SUGARCANE

Sugarcane Genotype Response to Phosphorus Fertilizer in the Everglades

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ABSTRACT

To protect the natural Everglades, federal legislation mandates a reduction of at least 25% in the P content of water discharged from the Everglades Agricultural Area (EAA). Work is needed to achieve these reductions while sustaining a productive agriculture in the EAA. The objective of this study was to identify differences in response to P fertilizer among 24 elite genotypes of sugarcane (interspecific hybrids of *Saccharum* spp.). Six yield characteristics were examined on Histosols at four field locations with no added P, an often used commercial rate of 24 kg P ha^{-1}, and 48 kg P ha^{-1} for the plant-cane, first-ratoon, and, in three locations, the second-ratoon crop. One group of eight genotypes was planted at two locations, and two other groups of eight genotypes each were planted at one of two other locations. Genotype × P fertilizer rate interactions were generally not significant. Of the eight genotypes tested at two locations, CL 61-620, CP 72-2086, and CP 85-1308 were cautiously ($P \leq 0.15$) identified at both locations as more sensitive than other genotypes to changes in P rates. Reduced P rates were recommended for CP 85-1308 on soils with low P. CL 73-239 and CP 81-1254 required more than commonly recommended P fertilizer on low-P soils. Identification of sugarcane genotypes that respond favorably to varying rates of P may evolve into a cost-effective strategy to reduce P content of EAA drainage water.

The Everglades Agricultural Area (EAA) is a 280 000-ha agricultural basin of Histosols in southern Florida. Sugarcane is grown on about 144 000 ha in the EAA (Glaz, 1998). Legislation mandates a reduction by at least 25% in the P content of water discharged from the EAA by the year 2002. This reduction will be compared with a 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 will be converted from agriculture to specially designed artificial wetlands to serve as storm water treatment areas (STAs) (Stone and Legg, 1992). The P concentration of water released from these STAs must be no more than 50 μg L^{-1} by the year 2002 (Walker, 1996). Walker (1996) further reported that 50 μg L^{-1} is much higher than the natural background levels of <10 μg P L^{-1} in the Everglades. Research has since documented changes in natural populations of Everglades flora and fauna at P concentrations >10 μg L^{-1} (McCormick et al., 1999).

Farmers in the EAA are using an extensive best management practice (BMP) program to meet P-reduction requirements (Izuno and Capone, 1995). Stone and Legg (1992) estimated that BMP implementation cost farmers \$153 ha^{-1} and annual operation and maintenance costs were about \$9 ha^{-1}. Two cost-effective BMPs would be productive sugarcane cultivars that either remove more P from a given soil or yield well at lower than currently recommended rates of P fertilizer. Glaz et al. (1997) reported on progress in developing the first of these two BMPs. They estimated that among 12 elite sugarcane genotypes, there was a range of 8.5 kg ha^{-1} in P removed from the soil and there was substantial variability for this trait among the 12 genotypes. In addition, two genotypes that represented high and low extremes for leaf P content had high cane yields. Kumar and Verna (1997) also reported differences in leaf P content of 11 genotypes in India. However, contrary to Glaz et al. (1997), Kumar and Verna (1997) reported high correlations between leaf P and sugar and cane yields.

Previous studies have evaluated genotype response to P for other crops. Nagata et al. (1992) concluded that six crisphead lettuce (*Latuca sativa* L.) cultivars responded similarly to several rates of P in the EAA. James et al. (1995) found a significant cultivar × P fertilizer interaction for five alfalfa (*Medicago sativa* L.) cultivars and three P rates and concluded that P-use efficiency in alfalfa could be improved. Mugwira and Haque (1993) reported a differential response to P in plant height in Ethiopia among *Sesbania* accessions, and concluded that *Sesbania* could be screened for tolerance to low P.

Sugarcane is by far the major crop in the EAA. If its genetic variability for water tolerance and P response is similar to that demonstrated for other characteristics, then research could help farmers use sugarcane to achieve lower P discharges (Glaz, 1995). Several other crops are grown in the EAA that require much higher rates of P than sugarcane (Sanchez, 1990). A common practice is to rotate such crops with sugarcane. This practice helps contain and reduce the residual P of the previous crop because of the low P requirement and flood tolerance of sugarcane. Due to its low P requirement, supplemental P fertilizer is not needed for sugar-

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Published in Agron. J. 92:887–894 (2000).

Abbreviations: BMP, best management practice; EAA, Everglades Agricultural Area; P, phosphorus; P_{24}, 24 kg P ha^{-1}; P_{48}, 48 kg P ha^{-1}; Pa, acetic acid–extractable soil P; P_{lin}, linear regression on P rate; P_{quad}, quadratic regression on P rate; P_{zero}, no P fertilizer applied; Pw, water extractable, labile soil P; STAs, storm water treatment areas; TCH, metric tons cane ha^{-1}; TRS, theoretical recoverable sugar; TSH, metric tons sugar ha^{-1}.

cane in this rotation. The relatively high water tolerance of sugarcane allows farmers to drain water from sugarcane fields more slowly than from most other crops in the EAA. Thus, following storms, farmers often pump out, at lower rates, less total water from sugarcane fields than from other fields. Such pumping practices help reduce P discharge (Izuno and Capone, 1995).

