Sugarcane Responses to Water-Table Depth and Periodic Flood

Barry Glaz* and Dolen R. Morris

ABSTRACT

Sugarcane (*Saccharum* spp.) is exposed to periodic floods and shallow water tables in Florida due to practices that reduce P discharge to the Everglades. This study examined the yields and juice quality of four sugarcane cultivars (CP 88-1762, CP 89-2143, CP 89-2376, and CP 96-1252) maintained at constant water-table depths near 20 (20CWT) and 45 cm (45CWT) and with periodic summer flooding. Prescribed lysimeters were flooded for the first 7 d of five, five, and four 21-d cycles in 2005 (plant-cane crop), 2006 (first-ratoon crop), and 2007 (second-ratoon crop), respectively. These treatments generally remained flooded during the next 7 d while they received no irrigation or drainage, and were drained to 20 (20FWT) or 45 cm (45FWT) for the final 7 d of each cycle. Water treatment affected CRS only in the plant-cane crop, where 45CWT had lower CRS than 20CWT, 20FWT, and 45FWT. Yields of cane and sucrose of CP 89-2143 were least affected by water treatments. Reductions in cane and sucrose yields at a 20 compared with a 45 cm water-table depth were common for the other three cultivars, but yields under the 20CWT vs. 20FWT or 45CWT vs. 45FWT treatments were generally similar. These results suggest that sugarcane roots function well in flood for up to 14 d, but do not grow well into saturated soil. This provides new options for sustaining high yields of sugarcane exposed to shallow water tables and floods; verification of root responses could enhance strategies to sustain yields while reducing P discharge.

Sugarcane is often exposed to frequent and heavy rains and therefore to shallow water tables and floods in many regions of the world. For example, in Louisiana (Carter, 1976), Australia (Roach and Mullins, 1985), Natal (Berning et al., 2000), and India (Vashist et al., 2003), studies have been conducted with flooded sugarcane. The Everglades Agricultural Area (EAA) is a 280,000 ha basin of Histosols that lie on limestone bedrock in the northern region of the historic Everglades in Florida. Sugarcane is grown on about 155,000 ha in the EAA (Glaz, 2008). Before construction of an extensive public and private system of canals through the northern Everglades, the EAA was usually flooded (Snyder and Davidson, 1994). Until the mid-1990s, farmers used the canal system to effectively manage desired water-table depths of 40 to 95 cm in sugarcane fields (Omary and Izuno, 1995).

The canal system is still the major structural means for controlling water tables in EAA sugarcane fields. However, it is now common for sugarcane to be exposed to shallow water tables and periodic floods. These shallow water tables occur most frequently during summers when heavy rainfalls are most likely. However, short-duration floods and subsequent shallow water tables occur throughout the year. Three major reasons for these changes since the mid-1990s are: water tables in the EAA rise about 10 cm for each cm of rainfall, loss of soil depth due to soil subsidence, and voluntary and regulated pumping restrictions to control P discharge from the EAA. The first two factors have been described previously in detail by Glaz et al. (2004). The primary reason that reductions of P discharge from the EAA were implemented was concern that increased P levels have contributed to large expanses of sawgrass (*Cladium jamaicense* Crantz) in the Everglades being replaced by cattails (*Typha* spp.) (Snyder and Davidson, 1994). Control of P discharge often results in shallow water tables on sugarcane fields because EAA farm managers control P movement to public canals primarily by reducing the quantity and rate of water discharged from their farms (Rice et al., 2002). A central focus of management practices that reduce P discharge is to allow water tables to drop primarily due to evapotranspiration and seepage and less from pumping to public canals (Daroub et al., 2002).

Long-duration flooding of sugarcane in the EAA would facilitate the successful attainment of low P discharge. However, in a field study, Gilbert et al. (2008) reported that although 3-mo duration floods on sugarcane in the EAA did not affect CRS, these floods resulted in substantial reductions of cane and sucrose yields. They suggested that strategies involving periodic flooding would be necessary for successful sugarcane production in the EAA.

In a lysimeter study with two unreleased sugarcane genotypes, Glaz et al. (2004) reported substantial yield losses of cane and sucrose attributable to periodic floods of 7-d duration and drainage to 50 cm compared with a continuous water-table depth of

---

B. Glaz and D.R. Morris (deceased), USDA-ARS Sugarcane Field Station, 12990 U.S. Highway 441 N, Canal Point, FL 33438. Received 2 July 2009. *Corresponding author (barry.glaz@ars.usda.gov).

Published in Agron. J. 102:372–380 (2010)

doi:10.2134/agronj2009.0262

Abbreviations: 20CWT, Constant 20-cm water-table depth; 20FWT, 20-cm water-table depth combined with repeated flood durations of 7–14 d; 45CWT, Constant 45-cm water-table depth; 45FWT, 45-cm water-table depth combined with repeated flood durations of 7–14 d; CRS, commercial recoverable sucrose; EAA, Everglades Agricultural Area.

50 cm for CP 95–1376, a genotype that did not form constitutive stalk aerenchyma. The importance of air cavities, such as aerenchyma for facilitating O_2 transport to flooded roots, has been described previously (Bendix et al., 1994; Grosse and Meyer, 1992; Yoshida and Eguchi, 1994). In species that are flood tolerant, aerenchyma formation is usually constitutive, meaning that it requires no external stimulus, such as flooding (Drew, 1997). During nonflood periods, as water-table depth increased from 16 to 50 cm, cane and sucrose yields of CP 95–1376 increased linearly (Glaz et al., 2004). Cane and sucrose yields of CP 95–1429, which formed constitutive stalk aerenchyma, were not affected by periodic floods or water-table depth. Glaz and Gilbert (2006) reported linear increases in cane and sucrose yields as water-table depth increased from 23 to 51 cm. However, they also found that eight 14-d cycles of 2 d of flooding and 12 d drainage at 44 cm resulted in moderate increases in cane and sucrose yields compared with a constant 51-cm water-table depth for sugarcane cultivars CP 72–2086 and CP 80–1827.

Responses of commercial sugarcane cultivars to flood durations between 2 d and 3 mo are still unknown. Also, it is necessary to establish the longest flood duration that sugarcane germplasm can withstand without yield loss. Currently we know that 2-d floods were beneficial for CP 72–2086 and CP 80–1827 (Glaz and Gilbert, 2006). Also, one unreleased genotype with constitutive stalk aerenchyma withstood 7-d floods repeated five, nine, and nine times in the plant-cane, first-ratoon, and second-ratoon crop cycles, respectively (Glaz et al., 2004). A final concern is that previous lysimeter studies used pumps to abruptly end floods. In commercial fields, one or more days are needed to drain floods to desired water-table depths. Also, it is best to allow floods to subside more by evapotranspiration and seepage and less by pumping to reduce P discharge. Thus, flood subsidence in commercial fields is more likely to occur over a period of days rather than hours. The purpose of this lysimeter study was to begin to address these concerns by examining the cane and sucrose yields and juice quality of four sugarcane cultivars maintained near 20 and 45 cm water-table depths with and without 7-d floods applied every 3 wk with subsequent drainage mimicking grower practices. Rather than abruptly draining the floods maintained for Days 1 to 7 of each 21-d cycle, there was no drainage of flooded lysimeters during Days 8 to 14. Thus, it was expected that floods would subside due to evapotranspiration and simulate how Florida sugarcane growers drain flooded fields.

