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Impact of Elevated Carbon Dioxide and Temperature on Fresh Weight and Sugar Yield of Sugar Cane

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ABSTRACT.

Rising atmospheric carbon dioxide (CO_2) concentration can change crop productivity directly by increasing photosynthesis, and indirectly by positive or negative modifications of growth responses to predicted global warming and changes in rainfall. The purpose of this experiment was to determine the effects of CO_2, temperature, soil type, and water table depth on growth of four cultivars of sugar cane, a C_4 photosynthetic pathway species (*Saccharum officinarum* L.). Studies were conducted in paired temperature-gradient greenhouses at ambient and enriched levels of CO_2 [≈ 360 and ≈ 710 μmol (CO_2) mol^{-1} (air), respectively] with four temperature zones along the length of each greenhouse: baseline, +1.5, +3.0, and +4.5°C. These 1.5°C steps were maintained by a combination of heat inputs (electric heaters and sunlight) and ventilation by computer-controlled fans. Other treatments were soil type (mineral vs. organic), water table depth (constant water table of 20 cm vs. ≈50-cm drained profile). The four cultivars were CP72-2086, CP73-1547, CP88-1508, and CP80-2086. Doubled CO_2 increased the following components of plant growth of the first sampling in late June-early July of 1997: leaf number = 7%; leaf area = 15%; leaf fresh weight = 13%; leaf dry weight = 8%; mainstem length = 32%; mainstem fresh weight = 31%; mainstem dry weight = 23%; juice volume = 40%; total fresh weight = 25%; juice dry weight = 36%; total dry weight = 21%. However, total fresh weight increase of that whole-crop harvest was somewhat less at 16%. Increasing temperatures caused a slight downward trend in sugar cane yield regardless of cultivar or CO_2 treatment. The order of cultivar yields for the first harvest was: CP73-1547 > CP80-1827 > CP88-1508 > CP72-2086. Doubling CO_2 appeared to benefit sugar cane productivity more than the anticipated 10% increase for a C_4 species. The apparent increase in sugar cane dry weight, fresh weight, and juice volume indicates greater yields as global atmospheric CO_2 continues to rise.

KEYWORDS: sugar cane, carbon dioxide, temperature, climate change, global warming

INTRODUCTION

Atmospheric carbon dioxide (CO_2) concentration is rising annually at the rate of about 1.5 to 2.0 μmol (CO_2) mol^{-1} (air). The CO_2 concentration was 315 μmol mol^{-1} in 1958 and it was more than 380 μmol mol^{-1} in 2008. The CO_2 concentration may increase to somewhere between 485 to 1000 µmol mol^{-1} before the end of the 21st century depending on CO_2 emissions scenario (IPCC 2001). Most of the increase is caused by burning of fossil fuels, although biomass burning and oxidation of biomass and soil organic matter as a consequence of land clearing also contribute CO_2 to the atmosphere. Since CO_2 is a greenhouse effect gas, many atmospheric scientists have predicted that a doubling of atmospheric CO_2 concentration could cause a global warming of 1.4 to 5.8°C (depending on scenario), and regional changes in patterns and amounts of cloudiness and rainfall (IPCC 2001).

A large amount of research has shown clearly that elevated CO_2 increases photosynthesis, growth, and productivity of C_3 photosynthetic pathway plants such as rice and soybean. Much less research has been conducted on CO_2 effects on plants with the C_4 photosynthetic pathway (such as sugar cane) because these plants have a biochemical/molecular mechanism of concentrating CO_2 in leaves at the chloroplastic site of CO_2 fixation, and these types of plants generally exhibit only small responses to elevated CO_2. Within the context of global climate change, little research has been conducted on high temperature, or the combination of elevated CO_2 and high temperature, on plants. Limited research has shown that warm-season species are not adversely affected by elevated temperatures up to a point.