A problem with growing sugarcane in a field after heavy fertilization with P is that t cane ha^{-1} (TCH) may increase and theoretical recoverable sugar (TRS), measured as kg sucrose t^{-1} of cane, may decrease due to high residual soil P (Glaz and Ulloa, 1994). Even though t sugar ha^{-1} (TSH) may stay the same or increase moderately in these rotations, profits may decline due to the increased expenses associated with handling and processing the extra cane tonnage (Deren et al., 1995). Thus, identification of genotypes that yield well in soils with high P levels would be useful in maintaining the desirability of growing sugarcane after crops that require high P fertilizer rates.

The objective of this study was to identify differences in response to P fertilizer among 24 elite sugarcane genotypes. Genotypes that yield well with less than recommended rates of P would serve directly as BMPs to reduce P in discharge water. Contrarily, sugarcane genotypes that yield well with more than recommended soil P would help farmers maintain crop diversity and still contain P discharge.

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 each were tested at one of two other field locations. All four locations were in Palm Beach County, Florida. Location 1 was at the "20-Mile Bend Farm" of Sugar Farm Cooperative, Eastern 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 southernmost area where sugarcane is produced in Palm Beach County.

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

At Locations 1 to 3, soil samples were collected soon after planting from two of the eight plots in each replication that were not fertilized with P. At Location 4, soil samples were collected before planting from the 24-ha field in which the experiment was conducted. The samples were analyzed for pH (Sanchez, 1990), water-extractable P (Pw) (Sanchez, 1990), and acetic acid–extractable P (Pa) in the Soil Testing Laboratory of the University of Florida/Institute of Food and Agricultural Sciences, Everglades Research and Education Center, Belle Glade. The Pw procedure measures labile P and the Pa procedure measures labile and reserve P.

All plots were fertilized with Cu, Mn, Zn, and B at commonly used commercial rates in the EAA (Sanchez, 1990) 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 rows, 10.7 m long, with 1.5 m between rows. The experiments at Locations 1, 3, and 4 were conducted for 3 crop years, the plant-cane, first-ratoon, and second-ratoon crops. The experiment at Location 2 was conducted for 2 crop years, the plant-cane and first-ratoon crops.

Randomized complete-block designs with four replications were used for all experiments. Each experiment had two factors, P fertilizer rates and sugarcane genotypes. Fertilizer rates were: no P fertilizer (P_{zero}); 24 kg P ha^{-1} (P_{24}); and 48 kg P ha^{-1} (P_{48}). These fertilizer treatments were applied in each crop year of each experiment. Fertilizer-application dates for all experiments are shown in Table 1. These dates coincided with the dates fertilizers were applied in the commercial field in which experiments were planted.

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. We purposely chose commercial cultivars or promising clones in a sugarcane cultivar-selection program. These genotypes comprised up to 81% of Florida's sugarcane while the present study was conducted (Glaz, 1998).

The yield characteristic on which sugarcane is primarily judged is TSH. The two major components of TSH are TRS and TCH. The product of TRS and TCH divided by 1000 equals TSH. To measure TRS, 10-stalk samples were collected from all plots. Dates these samples were collected are listed in Table 1. To choose stalks for each sample, a starting point was selected randomly from one of the two middle rows of each plot, and from that starting point, the next 10 mature stalks were collected. Usually between one and three stools of

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

	Fertilizer application dates		
	Crop year		
Location	Plant cane	First ratoon	Second ratoon
1	Dec. 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 sample dates		
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 dates		
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

sugarcane were needed to obtain the 10 stalks. Since sugarcane grows in large stools of primary, secondary, tertiary, etc. stalks, this sampling procedure helps collect a representative mixture of stalks.

Theoretical recoverable sugar was calculated from the Brix and polarimeter reading of each sample using a previously described procedure (Legendre, 1992). As described by Meade (1963), 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 juice temperature. The polarimeter reading, as described by Meade (1963), is a value without units obtained from polarization of the sugar solution in a saccharimeter. Stalk number ha^{-1} was multiplied by stalk weight to calculate TCH. Stalk weight was measured from the same sample of 10 stalks that was used to calculate TRS. Dates when stalk counts were conducted are shown in Table 1.

Analyses of variance were calculated with MSTATC (Freed et al., 1991) using a randomized complete-block design for genotypes and P rates with crop years as a split plot on genotypes and P rates. Genotypes, P rates, and crop years were classified as fixed effects. The main-plot error mean square was used as the best estimate of pooled error to test significance of linear and quadratic responses to P rates and all interactions involving genotype and P rates. The error mean square was used as the best estimate of pooled error to test significance of genotype × P rate × crop year interactions. The experiment at Location 1 was conducted for 3 yr and the experiment at Location 2 was conducted for 2 yr. Therefore, even though the same group of genotypes was tested at these two locations, each location was analyzed separately.

