SEASONALLY MAINTAINED SHALLOW WATER TABLES IMPROVE SUSTAINABILITY OF HISTOSOLS PLANTED TO SUGARCANE

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ABSTRACT

Subsidence of Histosols, caused by microbial degradation of these drained soils, is a major concern in the Everglades Agricultural Area (EAA) of south Florida. Our objective was to determine if seasonal maintenance of shallow water tables would effectively decrease soil degradation and subsidence while allowing conventional production of sugarcane (*Saccharum* spp.). We compared the effects of seasonally maintained water tables at 0.15 and 0.40 m depths, and the currently practiced 0.60 m depth, on microbial degradation of a Lauderhill soil (Lithic Medisaprist). We maintained seasonal water tables from the beginning of May through September during the typical wet season. Fields were drained to or below 0.6 m from the soil surface during the remainder of the year to allow for conventional harvest and cultural management. We took surface soil samples bimonthly, applied the substrate ^{14}C-benzoate, and monitored $^{14}CO_2$ respiration as an indicator of Histosol degradation. Seasonally maintained water tables at 0.15 and 0.40 m reduced microbial degradation of the organic soil, resulting in modeled subsidence rates of 1.4 cm y^{-1} and 2.0 cm y^{-1}, respectively, when compared to 4.3 cm y^{-1} for the conventional 0.6 m depth. Decreased soil degradation and increased sustainability resulting from shallow water table maintenance was a direct result of increased soil water content and the corresponding decrease in air-filled pore space. Seasonal maintenance of shallow water tables appears compatible with current production practices for sugarcane, and will enable significant conservation of EAA Histosols.

INTRODUCTION

Histosols, the organic soils common to the EAA, are fertile, with high native carbon (C), nitrogen (N), and phosphorus (P) levels. Conventional agricultural practices for sugarcane production in the EAA include maintenance of water tables at or below 0.6 m from the soil surface. The aerobic soil environment created by agricultural drainage enables microbial mineralization of the organic soil, and release of C, N, and P for microbial and plant uptake. Off-loading of excess N and P resulting from soil mineralization has been addressed through development and adoption of on-farm management practices (Izuno et. al., 1995). During soil mineralization, the rate of C lost as carbon dioxide (CO_2) exceeds the rate of C attenuation and storage. This results in land subsidence of up to 4 cm y^{-1} (Stephens and Johnson, 1951; Stephens et al., 1984). However, no sugarcane management practices have been adopted to address the land subsidence issue.

Considering the economic impact of sugarcane production on the EAA region and the state (Schueneman, 1998), it is important to maintain sugarcane production in this region. However, it is also important to explore sugarcane management practices that ensure soil resource and environmental sustainability. One way to reduce microbial degradation and to increase soil resource sustainability is to maintain shallow water tables. This practice would decrease aerobic soil degradation of the organic soil, primarily by reducing the air-filled pore space and the oxygen (O_2) available.

Past research shows that sugarcane is tolerant of, and can be successfully grown in, soils with a seasonally maintained shallow water table (Gascho and Shih, 1979; Kang et. al., 1986; Snyder et. al., 1978). However, past research relating shallow water table management to soil sustainability of EAA Histosols considers only full-season water table maintenance (Stephens and Johnson, 1951; Volk, 1972). The impacts of seasonally maintained water tables on Histosol sustainability are not adequately quantified. We suggest that seasonally maintained shallow water tables can substantially improve soil sustainability, while allowing for current crop management practices and yield. Our objective was to assay the effects of seasonal shallow water table management on soil sustainability.

MATERIALS AND METHODS

The research site was established in 1997 near South Bay, FL (Figure 1) and consisted of seven 6.7 ha fields (180 m x 370 m). The organic soil was a Lauderhill muck soil (Lithic Medisaprist). Bulk density and particle density were determined in the lab and were then used to determine pore space by calculation (Blake and Hartge, 1986a; Blake and Hartge, 1986b; Danielson and Sutherland, 1986).