MATERIALS AND METHODS

Sixteen custom-made fiberglass tanks, placed into the ground and filled with Pahokee muck soil (Euic, hyperthermic Lithic Haplosaprist) were equipped to function as lysimeters with pumps, solenoids, and floats to maintain desired water-table depths (Glaz et al., 2004). Lysimeters were 1.8 m wide by 3.0 m long with depths of 0.9 m to simulate the depth of many EAA soils (Shih et al., 1998). Stalk sections with one bud from four sugarcane cultivars were planted in trays on 7 Feb. 2005. Two rows of recently sprouted sugarcane plants from these trays were transplanted 15-cm apart within rows in the lysimeters on 23 Mar. 2005. Inter-row spacing was 1.5 m. Each cultivar was planted on half of the length of one row in each lysimeter. Cultivars were CP 88-1762 (Tai et al., 1997), CP 89-2143 (Glaz et al., 2000), CP 89-2376 (Glaz et al., 2005), and CP 96-1252 (Edmé et al., 2005). When this study was planted in 2005, CP 89-2143 and CP 88-1762 were the second and third most widely planted sugarcane cultivars in Florida, respectively (Glaz, 2006). CP 89-2376 was selected for this study because growers reported that it had better than normal emergence after exposure to flood durations of several days that occurred soon after planting. In addition, CP 96-1252 was selected for this study because preliminary information indicated that its stalks developed constitutive aerenchyma (unpublished data, 2003).

Soil samples drawn from the upper 15-cm were analyzed for pH (water) and water-extractable P and K (Sanchez, 1990). Based on soil-test recommendations (Sanchez, 1990), fertilizers were banded in the furrows with the planted sugarcane at rates of 39 and 268 kg ha^{-1} of P (triple superphosphate) and K (potash), respectively, and at rates of 0.9, 0.9, 0.9, 2.3, 0.9, and 0.9 kg ha^{-1} of B, Cu, Fe, Mn, Mo, and Zn, respectively. The source of the minor elements was a custom prepared fertilizer mix for a Florida sugarcane grower. The rates for the minor elements were not based on soil tests, but were instead standard preventive rates used on EAA muck soils (Sanchez, 1990). The same rates of P and K were applied on the rows in the first-ratoon crop in March 2006. In May 2007, P and K were applied at rates of 20 and 168 kg ha^{-1}. Also, in May 2007, Mg and S were applied in each lysimeter at rates of 8 and 90 kg ha^{-1}, respectively. In the two ratoon crops, all fertilizers were applied in 15-cm bands over the planted rows.

After transplanting, lysimeters were maintained at water-table depths of about 20 cm until 6 Apr. 2005 and then at about 45 cm until 6 July 2005, when the four water-table treatments were initiated. Two treatments, 20CWT and 45CWT, were continuous target water-table depths of 20 and 45 cm, respectively. These water-table depths were maintained until the second-ratoon harvest except that lysimeters with these treatments were flooded for 7 d in August of each crop cycle, as advised by Cherry (1984) to control white grubs (*Ligyrus subtropicus* Blatchley). The 45-cm depth was chosen because it was a desired commercial depth (Omary and Izuno, 1995), and the 20-cm depth was chosen because such depths were becoming increasingly common for extended durations in EAA commercial fields (Garcia et al., 2001). The two other water-table treatments, 20FWT and 45FWT, were constant target water-table depths of 20 and 45 cm, respectively, except that during portions of five, five, and four cycles during the plant-cane, first-ratoon, and second-ratoon crops, respectively, floods were applied. Each cycle duration was 21 d. Floods were applied during the first 7 d (Days 1–7) of each flood cycle to lysimeters that were assigned a flood treatment. Flooded lysimeters did not receive irrigation or drainage for the next 7 d (Days 8–14) of each cycle, as this was meant to be a gradual transition period from flood to drainage. The intent of this transition was to rely on evapotranspiration to imitate flood subsidence that would occur in commercial fields where growers strive to reduce pumping as a means of controlling P discharge. Pumping was used to maintain water tables at their target drained depths in lysimeters during the final 7 d (Days 15–21) of each cycle. Five flood-drain cycles occurred from 6 July 2005 to 19 Oct. 2005 in the plant-cane crop; from 7 June 2006 to 20 Sept. 2006 in the first-ratoon crop; and four cycles occurred from 9 July 2007 to 1 Oct. 2007 in the second-ratoon crop. Flooding cycles were initiated each year when the two rows of sugarcane covered the centers of the lysimeters.

Each year, all sugarcane stalks of all four cultivars were cut at the soil surface from each lysimeter. To simulate commercial harvesting, the top four internodes were removed and the remaining stalks were weighed to determine cane yield. All stalks were then milled to extract juice and juice quality was determined by estimating CRS, which was calculated using a previously described procedure (Legendre, 1992). To calculate CRS, the theoretical recoverable sucrose was multiplied by 0.86 to estimate commercial mill extraction. The value of 0.86 is a liquidation factor calculated from unpublished data. Legendre (1992) reported that liquidation factors in Louisiana ranged from 0.83 to 0.90. Sucrose yield, measured as kg m^{-2}, was calculated as:

$$\text{Sucrose yield} = (\text{CRS} \times \text{cane yield})/1000 \qquad [1]$$

The plant-cane crop was harvested on 9 Nov. 2005, the first-ratoon crop was harvested on 2 Dec. 2006, and the second-ratoon crop was harvested on 1 Nov. 2007.

Subjective ratings of relative size of stalk aerenchyma were assessed on the bottom, middle, and top internal portions of three stalks from all cultivars in each lysimeter at the plant-cane, first-ratoon, and second-ratoon harvests. The bottom portion was assessed at the second internode from the bottom, the middle from the approximate middle of the stalk, and the top was assessed at four nodes below the top visible dewlap. The ratings of aerenchyma formation ranged from 0 for none to 5 for an area that was equal to 50% of the stalk diameter.

A leaf porometer (Decagon Devices, Pullman, WA) was used to measure leaf stomatal conductance from the leaf at the top visible dewlap of two representative stalks of each cultivar in each lysimeter in both ratoon crops. Leaves were measured on their abaxial side, as far away from the tip of the leaf where the meter was able to close despite minimal protrusion of the midrib. Stomatal conductance was measured in the first-ratoon crop in 2006 on 21 and 28 June, and 5, 18, and 26 July; and in the second-ratoon crop in 2007 on 1, 7, and 22 February, and 18 September.