Sixteen preplanned single degree of freedom comparisons were used to identify differences in genotype responses to P fertilizer rates at each location for each response variable. We tested the interaction of each genotype mean vs. the mean of the other seven genotypes in the same experiment × the linear (P_{lin}) and quadratic (P_{quad}) regressions on P rate. For example, to examine responses of CL 72-321 at Location 1, *F* values for two single degree of freedom comparisons were calculated for each response variable as described by Steel and Torrie (1980). One comparison was CL 72-321 vs. the mean of the other seven genotypes tested at Location 1 × the linear response to P (CL 72-321 vs. mean of others × P_{lin}). The second comparison was CL 72-321 vs. the mean of the other seven genotypes × the quadratic response to P (CL 72-321 vs. mean of others × P_{quad}). Significant *F* values were sought at $P \leq 0.10$. When comparisons at $P > 0.10$ are discussed, the actual probabilities are provided.

RESULTS AND DISCUSSION

Soil pH, Pw, and Pa values at each location are shown in Table 2. The relationships between these soil measurements and yields are reviewed by Glaz et al. (2000). Commercial P fertilizer rates of 24 kg ha^{-1} were determined according to Pw values for Locations 2 to 4 (Sanchez, 1990). The grower at Location 1 used the lower Pa value and the somewhat higher Pw value to also decide on a commercial P fertilizer rate of 24 kg ha^{-1}. Since this study was initiated, more growers have begun using Pa rather than Pw, or combining their use as was done at Location 1. Thus, both Pw and Pa results are included in Table 2.

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

At each of the four locations, the interaction *genotype × P rate × crop year* was not significant for any characteristic. Therefore, discussions of genotype × P interactions are based on combined data of all crop years in each experiment.

Locations 2 to 4 had particularly low Pw values and the Pw at Location 1 was low when compared with the population of EAA soils. Additionally, the Pa at Location 1 was the lowest among the four locations in this study. These four locations were carefully chosen based on these low soil P values. Due to this selection of locations, our results pertain only to similar soils. However, one of our interests was to identify genotypes that needed less than recommended rates of P fertilizer. If such genotypes yield well with less than the recommended P rate on organic soils in the EAA with low P, they may also yield well with less than the recommended P rate on organic soils with higher P; however, this is conjecture. We were also interested in identifying genotypes that yield well when following crop species for which high amounts of P fertilizer were applied. To approximate this response, we chose the rate of 48 kg P ha^{-1}. This was double the P rate applied commercially at each location. However, available soil P may be higher for sugarcane following some crops than for conditions encountered in our P_{48} plots.

Location 1 ("20-Mile Bend Farm" of Sugar Farm Cooperative, Eastern Division)

The overall genotype × P interactions were not significant for all characters except TRS (Table 3). The preplanned single degree of freedom comparisons identified two genotypes, CP 81-1254 and CP 85-1308, that responded to P rates differently than the mean of the other seven genotypes for some of the six dependent variables.

Compared with the mean of the other seven genotypes, the linear responses to P of CP 81-1254 were different for Brix, TRS, stalk weight, and TCH, and for TSH at $P = 0.12$ (Table 3). Yields of CP 81-1254 increased more with increasing P rates than the mean of the other seven genotypes for each of these characteristics (Table 4). This identified CP 81-1254 as a genotype that yielded well at higher than recommended P fertilizer rates.

The TCH and TSH of CP 85-1308 (Table 3) rose more sharply from P_{zero} to P_{24} than the means of the other genotypes and then declined moderately from P_{24} to P_{48} as the mean TCH and TSH of the other genotypes increased moderately (Table 4). These responses identified CP 85-1308 as worthy of further testing at P rates between P_{zero} and P_{24}. The purpose of this further testing

Table 3. Variance ratios (*F*) of Brix, theoretical recoverable sugar (TRS), stalk weight, stalk number, metric tons cane ha^{-1} (TCH), and metric tons sugar ha^{-1} (TSH) averaged across 3 crop years for 16 preplanned single degree of freedom comparisons at Location 1.

	Variance ratio					
Single df comparison‡	Brix	TRS	Stalk wt.	Stalk no.	TCH	TSH
321 vs. others × P_{lin}	0.73	0.05	0.00	0.09	0.08	0.16
321 vs. others × P_{quad}	0.97	1.34	0.36	0.94	0.06	0.18
620 vs. others × P_{lin}	2.06	0.17	0.75	0.00	0.05	0.09
620 vs. others × P_{quad}	0.00	0.00	2.11	0.03	0.70	0.44
1254 vs. others × P_{lin}	3.46†	7.32**	3.59†	0.98	2.74†	2.44
1254 vs. others × P_{quad}	0.25	0.50	0.18	0.11	0.00	0.00
1308 vs. others × P_{lin}	0.35	0.09	0.00	0.37	0.16	0.06
1308 vs. others × P_{quad}	0.92	0.23	0.74	1.49	2.70†	2.82†
1382 vs. others × P_{lin}	0.01	0.73	1.22	0.08	0.45	0.49
1382 vs. others × P_{quad}	0.08	0.25	0.39	0.19	0.00	0.00
1547 vs. others × P_{lin}	0.01	0.78	0.01	0.70	0.41	0.40
1547 vs. others × P_{quad}	0.34	2.40	0.26	0.00	0.34	0.02
1827 vs. others × P_{lin}	0.52	0.42	0.01	0.01	0.01	0.00
1827 vs. others × P_{quad}	0.59	0.41	0.01	0.02	0.05	0.15
2086 vs. others × P_{lin}	0.53	0.18	0.01	0.00	0.01	0.00
2086 vs. others × P_{quad}	2.34	0.10	0.06	2.24	1.95	1.56
Genotype × P	1.44	1.64†	1.06	0.79	1.06	0.96
Main-plot error§	0.76	57.19	0.17	1187.36	246.66	4.41