In Florida, most sugar cane has been grown on organic soils (Stephens and Johnson, 1951; Stephens and Stewart, 1976; Stephens et al., 1984; Snyder, 2005). However, federal, state, and local programs oriented toward restoration of the South Florida ecosystem are seeking methods to ameliorate the impact of agriculture, especially in the Everglades Agricultural Area, on organic soil subsidence (Shih et al., 1979, 1998; Tate 1979, 1980; Tate and Terry, 1980) with concomitant emissions of CO_2 to the atmosphere (Allen, 2007; Knipling et al., 1971; Volk, 1973) and on nutrient outflows to natural and less managed parts of the ecosystem. One management option is to produce sugar cane on organic soil with shallow water tables maintained over a large part of the cropping cycle, using adapted cultivars (Allen, 2007; Gilbert et al., 2007; 2008; Glaz et al., 2005; Glaz and Gilbert, 2006; Glaz and Morris, 2006; Glaz, 2007; Glaz et al., 2008; Morris et al., 2004; Morris, 2005). Holding water on the fields rather than allowing rapid flow through the upper soil profile and subsequent drainage from the field should also decrease nutrient outflows from the farms. Given restoration policies, sugar cane production in South Florida might move in part from organic soils to mineral soils. With appropriate management of water and nutrients (especially nitrogen), yields should be as good on mineral soils as those on organic soils (Obreza et al. 1998).

Because of both global and local environmental questions, our purpose was to study effects of the combination of elevated CO_2, high temperatures, soil type (organic vs. mineral), and water table depths on growth and yield of several cultivars of sugar cane. This paper reports the early fresh weight and sugar yield results of this study.

MATERIALS AND METHODS

Temperature-gradient greenhouses. Four sugar cane cultivars were grown at CO_2 concentrations of ≈ 360 or ≈ 710 µmol (CO_2) mol^{-1} (air) in two temperature-gradient greenhouses (or TGGs) at four temperatures above ambient. The TGGs were 27.43 m in length and 4.27 m in width at the base. Semicircular arcs covered with greenhouse polyethylene with a center-line ridgepole height of 2.2 m formed the structure itself.

These TGGs have been described in general by Sinclair et al. (1996), Vu et al. (2002, 2006, 2009), and Allen et al. (2006; 2009). One TGG was equipped with a computer-controlled CO_2 injection system to maintain CO_2 concentration at 710 μmol (CO_2) mol^{-1} (air). The other TGG received only ambient air with a concentration of about 360 μmol (CO_2) mol^{-1} (air). Temperature gradients were maintained by a combination of electrical resistance heaters, sunlight, and computer-controlled ventilation fans along the length of each TGG within four 5.49-m sections or zones. The baseline temperature of the first working zone averaged 1.5°C above outside ambient conditions. Therefore, average temperatures above outside ambient were +1.5°C, +3.0°C, +4.5°C, and +6.0°C for Zone 1, Zone 2, Zone 3, and Zone 4, respectively at baseline temperature, +1.5, +3.0, and +4.5°C. A 3.66-m-long entry section and a 1.83-m-long exit section were not planted to sugar cane. Systems for measurements of temperatures and control of temperature gradients were controlled by a Supervisory Control and Data Acquisition (SCADA) system computer. The controller/data logger was a Keithley Metrabyte "Workhorse" system (Keithley Instruments, Boston MA USA) operated by a PC using FIX DMACS Version 3.03 software program (Intellution, Norwood, MA USA).

A 40.6-cm diameter fan with thermostat was placed at the top of the exit end of each TGG as a fail-safe device. The thermostat setting ranged from a minimum of 35°C during the winter to a maximum of 45°C during the summer.

Soil containers, soil treatments, and cultural practices. Thirty-two 150-gallon containers for soil were placed in each TGG, with 8 soil containers in each of the 4 temperature zones along the TGG length. Each temperature zone had a cluster of four soil containers that had been filled with topsoil of an onsite mineral soil (Arredondo fine sand, a loamy, siliceous, hyperthermic Grossarenic Paleudult of the Order Ultisol) and a cluster of four soil containers that were filled with an organic soil from a site near Florahome, Florida (Okeechobee muck, a euic, hyperthermic Hemic Medisaprist of the Order Histosol) during the first week of March 1997. Before planting and throughout the period of growth, fertilizers containing major and micro elements were applied generally at doses recommended for commercial sugar cane production in Florida (Obreza et al., 1998).

Stems of each of the sugar cane cultivars were provided by Dr. Jimmy Miller, USDA-ARS, Canal Point, Florida USA. On January 13, 1997, the stems were cut at the midpoint of each internode to provide vegetative propagules at each node (vegetative seed-pieces). The seed-pieces were then pre-treated for 30 min in water at 52°C to break dormancy and ensure more uniform regeneration and were planted in a seedbed of 12-cm depth of potting soil in a greenhouse with temperature controlled to 30°C. The seedbed was watered frequently during the growth of the seed-pieces. On March 21, 1997, the top growth was trimmed back to prevent excessive transpiration, and the seedlings were transplanted to the soil containers in the TGGs. Seven plants of four cultivars were transplanted to each soil container and labeled as follows: 1A + 1B, 2A + 2B, 3A + 3B and 4; (cultivar 1 = CP72-2086; cultivar 2 = CP73-1547; cultivar 3 = CP88-1508; cultivar 4 = CP80-1827). Eight similar soil containers were also set up outside the TGGs. There were insufficient seed-pieces of cultivar CP80-1827; therefore only one seed-piece was transplanted to each soil container.

