DIVISION S-10—WETLAND SOILS

Organic Matter Oxidation Potential Determination in a Periodically Flooded Histosol under Sugarcane

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ABSTRACT

Histosols of the Everglades Agricultural Area (EAA) are subsiding primarily from aerobic microbial oxidation. An experiment was conducted in a Histosol to evaluate methods [^{14}C-benzoate oxidation (BO), soil respiration (CO_2 evolution; RESP), and microbial biomass carbon (MBC)] of determining short-term organic matter (OM) oxidation potential under alternate flood and drain management. Sugarcane (interspecific hybrids of *Saccharum* species) was grown in field lysimeters containing Pahokee muck soil (euic, hyperthermic Lithic Haplosaprist). Soils were flooded for 7 d followed by drainage to three depths (16, 33, and 50 cm) for 14 d. A continuously drained control treatment was also included. Thus, soils under four flood and drain cycles were sampled during the drain period. Increased water table levels after flooding reduced BO, tended to increase MBC, and had little effect on RESP. Consequently, BO was not correlated with either MBC or RESP, which suggests that microbes responsible for OM oxidation are a small portion of the total microbial population. Alternate flooding and draining increased BO compared with the drain control. Soil moisture (SM) and soluble organic carbon (SOC) were both negatively correlated with BO, but not with either MBC or RESP. Soil moisture and SOC may provide alternate indicators for OM oxidation potential. Since BO responded according to soil OM oxidation on the basis of field measurements previously reported, BO was the best of the three methods for predicting short-term effects of water table management on soil OM oxidation potential.

Histosols of the EAA are subsiding at a rate of 1.4 cm yr^{-1} (Shih et al., 1998). Most of the subsidence is due to soil loss resulting from aerobic microbial activity (Tate, 1980a). Currently, continual net oxidative losses from these organic soils have a negative impact on farmers in the EAA because there are only about 0.3 to 1 m of soil left on top of limestone bedrock (Ingebritsen et al., 1999).

An additional problem for producers is mineralization of P from soil OM. Phosphorus release from OM oxidation has been estimated at 72 kg ha^{-1} yr^{-1} (Diaz et al., 1993). Since federal and state governments have targeted P for reductions in the waterways, producers must reduce P levels in drainage waters by 25%, pay a land use privilege tax of \$61.50 ha^{-1} yr^{-1}, and follow best management practices to reduce P levels in waterways (Izuno et al., 1999). Best management practices to control both soil oxidation and P losses include maintaining water tables as high as possible without jeopardizing crop yields and growing crops that are tolerant to high water table levels (Anderson and Flaig, 1995).

There are few methods that can be used to monitor soil loss under replicated field experiments (Lal, 1998). Soil subsidence in the EAA was measured approximately every 5 yr from the early 1900s until 1978 by surveying marker posts driven to bedrock (Shih et al., 1997). Marker posts cannot be placed in sugarcane fields because they would easily be damaged by heavy equipment that must pass through the fields during planting, fertilizing, cultivating, and harvesting. Short-term methods to monitor OM degradation potential under cropped conditions are necessary to evaluate the effects of crop and water table management practices in the EAA to reduce or prevent soil loss and mineralization of P. Three methods have potential for use. The first method applies a recalcitrant ^{14}C-labeled substrate to the soil to measure the oxidative activity of microorganisms. The second method measures soil CO_2 evolution to determine microbial respiration, and the third method estimates soil MBC to indicate changes in microbial populations.

The ^{14}C-labeled organic compound method was used by Tate and Terry (1980) who reported that oxidation of aromatic ring compounds (^{14}C-labeled salicylate) in aerobic Histosols was correlated to moisture content of the soil. Under flooded conditions for 25 d, measuring catabolism from aromatic ring compounds (salicylate) was better than measuring catabolism from simple carbohydrates (glucose) and amino acids (mixture), because the aromatic ring compound was more resistant to decomposition than the other chemicals (Tate, 1979a). In another study, extrapolation of oxidation rates from ^{14}C-labeled acetate and succinate applied to soil taken from a drained field showed close agreement with actual long-term rates for soil loss calculated from field marker posts (Tate, 1979b). Disadvantages for using the ^{14}C method are the high cost of purchasing and disposing of labeled compounds, and compliance with federal and state regulations regarding use of radioactive substances.

Carbon dioxide evolution by soil microorganisms is a direct measure of soil C loss and has been used to measure subsidence potential from fallow organic soil (>85% OM) in the laboratory (Knipling et al., 1970; and Volk, 1973). However, when plant roots are present,

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Published in Soil Sci. Soc. Am. J. 68:994–1001 (2004).

