

SUGARCANE YIELD AND RHIZOSPHERE CHARACTERISTICS IN FLOODED ORGANIC SOIL DETERMINED FROM A POT STUDY

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ABSTRACT

Growing sugarcane (interspecific hybrids of *Saccharum* spp.) under flooded conditions is an important management tool for decreasing soil organic matter loss in Histosols. But flooding often reduces crop yield. An experiment was conducted for 10 months in 38-L plastic pots to determine sugarcane yields and the rhizosphere properties in an organic soil under varying water-table levels and to relate soil rhizosphere properties with sugar production. Five sugarcane genotypes (representing a wide range in genetic characteristics) were grown under three water-table levels (0, 15 and 30 (drained) cm from the soil surface). Stalk dry matter and sugar yields were reduced when pots were flooded. Averaged across water-table treatments, genotypes had as high as a 60 % difference in rhizosphere soluble organic carbon (SOC), which indicates differential leakage of carbohydrates. Correlation analysis showed a negative relationship between sugar yield and SOC ($r=-0.73$, $P<0.01$) and a positive relationship between sugar yield and depth to water table ($r=0.84$, $P<0.01$), which suggests that carbon loss from roots has a detrimental impact on yield when water table levels are high. Soluble organic C was also negatively related with bacterial ($r=-0.58$, $P<0.05$) and actinomycete ($r=-0.47$, $P<0.10$) populations. Soil pH, total $\text{PO}_4\text{-P}$, $\text{NH}_4\text{-N}$, and $(\text{NO}_3+\text{NO}_2)\text{-N}$ were affected neither by water table nor cultivar nor correlated with any plant parameter. There was a correlation between SOC and water table depth ($r=-0.69$, $P<0.01$). Our data suggest that elevated levels of SOC resulting from flooding of the sugarcane rhizosphere may serve as an indicator of sugarcane water stress and lower activity of aerobic bacteria and actinomycetes.

INTRODUCTION

Sugarcane is a major crop grown on drained Histosols of the Everglades Agricultural Area (EAA) in south Florida, USA, which are subsiding at a rate of 1.4 cm yr^{-1} (Shih et al., 1997) due mostly to aerobic microbial oxidation of soil organic matter (Volk, 1973). Upon organic matter oxidation, large quantities of nutrients may be released into the soil solution reducing off-site water quality. Mineralization rates as high as $1200 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ and $72 \text{ kg P ha}^{-1} \text{ yr}^{-1}$ have been reported by Terry (1980) and Diaz et al. (1993), respectively. Soil oxidation rates can be reduced by raising water tables. Stephens et al. (1984) indicated that generally, soil loss in Histosols could be decreased by half every time water tables are raised to half the distance to the soil surface.

A benefit for growing sugarcane in organic soils is that subsidence rates may be reduced compared to other crops at the same water-table level. Stephens and Johnson (1951) reported results from a 7-yr experiment of truck crops (vegetables, types not stated), sugarcane, and a grass (species not given) grown

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in Histosols at water tables of 30 to 91 cm from the soil surface. Sugarcane resulted in a lower soil subsidence (2.0 cm yr^{-1}) compared with grass and truck crops (2.7 and 2.6 cm yr^{-1} , respectively). Tate (1980a) used ^{14}C labelled salicylate (representing oxidation resistant compounds) applied to a Pahokee muck soil taken from a fallow, St. Augustine (*Stenotaphrum secundatum* (Walt) Kuntz) grass, and sugarcane field. Salicylate oxidation was greater from soil under St. Augustine grass compared with fallow or sugarcane.

Plants excrete organic compounds through roots, which could stimulate microbial activity (Russell, 1977). In young apple trees, Rogers and Head (1969) indicated that an amount of carbohydrate excreted into the rhizosphere was equivalent to almost half the dry weight of the young roots during the first year. Available C would allow microbes to incorporate N and P from the soil solution, thus reducing the potential for leaching and improving water quality. An increase in microbial numbers that results in greater activity could also increase soil subsidence, since microbes are directly responsible for most of the Histosol losses (Tate, 1980b).