Watering procedures. For convenience in the water treatments, the soil containers that extended toward the east side of the TGGs were selected for the drained soil treatment and the soil containers that extended toward the west side were selected for the high water table treatment (20 cm depth). The water levels of each of the containers of each of the 32 high water table treatments of each TGG were controlled with individual constant water level buckets equipped with float valves. The height of each bucket was adjusted to provide the constant water table level of each soil container as controlled by the float valve. The drained soils were watered manually with a garden hose two to three times weekly. An in-line water meter at the spray nozzle was used to meter water precisely to each soil container. Clear plastic sight tubes were installed on each soil container to avoid overwatering. The amounts of irrigation increased with increasing distance into the TGG to compensate for the increase of evapotranspiration requirements with increasing temperature. Furthermore, the amount of water applied in the high-CO_2 TGG was slightly less to account for the decreased stomatal conductance induced by elevated CO_2. Adjustments to the amount of water applied were made by inspection of the sight tubes before each irrigation. If any residual water was observed, then the amount of irrigation water applied was decreased in quantitative proportion to the level of the water above the bottom of the soil container. This treatment was called ≈ 50 cm drained profile treatment.

Sampling and harvesting. For several purposes beyond the scope of this paper, the detailed sampling of the sugar cane plant-crop beginning in June 1997 was revised with a simpler sampling of subsequent ratoon-crop harvests. On June 24-27, 1997, plants of each sugar cane cultivar in eight of the 32 soil containers in each TGG were harvested for detailed measurements of mainstems and leaves. The mainstem cane was cut about 3 cm above the soil surface and transported immediately to a field laboratory. The leaves were cut from the mainstems for measurements of number of green leaves, leaf area, and leaf fresh weight. The measurements on the mainstems were length of the cane to the top leaf ligule, mainstem fresh weight, and length of sequential internodes. The leaves from each mainstem were bagged and dried for at least one week at 80°C for determination of dry weights. The mainstems were juiced by crushing the canes in a small rolling cylinder mill and subsequently the crushed mainstems were dried at 80°C for dry weight determinations. Juice volume was recorded and both hydrometer and Brix measurements made. Juice dry weight was computed from juice volume and sucrose concentration. Total fresh weights of the remaining stems plus leaves for each cultivar in these eight soil containers were collected over the period June 30 to July 3, 1997. The juice was crushed from the stems and juice volume measured.

For fresh weights only, on July 9-11, 1997, the sugar cane in the remaining 24 of the 32 soil containers was cut and weighed for determination of total fresh weight of stems plus leaves. After weighing the plant materials were discarded. From these complex samplings, all sources of fresh weights were summed to provide data for total aboveground fresh weights of each cultivar in soil container within each combination of TGG (CO_2 treatment), temperature zone, type of soil, and water treatment.

For subsequent harvests, (December 1997, June 1998, and December 1999) total fresh weights of stems plus leaves were measured for each cultivar in eight of the 32 soil containers. Then the leaves were separated from the stems and stems were juiced by crushing in a small rolling mill for juice volume and Brix measurements. Dry matter components of leaves, crushed stems and sugar were determined. The total plant fresh weights in the remaining 24 soil containers of each TGG were determined. For overall aboveground fresh weight analyses, all data were assembled for statistical analyses.

Statistical Analysis. An analysis of variance ANOVA was conducted on various components of the data as presented in the results and discussion section. In many cases, data were pooled across one or more treatments or across the four cultivars or across the four individual harvests. A Duncan's multiple range test was applied to infer statistical differences. The general linear model (GLM) procedure of SAS was used in the data analyses. Interactions were not prevalent and are not reported.

RESULTS AND DISCUSSION

Sugar cane total above-ground fresh weight data were pooled for all cultivars, CO_2 concentrations, temperatures, soil types, and water table depths at the plant crop harvest (June 1997) and for the subsequent three ratoon crop harvests in December 1997, June 1998, and December 1998 (Fig. 1). The fresh weight yield was greatest for the plant crop, but the subsequent harvests were somewhat similar. Since 3/4 of the fresh weights of the plant-cane harvest were not obtained until July 9-11, this delay might have caused higher values in the "June harvest" and lower values in the December 1997 harvest.

