.26	NS
P quadratic	NS	0.30	NS	NS	NS	0.22

† SE of the difference between means of two fertlizer rates at the same crop year or different crop years.

Table 5. Mean theroetical recoverable sugar (TRS), metric tons of cane ha^{-1} (TCH), and metric tons of sugar ha^{-1} (TSH) for three crop years and three P fertilizer rates at Location 3.

P level	TRS Plant cane	TRS First ratoon	TRS Second ratoon	TCH Plant cane	TCH First ratoon	TCH Second ratoon	TSH Plant cane	TSH First ratoon	TSH Second ratoon
kg ha^{-1}		g kg^{-1}				t ha^{-1}			
0	119.0	127.6	124.1	77.13	70.12	41.95	9.189	9.001	5.243
24	121.8	130.8	117.1	99.63	122.34	75.81	12.135	16.032	8.865
48	121.0	129.1	120.2	106.48	136.40	79.52	12.857	17.575	9.552
SE†		1.8			4.43			0.557	
Contrasts (*F* values)									
P linear	0.93	0.48	3.44	36.55	186.34	59.85	36.59	199.91	50.49
P quadratic	1.04	1.80	7.93	3.46	20.58	12.86	4.48	27.30	7.81
$P > F$									
P linear	NS	NS	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P quadratic	0.31	0.18	<0.01	0.06	<0.01	<0.01	0.04	<0.01	0.01

† SE of the difference between means of two fertlizer rates at the same crop year or different crop years.

test was a better predictor of responses to P fertilizer than the Pw test. At Location 1, a high Pw correctly predicted responses to P in the ratoon crops, but incorrectly predicted no response to P fertilizer in the plant-cane crop. At Location 2, the low Pw incorrectly predicted a response to P fertilizer. Conversely, a moderately low Pa at Location 1 correctly predicted positive responses to P in all three crop years. The moderately high Pa at Location 2 approached, but did not reach, the Pa range where supplemental P fertilizer is not recommended.

The soil at Location 3 was similar in pH and Pw to Location 2, however, its Pa was more similar to that of Location 1 (Table 2). The yield responses at Location 3 also were more similar to those of Location 1 than Location 2. From the plant-cane through the second-ratoon crops, TCH and TSH had positive linear responses to increasing rates of P fertilizer (Table 5). However, quadratic models also described the responses well in all three crops. These quadratic responses were due to large increases from P0 to P1 and then moderate increases from P1 to P2. Both the Pw and Pa results predicted the positive TCH and TSH responses to increasing rates of P fertilizer at Location 3.

A major difference between Locations 1 and 3 were the TRS responses. In two of the three crops at each location, P fertilizer level did not affect TRS. However, in the first-ratoon crop at Location 1, TRS responded positively to P increases from P0 to P1 (Table 3). At Location 3, the only TRS response to increasing P fertilizer rates was negative and this occurred in the second-ratoon crop (Table 5).

Glaz and Ulloa (1994) reported that more available P caused reductions in TRS on a soil similar in pH and Pw to that of Location 1 and higher in Pw than that of Location 3. Based on these previous results, we expected increasing P to cause decreases in TRS at Location 1 rather than at Location 3. Similarly, the Pa results did not explain the second-ratoon decrease in TRS. A possible explanation for these unexpected results is that the TRS response is genotype dependent, because a different group of eight genotypes was used at Locations 1 and 3.

Location 4 was similar in pH and Pw to Locations 2 and 3 and more similar in Pa to Location 3 than Location 2 (Table 2). Yield responses to P at Location 4 resembled those at Location 3 more than Location 2. The TRS at Location 4 declined linearly with increasing P rates in the plant-cane crop and showed a tendency to decline in the second-ratoon crop (Table 6). Quadratic fits best described the plant-cane and second-ratoon responses of TCH and TSH at Location 4. In the plant-cane crop, the TCH declined from P1 to P2. This decline, along with the linear TRS decline, resulted in a TSH

Table 6. Mean theoretical recoverable sugar (TRS), metric tons of cane ha^{-1} (TCH), and metric tons of sugar ha^{-1} (TSH) for three crop years and three P fertlizer rates at Location 4.