Three fields under water table management, one each at target water table depths of 0.15 (WT-1), 0.40 (WT-2), and 0.60 m (WT-3) below soil surface (Figure 2), were planted to sugarcane and were separated by four unplanted buffer fields of equal size. Water tables in each field were controlled at the previously mentioned depths using automatically-controlled, diesel-powered pumps positioned at the supply canal inlet and outlet for each experimental field. In response to needs expressed by Glaz (1995), water tables were maintained from approximately May (following Spring germination and stand establishment) through September (Figure 2). This corresponds with the warm, high-rainfall portion of the growing season. During the remainder of the year, fields were drained, with a target water table depth of 0.6 m (Figure 2) to allow for conventional harvest and cultural practices.

Using a stainless steel bucket auger (0.07 m diameter), field soil samples were collected every two months from the surface 0.00-0.15 m of the soil profile, midway between sugarcane rows. We weighed triplicate soil samples, dried them in a 105°C oven for 24 h, and determined soil water content by difference.

Tate (1979a and 1979b) used a substrate-induced respiration assay to successfully model effects of flooded management on microbial decomposition of Histosols of the EAA. We modified the assay, using benzoate instead of salicylate to model organic soil mineralization, as suggested by Williams and Crawford (1983). Williams and Crawford (1983) successfully used benzoate to model degradation of peat similar in many respects to Histosols of the EAA. In concurrent studies the benzoate assay was sensitive to changes in water management on EAA Histosols (data not shown). We applied ^{14}C(carboxyl)-benzoate at a rate of 861 MBq kg^{-1} wet soil (specific activity, 577MBq $\mu mole^{-1}$, Sigma Chemicals, St. Louis, MO).

We assayed 6 homogenous soil samples from each field. We conducted substrate assays at room temperature (22 ± 1° C) within 6 h of sample collection. Substrates were mixed with 10 g (wet weight) of soil from each of the field samples. Samples were incubated for 2 h (Zibilske, 1994), and evolved CO_2 including $^{14}CO_2$ was collected in a 1M NaOH trap solution. Following incubation, we mixed 1 mL of the trap solution with 5 mL of scintillation cocktail (ScintoSafe Plus 50%, Fisher Scientific, Pittsburgh, PA) and determined rate of $^{14}CO_2$ respired by microorganisms in the soil degradation process (Model LS 3801, Beckman Instruments, Fullerton, CA).

Data were analyzed using the Analysis of Variance procedure in SAS v.8 software (SAS, 1999), and statistical differences between means were determined using Fisher's LSD (a=0.05). Regression analysis was also conducted using the SAS v.8 software.

RESULTS AND DISCUSSION

Seasonal shallow water table maintenance treatments resulted in significant differences in soil water content (Table 1). Seasonal maintenance of water tables at the 0.15 m depth (WT-1) significantly increased water content of the surface soil. Only WT-1 caused soil aeration to fall below 10 % air-filled porosity (Table 1), a minimum volume required for adequate soil aeration and aerobic microbial activity (Paul and Clark, 1989). The depth to the shallow water table was highly variable during the free-drainage period resulting in no significant differences in soil water content, however there was a trend for greater soil water content and decreased air-filled porosity with the seasonal WT-1 treatment when compared to either WT-2 or WT-3 treatments (Table 1). While the seasonal shallow water tables were maintained, WT-2 increased soil water content in comparison to conventional water table management (WT-3). This difference was not significant at the a=0.05 level, but was significant at the a=0.10 level.

Assay results (Table 2) indicated shifts in responses to changes in water table management similar in magnitude to those for gross respiration reported by Volk (1972), who evaluated water table impacts on subsidence of EAA Histosols in lysimeters with re-packed soil. During periods of shallow water table maintenance, the conventional water management practice (WT-3) resulted in the greatest assayed microbial activities (Table 2 and Figure 3).

Elevated assay results associated with conventional management (WT-3) indicate significantly reduced sustainability of the organic soil relative to either WT-1 or WT-2, the seasonally maintained shallow water tables. Moreover, when compared to WT-3, seasonal shallow water table treatments generally improved sustainability of organic matter throughout the periods of free drainage (Table 2). We maintained shallow water tables for only four to five months during the warm, wet portion of each year. This suggests that WT-1 and WT-2 result in residual suppression of soil degradation which has not been previously reported for Histosols of the EAA region. This is likely a result of reduced aerobic microbial populations during the beginning of the free drainage periods (Table 1).

The WT-1 treatment resulted in greater overall Histosol sustainability when compared to WT-2 (Table 2). However, maintenance of either WT-1 or WT-2 decreased microbial degradation of the organic soil by up to 50 % when compared to WT-3. This in turn suggests that WT-1 and WT-2 increase Histosol sustainability by as much as two times that of WT-3, the conventional water management practice.