If water tables are raised, adapted cultivars of sugarcane will be needed. Roach and Mullens (1985) reported that tolerance to high water tables is probably a heritable character in sugarcane. Glaz et al. (2000) tested nine sugarcane cultivars using 15- and 38-cm water tables and reported that one cultivar had the same sugar yields at both water table levels, and some genotypes could tolerate high water tables. Kang et al. (1986) reported that some sugarcane clones produced greater biomass under a high water table (29.8 cm) than under a low water table (56.8 cm).

Sugarcane is an ideal crop for the Florida Everglades and has potential for further increase in water tolerance through plant breeding in the tropical soils of this region. Currently, reasons for sugarcane tolerance to high water tables are not well understood. Since plant roots are in direct contact with soil and water, reasons may lie with a better understanding of rhizosphere characteristics. Therefore, this experiment was conducted to determine sugarcane yields and the rhizosphere properties of an organic soil under varying water-table levels and to relate soil rhizosphere properties with yield components of sugar production.

MATERIALS AND METHODS

Four sugarcane genotypes (US 87-1006 - tall white-stemmed stalk, US 96-1098 - small white-stemmed stalk, US 96-1106 - small white-stemmed stalk, and US 96-1112 - tall purple-stemmed stalk) were randomly selected from the cold-tolerant breeding stock at Canal Point, FL and represented a wide range in genetic variability based on stalk characteristics. A commercial cultivar (CP 65-357 - tall, white-stemmed stalk) was included as a check. Plants were grown out of doors for 10 months in 38-L pots that were 30-cm deep with three water-table treatments: 0, 15, and 30 (drained) cm from the soil surface. The five sugarcane genotype treatments were arranged in a completely randomized design within a split plot experiment (three water-table treatments) with three replications at USDA-ARS Sugarcane Field Station,

Canal Point. A split plot design was chosen to facilitate watering procedures.

A mixture of one part sand to two parts organic muck soil was used to fill the pots. The soil/sand mixture was used in order to promote water infiltration into the pots. Pre-plant soil/sand mixture had a pH (water) of 7.4 (Thomas, 1996), 11 % organic matter (weight loss after combustion; Nelson and Sommers, 1996) and 13 and 26 mg kg⁻¹ soil of P (NaHCO₃ extractable; Kuo, 1996) and K (ammonium acetate extractable; Helmke and Sparks, 1996), respectively. Single budded cuttings (2.5-cm length) were taken in April 1999 from mature stalks of each genotype and planted in 60- by 30- by 10-cm flats containing the same soil used to fill the pots. Flats were watered twice daily, and after one month, one healthy plant was transplanted to each plastic pot. Slow release fertilizer (50 g of 14-14-14, Scotts Osmocote, Sierra Hort. Products, Co., Marysville, OH¹) were sprinkled over the soil surface of each container one week after transplanting. The same amount of fertilizer was applied after peak stalk formation. This fertilizing method was used because it is used by plant breeders at Canal Point to grow healthy sugarcane plants to tasseling stage. The slow release fertilizer would prevent excessive leaching of soluble nutrients in the drained pot compared with the flooded pot.

All plants were grown under non-flooded conditions during the first two months to allow the plants to establish healthy shoot and root systems. Water was supplied as needed to keep the soil moist. Water-table treatments were imposed two months after planting (July) by drilling 2.5-cm diameter drainage holes in the sides of the pots at the appropriate depths. Drip irrigation, twice per day, was used throughout the course of the study to maintain desired water levels. This watering scheme was used because past experience had indicated it was sufficient to keep the soil saturated to the desired depths with growing plants.

In the first week of February 2000, stalks were counted and plants were harvested by cutting stalks at the soil surface and weighing. Stalks were crushed for juice quality analysis. Bagasse (fiber remaining after juice extraction) and juice were weighed separately after milling. Two randomly selected stalks from each treatment were dried to constant weight at 60° C to determine dry yield. Brix and polarization measurements on the juice were used to calculate sucrose content according to the method described by Chen (1985).

After stalk removal, the soil/root core was removed from the plastic pots. Soil cores were then cut in half, and a sample was taken from the upper 0- to 15-cm soil layer of each core using a garden trowel. All the pots had roots completely encased in the upper soil core, and the soil did not fall from the roots when lifted into the air and shaken. Therefore, the root-adhearing soil in the upper core minus roots were assumed to represent the soil rhizosphere. Soil samples from the lower soil/root core were not analyzed,

¹ Mention of a specific proprietary product does not constitute a recommendation by the USDA and does not imply approval to the exclusion of other suitable products.