A Minolta SPAD-502 chlorophyll meter (Spectrum Technologies, Plainfield, IL) was used to obtain preliminary estimates of the effect of treatments on relative leaf chlorophyll content. Two measurements of relative leaf chlorophyll content were made from a representative stalk of each cultivar in each lysimeter, one on the leaf at the top visible dewlap and another at the next leaf below the top visible dewlap. Leaves were measured on their abaxial side away from the midrib about 3 cm from the tip of the leaf. Leaf chlorophyll content was measured in the plant-cane crop on 2 Sept. 2005 and in the second-ratoon crop in 2007 on 30 January, and 15, 21, and 28 February.

Four replications of water-table treatments were arranged as main plots (lysimeters) in a randomized complete block design. Cultivars were arranged as split plots (half rows) in lysimeters. Statistical analyses were performed using the MIXED procedure of SAS (SAS Institute, 2003). Data were analyzed for each crop-growth cycle separately and analyses were also conducted with the combined data of the plant-cane, first-ratoon, and second-ratoon crops treating crop-growth cycles as repeated measures. Based on procedures described by Tao et al. (2002), the ante-dependence model was used to describe repeated measures covariance for CRS. The heterogeneous compound symmetry model was used to describe repeated measures covariance for cane and sucrose yields. Water treatment, cultivar, and crop-growth cycle were regarded as fixed effects, whereas block and interactions with block were regarded as random effects. Significant fixed effects were further analyzed by separating least square means with the DIFF option in SAS. Differences were identified as significant at $P \le 0.05$ and as highly significant at $P \le 0.01$.

Analyses of relative leaf chlorophyll content and stomatal conductance were first conducted separately for each crop cycle treating day of measurement as repeated measures. Analyses of relative leaf chlorophyll content were conducted on the mean of the two leaves sampled per experimental unit, and means were used for stomatal conductance on days when more than one measurement was taken per experimental unit. Based on procedures described by Tao et al. (2002), compound symmetry was used to describe repeated measures covariance for both stomatal conductance analyses. There was only one measurement date for relative leaf chlorophyll content in the plant-cane crop. In the first-ratoon crop, the heterogeneous compound symmetry model was used to describe repeated measures covariance for relative leaf chlorophyll content. There were no significant interactions with measurement date for any treatment in the repeated analyses for relative leaf chlorophyll content or stomatal conductance. Therefore, analyses of variance that included effects of crop cycle were conducted using the means of all measurement days within crop cycles for relative leaf chlorophyll content and stomatal conductance.

RESULTS AND DISCUSSION

The drained water-tables were generally close to their target depths of 20 or 45 cm (Table 1). In the first-ratoon crop, the actual depth was 2.4 cm lower than the 20-cm target depth; this was the greatest absolute-value difference from the 20-cm target depth. Excluding the 35.6-cm drained water-table depth of the 45FWT treatment in the plant-cane crop, the other five crop-cycle depths with targets of 45 cm had a mean difference

Table 1. Target and measured water-table depths in the plant-cane (2005), first-ratoon (2006), and second-ratoon (2007) crop cycles.

Target depth†	Plant cane		First ratoon		Second ratoon		Combined crops	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
	cm							
20CWT	–22.2	0.90	–17.8	0.55	–19.6	0.56	–19.6	0.42
45CWT	–41.5	1.06	–48.5	0.57	–49.4	0.54	–47.2	0.43
20FWT								
Drain	–20.7	0.86	–17.6	0.94	–20.5	0.84	–18.9	0.53
Flood	2.2	0.83	3.8	1.07	0.4	0.68	2.0	0.57
NID	3.6	2.45	4.9	1.01	–5.2	1.71	0.8	1.03
45FWT								
Drain	–35.6	1.59	–46.3	1.03	–50.2	0.60	–45.5	0.63
Flood	3.1	1.17	5.5	1.02	1.9	0.51	3.4	0.68
NID	3.0	3.09	2.2	1.73	–2.2	1.91	0.6	1.75

† Target depths are continuous 20 (20CWT) and 45 (45CWT) cm, and 20 (20FWT) or 45 (45FWT) cm with periodic flooding. The 20FWT and 45FWT treatments had five 1-wk floods in the plant-cane and first-ratoon crops and four 1-wk floods in the second-ratoon crop. Each flood was followed by 1 wk of no irrigation or drainage (NID), after which water-table depths were returned to 20 or 45 cm for the 20FWT or 45FWT treatments, respectively. Negative water-table depths were below the soil surface and positive values were above the soil surface.

of 3.5 cm. The 1-wk floods averaged 2.0 and 3.4 cm above the soil surface for the 20FWT and 45FWT treatments, respectively. The mean water-table depths during the 1-wk period of no irrigation or drainage that followed each flood in the 20FWT and 45FWT treatments generally did not differ substantially from the water-table depths during flood periods. During some of these periods of no irrigation or drainage that followed 1-wk prescribed floods, rainfall was apparently higher than evapotranspiration, which resulted in higher water tables above the soil surface than during the previous week. Variability of water-table depth generally increased substantially during the period of no irrigation or drainage compared with the applied flood during the previous week. A probable explanation for this increased variability is that water tables were not controlled by water input and drainage during this period.

Table 2. Probabilities of *F* values of fixed effects for commercial recoverable sucrose (CRS), cane yield, sucrose yield, aerenchyma, stomatal conductance (SC), and relative leaf chlorophyll content (Chl) of four sugarcane cultivars exposed to four water-table treatments in the plant-cane, first-ratoon, and second-ratoon crops.

	Combined crops							
	Yields			Aerenchyma†				
Fixed effect	CRS	Cane	Sucrose	Bottom	Middle	Top	SC	Chl
Water (W)	0.087	<0.001	<0.001	<0.001	0.027	0.178	0.822	<0.001
Cultivar (C)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
W × C	0.229	0.002	0.006	0.377	0.004	0.659	0.996	0.705
Crop	<0.001	<0.001	<0.001	<0.001	<0.001	0.780	0.001	<0.001
Crop × W	<0.001	<0.001	<0.001	<0.001	0.055	0.861	0.468	<0.001
Crop × C	0.061	<0.001	<0.001	0.001	<0.001	0.713	0.545	0.204
Crop × W × C	0.870	0.027	0.039	0.633	0.218	0.998	0.991	0.547

Fixed effect	Plant-cane crop (2005)	First-ratoon crop (2006)	Second-ratoon crop (2007)
Water (W)			
Cane	<0.001	<0.001	0.010
Sucrose	<0.001	<0.001	0.031
Cultivar (C)			
Cane	<0.001	<0.001	<0.001
Sucrose	<0.001	<0.001	<0.001
W × C			
Cane	0.049	<0.001	0.006
Sucrose	0.104	<0.001	0.015

† Aerenchyma measurements were from bottom, middle, and top stalk sections.

Commercial Recoverable Sucrose

The interaction of crop cycle × water treatment was highly significant for CRS (Table 2). In the plant-cane crop, all three treatments with a shallow water-table depth or periodic flood (20CWT, 20FWT, and 45FWT) had higher CRS than the water-table depth continuously maintained at 45 cm (Table 3). There were no differences in CRS due to water-management in either ratoon crop. Thus, in only the plant-cane crop did the shallow water tables and floods benefit CRS.