During the short duration of this study, direct measurement of subsidence was not practicable. To relate our benzoate assay to soil subsidence, we regressed our benzoate assay results (periods under shallow water table management) on subsidence rates for full-season shallow water table management as reported by Stephens and Johnson (1951). This regression analysis resulted in the following equation:

$$\text{Subsidence} = 3.63 \times \text{BA} - 1.63 \qquad \text{Adjusted } R^2 = 0.90 \qquad [1]$$

where subsidence is in units of cm y^{-1}, and BA (benzoate assay) is in units of mmoles h^{-1} Mg^{-1}. We then fit our data for overall treatment effects to equation [1], resulting in modeled overall subsidence rates of 1.4 cm y^{-1} and 2.0 cm y^{-1}, for WT-1 and WT-2, respectively. The conventional water management practice, WT-3, resulted in an overall subsidence rate of 4.3 cm y^{-1} using the same fitting procedure.

These estimates are comparable to projections of Stephens and Johnson (1951) that indicate WT-1, WT-2 and WT-3 would result in subsidence rates of 0.6, 2.2 and 3.7 cm y^{-1}, respectively, if maintained throughout the year. Maintaining seasonal shallow water tables for only five months out of a year resulted in projected subsidence rates only slightly higher than those projected by Stephens and Johnson (1951) for full-season shallow water table management. Stephens and Johnson (1951) used elevation changes to measure subsidence rather than an assay. This would take into account decomposition throughout the soil profile. Our projections likely overestimate subsidence rates for the entire soil profile, as they are based on assay of the surface 0.00-0.15 m of the soil profile, and the greatest potential soil degradation rates. Correlation of benzoate assay results with directly measured soil subsidence rates is needed to validate the model for the Lauderhill soil and other Histosols of the EAA.

CONCLUSIONS

As a result of maintaining seasonal shallow water tables for only five months out of a year, our assay indicates subsidence rates slightly greater than that projected for full-season shallow water table management. These data support seasonal shallow water table management as a means of reducing subsidence and improving sustainability of valuable EAA soil resources. Shallow water tables not only increase soil sustainability during the portion of the year when they are maintained, but can also residually increase sustainability during the harvest season when fields are drained. This study should be replicated on other sites with different organic soil characteristics. Improved correlation of assay results to directly measured subsidence rates should show that seasonal water table management is as effective as full-season maintenance in improving soil sustainability.

Given the current sugarcane varieties and production technology, an immediate shift to full-season shallow water table management is not realistic without negatively influencing sugarcane production and the EAA and Florida agricultural economies. WT-2 appears the best fit with current sugarcane varieties and production technology. The WT-1 treatment provides the greatest potential increase in soil sustainability. Research should be conducted to develop new sugarcane varieties suitable for production under seasonally maintained shallow water tables.

Shih and others (1997) reported decreased subsidence rates for the last 10 years based on changes in soil elevation on known transects throughout the EAA. They attribute decreased subsidence in part to shallow water table management, a result of Best Management Practice implementation for P off-loading (Shih et al., 1997). Decreased soil degradation and mineralization would result in reduced nutrient off-loading as indicated by Davis (1991). Future research should also address the effects of seasonal shallow water table management on nutrient off-loading. Improved sugarcane management including shallow water table maintenance can be an environmentally and economically sound production system. As a conservation practice, seasonal shallow water table management could double the production life of valuable EAA soil resources.

ACKNOWLEDGEMENTS

We express our appreciation to the Florida Sugar Cane League, Clewiston, FL, for financial support, and the U.S. Sugar Corporation, Clewiston, FL, for providing and maintaining the research site. We thank Dr. Robert Tate III, Department of Environmental Sciences, Rutgers University, New Brunswick, NJ, for consultation on methodology. We also thank Drs. Joan Dusky and Van Waddill of the Everglades Research and Education Center, Belle Glade, FL, for providing equipment and facilities for this research project.

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Table 1. Treatment impacts on soil water content and air-filled porosity for the period when shallow water tables were maintained, for the drained period enabling conventional harvest and cultivation, and for the water management practice overall.