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because a small quantity of soil fell from the roots when lifted into the air, and thus, would not represent the rhizosphere. Soil samples were then placed in 5° C storage until analysis.

Microbial numbers in the soil samples were counted using the pour plate method (Zuberer, 1994). After removing roots by hand, 10 g of fresh soil were placed in 95 ml of 0.1 % NaCl, then shaken at 200 rpm on a rotary shaker for 20 minutes, and finally serially diluted in 0.1 % saline solution. Bacteria, actinomycetes, and fungi were enumerated on premixed, selective medium (full strength R2A, actinomycete isolation, and rose bengal agars, respectively; BD Biosciences, Sparks MD¹). The R2A media is a low nutrient medium that was developed to enumerate heterotrophic bacteria in water and wastewater (APHA, 1995; DIFCO, 1998). The actinomycete medium, containing glycerol as a source of C and energy, is used for isolating and culturing actinomycetes in soil and water (DIFCO, 1998). Rose bengal medium, containing rose bengal dye and streptomycin to inhibit bacteria, is used to culture and enumerate fungi in soil, sewage, and foodstuffs (DIFCO, 1998). Since some soils were wetter than others, and we wanted to compare microbial populations across water-table treatments, all microbial populations were calculated on a dry soil basis.

Soil pH was measured in water (Thomas, 1996) from root-free soil samples at harvest, and extracts of soil were taken by weighing 2 g of fresh soil into a 50 ml centrifuge tube, adding 10 ml of reverse osmosis water, shaking for 30 minutes at 200 rpm on a rotary shaker, centrifuging at 1000 g for 30 minutes, and filtering through a 0.2 µm filter. Extracts from samples were immediately frozen at -10° C. Analysis consisted of water soluble organic carbon (SOC) (EPA, 1987), total PO₄-P (APHA, 1995), and NH₄-N and (NO₃+NO₂)-N (APHA, 1995). These variables were measured because they would be expected to affect not only water quality but plant and soil microbial growth. Lower water tables result in increased oxidation of organic matter that increases mineralization of N and P (Terry, 1980; and Diaz et al., 1993), while higher water tables result in increased SOC (Reddy, 1982).

Data were analyzed as a completely randomized design within a split plot (water-table depth) experiment (SAS, 1999). A Duncan's multiple range test (P=0.05) was used to compare means. Correlations between parameters were calculated from sample means (genotype x water-table depth, n=15). Significance of linear and quadratic responses of plant growth and SOC vs. water-table depth was determined by regression analysis using the means from the correlation analysis (SPSS, 2001).

RESULTS AND DISCUSSION

Sugarcane is a genetically diverse plant, allowing breeders to select varieties adapted to a wide range of environmental conditions in tropical and subtropical regions (Gascho and Shih, 1983). In our experiment, this diversity was observed in the wide range of stalk dry matter yields averaged over water-table treatments (Table 1). There was no interactive effect between genotype and water-table treatments, which held true for all the other plant yield parameters. Genotypes US 96-1106, US 96-1112, and CP 65-357 had the lowest stalk dry matter yields (mean 1.4 kg pot⁻¹), while genotypes US 87-1006 and US 96-

1098 had the highest dry yield (mean 2.0 kg pot⁻¹). Sugarcane average dry matter yields were also significantly correlated ($r=0.67$, $P<0.01$) with water-table depth (Table 2). A regression analysis of dry matter yield vs. water table depth, indicated the linear and not quadratic response was significant ($P<0.05$). When sugarcane was completely flooded compared with 30-cm (drained) water table, dry matter yield declined by 45 % (Table 2), but flooding the soil did not cause the death of any plants. These data confirmed the findings of Glaz et al. (2000) and Roach and Mullens (1985) that sugarcane has some tolerance to high water tables.

Table 1. Sugarcane production soil soluble organic carbon as affected by sugarcane variety. Values are averaged across water-table depths.

Genotype	Stalk dry wt, kg pot ⁻¹	No. stalks pot ⁻¹	Sugar yield, g pot ⁻¹	Sugar content, g kg ⁻¹ stalk dry wt	Soluble organic C, mg kg ⁻¹ dry soil
US 87-1006	1.9 A ^h	8 B	300 A	158 BC	40 A
US 96-1098	2.1 A	10 A	277 A	132 CD	28 BC
US 96-1106	1.5 B	9 AB	184 B	123 D	37 AB
US 96-1112	1.5 B	8 B	258 A	172 B	35 AB
CP 65-357	1.3 B	6 C	286 A	220 A	25 C

^hMeans followed by the same letter within a column are not significantly different at the 0.05 level of probability according to Duncan's multiple range test ($P=0.05$).