** Significant at 0.01 probability level.
† Significant at 0.10 probability level.
‡ Complete names of genotypes in single df comparisons are CL 72-321, CL 61-620, CP 81-1254, CP 85-1308, CP 85-1382, CP 73-1547, CP 80-1827, and CP 72-2086. P_{lin} is linear response to P rate and P_{quad} is quadratic response to P rate.
§ Main-plot error mean square with 69 df.

would be to determine if CP 85-1308 would reach maximum TCH and TSH yields at a rate less than P_{24}.

Location 2 (First Experiment Planted at Okeelanta Corp.)

There were no significant *F* values for overall genotype × P interactions at Location 2 (Table 5). Four of the eight genotypes—CL 61-620, CP 85-1308, CP 73-1547, and CP 72-2086—had significant preplanned single degree of freedom comparisons for some characteristics. Genotype CP 85-1308 also had significant preplanned single df comparisons at Location 1. Additionally, two of the other three genotypes—CL 61-620 and CP 72-2086—had nearly significant preplanned comparisons at Location 1. For CL 61-620, these preplanned comparisons were for Brix ($P = 0.15$) and stalk weight ($P = 0.15$) and for CP 72-2086, the comparisons were for Brix ($P = 0.13$) and stalk number ($P = 0.14$) (Table 3).

The linear TRS response to increased P rates for CL 61-620 differed relative to the mean of the other seven genotypes (Table 5). The TRS of CL 61-620 increased as P fertilizer rates increased, whereas the mean TRS of the other seven genotypes decreased moderately as P fertilizer increased, particularly from P_{zero} to P_{24} (Table 6). The quadratic response of stalk weight of CL 61-620 ($P = 0.13$) was also of interest at Location 2 (Table 5). The stalk weight of CL 61-620 was lowest at the recommended P rate (P_{24}), whereas the stalk weight of the mean of the other genotypes was similar at all three P rates (Table 6). Based on its linear increase in TRS and its similar TCH yields from P_{zero} through P_{48}, CL 61-620 was identified as a genotype that yielded well at higher than recommended P rates.

The linear response of CP 85-1308 to increasing rates of P for TRS differed from the mean response of the other genotypes (Table 5). Compared with that of the other genotypes, the TRS of CP 85-1308 declined more sharply with increasing P rates (Table 6). Thus, CP 85-1308 was identified as a genotype that yielded well at lower than recommended P rates. Based on results at Location 1, it was concluded that further testing at rates between P_{zero} and P_{24} was needed to determine if CP 85-1308 could be similarly categorized.

The mean Brix of the other seven genotypes declined moderately with increasing P levels compared with the

Table 4. Yields of Brix, theoretical recoverable sugar (TRS), stalk weight, stalk number, metric tons cane ha^{-1} (TCH), and metric tons sugar ha^{-1} (TSH) averaged across 3 crop years for two genotypes, the mean of eight genotypes, and three P rates at Location 1.

Cultivar	P fertilizer	Brix	TRS	Stalk wt.	Stalk no.†	TCH	TSH
	kg ha^{-1}	%	kg t^{-1}	kg	ha^{-1} × 10 000	t ha^{-1}	
CP 81-1254	0	19.2	109.7	0.90	4.65	46.56	5.56
CP 81-1254	24	19.9	119.4	1.20	6.23	76.35	9.49
CP 81-1254	48	19.9	121.1	1.29	6.92	88.48	10.87
CP 85-1308	0	20.2	124.8	0.95	5.52	54.28	6.71
CP 85-1308	24	20.0	129.1	1.20	7.39	87.60	11.20
CP 85-1308	48	20.3	127.0	1.16	6.93	79.95	10.11
Mean	0	20.3	124.2	1.02	5.01	53.64	6.72
Mean	24	20.3	126.4	1.19	6.48	77.24	9.80
Mean	48	20.1	125.3	1.22	6.75	82.43	10.38

† Numbers should be multiplied by 10 000 for the actual value.

Table 5. Variance ratios (*F*) of Brix, theoretical recoverable sugar (TRS), stalk weight, stalk number, metric tons cane ha^{-1} (TCH), and metric tons sugar ha^{-1} (TSH) averaged across 2 crop years for 16 preplanned single degree of freedom comparisons at Location 2.