Inconsistent effects of shallow-water-table depths on CRS have been reported previously. Glaz and Gilbert (2006) reported that as nonflooded water tables became increasingly shallow, CRS increased in the plant-cane and first-ratoon crops but decreased in the second-ratoon crop. Glaz (2007) reported that increasing durations of flood imposed about 6 wk before harvest, from 0 to 20 d resulted in a linear reduction of CRS from about 135.0 to 132.5 g kg^{-1} in the plant-cane crop, but did not affect CRS in the first-ratoon crop. These inconsistent effects on CRS of shallow water tables suggest that further research may identify more precise applications of shallow water tables or flood durations of < 20 d that improve CRS.

Cane Yield

All fixed effects and their interactions for cane yield in the combined crop analysis and each individual crop analysis were significant (Table 2). In all three crop cycles, CP 89-2376 had its highest cane yields under the 45CWT and 45FWT treatments and its lowest cane yields under the 20CWT and 20FWT treatments (Table 4). Responses of CP 88-1762 cane yields to water-table treatments were similar to those of CP 89-2376 except that in the plant-cane crop, cane yields of CP 88-1762 in the 45FWT and 20CWT treatments did not differ significantly.

In the plant-cane crop, CP 89-2143 had its lowest cane yield under the 20CWT treatment; otherwise, water-table treatment did not affect cane yields of CP 89-2143 in the plant-cane and the first-ratoon crops (Table 4). In the plant-cane crop, CP 89-2143 had higher cane yields in the 20FWT than in the 20CWT water treatment. Otherwise, CP 89-2143 cane yields did not differ between the 20CWT and 20FWT treatments. In the second-ratoon crop, CP 89-2143 had its highest cane yields under the 45FWT treatment.

CP 96-1252 had its highest plant-cane crop cane yield under the 45CWT treatment (Table 4). Adding periodic flooding to a target 45-cm water-table depth (45FWT) reduced cane yield in the plant-cane crop for CP 96-1252. Cane yields of CP 96-1252 in the 20CWT and 45FWT treatments did not differ significantly, but adding periodic flooding to the 20-cm water table (20FWT) resulted in lower CP 96-1252 cane yields

Table 3. Commercial recoverable sucrose of four water- table treatments in the plant-cane, first-ratoon, and second-ratoon crop cycles.

	Crop cycle		
Water†	Plant cane	First ratoon	Second ratoon
		g kg^{-1}	
20CWT	123.3 a‡	127.7 a	104.7 a
45CWT	111.1 b	127.9 a	104.0 a
20FWT	124.9 a	124.9 a	102.8 a
45FWT	121.5 a	126.5 a	104.3 a
Mean§	120.2 b	126.8 a	104.0 c

† Target water-table depths are continuous 20 (20CWT) or 45 (45CWT) cm, and 20 (20FWT) or 45 (45FWT) cm with periodic flooding. The 20FWT and 45FWT treatments had five 1-wk floods in the plant-cane crop.

‡ Least square means of water-table treatments in the same column and of crop means in the same row followed by the same letter are not significantly different (P = 0.05) based on the DIFF option in SAS.

§ SEM for crop and crop × water interaction were 1.0 and 3.9 g kg^{-1}, respectively.

compared with its yields under 45FWT. In the two ratoon crops, as for CP 88-1762 and CP 89-2376, the 45CWT and 45FWT treatments resulted in similarly high cane yields for CP 96-1252, while the 20-cm water-table depth with and without periodic flooding resulted in lower cane yields than 45CWT and 45FWT. In the first-ratoon crop, 20FWT resulted in lower cane yield for CP 96-1252 than 20CWT. However, the cane yield of CP 96-1252 with 20CWT was higher than the 20FWT or 20CWT cane yield of any other cultivar ($P \leq 0.004$). These were the only treatment differences among cultivars within water treatments for cane yield.

Sucrose Yield

Cultivar, water treatment, and crop cycle and their interactions were all significant for sucrose yield in the combined crop analysis (Table 2). Similarly, cultivar, water treatment, and their interaction were highly significant in each crop-cycle analysis except that in the plant-cane crop, the water treatment × cultivar interaction was not significant and in the second-ratoon crop, water treatment was significant at $P = 0.031$. The 45CWT and 45FWT had similar sucrose yields in the plant-cane crop for all cultivars, and the mean 45CWT and 45FWT sucrose yields were significantly higher than the similar sucrose yields at 20CWT and 20FWT (Table 5). Also, in the plant-cane crop, CP 96-1252 had the highest overall sucrose yield among cultivars ($P = 0.016$), and the sucrose yield of CP 89-2376 was higher than that of CP 89-2143 ($P = 0.002$).

In the ratoon crops, CP 89-2376 and CP 96-1252 had high sucrose yields with the 45-cm water-table treatments, but reduced sucrose yields with the 20-cm water-table treatments (Table 5). In each ratoon crop cycle, sucrose yields of CP 89-2376 and CP 96-1252 exposed to the 45CWT and 45FWT treatments did not differ. Also, the sucrose yields at 20CWT did not differ from those at 20FWT for CP 89-2376, but CP 96-1252 had higher sucrose yields at 20CWT than 20FWT in the first-ratoon crop.

As with CP 89-2376 and CP 96-1252, sucrose yield of CP 88-1762 was also generally reduced by the shallow water table in the ratoon crops (Table 5). However, at least one 45-cm treatment and one 20-cm treatment with CP 88-1762 had similar sucrose yields in each crop cycle. In the first-ratoon crop, water treatment did not affect sucrose yields of CP 89-2143. In the second-ratoon crop, all water treatments affected CP 89-2143 similarly except that the 45FWT treatment resulted in higher sucrose yield than the other three treatments.

There were also important sucrose yield differences among cultivars within water treatments. These differences indicated that CP 96-1252 sometimes had superior sucrose yields under the 20CWT and 20FWT (Table 5). Although CP 96-1252 sucrose yields were substantially reduced by the shallow water table with

Table 4. Cane yields of four sugarcane cultivars exposed to four water-table treatments in the plant-cane, first-ratoon, and second-ratoon crops.