	Average Soil Water Content [Air-Filled Porosity[†]]		
Treatment	Shallow Water Table	Drained	Overall[‡]
	m^3m^{-3} [%]		
WT-1[§]	0.77 [1] a[¶]	0.72 [6] a	0.74 [4] a
WT-2	0.67 [11] b	0.59 [19] a	0.62 [16] b
WT-3	0.59 [19] b	0.59 [19] a	0.59 [19] b

[†] Air-filled porosity determined as the difference between calculated total porosity and volumetric water content.

[‡] Overall refers to the overall water treatment effect, being the average water content or air-filled porosity for the entire year, including the periods of shallow water table management and free drainage.

[§] Treatments are based on the depth at which the seasonal shallow water table was maintained with WT-1=0.15 m depth, WT-2=0.4 m depth, and WT-3=0.6 m depth.

[¶] Statistical comparisons are valid in a soil depth, within a column. Means followed by the same letter are not significantly different (Fisher's LSD, a = 0.05).

Table 2. Water management impacts on the benzoate assay of soil degradation for the period when shallow water tables were maintained, for the drained period enabling conventional harvest and cultivation, and for the water management practice overall.

	Benzoate Assay of Histosol Degradation		
Treatment	Shallow Water Table	Drained	Overall[†]
	mmoles h^{-1} Mg^{-1} dry soil		
WT-1[‡]	0.68 a[§]	0.97 a	0.84 a
WT-2	0.95 b	1.05 a	1.00 b
WT-3	1.50 b	1.71 a	1.63 b

[†] Overall refers to the overall water treatment effect, being the average benzoate assay of Histosol degradation for the entire year, including the periods of shallow water table management and free drainage.

[‡] Treatments are based on the depth at which the seasonal shallow water table was maintained with WT-1=0.15 m depth, WT-2=0.4 m depth, and WT-3=0.6 m depth.

[§] Statistical comparisons are valid in a soil depth, within a column. Means followed by the same letter are not significantly different (Fisher's LSD, a = 0.05).

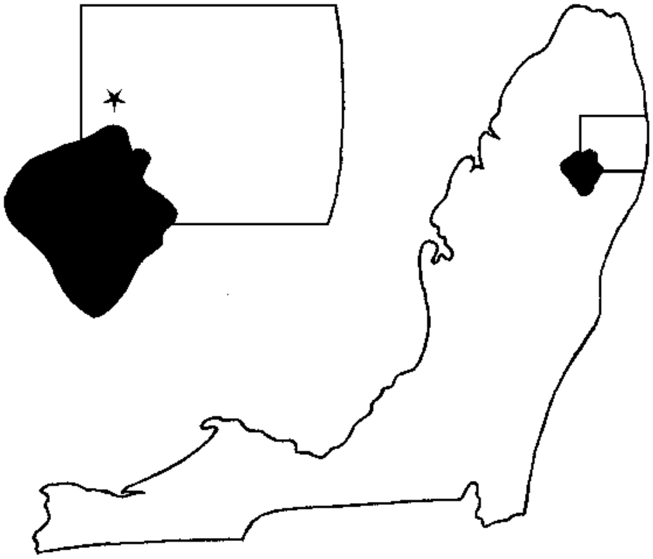

Figure 1. The research site (★) located in the Everglades Agricultural Area lies south of Lake Okeechobee (shaded black) in western Palm Beach County, Florida.