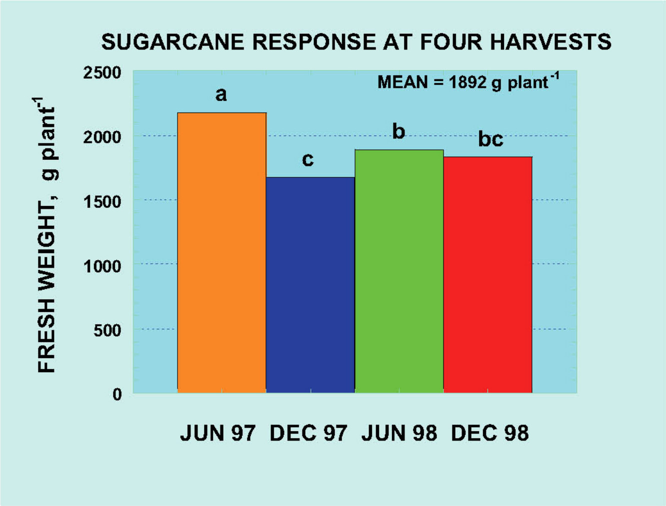

Figure 1. Sugar cane total above-ground fresh weight pooled for all cultivars, CO_2 concentrations, temperatures, soil types, and water table depths at the plant harvest (June 1997) and at three subsequent ratoon harvests. Means of columns with the same letter are not significantly different.

Since none of the four harvests showed a significant response to temperature over the four levels (1.5, 3.0, 4.5, and 6.0°C) above Gainesville ambient, all the fresh weight harvest data were pooled as shown in Fig. 2. Potential global warming would not likely be detrimental to vegetative productivity of sugar cane.

With data pooled across all four harvests, sugar cane fresh weight showed a response to CO_2 concentration, soil type (mineral versus organic), and water treatment

(20-cm water table versus ≈ 50 cm drained profile (Fig. 3). The CO_2-enriched sugar cane had both a larger fresh weight (16% greater) and a larger dry weight (21% greater, data not shown) than the sugar cane exposed to ambient CO_2 concentrations. Plants that were grown in mineral soil rather than organic soil had a greater fresh weight (27% greater) likely because more nitrogen fertilizer had been added to the mineral soil than the organic soil. Plants grown at the controlled water table depth of 20 cm had about 11% greater fresh weight.

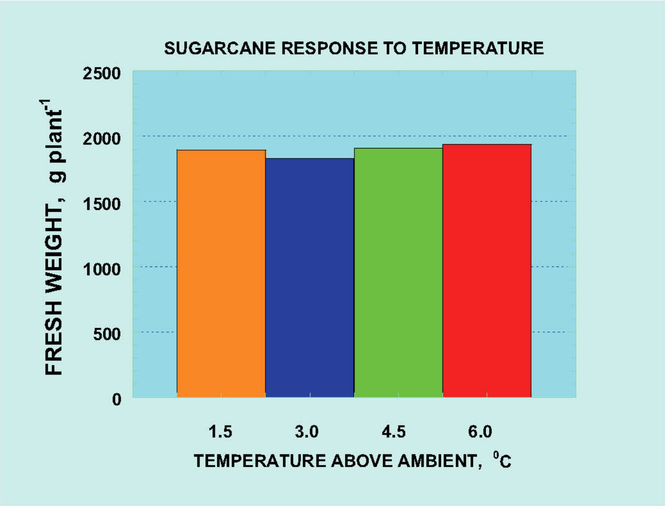

Figure 2. Sugarcane total above-ground fresh weight at four temperatures (above Gainesville ambient temperatures) pooled for all cultivars, CO_2 concentrations, soil types, and water-table depths for the first four harvests. There were no significant differences among temperature treatments.