	Cultivar				
Water†	CP 88-1762	CP 89-2143	CP 89-2376	CP 96-1252	Mean
	kg m^{-2}				
	Plant-cane crop				
20CWT	11.56 bc‡	7.37 b	10.37 b	12.56 bc	10.46 c
45CWT	15.73 a	11.28 a	16.23 a	19.89 a	15.79 a
20FWT	8.07 c	10.88 a	11.00 b	11.83 c	10.44 c
45FWT	13.15 b	11.32 a	15.39 a	15.72 b	13.89 b
Mean	12.13	10.21	13.24	15.00	12.65
SEM		1.62			0.81
	First-ratoon crop				
20CWT	10.75 b	7.09 a	13.32 b	19.50 b	12.66 b
45CWT	21.20 a	9.37 a	29.54 a	32.76 a	23.22 a
20FWT	8.58 b	9.85 a	11.59 b	13.82 c	10.96 b
45FWT	19.82 a	11.07 a	31.99 a	31.47 a	23.59 a
Mean	15.09	9.34	21.61	24.39	17.60
SEM		2.40			1.33
	Second-ratoon crop				
20CWT	16.37 b	11.42 b	19.54 b	25.84 b	18.29 b
45CWT	29.97 a	14.15 b	36.76 a	39.75 a	30.15 a
20FWT	17.74 b	14.54 b	21.56 b	25.48 b	19.82 b
45FWT	32.10 a	30.07 a	40.33 a	37.29 a	34.95 a
Mean	24.04	17.54	29.55	32.09	25.81
SEM		4.57			4.77

† Target water-table depths are continuous 20 (20CWT) or 45 (45CWT) cm, and 20 (20FWT) or 45 (45FWT) cm with periodic flooding. The 20FWT and 45FWT treatments had five 1-wk floods in the plant-cane and first-ratoon crops and four 1-wk floods in the second-ratoon crop.

‡ Least square means in the same column and crop cycle followed by the same letter are not significantly different ($P = 0.05$) based on the DIFF option in SAS.

Table 5. Sucrose yields of four sugarcane cultivars exposed to four water-table treatments in the plant-cane, first-ratoon, and second-ratoon crops.

	Cultivar				
Water†	CP 88-1762	CP 89-2143	CP 89-2376	CP 96-1252	Mean
	kg m^{-2}				
	Plant-cane crop‡				
20CWT	1.41	0.91	1.28	1.61	1.30 b§
45CWT	1.63	1.33	1.78	2.27	1.75 a
20FWT	0.99	1.39	1.39	1.54	1.33 b
45FWT	1.57	1.37	1.90	1.96	1.70 a
Mean	1.39	1.25	1.59	1.84	1.52
SEM		0.21			0.10
	First-ratoon crop				
20CWT	1.34 bc	0.89 a	1.71 b	2.60 b	1.63 b
45CWT	2.64 a	1.21 a	3.84 a	4.31 a	2.99 a
20FWT	1.06 c	1.24 a	1.46 b	1.82 c	1.39 b
45FWT	2.47 ab	1.43 a	4.06 a	4.10 a	3.02 a
Mean	1.88	1.20	2.76	3.20	2.26
SEM		0.34			0.16
	Second-ratoon crop				
20CWT	1.78 c	1.21 b	1.97 b	2.81 b	1.94 b
45CWT	3.08 ab	1.50 b	3.82 a	4.18 a	3.15 a
20FWT	1.85 bc	1.47 b	2.16 b	2.75 b	2.06 b
45FWT	3.43 a	3.18 a	4.10 a	3.97 ab	3.67 a
Mean	2.53	1.84	3.02	3.43	2.71
SEM		0.61			0.50

† Target water-table depths are continuous 20 (20CWT) or 45 (45CWT) cm, and 20 (20FWT) or 45 (45FWT) cm with periodic flooding. The 20FWT and 45FWT treatments had five 1-wk floods in the plant-cane and first-ratoon crops and four 1-wk floods in the second-ratoon crop.

‡ In the plant-cane crop, the water × cultivar interaction was not significant and the means were not separated.

§ Least square means in the same column and crop cycle followed by the same letter are not significantly different ($P = 0.05$) based on the DIFF option in SAS.

or without flooding, its first-ratoon yield at 20CWT was significantly higher than that of each other cultivar exposed to the 20CWT treatment in the first-ratoon crop ($P \leq 0.010$) and significantly higher than the 20CWT sucrose yield of CP 89-2143 in the second-ratoon crop ($P \leq 0.010$). Also, the sucrose yield of CP 96-1252 exposed to 20FWT was significantly higher than the 20FWT sucrose yield of CP 88-1762 in the first-ratoon crop cycle ($P = 0.026$) and higher than the 20FWT sucrose yield of CP 89-2143 in the second-ratoon crop ($P = 0.001$).

Previous research showed that cane and sucrose yields of a sugarcane genotype with constitutive stalk aerenchyma were not reduced by flood durations of 7 d when applied periodically during the summer and drained to depths of 16, 33, or 50 cm (Glaz et al., 2004). Further research showed that flood durations of 2 d applied periodically to two sugarcane cultivars during the summer resulted in moderate cane and sucrose yield improvements in the plant-cane and first-ratoon crops (Glaz and Gilbert, 2006). However, in commercial sugarcane fields in Florida, drainage is usually not accomplished quickly because the most efficient way to reduce P discharge is to allow water-tables to subside more by evapotranspiration and seepage than by pumping and draining (Daroub et al., 2002). One of the goals of this research was to test the effect on yields of flooding periodically for 7 d and allowing each flood to subside for the next 7 d by evapotranspiration rather than by pumping. However, rainfall was generally sufficient such that these evapotranspiration periods resulted in extending flood durations from 7 to 14 d (Table 1).

Three of the four cultivars generally had reduced cane and sucrose yields at 20 compared with 45-cm water-table depths (Tables 4 and 5). Cane and sucrose yields of CP 89-2143 were often not affected by water-table depth. These lysimeter results suggest that continuously shallow water-table depths (20 cm) reduce commercial cane and sucrose yields compared with moderate water-table depths (45 cm). This conclusion is in agreement with Glaz and Gilbert (2006).

An important finding of this study was that the four sugarcane cultivars, for a given water-table depth, were generally tolerant to repeated flood durations of up to 14 d in repeated crop cycles. Comparing the 45CWT and 45FWT treatments for each cultivar in each of the three crop cycles resulted in a total of 12 comparisons for cane yield and sucrose yield (Tables 4 and 5). Ten of 12 45CWT and 45FWT cane yield comparisons did not differ significantly. Of the two significant differences, one resulted in higher yields due to periodic flooding (CP 89-2143) and one in higher yields due to a continuous water-table depth of 45 cm (CP 96-1252). Eleven of 12 comparisons were not significant for sucrose yield. The significant comparison indicated that the CP 89-2143 sucrose yield was higher with than without periodic flooding in the second-ratoon crop.

Periodic flooding combined with drainage to a target depth of 20 cm generally did not affect cane and sucrose yields compared with a continuous 20-cm water-table depth. One exception was that periodic flooding improved cane yields of CP 89-2143 in the plant-cane crop compared with a constant water-table depth of 20 cm (Table 4). Conversely, first-ratoon cane and sucrose yields for CP 96-1252 were higher with the 20CWT than with the 20FWT treatment.