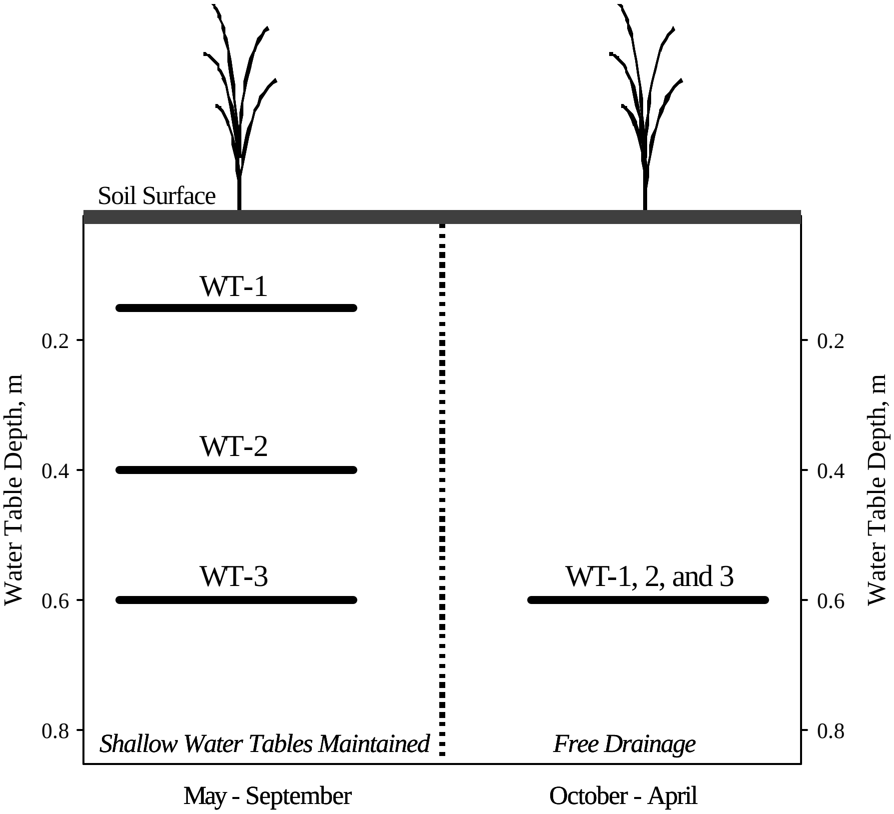

Figure 2. Water table depth for each treatment [WT-1=0.15 m depth, WT-2=0.4 m depth, and WT-3=0.6 m depth] during seasonal shallow water table maintenance and during free drainage.

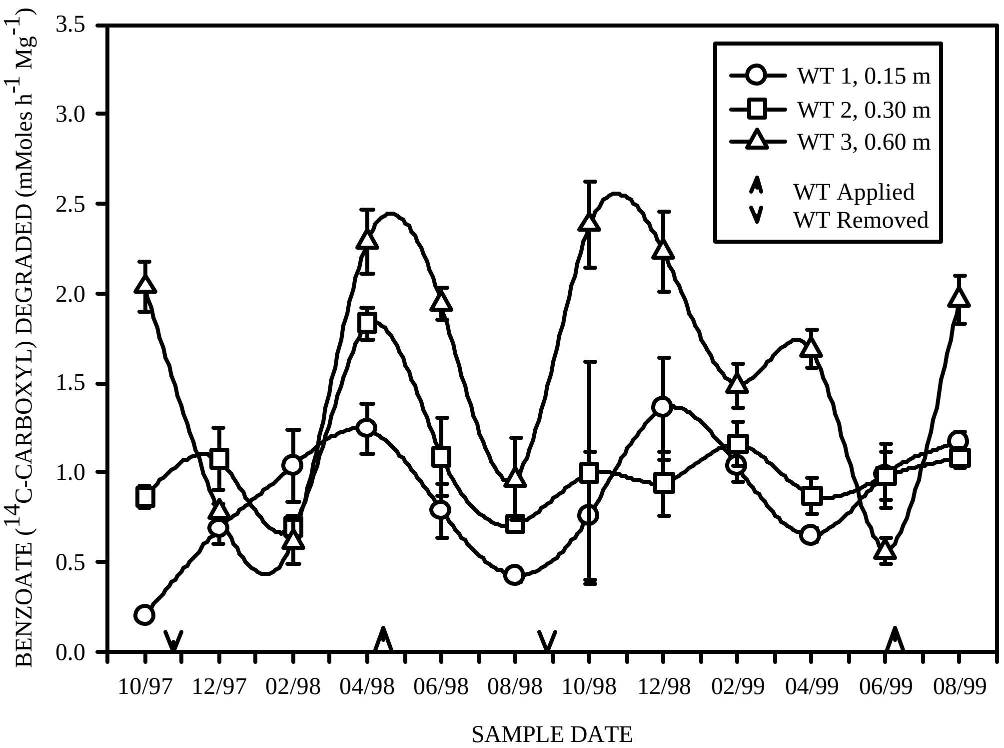

Figure 3. Study-long assay results as affected by water table management. Error bars indicate standard error of the mean. Treatments are based on the depth at which the seasonal shallow water table was maintained with WT-1=0.15 m depth, WT-2=0.4 m depth, and WT-3=0.6 m depth.