Single df comparison‡	Variance ratio					
	Brix	TRS	Stalk wt.	Stalk no.	TCH	TSH
321 vs. others × P_{lin}	0.20	0.48	0.37	0.02	0.39	0.23
321 vs. others × P_{quad}	0.23	0.06	0.84	0.00	0.27	0.18
620 vs. others × P_{lin}	0.63	3.01†	1.93	1.23	0.05	0.03
620 vs. others × P_{quad}	0.10	0.02	2.32	1.06	0.00	0.00
1254 vs. others × P_{lin}	0.04	1.18	0.56	0.33	0.00	0.06
1254 vs. others × P_{quad}	0.17	0.31	0.31	0.70	0.14	0.11
1308 vs. others × P_{lin}	0.77	3.48†	0.01	0.10	0.08	0.53
1308 vs. others × P_{quad}	0.13	0.58	1.79	0.32	0.13	0.21
1382 vs. others × P_{lin}	0.00	0.00	0.21	0.14	0.37	0.40
1382 vs. others × P_{quad}	0.09	0.38	0.01	0.12	0.14	0.19
1547 vs. others × P_{lin}	3.46†	0.03	0.01	0.02	0.03	0.02
1547 vs. others × P_{quad}	0.01	0.20	0.21	0.30	0.65	0.88
1827 vs. others × P_{lin}	1.78	1.02	0.93	0.02	0.37	0.13
1827 vs. others × P_{quad}	0.09	0.00	0.68	0.15	0.00	0.01
2086 vs. others × P_{lin}	0.07	0.40	0.05	0.08	0.01	0.07
2086 vs. others × P_{quad}	2.36	1.70	3.40†	1.61	0.00	0.05
Genotype × P	1.10	1.40	1.48	0.68	0.29	0.34
Main-plot error§	0.38	24.22	0.07	992.73	182.21	3.01

† Significant at the 0.10 probability level.
‡ Complete names of genotypes in single df comparisons are CL 72-321, CL 61-620, CP 81-1254, CP 85-1308, CP 85-1382, CP 73-1547, CP 80-1827, and CP 72-2086. P_{lin} is linear response to P rate and P_{quad} is quadratic response to P rate.
§ Main-plot error mean square with 69 df.

moderate increase in Brix of CP 73-1547 (Tables 5 and 6). However, this did not translate into a significant single df genotype × P interaction for TRS. Thus, there are no immediate commercial uses for this mild sensitivity of CP 73-1547 to P. However, this response identified CP 73-1547 as a genotype that may be useful for developing genotypes that yield well at higher than recommended rates of P fertilizer.

The quadratic response of CP 72-2086 for stalk weight differed from that of the mean of the other seven genotypes (Table 5). However, the TCH response of CP 72-2086 was similar to that of the mean of the other seven genotypes (Tables 5 and 6). Like CL 61-620, CP 72-2086 had several nearly significant interactions at Locations 1 and 2. The quadratic Brix reactions of CP 72-2086 differed from those of the other seven genotypes at $P = 0.13$ at both Locations 1 and 2 (Tables 3 and 5). Similarly, the preplanned comparison for CP 72-2086 for stalk number was significant at $P = 0.14$ at Location 1 (Table 3). Due to these elevated probability levels, CP 72-2086 should be cautiously categorized as a genotype that responded to P rates differently than other genotypes at Locations 1 and 2. Due to its substantial commercial use in Florida (Glaz, 1998), CP 72-2086 is a likely candidate for further testing aimed at better identifying its response to P rates.

Location 3 (Second Experiment Planted at Okeelanta Corp.)

The *F* values for overall genotype × P interactions were significant for stalk weight and highly significant for stalk number, TCH, and TSH at Location 3 (Table 7). Genotypes CL 73-239, CP 85-1432, CP 85-1491, CP

Table 6. Yields of Brix, theoretical recoverable sugar (TRS), stalk weight, stalk number, metric tons cane ha^{-1} (TCH), and metric tons sugar ha^{-1} (TSH) averaged across 2 crop years for five genotypes, the mean of eight genotypes, and three P rates at Location 2.

Cultivar	P fertilizer	Brix	TRS	Stalk wt.	Stalk no.†	TCH	TSH
	kg ha^{-1}	%	kg t^{-1}	kg	ha^{-1} × 10 000	t ha^{-1}	
CL 61-620	0	21.1	129.1	1.03	7.17	72.33	9.31
CL 61-620	24	21.1	131.5	0.89	8.08	72.57	9.51
CL 61-620	48	21.0	133.5	0.94	8.03	73.99	9.90
CP 85-1308	0	19.4	124.8	1.13	7.69	85.38	10.63
CP 85-1308	24	18.9	119.3	1.06	7.93	82.82	9.92
CP 85-1308	48	18.7	118.2	1.11	7.70	86.62	10.24
CP 73-1547	0	19.9	126.2	1.21	6.71	81.58	10.31
CP 73-1547	24	20.0	127.0	1.25	7.00	88.05	11.21
CP 73-1547	48	20.2	125.8	1.22	6.82	83.87	10.54
CP 80-1827	0	20.5	131.9	1.25	6.78	83.87	11.07
CP 80-1827	24	20.2	129.8	1.36	6.57	88.10	11.45
CP 80-1827	48	19.7	127.9	1.34	6.88	92.53	11.84
CP 72-2086	0	20.5	132.6	1.16	6.80	78.53	10.43
CP 72-2086	24	19.8	129.5	1.29	6.28	80.37	10.46
CP 72-2086	48	20.3	133.6	1.16	7.17	82.97	11.09
Mean	0	20.7	129.5	1.15	6.94	79.04	10.23
Mean	24	20.4	128.8	1.16	6.98	80.33	10.34
Mean	48	20.3	128.5	1.17	7.13	82.66	10.62