P level	TRS Plant cane	TRS First ratoon	TRS Second ratoon	TCH Plant cane	TCH First ratoon	TCH Second ratoon	TSH Plant cane	TSH First ratoon	TSH Second ratoon
kg ha^{-1}		g kg^{-1}				t ha^{-1}			
0	118.4	122.8	122.3	135.71	98.30	85.43	16.004	12.067	10.407
24	115.9	122.1	120.8	151.05	109.50	106.71	17.482	13.384	12.800
48	112.9	121.0	119.5	143.41	114.79	108.29	16.201	13.780	12.872
SE†		1.8			2.65			0.357	
Contrasts (*F* values)									
P linear	8.22	0.95	2.14	2.79	12.82	24.61	0.07	8.08	16.71
P quadratic	0.02	0.01	0.00	8.29	0.55	6.10	6.78	0.78	4.94
$P > F$									
P linear	<0.01	NS	0.15	0.10	<0.01	<0.01	NS	<0.01	<0.01
P quadratic	NS	NS	NS	<0.01	NS	0.01	0.01	NS	0.03

† SE of the difference between means of two fertlizer rates at the same crop year or different crop years.

yield at P2 similar to that at P0. Second-ratoon TCH and TSH responses were similar to those of plant cane except that yields remained similar at P1 and P2. In the first-ratoon crop at Location 4, TRS did not respond to P while TCH and TSH had moderate linear increases with increasing P fertilizer. Both the Pw and Pa tests were effective at predicting TCH and TSH increases from P0 to P1. However, the moderate Pa result was more indicative that positive yield responses would not continue from P1 to P2. Neither Pw nor Pa was effective at predicting the negative TRS responses.

Responses of TRS, TCH, and TSH were not consistent across crop years in some of the experiments. Andreis and McCray (1998) reported differences in response across crop years and advised that P should be applied in each crop year to ensure adequate yields. We cannot offer the same advice because some of our observed responses were negative. Farmers in the EAA could achieve more consistently high yields and reduce P discharge to the Everglades if further studies could predict under what conditions such negative responses occur. A second minor difference between our results and those of Andreis and McCray (1998) was that we observed some linear yield increases with P fertilizer rates up to 48 kg ha^{-1}. Andreis and McCray (1998) reported that there were no yield increases beyond P rates of 36 kg ha^{-1}. However, three of our experiments were conducted on soils with very low Pw values (Table 2).

Choosing P fertilizer rates in the EAA is a difficult process. As with other farm operations, an important consideration is to choose the level of P fertilizer that will result in the greatest profit margin. In addition, P is naturally a limiting nutrient in the Everglades. Therefore, EAA farmers are being requested to reduce the P content of their drainage water to the greatest extent practical. These farmers already pay a tax of \$62 ha^{-1}, which was based on previous P enrichment to the Everglades from the EAA. The possibility that new, more stringent P regulations will be adopted has persuaded EAA farmers to proactively seek more effective P reduction measures. One such measure would be to refine soil-test P calibrations.

Further adding to the complexity of the P issue for EAA farmers is that, as shown in this study, sugarcane yield responses to P are difficult to predict on the Histosols of the EAA. The yield correlations upon which P recommendations are based were reported in 1974 and 1979 (Gascho and Freeman, 1974; Gascho and Kidder, 1979). Diaz et al. (1993) explained that P mineralization rates in Histosols vary due to factors such as soil mineral content, cultivation, crop type, and moisture content. They estimated that under well-drained conditions, EAA Histosols mineralize 17 to 39 kg P ha^{-1} yr^{-1}. Excepting crop type, all the factors that affect soil P mineralization have changed considerably since 1979, when the P calibrations now in use were reported. Also, the genotypes used now by EAA growers are separated by several generations from the genotypes used before 1979, so perhaps crop type also has changed.

The present study offered some clarification, but also raised several questions. We found that testing the soil for Pa as described by Korndörfer et al. (1995) provided a better basis for P-fertilizer recommendations than the Pw test on organic soils with low Pw values. However, previous findings relating pH and P were not confirmed in this study. Further, there were some important, but not well defined, differences in TCH and TSH responses due to crop year (i.e., plant cane, first ratoon, or second ratoon). TRS responded positively, not significantly, or negatively to increasing P rates, and neither Pw nor Pa were useful in predicting these responses. Crop year may have affected this response, although as with TCH and TSH, this effect was not well defined. As explained in more detail in another report (unpublished data, 1999), one possible explanation for the unexpected TRS responses to P may be that they are more genotype-dependent than TCH responses.