This study was characterized by consistent reductions in cane and sucrose yields in the plant-cane, first-ratoon, and second-ratoon crops for three of four sugarcane cultivars growing at a water-table depth of 20 cm with or without periodic flooding compared with a water-table depth of 45 cm with or without periodic flooding (Tables 4 and 5). However, cane and sucrose yields were not generally affected by five, five, and four cycles of periodic flooding for up to 14 d in the plant-cane, first-ratoon, and second-ratoon crops, respectively. Also, water-table treatment did not affect CRS except that in the plant-cane crop, periodic flooding or shallow water-table depth resulted in higher CRS than a constant water-table depth of 45 cm. These results suggest that commercial sugarcane cultivars can withstand up to five cycles of flooding with 14-d durations if they are drained to 45 cm. This substantially extends the utility of the finding of Glaz and Gilbert (2006) that periodic floods with 2-d durations resulted in moderate yield increases. With the knowledge that flood durations of up to 14 d will generally not reduce cane and sucrose yields, and may increase CRS, sugarcane growers in Florida will have increased flexibility in reducing P discharge to the Everglades without reducing profits.

Yield responses in this study suggest a new mechanism, in addition to constitutive stalk aerenchyma, that helps sugarcane tolerate periodic flooding. Cane and sucrose yields of three of the four cultivars were consistently reduced more by a water-table depth of 20 cm than by periodic flooding. A possible physiological explanation for this unexpected result is that sugarcane roots can function equally well under drainage and flood, perhaps due to air supplied through stalk and root aerenchyma, for up to 14 d. However, although they may function well for up to 14 d once in water, perhaps sugarcane roots will not grow well into soil that is saturated. This would explain why a constant 20-cm water-table depth was more detrimental to sugarcane yields than repeated 21-d cycles that included 14-d of flooding. Further research is warranted to elucidate this hypothesis. If the hypothesis adequately explains sugarcane root responses to shallow water tables, this knowledge would be valuable for Florida sugarcane growers in managing water tables to meet P reduction goals while sustaining yields. Internationally, for sugarcane that is often exposed to flood and shallow water tables, this hypothesis would explain inconsistent yield responses to shallow water tables and floods and facilitate water-management options to sustain yields in response to these conditions.

Aerenchyma

Aerenchyma ratings in the top portions of stalks differed significantly among cultivars, but not for water-table treatment, crop cycle, or any interaction (Table 2). Aerenchyma ratings in the top portions of CP 96-1252 and CP 89-2143 stalks ranked first and second in size, respectively. CP 88-1762 and CP 89-2376 had similarly low aerenchyma ratings in their top stalk portions. Aerenchyma ratings in these top stalk portions were 0.51, 0.33, 0.07, and 0.06 for CP 96-1252, CP 89-2143, CP 89-2376, and CP 88-1762, respectively.

The cultivar × water-table interaction for aerenchyma ratings was significant for middle stalk portions (Table 2). CP 88-1762 and CP 89-2376 had similarly low aerenchyma ratings in the middle portions of their stalks across all water treatments (Table 6). The aerenchyma rating for the middle of CP 89-2143 stalks subjected to 20CWT was significantly higher than when subjected to the 45CWT, 20FWT, or 45FWT treatments. For CP 96-1252, the aerenchyma rating was significantly lower for 45CWT than

Table 6. Aerenchyma ratings from middle stalk sections of four sugarcane cultivars exposed to four water-table treatments averaged over the plant- cane, first-ratoon, and second-ratoon crops.

	Cultivar				
Water†	CP 88-1762	CP 89-2143	CP 89-2376	CP 96-1252	Mean
	Rating‡				
20CWT	0.19 a§	2.68 a	0.22 a	3.29 a	1.59 a
45CWT	0.20 a	1.84 b	0.23 a	2.26 b	1.13 b
20FWT	0.33 a	1.91 b	0.64 a	3.19 a	1.52 a
45FWT	0.35 a	2.20 b	0.45 a	3.24 a	1.56 a
Mean	0.27 c	2.16 b	0.39 c	2.99 a	1.45

† Target water-table depths are continuous 20 (20CWT) or 45 (45CWT) cm, and 20 (20FWT) or 45 (45FWT) cm with periodic flooding. The 20FWT and 45FWT treatments had five 1-wk floods in the plant-cane and first-ratoon crops and four 1-wk floods in the second-ratoon crop.

‡ Subjective ratings for aerenchyma ranged from 0 for no aerenchyma to 5 for an area that was equal to about 50% of the stalk diameter.

§ Least square means in the same column separating water treatments, or in the final row separating cultivars, followed by the same letter are not significantly different ($P = 0.05$) based on the DIFF option in SAS. The SEMs for water treatments, cultivars, and their interaction were 0.16, 0.11, and 0.23, respectively.

for the other water treatments, but higher than the aerenchyma ratings for CP 88-1762 and CP 89-2376 with all water-table treatments ($P < 0.001$) and higher than the aerenchyma rating of CP 89-2143 subjected to 45CWT ($P = 0.049$). The aerenchyma ratings for middle stalk portions of CP 96-1252 subjected to the 45FWT, 20CWT, and 20FWT did not differ significantly (Table 6). Glaz et al. (2004) reported that enhanced sugarcane water tolerance was found in a genotype that formed constitutive stalk aerenchyma. It is not known if any stalk aerenchyma formation in this study was constitutive because all lysimeters were flooded for at least 1 wk each growing season to control grubs. However, the large aerenchyma of CP 96-1252 in the 45CWT treatment plus previous information that CP 96-1252 formed constitutive stalk aerenchyma (unpublished data) suggest that CP 96-1252 had constitutive aerenchyma in the mid-stalk region. CP 96-1252 was also the cultivar most apt to have its mid-stalk aerenchyma increase in size due either to periodic flooding or the 20CWT water treatment. Also, although CP 96-1252 had high cane and sucrose yields in the ratoon crops compared with other cultivars in the 20CWT or 20FWT treatments, there was no indication based on the significant cultivar × water treatment interactions that probable constitutive stalk aerenchyma enabled CP 96-1252 to sustain yields in the 20-cm water-table treatments.

Table 7. Aerenchyma ratings from bottom stalk sections of four water-table treatments and from bottom and middle stalk sections of four sugarcane cultivars in the plant-cane, first-ratoon, and second-ratoon crops.

Water† or cultivar	Stalk section	Aerenchyma rating‡		
		Plant cane	First ratoon	Second ratoon
20CWT	bottom	2.96 bc§	2.19 b	2.16 a
45CWT	bottom	2.50 c	1.17 c	0.73 b
20FWT	bottom	3.98 a	2.75 ab	1.53 ab
45FWT	bottom	3.70 ab	3.10 a	1.67 a
SEM	bottom	0.39	0.75	0.36
CP 88-1762	bottom	2.05 d	1.10 c	0.91 c
CP 89-2143	bottom	3.92 b	3.08 a	1.55 b
CP 89-2376	bottom	2.49 c	1.77 b	1.18 c
CP 96-1252	bottom	4.69 a	3.25 a	2.45 a
SEM	bottom	0.19	0.27	0.15
CP 88-1762	middle	0.41 c	0.65 b	0.11 c
CP 89-2143	middle	3.31 b	2.40 a	0.77 b
CP 89-2376	middle	0.59 c	0.71 b	0.06 c
CP 96-1252	middle	4.08 a	2.52 a	1.80 a
SEM	middle	0.14	0.24	0.12

† Target water-table depths are continuous 20 (20CWT) or 45 (45CWT) cm, and 20 (20FWT) or 45 (45FWT) cm with periodic flooding. The 20FWT and 45FWT treatments had five 1-wk floods in the plant-cane and first-ratoon crops and four 1-wk floods in the second-ratoon crop.