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Abbreviations: BO, ^{14}C-benzoate oxidation; EAA, Everglades Agricultural Area; MBC, microbial biomass carbon; OM, organic matter; RESP, soil respiration (CO_2 evolution); SM, soil moisture; SOC, soluble organic carbon; T7, temperature at the 7-cm depth.

CO_2 evolution may overestimate subsidence because plant roots contribute as much as 40% of the total CO_2 respiration in the rhizosphere as shown for a mineral soil (<5% OM) (Cheng et al., 1993). In Histosols, the relative contribution of CO_2 respiration from plants and microbes has not been reported. Since Histosols in the EAA often contain >85% OM in the upper 21 cm of their profiles (Zelazny and Carlisle, 1974), it is possible that the influence of microbial respiration is much greater than that from plant roots. Therefore, measuring CO_2 evolution could provide an accurate method to monitor OM oxidation potential with different water table management schemes.

Microbial biomass is an important portion of the soil OM, ranging between 7 and 66 mg biomass C g^{-1} total C in organic soils (Tate and Terry, 1980). Estimation of MBC has been reported to be a sensitive indicator for detecting changes in SM and input of organic materials over the crop season (He et al., 1997). Since increasing the water table reduces soil O_2 levels, which results in lower populations of aerobic microorganisms (Robert and Chenu, 1995), monitoring MBC is likely a viable method to determine potential soil OM oxidation at varying water table depths.

An experiment was conducted in a Histosol to evaluate methods (BO, RESP, and MBC) of determining short-term OM oxidation potential under alternate flood and drain management. Sugarcane was used because it is grown on about 80% of the land area in the EAA (Izuno et al., 1999). Results from this study should provide a better understanding of the relationships among microbial parameters in soils planted to sugarcane and improve our basis for making water table management recommendations that will result in better control of soil oxidation rates.

MATERIALS AND METHODS

Lysimeters

Polyethylene containers (lysimeters, 1.5 m wide by 2.6 m long by 0.6 m deep; Part no. T60015, Chemical Containers, Inc., Lake Worth, FL) were placed into the ground, outside, and filled with Pahokee muck soil. The containers were deep enough to obtain appropriate root development, because >85% of sugarcane root mass is located between the 0- and 40-cm soil depth (Gascho and Shih, 1983). The soil was collected in a field from 0- to 20-, 20- to 40-, and 40- to 60-cm horizons. Each soil horizon was thoroughly mixed and placed into the lysimeters at the depth that corresponded from which it was collected. Soil in the lysimeters were packed after each horizon addition. Resulting bulk densities at 15- and 30-cm depths (0.29 and 0.21 g cm^{-3}, respectively) were within the range of bulk densities of EAA soil (Lucas, 1982).

Each lysimeter was equipped with one pump to move excess water out. Pumps were regulated by ball floats located inside the lysimeters that switched a solenoid valve to an on or off position, depending on the water table level. A timer regulated another solenoid valve in each lysimeter to allow well water to enter the lysimeters once per day for 2 min., which amounted to a total volume of 40 L. Onsite observations of lysimeters containing sugarcane in grand growth stage of development (time of greatest rate of dry matter accumulation; Fageria et al., 1997), indicated that this volume of water was sufficient to maintain daily water table levels within 5 cm. The well water entered each lysimeter through a perforated pipe that ran down one side and then diagonally across its bottom. Water was allowed to enter from the bottom of the lysimeter because most water enters fields in the EAA from canals by passing through cracks in the bedrock and horizontally through the soil profile.

Before initiation of the experiment, soils in the lysimeters were sampled between the 0- to 15-cm depth and analyzed for nutrient content (Sanchez, 1990). On the basis of soil-test recommendations for sugarcane, we applied 19 and 139 kg ha^{-1} of elemental P as $Ca(H_2PO_4)_2$ and K as KCl, respectively. In addition, a commercial micronutrient mix (Product F-503 G, Frit Industries, Ozark, AL) containing B, Cu, Fe, Mn, Mo, and Zn were uniformly applied across the soil surface at elemental rates of 0.1, 0.1, 0.7, 0.3, 0.1, and 0.3 kg ha^{-1}, respectively. Nitrogen was not applied because mineralization rates of EAA organic soils may be as high as 1200 kg N ha^{-1} yr^{-1} (Terry, 1980). Consequently, fertilizer N is not recommended for sugarcane growing in Histosols of the EAA (Sanchez, 1990). Average soil pH (water) was 7.8, which is expected for these soils because they overlay limestone bedrock (Anderson and Ulloa 1989; and Sanchez, 1990).