There are substantial gaps regarding the response of sugarcane to P in the EAA. Due to ecological concerns, a critical research program for sugarcane farmers is to have these knowledge gaps filled. Evidence in the present study suggests that more detailed studies of soil pH and sugarcane genotype and their interactions with soil P are logical subject areas for further research. As previously explained by Diaz et al. (1993), more knowledge about factors affecting P mineralization rates probably also would improve P soil test calibrations for sugarcane yields.

REFERENCES

Andreis, H.J., and J.M. McCray. 1998. Phosphorus soil test calibration for sugarcane grown on Everglades Histosols. Commun. Soil Sci. Plant Anal. 29:741–754.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39–45.

Diaz, O.A., D.L. Anderson, and E.A. Hanlon. 1993. Phosphorus mineralization from Histosols of the Everglades agricultural area. Soil Sci. 156:178–185.

Gascho, G.J., and C.E. Freeman. 1974. Fertilizer recommendations for sugarcane. Res. Rep. EV-1974-18. Agric. Res. and Education Cent., Belle Glade, FL.

Gascho, G.J., and G. Kidder. 1979. Response to phosphorus and potassium and fertilizer recomendations for sugarcane in south Florida. Bull. 809. Florida Agric. Experiment Stn., Gainesville.

Glaz, B. 1998. Sugarcane variety census: Florida 1998. Sugar y Azucar 93(12):30–34, 36–37.

Glaz, B., and M.F. Ulloa. 1994. Sugarcane in monoculture or in rotation with sweet corn. Field Crops Res. 36:167–173.

Izuno, F.T., and L.T. Capone. 1995. Strategies for protecting Florida's Everglades: The best management practice approach. Water Sci. Technol. 31:123–131.

Korndörfer, G.H., D.L. Anderson, K.M. Portier, and E.A. Hanlon. 1995. Phosphorus soil test correlation to sugarcane grown on Histosols in the Everglades. Soil Sci. Soc. Am. J. 59:1655–1661.

Legendre, B.L. 1992. The core/press method for predicting the sugar yield from cane for use in cane payment. Sugar J. 54:2–7.

Lucas, R.E. 1982. Organic soils (Histosols): Formation, distribution, physical and chemical properties, and management for crop production. Res. Rep. 435. Michigan State Univ. Agric. Exp. Stn., East Lansing.

McCollum, S.H., V.W. Carlisle, and B.G. Volk. 1976. Historical and current classification of organic soils in the Florida Everglades. Soil Crop Sci. Soc. Fla. Proc. 35:173–177.

McCormick, P.V., S. Newman, S.L. Miao, K.R. Reddy, D. Gawlik, C. Fitz, T.D. Fontaine, and D. Marley. 1999. Ch. 3. Ecological needs of the Everglades. *In* Everglades Interim Report. South Florida Water Management District, West Palm Beach.

Meade, G.P. 1963. Spencer–Meade cane sugar handbook. John Wiley & Sons, New York.
Sanchez, C.A. 1990. Soil-testing fertilization recommendations for crop production on organic soils in Florida. Florida Agric. Exp. Stn. Bull. 876 (technical). Gainesville.
SAS Institute. 1985. SAS user's guide: Statistics. 5th ed. SAS Inst., Cary, NC.
Steel, R.G., and J.H. Torrie. 1980. Principles and procedures of statistics. McGraw–Hill, New York.
Stone, J.A., and D.E. Legg. 1992. Agriculture and the Everglades. J. Soil Water Conserv. 47:207–215.
Walker, W.W., Jr. 1996. Design basis for Everglades stormwater treatment areas. Paper no. 94139. Water Resour. Bull. 31:671–685.
Whalen, B.M., and P.J. Whalen. 1994. Nonpoint source regulatory program for the Everglades Agricultural Area. Paper FL94-101. Florida Section of the American Society of Agricultural Engineers, St. Joseph, MI.
Zelazny, L.W., and W.H. Carlisle. 1974. p. 63–78. Physical, chemical, elemental and oxygen-containing functional group analysis of selected Florida Histosols. *In* R.C. Dinauer (ed.) Histosols. Soil Sci. Soc. Amer. Special Publ. 6. SSSA, Madison, WI.