† Numbers should be multiplied by 10 000 for the actual value.

Table 7. Variance ratios (F) of Brix, theoretical recoverable sugar (TRS), stalk weight, stalk number, metric tons cane ha^{-1} (TCH), and metric tons sugar ha^{-1} (TSH) averaged across 3 crop years for 16 preplanned single degree of freedom comparisons at Location 3.

Single df comparison‡	Variance ratio					
	Brix	TRS	Stalk wt.	Stalk no.	TCH	TSH
239 vs. others × P_{lin}	0.56	1.27	0.17	16.09**	8.31**	4.79*
239 vs. others × P_{quad}	0.21	0.00	0.01	3.01†	0.85	0.58
1133 vs. others × P_{lin}	0.01	0.01	0.00	0.28	0.07	0.15
1133 vs. others × P_{quad}	0.00	0.22	0.79	0.06	0.59	0.37
1198 vs. others × P_{lin}	0.05	0.69	0.62	0.06	0.26	0.76
1198 vs. others × P_{quad}	0.35	0.00	0.60	1.17	1.67	2.00
1210 vs. others × P_{lin}	0.24	0.31	0.33	0.51	0.75	1.06
1210 vs. others × P_{quad}	0.93	0.04	0.02	0.19	0.26	0.23
1432 vs. others × P_{lin}	0.45	2.13	3.31†	1.55	0.03	0.05
1432 vs. others × P_{quad}	0.01	0.09	0.05	0.02	0.02	0.00
1491 vs. others × P_{lin}	0.49	0.03	5.51*	2.83†	7.47**	6.13**
1491 vs. others × P_{quad}	0.23	0.62	3.31†	0.44	2.96†	2.15
1628 vs. others × P_{lin}	0.17	1.11	1.14	2.73†	0.06	0.20
1628 vs. others × P_{quad}	0.07	4.75*	2.88†	2.45	0.02	0.24
1743 vs. others × P_{lin}	0.03	0.01	0.02	7.15**	2.81†	2.10
1743 vs. others × P_{quad}	0.34	0.93	0.07	0.06	0.25	0.75
Genotype × P	0.46	1.36	2.03*	4.42**	2.89**	2.36**
Main-plot error a§	0.92	39.90	0.15	1352.15	379.31	6.21

†, *, ** Significant at the 0.10, 0.05 and 0.01 probability levels, respectively.

‡ Complete names of genotypes in single df comparisons are CL 73-239, CP 70-1133, CP 84-1198, CP 72-1210, CP 85-1432, CP 85-1491, CP 78-1628, and CP 80-1743. P_{lin} is linear response to P rate and P_{quad} is quadratic response to P rate.

§ Main-plot error mean square with 69 df.

78-1628, and CP 80-1743 had significant preplanned single degree of freedom comparisons (Table 7).

The positive linear responses of CL 73-239 to P for stalk number, TCH, and TSH were steeper than those of the means of the other genotypes (Tables 7 and 8). The means of the other genotypes were higher than those of CL 73-239 at P_{zero} and lower at P_{48} for all three characters. Based on these reactions, CL 73-239 was classified as a genotype that yielded poorly with low P fertilizer and yielded well at higher than recommended P rates.

The linear response of CP 85-1432 for stalk weight differed from that of the mean of the other seven genotypes (Table 7). However, the nature of the response of CP 85-1432 suggested that it responded well to the recommended P rate of P_{24} because its stalk weight rose sharply from P_{zero} to P_{24} (Table 8).

Genotype CP 85-1491 had higher stalk weight, stalk number, TCH, and TSH at P_{zero} than the mean of the other genotypes (Tables 7 and 8). Also, these characters showed less of a positive response to increasing P for CP 85-1491 than for the mean of the other genotypes (Tables 7 and 8). Although this identified CP 85-1491 as a genotype that may require less P fertilizer than

Table 8. Yields of Brix, theoretical recoverable sugar (TRS), stalk weight, stalk number, metric tons cane ha^{-1} (TCH), and metric tons sugar ha^{-1} (TSH) averaged across 3 crop years, for five genotypes, the mean of eight genotypes, and three P rates at Location 3 and for one genotype, the mean of eight genotypes, and three P rates at Location 4.