Stalk dry matter yields of sugarcane are related to the number of stalks produced by the plant (Mariotti, 1972; Miller and James, 1974). Consequently, the response for number of stalks produced was similar to that for stalk dry yield (Table 1). Averaged across water table levels, CP 65-357 had the least stalks (6 pot⁻¹), while cultivars US 96-1098 and US 96-1106 had the most stalks (mean of 10 pot⁻¹). Number of stalks was correlated with water-table depth ($P<0.10$), and the number of stalks in the flooded compared with the drained treatment was reduced by 22 %. A regression analysis of stalk number vs. water table depth showed a significant ($P<0.05$) linear and not quadratic response.

Sugar yields could not be assessed according to stalk dry matter yields, because sugar yields and sugar content did not consistently correspond to dry matter yields or stalk number (Table 1). Genotypes US 87-1006, CP 65-357, US 96-1098, and US 96-1112 were the highest sugar producers (300, 286, 277, and 258 g pot⁻¹, respectively) and CP 65-357 had the highest sugar content (220 g kg⁻¹), while US 96-1112 and CP 65-357 were among the lowest in stalk dry weight (1.5 and 1.3 kg pot⁻¹, respectively). However, sugar yield and content were significantly correlated ($r=0.84$, $P<0.01$ and $r=0.52$, $P<0.05$, respectively) with water-table depth (Table 2). The linear response (not quadratic) of sugar yield and content vs. water table depth was statistically significant ($P<0.05$). When comparing the flooded with

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the drained treatment, sugar yield and content were reduced by 61 and 30 %, respectively (Table 2).

Reasons for sugarcane not dying under flooded conditions may be related to aerenchyma tissue in the shoots and roots that allows oxygen to diffuse from the leaf to the cells in the root (Drew, 1997). Ray and Sinclair (1999) examined more than 30 sugarcane genotypes and found that all sugarcane varieties have aerenchyma whether grown under flooded or non-flooded conditions. Even though the genotypes tested in our study did not show interactive effects due to water table, some varieties have been reported to be very tolerant to waterlogged soils. In low-lying sugarcane regions of India, some sugarcane varieties have been seen growing in 1.2 m of water (Rege and Mascarenhas, 1956). Perhaps a world-wide selection process could identify genotypes with greater tolerance to high water tables.

Table 2. Stalk dry yield, number of stalks, sugar yield, and sugar content and soil soluble organic carbon as affected by depth to water table. Values are averaged across genotypes. The bottom portion of the table shows the correlations (r) between water table depths and plant and soil parameters.

Depth to water table ¹ , cm	Stalk dry wt, kg pot ⁻¹	No. stalks pot ⁻¹	Sugar yield, g pot ⁻¹	Sugar content, g kg ⁻¹ stalk dry wt	Soluble organic C, mg kg ⁻¹ dry soil
0	1.1 B ^h	7 B	142 B	129 B	43
15	1.9 A	9 A	323 A	170 A	30
30 (drained)	2.0 A	9 A	368 A	184 A	25
r	0.67***	0.47*	0.84***	0.52**	-0.69***

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

^hMeans followed by the same letter within a column are not significantly different at the 0.05 level of probability according to Duncan's multiple range test (P=0.05).

Among the rhizosphere parameters measured, SOC content was the only one affected by genotype (Table 1). Sugar yields did not always correspond to SOC in the rhizosphere. Cultivar CP 65-357 was ranked among the highest in sugar yields, but CP 65-357 was ranked last in SOC level (25 mg kg⁻¹). The greater quantities of SOC under some sugarcane varieties (averaged across water-table treatments) indicates inefficient carbon storage of the root exudation. Total amounts of C loss could not be determined from this experiment, but plants can excrete significant amounts of C into the rhizosphere. In an aerobic sand culture, Haller and Stolp (1985) reported that 25 % of the carbohydrates flowing to maize (*Zea mays* L.) roots were excreted into the rhizosphere. Using ¹⁴C labelling in aerated soil, Barber and Martin (1976) indicated that between 18 and 25 % of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) dry matter were excreted by roots. Since plant breeders select sugarcane varieties based on sugar yields of stalks and SOC in the rhizosphere represents a direct loss of sugar, perhaps selecting varieties against the loss of sugars through their roots could be a means of improving sugar yields.