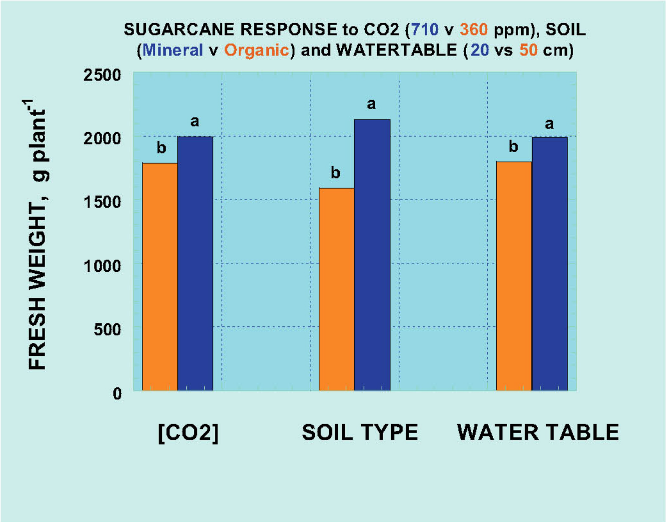

Figure 3. Sugar cane total above-ground fresh weight (pooled across temperatures and four harvests) responses to CO_2 concentration, soil type (mineral vs. organic), and water table depth. Within each treatment, different letters indicate significant differences of mean values.

Sugar cane total above-ground fresh weight responses of each of the four cultivars pooled across all treatments of the first four harvests are shown in Fig. 4. Productivity and survivability of the cultivar CP88-1508 declined continuously after the first plant cane harvest, whereas most of the plants of the other three cultivars survived.

Fresh weight responses to CO_2 enrichment were significant for the first two harvests, but not for the second two harvests (Fig. 5). However, the mean fresh weight responses to CO_2 across all four harvests were significant.

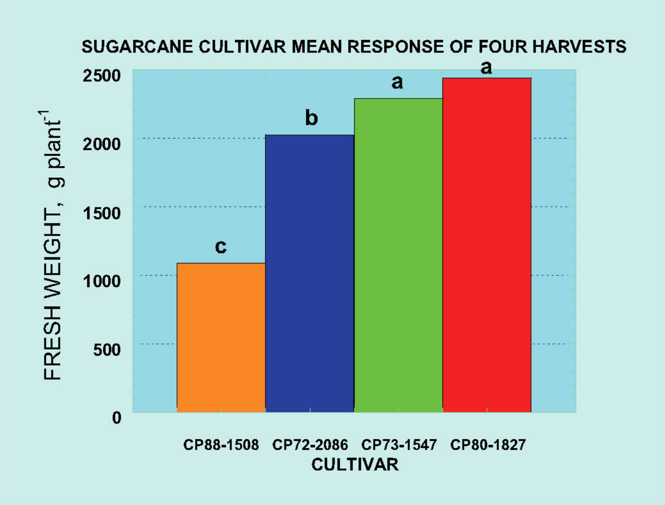

Figure 4. Sugar cane total above-ground fresh weight response of each cultivar pooled across all treatments of the first four harvests. Means of columns with the same letter are not significantly different. Many plants of Cultivar CP88-1508 had failed to survive after the four harvests.

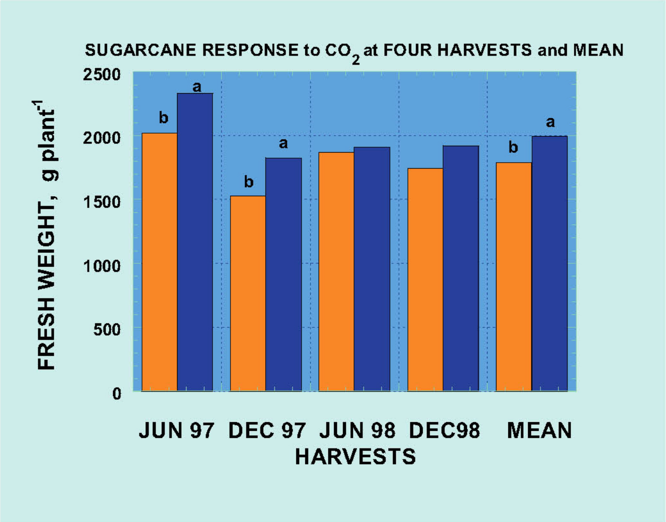

Figure 5. Sugar cane total aboveground fresh weight responses to CO_2 concentration (pooled across all other treatments) for the first four harvests and for the mean of the first four harvests. Paired columns with different letter had significantly different means.