Cultivar	P fertilizer	Brix	TRS	Stalk wt.	Stalk no.†	TCH	TSH
	kg ha^{-1}	%	kg t^{-1}	kg	ha^{-1} × 10 000	t ha^{-1}	
CL 73-239	0	19.3	117.5	1.01	4.57	46.26	5.37
CL 73-239	24	19.7	115.6	1.19	8.75	104.48	12.11
CL 73-239	48	19.7	113.8	1.25	9.52	119.03	13.65
CP 85-1432	0	20.1	120.3	1.14	5.08	57.24	6.90
CP 85-1432	24	20.0	116.8	1.41	6.82	95.43	11.30
CP 85-1432	48	19.8	115.5	1.51	7.02	103.43	12.14
CP 85-1491	0	20.4	124.7	1.27	6.24	82.42	10.17
CP 85-1491	24	20.2	126.8	1.19	7.60	90.50	11.55
CP 85-1491	48	20.2	125.1	1.27	7.93	99.92	12.57
CP 78-1628	0	20.2	125.2	1.01	6.69	69.64	8.85
CP 78-1628	24	20.3	120.5	1.26	8.56	108.34	13.12
CP 78-1628	48	20.5	128.4	1.12	10.29	116.39	14.92
CP 80-1743	0	20.8	132.2	0.99	7.51	74.74	9.84
CP 80-1743	24	21.1	134.3	1.18	9.04	106.95	14.41
CP 80-1743	48	20.8	131.7	1.18	8.64	102.64	13.53
Mean (Loc. 3)	0	20.2	123.6	1.08	5.74	63.07	7.81
Mean (Loc. 3)	24	20.3	123.2	1.25	7.91	99.26	12.34
Mean (Loc. 3)	48	20.3	123.4	1.29	8.39	107.47	13.33
CP-90-1428	0	19.2	112.9	1.04	8.04	85.14	9.64
CP-90-1428	24	19.4	113.8	1.15	10.00	114.48	12.91
CP-90-1428	48	19.4	110.9	1.16	8.79	113.66	12.53
Mean (Loc. 4)	0	20.1	121.2	1.42	7.55	106.48	12.84
Mean (Loc. 4)	24	19.8	119.6	1.47	8.52	122.42	14.56
Mean (Loc. 4)	48	19.7	117.8	1.44	8.65	122.16	14.28

† Numbers should be multiplied by 10 000 for the actual value.

Table 9. Variance ratios (F) of Brix, theoretical recoverable sugar (TRS), stalk weight, stalk number, metric tons cane ha^{-1} (TCH), and metric tons sugar ha^{-1} (TSH) averaged across 3 crop years for 16 preplanned single degree of freedom comparisons at Location 4.

	Variance ratio					
Single df comparison‡	Brix	TRS	Stalk wt.	Stalk no.	TCH	TSH
1113 vs. others × P_{lin}	0.53	0.05	0.05	2.20	0.77	0.68
1113 vs. others × P_{quad}	0.16	0.06	0.00	0.02	0.00	0.02
1428 vs. others × P_{lin}	2.52	0.10	0.97	2.66†	1.54	1.11
1428 vs. others × P_{quad}	0.19	0.21	0.02	3.18†	0.61	0.49
1435 vs. others × P_{lin}	0.68	0.09	0.60	0.23	0.00	0.02
1435 vs. others × P_{quad}	0.32	0.07	0.08	0.12	0.22	0.28
1464 vs. others × P_{lin}	0.03	0.03	2.33	1.28	0.29	0.60
1464 vs. others × P_{quad}	0.08	0.45	0.01	0.03	0.00	0.02
1508 vs. others × P_{lin}	0.81	1.49	0.08	1.53	0.15	0.02
1508 vs. others × P_{quad}	0.47	0.55	0.01	1.27	0.27	0.63
1535 vs. others × P_{lin}	0.07	0.00	1.29	0.04	1.16	0.79
1535 vs. others × P_{quad}	0.03	2.11	0.01	0.00	0.00	0.29
1549 vs. others × P_{lin}	0.04	0.19	0.35	1.32	0.00	0.07
1549 vs. others × P_{quad}	0.24	0.03	0.23	0.46	0.47	0.43
1762 vs. others × P_{lin}	1.38	0.53	0.01	0.63	0.26	0.03
1762 vs. others × P_{quad}	0.12	0.09	0.59	0.00	0.74	0.53
Genotype × P	0.84	0.66	0.72	1.64†	0.71	0.66
Main-plot error§	0.49	76.03	0.20	726.85	419.03	7.38

† Significant at the 0.10 probability level.
‡ Complete names of genotypes in single df comparisons are CP 90-1113, CP 90-1428, CP 92-1435, CP 90-1464, CP 88-1508, CP 90-1535, CP 90-1549, and CP 88-1762. P_{lin} is linear response to P rate and P_{quad} is quadratic response to P rate.
§ Main-plot error mean square with 69 df.

others, the classification was not as desirable as for CP 85-1308 at Location 2 where CP 85-1308 did not have yield losses associated with decreased P fertilizer (Table 6). With CP 85-1491, there were losses with decreased P, but the losses were not as severe as for the means of the other genotypes. These responses identified CP 85-1491 as a desirable parent in a program designed to develop genotypes that yield well at low P rates.