Soluble organic carbon concentrations were negatively correlated ($r=-0.69$, $P<0.01$) with water-table depths (Table 2). Even though ANOVA did not show a significant influence of water-table depth on SOC (Table 2), SOC tended to decrease as depth to water table was increased. The linear and quadratic regression analysis of SOC vs. water table level revealed only the linear response to be significant ($P<0.05$). The cultivar by water-table treatment interaction was not significant. The drained soil averaged about half the SOC kg^{-1} soil of the flooded soil.

The tendency of SOC to increase as water tables were decreased may be due to a combination of several factors. First, not only do plants exude carbohydrates through their roots, but carbohydrate exudation is increased under flood stress conditions (Drew, 1997). Water stress of sugarcane was evidenced in our experiment by the reduced dry stalk weight, number of stalks, sugar yield, and sugar content under flooded conditions. Secondly, simply flooding an organic soil increases SOC (Reddy, 1982). The relative contribution of SOC from plants and soil could not be determined from this experiment, and represented the quantity remaining after microbial utilization and leaching. But, regardless of whether the primary source of SOC was from plant or soil there was a negative correlation between SOC and dry stalk weight ($r= -0.59$, $P<0.05$), sugar yield ($r= -0.73$, $P<0.05$), and sugar content ($r= -0.49$, $P<0.10$) (Table 3). Plant growth parameters were not correlated with any other soil parameter. Since water-table level had a negative relationship with plant yield and a positive effect on SOC, our data suggest that high SOC in the rhizosphere could also be an indicator of the potential for water stress in sugarcane.

Table 3. Correlation coefficients (r) of plant growth and rhizosphere parameters across water table and genotype treatments.

Soil parameters	Plant growth parameters			
	Stalk dry wt.	No. of stalks	Sugar yields	Sugar content
Bacteria	0.28	0.25	0.32	0.22
Actinomycetes	0.13	-0.07	0.41	0.46
Fungi	0.19	0.01	0.37	0.33
SOC	-0.59**	-0.29	-0.73***	-0.49*
pH	-0.13	0.07	-0.19	-0.21
PO ₄ -P	0.28	0.18	-0.03	-0.23
NH ₄ -N	-0.28	0.18	-0.16	0.12
(NO ₃ +NO ₂)-N	0.13	-0.41	0.26	0.18

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

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Concentrations of SOC were negatively correlated with bacterial and actinomycete populations ($r=-0.58$, $P<0.05$ and $r=-0.47$, $P<0.10$, respectively) (Table 4). Significant correlations were not observed between SOC and fungal populations. Soil chemical parameters were not correlated with any of the other microbial parameters. Flooded conditions result in reduced O_2 diffusion, and O_2 in soil drops within a few hours after flooding (Reddy, 1987). Soil bacterial and actinomycete numbers could have decreased as a result of low O_2 tensions. However, if O_2 alone were responsible for low microbial numbers, then there should also have been similar negative correlations with NH_4-N , $(NO_3+NO_2)-N$, and PO_4-P , because mineralization of N and P is partially dependent on soil aeration. Another explanation is that plants can excrete toxic substances that inhibit microorganisms (Bowen and Rovira, 1999; Stolzy and Sojka, 1984; Drew, 1997). Significant amounts of toxic substance are excreted into the rhizosphere as a response to flooded conditions (Drew, 1997), and perhaps this could explain the reduced bacterial and actinomycete numbers with high SOC in flooded soil. Furthermore, if sugarcane roots excrete toxic or selective compounds that inhibit aerobic microorganisms responsible for organic matter degradation, it could explain the lower soil subsidence in soil growing sugarcane compared with other crops (Stephens and Johnson, 1951; Tate, 1980a).

Table 4. Correlation coefficients (r) of microbial numbers and soil chemical parameters across water table and genotype treatments.