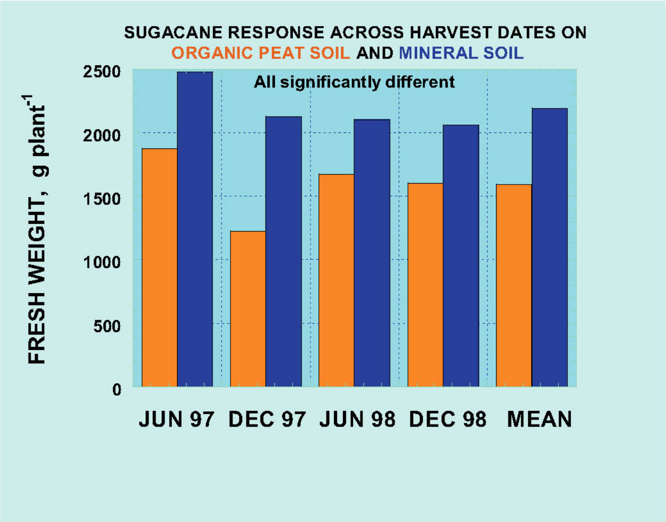

Figure 6. Sugar cane total aboveground fresh weight responses of plants grown in organic peat soil compared with plants grown in sandy mineral soil (pooled across all other treatments) for the four harvests. Mean values of all paired columns were significantly different.

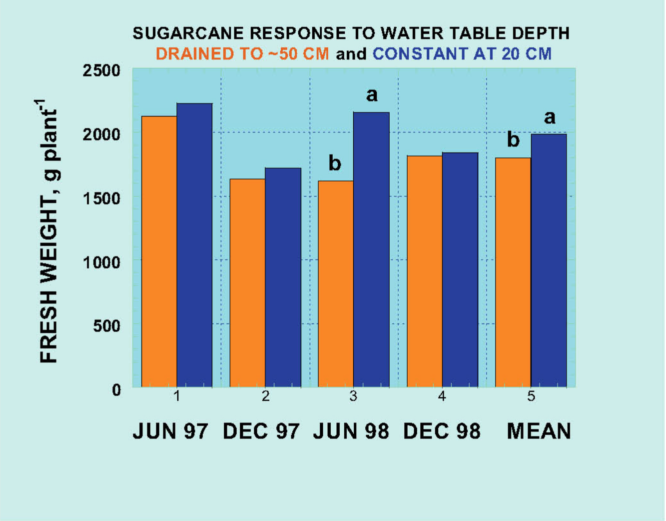

Figure 7. Sugar cane total aboveground fresh weight responses of plants to water table depths. Mean values within paired columns with different letters were significantly different.

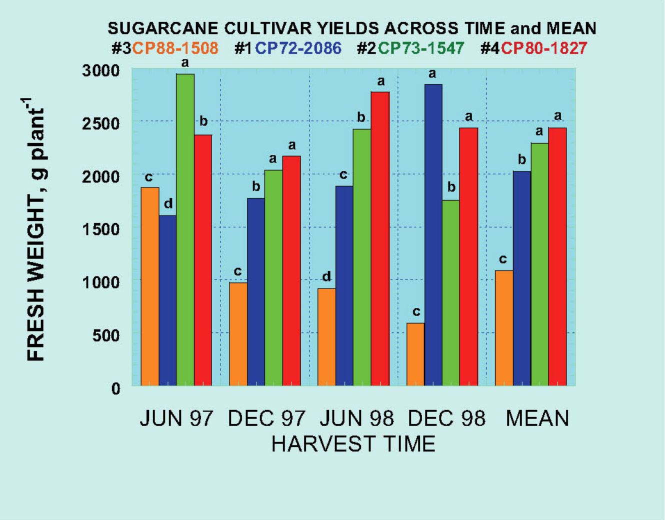

Figure 8. Sugar cane total aboveground fresh weights of the four cultivars compared at each of the four harvest dates and compared for all harvest dates pooled. Within dates, columns with the same letter are not significantly different. Cultivar CP88-1508 declined with each succeeding harvest.

All sugar cane harvests showed significantly larger fresh weight responses of plants grown in sandy mineral soil compared to plants grown in organic peat soil, with data pooled across all other treatments (Fig. 6). This occurred despite the fact that we added equivalent nitrogen to the organic peat soil after the first two harvests. However, it should be pointed out that the organic soil was obtained from sources near Florahome, Florida and the peat might be quite different from the sugarcane producing Histosols of the Everglades Agricultural Area in southern Florida.

Within individual harvests, only the June 1998 harvest showed a significant difference between water treatments, wherein the 20-cm constant water table plants had a higher fresh weight yield (Fig. 7). However, the tendency across all four harvests resulted in the mean data for the four harvests also showing a significantly higher fresh weight yield for the 20-cm constant water table treatment. This finding indicates that sugar cane could be produced in relatively high water table soil, which would be beneficial in ameliorating the microbial oxidative subsidence or organic soils.