The quadratic responses of CP 78-1628 for TRS and stalk weight as well as the linear response for stalk number differed from those for the means of the other genotypes (Table 7). The TRS of CP 78-1628 declined from P_{zero} to P_{24} but increased to its maximum from P_{24} to P_{48} (Tables 7 and 8). The TRS of the mean of the other genotypes was similar across the three P rates (Table 8). Since the stalk weight and stalk number responses of CP 78-1628 from P_{24} to P_{48} canceled their effects on TCH, the TRS response of CP 78-1628 identified it as a genotype that yielded well at both lower and higher than recommended P rates.

The linear responses to increasing P rates of CP 80-1743 for stalk number and TCH differed from those of the other genotypes (Table 7). The mean stalk number and TCH of the other genotypes increased quadratically as P increased, but for CP 80-1743 these traits increased from P_{zero} to P_{24} and then decreased from P_{24} to P_{48} (Tables 7 and 8). Thus, CP 80-1743 had its highest yields at P_{24}, the recommended P fertilizer rate. Further testing of CP 80-1743 between P_{zero} and P_{24} is warranted to determine if maximum yields would be reached at rates less than P_{24}. Based on its loss of yield at P_{48}, CP 80-1743 would not be recommended for planting after crop species that require high rates of P fertilizer.

Location 4 (Third Experiment Planted at Okeelanta Corp.)

The F values at Location 4 for overall genotype × P interactions for all characteristics except stalk number were <1, and the F value for stalk number was significant (Table 9). Of the eight genotypes at Location 4, only CP 90-1428 had significant preplanned single degree of freedom comparisons (Table 9). Like CP 80-1743 at Location 3, these interactions for stalk number identified CP 90-1428 as a genotype that yielded well at recommended rates of P and should not be used where P rates are high (Table 8). However, based on its lack of TRS, TCH, and TSH increases from P_{24} to P_{48}, CP 90-1428 should be tested at additional P rates between P_{zero} and P_{24} to determine if its yields would peak before P_{24}.

The mean TRS response of all eight genotypes identified them as genotypes with high TRS yields at lower than recommended P rates because the highest TRS occurred at P_{zero} (Table 8). Genotype CP 90-1428 should not be included in this group because its TRS is greater at P_{24} than at P_{zero} (Table 8). The five genotypes that most characterized high TRS yields at P_{zero} are CP 90-1113, CP 90-1435, CP 90-1464, CP 90-1549, and CP 88-1762 (data not shown). However, the mean TCH (Table 8) at Location 4 increased sufficiently from P_{zero} to P_{24} so that the highest profits for these genotypes occurred at P_{24} according to the formula of Deren et al. (1995). However, based on the mean TRS and TCH responses at Location 4, these five genotypes warranted further testing at intervals between P_{zero} and P_{24}.

SUMMARY

Twenty-four genotypes were tested at three P fertilizer rates. Genotypes CL 61-620, CL 73-239, CP 78-1628, and CP 81-1254 were the most promising genotypes identified for use when sugarcane follows a crop that requires high P fertilizer rates. Genotypes CL 73-239 and CP 81-1254 were further identified as particularly poor choices for reducing P content of discharge water from soils with low P. Conversely, CP 85-1308 (based on results at one of two locations), CP 80-1743, and CP 90-1428 should not be used with higher than recommended rates of P.

Genotypes CP 85-1308 and CP 78-1628 had high yields relative to the other genotypes with no added P fertilizer. A reduced rate of P for CP 85-1308 can be immediately recommended for soils with low Pw and moderate Pa values. Genotype CP 72-2086 should be tested further since it is a widely used cultivar and data suggested that its reactions to changes in P rates were sometimes different from the reactions of other genotypes. Candidates identified for follow-up testing with P fertilizer rates between 0 and 24 kg ha^{-1} were CP 80-1743, CP 85-1308, CP 85-1491, CP 88-1762, CP 90-1113, CP 90-1428, CP 90-1435, CP 90-1464, and CP 90-1549. Genotype CP 73-1547 may be useful for developing genotypes that yield well under high P conditions. Conversely, CP 85-1491 may be useful for developing genotypes that yield well at less than recommended P rates.

Variance ratios for single df comparisons testing genotype × P rate interactions were not significant for most traits of most genotypes. One group of eight genotypes was tested at two locations. Not one of these eight genotypes had significant *F* values for the same preplanned comparison at both locations. However, sufficient variability for response to P rates was identified in this study to suggest that breeding programs could improve desired characteristics. The purpose of such a breeding program would be to seek genotypes that yield well under certain P conditions to become one of several BMPs in a long-term effort to reduce P in EAA drainage water. The strategy could yield positive consequences similar to those expected from reducing P fertilizer by adhering to fertilizer recommendations from calibrated soil tests.

ACKNOWLEDGMENT

The authors acknowledge that several helpful comments originated from the anonymous review process.

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