‡ Subjective ratings for aerenchyma ranged from 0 for no aerenchyma to 5 for an area that was equal to about 50% of the stalk diameter.

§ Least square means in the same group and column followed by the same letter are not significantly different ($P = 0.05$) based on the DIFF option in SAS.

The significant crop cycle × water treatment interaction for bottom stalk portions (Table 2) was due to minor changes in aerenchyma ratings. The 20FWT, 20CWT, and 45FWT treatments generally had higher aerenchyma ratings than the 45CWT treatment (Table 7). However, in the plant-cane crop, aerenchyma ratings for 20CWT and 45CWT were similar and in the second-ratoon crop, ratings for 45CWT and 20FWT were similar. A general conclusion is that shallow water tables or periodic flooding (20CWT, 20FWT, and 45FWT) tended to result in larger aerenchyma than a constant water-table depth of 45 cm in the bottom portions of stalks. The crop cycle × cultivar interaction was also significant for bottom and middle stalk portions (Table 2). One cause of these interactions was that CP 96-1252 had larger aerenchyma ratings than all cultivars across crop cycles except that in the first-ratoon crop, bottom and middle stalk sections of CP 96-1252 and CP 89-2143 had similar aerenchyma ratings (Table 7). Also, for bottom stalk sections, CP 89-2376 had larger aerenchyma ratings than CP 88-1762 in the first two crop cycles, but the two cultivars had similar aerenchyma ratings in the second-ratoon crop cycle.

Stomatal Conductance and Relative Leaf Chlorophyll Content

Stomatal conductance was measured during drainage and flood periods in the first-ratoon crop (five measurement days) and in the second-ratoon crop (four measurement days). The main effects of cultivar and crop cycle were highly significant for stomatal conductance in the analysis combined across crops (Table 2). The mean stomatal conductance of 172 μmol m^{-2} s^{-1} in the first-ratoon crop was significantly less ($P = 0.001$) than that in the second-ratoon crop (206 μmol m^{-2} s^{-1}). The stomatal conductance of CP 96-1252 (219 μmol m^{-2} s^{-1}) was higher than the stomatal conductance rates of CP 88-1762 (173 μmol m^{-2} s^{-1}) and CP 89-2143 (172 μmol m^{-2} s^{-1}) ($P = 0.001$). The stomatal conductance of CP 89-2376 (196 μmol m^{-2} s^{-1}) did not differ significantly from the other cultivars. The cultivar rankings for cane yield in the first-ratoon crop were CP 96-1252 > CP 89-2376 > CP 88-1762 > CP 89-2143 and in the second-ratoon crop were CP 96-1252 = CP 89-2376 > CP 88-1762 > CP 89-2143. This suggests that higher stomatal conductance was advantageous under these soil-water conditions that ranged from adequate (45CWT) to periods of excessive (45FWT) to constantly excessive (20CWT and 20FWT).

Relative leaf chlorophyll content was measured on 1 d in the plant-cane crop and on 4 d during the second-ratoon crop.

Table 8. Relative leaf chlorophyll content of four sugarcane cultivars and four water-table treatments in the plant-cane and second-ratoon crops. Relative chlorophyll content was measured on 1 d in the plant-cane crop, and values are means of 4 d in the second-ratoon crop.

Water†	Relative leaf chlorophyll content	
	Plant cane	Second ratoon
20CWT	36.8 b‡	30.9 b
45CWT	41.0 a	35.9 a
20FWT	35.8 b	30.0 b
45FWT	36.4 b	36.0 a
SEM	0.7	0.7

† Target water-table depths are continuous 20 (20CWT) or 45 (45CWT) cm, and 20 (20FWT) or 45 (45FWT) cm with periodic flooding. The 20FWT and 45FWT treatments had five 1-wk floods in the plant-cane and first-ratoon crops and four 1-wk floods in the second-ratoon crop.

‡ Least square means in the same column followed by the same letter are not significantly different ($P = 0.05$) based on the DIFF option in SAS.

Main effects of cultivar, water treatment, and crop cycle, as well as the crop × water treatment interaction on relative leaf chlorophyll content were highly significant (Table 2). Results of relative leaf chlorophyll content among cultivars were similar to those of stomatal conductance. CP 96-1252 had the highest relative leaf chlorophyll content (38.7) ($P < 0.001$). CP 89-2376 ranked second in relative leaf chlorophyll content (36.1) ($P < 0.001$) and the relative leaf chlorophyll content of CP 88-1762 (33.7) was higher than that of CP 89-2143 ($P = 0.001$).

In the plant-cane crop, relative leaf chlorophyll content of the 45CWT treatment was higher than the other three water treatments, all of which had similar relative leaf chlorophyll contents (Table 8). In the second-ratoon crop, relative leaf chlorophyll contents of 45CWT and 45FWT were similarly high. Stomatal conductance and relative leaf chlorophyll content differentiated among cultivars similarly, but differences among water treatments were better identified by relative leaf chlorophyll content. Thus, measuring relative leaf chlorophyll content appears more promising than stomatal conductance as a means of quantifying sugarcane responses to shallow water tables and periodic flooding during the growing season. Also in its favor, relative leaf chlorophyll content is measured more easily and quickly than stomatal conductance; and relative leaf chlorophyll content, unlike stomatal conductance, is not influenced by changes in sunlight and wind speed at the time of measurement.

CONCLUSIONS

This lysimeter study compared responses of four sugarcane cultivars to adequate (45 cm) and shallow (20 cm) water-table depths with and without periodic flooding in the EAA for the plant-cane through the second-ratoon crop cycle. Flood durations were 7 d followed by 7 d without irrigation or drainage and due to high rainfall during this period in most cycles, this resulted in many 14-d flood durations. Yields of CRS were not affected by water treatment except that the most commercially desirable treatment, a constant 45-cm water-table depth, had the lowest CRS in the plant-cane crop. A major finding was that shallow water-table depths were more detrimental to cane and sucrose yields than repeated flood-drain cycles with drainage depths of 45 cm. This conclusion was based on the consistently lower yields of treatments with drained water-table depths of 20 compared with 45 cm combined with consistently similar yields under 20CWT and 20FWT as well as under 45CWT and 45FWT. CP 89-2143 and CP 96-1252 had large stalk aerenchyma. Cane and sucrose yields of CP 89-2143 were low, but were the least affected by water-table treatments. The two cultivars with smaller stalk aerenchyma (CP 88-1762 and CP 89-2376), as well as CP 96-1252, had high yields and were generally not affected by flooding, but had consistent yield losses due to shallow water-table depth. These results suggest that although stalk aerenchyma may provide tolerance to shallow water tables and periodic flooding, there may be other mechanisms contributing to this tolerance. Stomatal conductance measurements were not affected by water-table treatment. Relative leaf chlorophyll contents were high for 45CWT in the plant-cane crop and for 45CWT and 45FWT in the second-ratoon crop. CP 96-1252 had the highest yields, stomatal conductance, and relative leaf chlorophyll contents. Measurements of relative leaf chlorophyll content rather than stomatal conductance may be better for identifying sugarcane genotypes that yield well under shallow water-tables and periodic flooding.