Fresh weight yields of the four cultivars across the four harvests are compared in Fig. 8. Growth and fresh weight yields of cultivar CP88-1508 declined sharply after the plant crop. This cultivar did not survive well or compete well with other cultivars. The relative performance of the other three cultivars was somewhat variable but they all survived well after the plant crop harvest.

The final figure shows many of the percentage increase responses of various components of sugar cane growth to elevated CO_2 concentration for the first (plant-crop) harvest (Fig. 9). These responses are pooled across all cultivars and other treatments. Note that percentage increase of juice dry weight (column #11) was greater than percentage increase of stem dry weight (column #6) which in turn was greater than percentage increase in leaf dry weight (column #4). Percentage increase of stem length (column #9) probably contributed to the percentage increase of stem fresh weight (column #5) and percentage increase of juice volume (column #10) which led to the large percentage increase in juice dry weight (column #11), the economically valuable yield product.

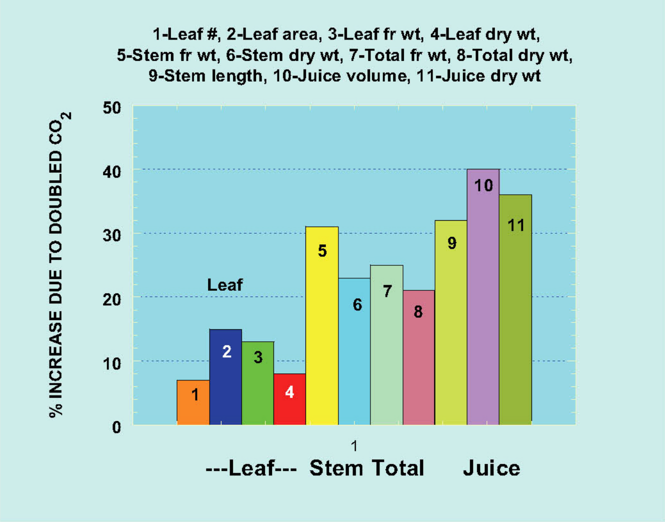

Figure 9. Percentage increases of components of sugar cane in response to elevated CO_2 concentration for the first harvest in June 1997 pooled across all cultivars and other treatments. Note that percentage increase of juice dry weight (column #11) was greater than percentage increase of stem dry weight (column #6) which in turn was greater than percentage increase in leaf dry weight (column #4). Percentage increase of stem length (column #9) probably contribute to the percentage increase of stem fresh weight (column #5) and percentage increase of juice volume (column #10) which led to the large percentage increase in juice dry weight (column #11), the economically valuable yield product.

CONCLUSIONS

Several conclusions can be drawn from the results of this study. First, fresh weight of sugar cane, a C4 crop, responds slightly to a doubled CO_2 concentration. Second, sugar cane did not respond to temperature over the range of treatments in this study. Global warming should not be a problem for this crop. Third, fresh weight production was consistently greater on sandy mineral soil than on organic peat soil in this study. The reason is not known, but it might be related to the source of the peat soil. Fourth, fresh weight productivity was slightly greater in soil with the water table maintained at 20 cm depth than in a drained profile to 50 cm. This finding implies that sugar cane could be grown at high water table in organic soils which would reduce subsidence by microbial oxidation of organic matter. Fifth, cultivars differed in their ability to compete with each other, at least in this system of soil containers in TGGs.

Finally, and most importantly, juice and sugar production appeared to respond more to elevated CO_2 concentration than did the fresh weight (and overall dry weight). This is an important finding, and if confirmed to be generally true, would mean that sugar cane productivity should be enhanced by rising atmospheric CO_2 concentration. This would be even more important since higher temperatures did not adversely affect fresh weight production.

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REFERENCES

Allen, L.H., Jr. 2007. Carbon balance of sugarcane agriculture on Histosols of the Everglades Agricultural Area: Review, analysis, and global energy perspectives. Soil and Crop Science Society of Florida Proceedings 66:00-00 (in press).

Allen, L.H., Jr., S.L. Albrecht, K.J. Boote, J.M.G. Thomas, Y.C. Newman and K.W. Skirvin. 2006. Soil organic carbon and nitrogen accumulation in plots of rhizoma perennial peanut and bahiagrass grown in elevated carbon dioxide and temperature. Journal of Environmental Quality. 35:1405-1412.

Allen, L.H., Jr. and J.C.C. Vu. 2009. Carbon dioxide and high temperature effects on growth of young orange trees in a humid, subtropical environment. Agricultural and Forest Meteorology. 149:820-830.