Grain Yield, Early Growth, and Nutrient Uptake of No-Till Soybean as Affected by Phosphorus and Potassium Placement

Rogerio Borges and Antonio P. Mallarino*

ABSTRACT

More information is needed about P and K placement for no-till soybean [*Glycine max* (L.) Merr.]. This study evaluated plant responses to P and K fertilization and placement in 10 long-term trials and 11 short-term trials in Iowa from 1994 to 1997. Treatments were various P and K rates broadcast, banded with the planter, and deep banded (at a 15- to 20-cm depth). Measurements were plant weight, P uptake, and K uptake at the V5 stage and grain yield. Phosphorus fertilization increased yield when soil-test P (STP) was less than 9 mg P kg^{-1} (Bray-P$_1$) at a 0- to 15-cm depth or 12 mg P kg^{-1} at a 0- to 7.5-cm depth. The P placement did not influence yield. The band K placements produced slightly higher yield than the broadcast placement. Responses to K were not related to soil-test K (STK) levels, which varied from 90 to 262 mg K kg^{-1} (ammonium acetate), or stratification. The P or K placement had little influence on early growth but influenced early P and K uptake. Banding with the planter was more effective than broadcasting for P uptake, and the two band placements were more effective for K uptake. Only the responses of K uptake and grain yield to banded K were correlated across sites. A shallow sampling depth will improve only slightly the prediction of response to P. The observed small no-till soybean yield response to banded K would seldom offset increased application costs in similar soils.

The area of no-till management in Iowa and many regions of the Midwest increased markedly during the late 1980s and early 1990s, but it has increased little since then (CTIC, 1997). Several reasons may explain this trend. One likely reason, although not necessarily the most important, is farmers' uncertainty about appropriate fertilization management for this system. No-till management usually leads to P and K stratification in soils. These nutrients accumulate in the soil surface as a result of minimal mixing of surface-applied fertilizers and crop residues with soil, limited vertical movement of P and K in most soils, and cycling of nutrients from deep soil layers to shallow layers through nutrient uptake by roots (Shear and Moschler, 1969; Griffith et al., 1977; Mackay et al., 1987; Karathanasis and Wells, 1990; Karlen et al., 1991). Phosphorus sorption and K retention by soil constituents is reduced in surface layers of no-till soils (Karathanasis and Wells, 1990; Guertal et al., 1991). A relative accumulation of P and K near the soil surface may decrease nutrient availability to plants in dry periods, however. High residue coverage in no-tilled soils usually increases soil moisture and reduces soil temperature at shallow depths, which can inhibit plant growth and nutrient availability early in the season but can increase root activity in drier periods (Barber, 1971; Al-Darby and Lowery, 1987; Fortin, 1993).

Several reports showed infrequent and small decreases in nutrient availability for crops due to nutrient stratification in high rainfall areas of the Corn Belt (Singh et al., 1966; Belcher and Ragland, 1972; Moschler and Martens, 1975). Other work (Eckert and Johnson, 1985; Yibirin et al., 1993; Lauson and Miller, 1997) showed, however, that shallow subsurface banding (5 cm beside and below the seeds) can significantly increase P and K fertilizer use efficiency compared with broadcast fertilization for no-till soybean and corn. This result coincides with long known effects of banding in minimizing retention of these nutrients by soil constituents and in increasing fertilizer use efficiency by crops.

Several studies (deMooy et al., 1973; Bharati et al., 1986; Rehm, 1986; Mallarino et al., 1991a and 1991b; Webb et al., 1992; Randall et al., 1997) showed that yield increases due to broadcast P or K fertilization of soybean in predominant Corn Belt soils are large and likely only in low-testing soils (less than approximately 16 to 20 mg P kg^{-1} by the Bray-P$_1$ extractant or 90 to 130 mg K kg^{-1} by the ammonium acetate extractant applied to dry soil samples). Published research comparing deep-banding with other placements for no-till soybean is scarce and conflicting. Hairston et al. (1990) showed that deep injection (15-cm depth) of P and K fertilizer gave yield responses superior to broadcast placement on no-till soybean in some Mississippi soils testing low in P and K. Other research (Hudak et al., 1989) showed no K placement effect on yield of no-till soybean grown in a silt loam soil in Ohio. Recently published Iowa research for no-till corn (Bordoli and

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*Corresponding author (apmallar@iastate.edu).

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Abbreviations: H, high; L, low; O, optimum; STK, soil-test K; STP, soil-test P; VH, very high; VL, very low.