The finding that shallow water-table depths were more detrimental to sugarcane yields than periodic flooding suggests that sugarcane roots function well in water for up to 14 d, but that water tables below the roots inhibit their growth further into the soil. Being grown in tropical climates, sugarcane in many regions of the world is often exposed to heavy rains and periodic flooding. Based on results of this study, sugarcane growers should consider that constantly shallow water-table depths near 20 cm are more detrimental than periodic flooding with flood durations of up to 14 d. Further research that confirms responses of sugarcane root growth to floods and shallow water tables would allow sugarcane growers to develop enhanced strategies to sustain high yields under these conditions.

ACKNOWLEDGMENTS

The authors acknowledge the technical assistance of Christine Rainbolt throughout this study.

REFERENCES

Bendix, M., T. Tornberj, and H. Brix. 1994. Internal gas transport in *Typha latifolia* L. and *Typha angustifolia* L. 1. Humidity-induced pressurization and convective through flow. Aquat. Bot. 49:75–89.

Berning, C., M.F. Viljoen, and L.A. DuPlessis. 2000. Loss functions for sugarcane: Depth and duration of inundation as determinants of extent of flood damage. Water S.A. 26:527–530.

Carter, C.E. 1976. Excess water decreases cane and sugar yields. Proc. Am. Soc. Sugar Cane Technol. 6:44–51.

Cherry, R. 1984. Flooding to control the grub *Ligyrus subtropicus* (Coleoptera: Scarabaeidae) in Florida sugarcane. J. Econ. Entomol. 77:254–257.

Daroub, S.H., J.D. Stuck, T.A. Lang, and O.A. Diaz. 2002. Particulate phosphorus in the Everglades Agricultural Area: II–Transport mechanisms. Available at http://edis.ifas.ufl.edu/SS417 (verified 15 Dec. 2009). Inst. of Food and Agric. Sci., Ext. Office, Univ. of Florida, Gainesville.

Drew, M.C. 1997. Oxygen deficiency and root metabolism: Injury and acclimation under hypoxia and anoxia. Annu. Rev. Plant Physiol. Plant Mol. Biol. 48:223–250.

Edmé, S.J., P.Y.P. Tai, B. Glaz, R.A. Gilbert, J.D. Miller, J.O. Davidson, J.W. Dunckelman, and J.C. Comstock. 2005. Registration of 'CP 96-1252' sugarcane. Crop Sci. 45:423.

Garcia, R., F. Izuno, and S. Panagiotis. 2001. Water tables and drainage uniformity in the Everglades Agricultural Area. ASAE Meet. Paper no. 01–2299. ASAE, St. Joseph, MI.

Gilbert, R.A., C.R. Rainbolt, D.R. Morris, and J.M. McCray. 2008. Sugarcane growth and yield responses to a 3-month summer flood. Agric. Water Manage. 95:283–291.

Glaz, B. 2006. Sugarcane variety census: Florida 2005. Sugar J. 69:12, 13, 16-19.

Glaz, B. 2008. Sugarcane variety census: Florida 2007. Sugar J. 71:6-11.

Glaz, B. 2007. Sugarcane response to month and duration of preharvest flood. J. Crop Improv. 20:137–152.

Glaz, B., and R.A. Gilbert. 2006. Sugarcane response to water table, periodic flood, and foliar nitrogen on organic soil. Agron. J. 98:616-621.

Glaz, B., J.D. Miller, C.W. Deren, P.Y.P. Tai, J.M. Shine, Jr., and J.C. Comstock. 2000. Registration of 'CP 89-2143' sugarcane. Crop Sci. 40:577.

Glaz, B., D.R. Morris, and S.H. Daroub. 2004. Periodic flooding and water table effects on two sugarcane genotypes. Agron. J. 96:832–838.

Glaz, B., P.Y.P. Tai, J.D. Miller, S.J. Edme, R.A. Gilbert, J.O. Davidson, J.W. Dunckelman, and J.C. Comstock. 2005. Registration of 'CP 89-2376' sugarcane. Crop Sci. 45:785.

Grosse, W., and D. Meyer. 1992. The effect of pressurized gas transport on nutrient uptake during hypoxia of altered roots. Bot. Acta 105:223–226.

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.

Omary, M., and F.T. Izuno. 1995. Evaluation of sugarcane evapotranspiration from water table data in the everglades agricultural area. Agric. Water Manage. 27:309–319.

Rice, R.W., F.T. Izuno, and R.M. Garcia. 2002. Phosphorus load reductions under best management practices for sugarcane cropping systems in the Everglades Agricultural Area. Agric. Water Manage. 56:17–39.

Roach, B.T., and R.T. Mullins. 1985. Testing sugarcane for waterlogging tolerance. Proc. Aust. Soc. Sugar Cane Technol. 7:95–102.

Sanchez, C.A. 1990. Soil-testing and fertilization recommendations for crop production on organic soils in Florida. Bull. 87. Univ. of Florida, Gainesville.

SAS Institute. 2003. SAS system for Windows release 9.1. SAS Inst., Cary, NC.

Shih, S.F., B. Glaz, and R.E. Barnes, Jr. 1998. Subsidence of organic soils in the Everglades Agricultural Area during the past 19 years. Proc. Soil Crop Sci. Soc. Fla. 57:20–29.

Snyder, G.H., and J.M. Davidson. 1994. Everglades agriculture, past, present, and future. *In* S.M. Davis and J.C. Ogden (ed.) Everglades: The ecosystem and its restoration. St. Lucie Press, Delray Beach, FL.

Tai, P.Y.P., J.M. Shine, Jr., C.W. Deren, B. Glaz, J.D. Miller, and J.C. Comstock. 1997. Registration of 'CP 88-1762' Sugarcane. Crop Sci. 37:1388.

Tao, J., R. Littell, M. Patetta, C. Truxillo, and R. Wolfinger. 2002. Mixed models analyses using the SAS system: Course notes. SAS Inst., Inc., Cary, NC.

Vashist, K.K., H. Singh, and A. Singh. 2003. Intercropping studies in spring planted sugarcane under flood plain conditions. Sugar Tech 5:79–80.

Yoshida, S., and H. Eguchi. 1994. Environmental analysis of aerial O_2 transport through leaves for root respiration in relation to water uptake in cucumber plants (*Cucumis sativus* L.) in O_2 deficient nutrient solution. J. Exp. Bot. 45:187–192.