Soil chemical parameters	Microbial numbers		
	Bacteria	Actinomycetes	Fungi
pH	-0.16	-0.01	0.13
NH_4-N	-0.05	-0.13	-0.31
$(NO_3+NO_2)-N$	0.41	-0.21	0.30
SOC	-0.58**	-0.47*	-0.36
PO_4-P	-0.21	0.26	0.37

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

Bacterial, actinomycete, and fungal populations in the rhizosphere were not significantly affected by cultivar or water table and averaged 1.2×10^6 , 3.7×10^4 , 2.7×10^3 cells g^{-1} soil, respectively (data not shown). Our bacterial counts conform to those of Tate (1979) who took soil samples from different cropped and fallow fields of organic soil in the EAA and counted bacteria in the range of 1×10^6 g^{-1} soil according to plate counts on soil extract agar. The populations are lower than expected given the high organic matter content of the soil and the close proximity to the plant root. Alexander (1977) indicated that aerobic bacteria, actinomycetes, and fungi in a fertile mineral soil may be around 8×10^6 , 2×10^6 , and 1×10^5 cells g^{-1} soil,

respectively. Also, Bowen and Rovira (1969) stated there may be 10 to 50 times more bacteria and fungi in the rhizosphere compared with the soil beyond the root zone. But, plate counts give lower values than actual number of microorganisms (Zuberer, 1994), and even though organic soil may contain greater than 20 % organic matter, much of the carbon is unavailable for microbial growth, and so carbon is also a limiting factor in organic soils (Broadbent, 1960; Waksman and Stevens, 1929).

Fungi generally are aerobic and do not survive well under reduced oxygen tensions (Alexander, 1977), such as could have occurred in our experiment with high root density in the rhizosphere that would reduce oxygen levels in all water-table treatments. Frequent watering would also keep the soil moist and reduce oxygen diffusion into the soil. Soil pH at harvest was around 7.9, which was not optimal for fungal growth (Alexander, 1977).

Similar to microbial counts, pH and available N and P nutrients around plant roots were not affected by cultivar or water-table treatment (data not shown). Rhizospheres had an average soil pH of 7.9 and $\text{NH}_4\text{-N}$, $(\text{NO}_3+\text{NO}_2)\text{-N}$, and $\text{PO}_4\text{-P}$ levels averaged 0.16, 1.37, and 0.18 $\mu\text{g g}^{-1}$ soil. The reason for the lack of differences in available N and P nutrients due to genotype and water-table depth treatments was probably because the sugarcane plants used the nutrients as they were released from the slow release fertilizer or mineralized from the soil organic matter, so that excess nutrients did not accumulate in the pots. Organic soils in south Florida, USA overlie limestone (CaCO_3) bedrock resulting in pH values that range from 5.0 (Diaz et al., 1993) to 7.8 (Coale et al., 1994), thus high soil pH is expected for those soils. Also, Terry et al. (1980) grew sugarcane in lysimeters at 30-, 60-, and 90 cm-water table depths and measured the content of nutrients in the water. The soil pH and $\text{NH}_4\text{-N}$, $(\text{NO}_3+\text{NO}_2)\text{-N}$, and $\text{PO}_4\text{-P}$ levels in our study are within the range of values obtained in their study.

CONCLUSIONS

Based on a comparison of genotypes with a wide range in genetic characteristics, sugarcane growth is reduced under flooded condition, but the plants do not succumb to the water stress. Even though sugarcane has been reported to have aerenchyma, the aerenchyma is apparently not sufficient to prevent stress in flooded soil. Since sugarcane is usually grown and bred in aerobic soils, commercially available sugarcane genotypes may have lost their ability to fully utilize aerenchyma in water-logged soil. A high water table may cause a greater reduction in sugar than in dry matter yield, which could be due to C loss through the root system. Some genotypes exude greater quantities of SOC in the rhizosphere than others, which indicates inefficient storage of carbohydrates. According to correlation analysis, raising the water table increased the SOC levels, demonstrating that the rhizosphere microorganisms could not rapidly utilize the readily available carbon possibly due a combination of reduced concentrations and diffusion of O_2 and excretion of toxic substances by plant roots in the flooded soil. The increase in SOC comes from excretions by plant roots and release from soil organic matter. Because SOC levels were also negatively related to sugarcane stalk dry weight, sugar yield, sugar content, and populations of bacterial and actinomycetes, SOC in the rhizosphere of sugarcane may be a good indicator in flooded soils for plant water stress response and microbial activity.

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