Gilbert, R.A., C.R. Rainbolt, D.R. Morris, and A.C. Bennett. 2007. Morphological responses of sugarcane to long-term flooding. Agron. J. 99:1622-1628.

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. 95:383-291.

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

Glaz, B., J.C. Comstock, P.Y.P. Tai, S.J. Edme, R. Gilbert, J.D. Miller, and J.O. Davidson. 2005. Evaluation of new Canal Point sugarcane clones - 2003-2004 harvest season. USDA, ARS, ARS-165, 32 pp.

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

Glaz, B., and D.R. Morris. 2006. Sugarcane morphological, photosynthetic, and growth responses to water-table depth. J. Sustainable Agric. 28:77-97.

Glaz, B., S.T. Reed, and J.P. Albano. 2008. Sugarcane response to nitrogen fertilization on a Histosol with shallow water table and periodic flooding. J. Agron. & Crop Sci. 194:369-379.

IPCC. 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, UK.

Knipling, E.B, V.N. Schroder, and W.G. Duncan. 1971. CO_2 evolution from Florida organic soils. Soil Crop Sci. Soc. Florida Proc. 30:320-326.

Morris, D.R. 2005. Dry matter allocation and root morphology of sugarcane, sawgrass, and St. Augustinegrass due to water-table depth. Soil Crop Sci. Soc. Florida Proc. 64:80-86.

Morris, D.R., B. Glaz, and S.H. Daroub. 2004. Organic soil oxidation potential due to periodic flood and drainage depth under sugarcane. Soil Sci. 169:600-608.

Obreza, T.A., D.L. Anderson, and D.J. Pitts. 1998. Water and nitrogen management of sugarcane grown on sandy, high water table soil. Soil Science Society of America Journal. 62:992-999.

Shih, S.F., E.H. Stewart, L.H. Allen, Jr., and J.W. Hilliard. 1979. Variability of depth to bedrock in Everglades organic soil. Soil Crop Sci. Soc. Florida Proc. 38:66-71.

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. Soil Crop Sci. Soc. Florida Proc. 57:20-29.

Snyder, G.H. 2005. Everglades Agricultural Area soil subsidence and land use projections. Soil Crop Sci. Soc. Florida Proc. 64:44-51.

Stephens, J.C., L.H. Allen, Jr., and E. Chen. 1984. Organic soil subsidence. pp. 107-122. In: T.L. Holzer (ed.). Reviews in Engineering Geology, v. VI. Geological Soc. of America.

Stephens, J.C., and L. Johnson. 1951. Subsidence of organic soils in the upper Everglades region of Florida. Soil Crop Sci. Soc. Florida Proc. 11:191-237.

Stephens, J.C., and E.H. Stewart. 1976. Effect of climate on organic soil subsidence. Proceedings of the Second International Symposium on Land Subsidence, Anaheim, CA, 13-17 December 1976. IAHS-AISH Pub. No. 121, pp. 647-655.

Tate, R.L. III. 1979. Microbial activity in organic soils as affected by soil depth and crop. Appl. Environ. Microbiol. 37:1085-1090.

Tate, R.L., III. 1980. Microbial oxidation of organic matter of Histosols. pp. 169-201. In: M. Alexander, (ed.) Advances in Microbial Ecology, vol. 4, Chap. 5. Plenum Publishing Corp.

Tate, R.L.III, and R.E. Terry. 1980. Variations in Microbial activity in Histosols and its relationship to soil moisture. Appl. Environ. Microbiol. 40:313-317.

Volk, B.G. 1973. Everglades Histosol subsidence: 1. CO_2 evolution as affected by soil type, temperature and moisture. Soil Crop Sci. Soc. Florida Proc. 32:132-135.

Vu, J.C.V., Newman, Y.C., Allen, L.H., Jr., Gallo-Meagher, M. and Zhang, M.Q. 2002. Photosynthetic acclimation of young sweet orange trees to elevated growth CO_2 and temperature. Journal of Plant Physiology. 159:147-157.

Vu, J.C.V., Allen, L.H., Jr. and Gesch, R.W. 2006. Up-regulation of photosynthesis and sucrose metabolism enzymes in young expanding leaves of sugarcane under elevated growth CO_2. Plant Science 171:123-131.

Vu, J.C.V. and Allen, L.H., Jr. 2009. Growth at elevated CO_2 delays the adverse effects of drought stress on leaf photosynthesis of the C4 sugarcane. Journal of Plant Physiology. 166:107-116.