Planting

On 1 Feb. 2001, lysimeters were drained and two rows of sugarcane stalk pieces (≈45-cm length) were planted along the greatest length in each lysimeter at a row spacing of 1.2 m. Two genotypes were selected from a group of high-yielding genotypes in the final selection stages of a breeding program at the USDA–ARS Sugarcane Field Station, Canal Point, FL. Within each lysimeter, one row of sugarcane was genotype CP 95-1376 and the other row was genotype CP 95-1429. After planting, water tables were raised to 16 cm for 2 wk to allow for rapid eye germination on stalks pieces, followed by 33-cm water tables until the plants were established and treatments imposed on the lysimeters.

Treatments

Four water table treatments were arranged in a randomized complete block design with three replications starting on 3 Apr. 2001: (i) continuously drained to a 50-cm depth, (ii) flooded for 7 d followed by drainage to a 50-cm depth for 14 d, (iii) flooded for 7 d followed by drainage to a 33-cm depth for 14 d, and (iv) flooded for 7 d followed by drainage to a 16-cm depth for 14 d. All water table treatments were cycled continuously during the summer growing season. Water level for flood treatments during the flooded periods were maintained 0 to 5 cm above the soil surface. The 7-d flood was chosen because EAA soils planted with sugarcane are rarely flooded for more than a week after heavy rains. The 14-d drainage period was selected to allow for recovery of the aerobic microorganisms. The length of time needed for stability of microbial activity and mass in Histosols after short periods of flood has not been reported.

Soil Sampling

Soils under four consecutive flood and drain cycles were sampled from 16 July through 3 Oct. 2001. Within each cycle, soil samples were taken during the drain period at 0, 3, 7, and 14 d of drainage. A soil sample was also taken during the flood period on the day immediately before drainage (−1 d). Thus, the −1 and 0 represent the last day of flood and first few hours of drain, respectively. A sample was not taken on the last day of flood from the continuously drained treatment

because there was no flood period in that treatment. At each sampling date, six soil samples were taken between the two rows of sugarcane from both ends of each lysimeter at the 0- to 15-cm depth with a 2-cm diameter probe. The six soil samples from the ends of the lysimeters were then composited to provide two subsamples for each lysimeter. One soil temperature (T7) measurement was taken from each lysimeter at the 7-cm depth.

Soil Analysis

On the same day of sampling, SM was determined gravimetrically and BO was measured by benzoate with a ^{14}C-carboxyl label according to the method of Tate (1979b). Soil samples were mixed thoroughly inside plastic bags. All samples were analyzed by adding 0.5 mL of deionized water containing 12 nmol ^{14}C (carboxyl)-benzoate (specific activity of 344 mBq μmol^{-1}) to 10 g fresh soil inside a glass culture tube (20 × 150 mm). Benzoate was used because it is a major intermediate in the decomposition of aromatic compounds that are prevalent in organic soil, and it worked well in evaluating potential soil degradation in other organic soil studies (Williams and Crawford, 1983). The culture tube was stoppered, and the contents were mixed end-over-end, 20 times. The samples were then incubated for 2 h while a stream of air was passed over the soil surface and into 10 mL of 1 *M* NaOH trap solution. The apparatus was similar to that described by Zibilske (1994). At the conclusion of the incubations, the NaOH trap solution was analyzed for $^{14}CO_2$ content using a scintillation counter (Model LS 3801, Beckman, Inc., Fullerton, CA). The quantity of CO_2 evolved was calculated based on ^{14}C content in benzoate.

Soil samples had different moisture contents ranging from 1.0 to 3.2 g H_2O g^{-1} dry soil, which resulted in every sample having a different substrate concentration. Because enzyme activity depends on substrate concentration, all data were adjusted to the average substrate concentration (1.67 μM) after ^{14}C evolution analysis for microbial activities. Adjustments could be made because substrate was applied at less than saturating concentrations. At the levels of substrate applied in this study, there was a linear relationship between microbial activity and substrate concentration with origin at 0 for all treatments (Morris and Snyder, 2002). The adjustments to average substrate concentration was done according to the following equation:

$$Y = mX + a \quad [1]$$

where Y = microbial activity, m = slope, X = substrate concentration, and a = intercept. In the situation with a linear enzymatic relationship between microbial activity vs. substrate concentration and the intercept is 0, the following relationship applies:

$$Y_N = \frac{(Y_A - Y_O)}{(X_A - X_O)}(X_N) + a = \frac{(Y_A - 0)}{(X_A - 0)}(X_N) + 0 = \frac{Y_A}{X_A}X_N \quad [2]$$

where Y_N = adjusted microbial activity at mean substrate concentration X_N, Y_O = microbial activity at the origin, Y_A = actual microbial activity obtained from soil sample, X_O = substrate concentration at the origin, X_A = actual substrate concentration calculated from moisture content in sample, X_N = mean substrate concentration used for all samples in the experiment.

Soil respiration was determined at time of soil sampling with a RESP module (9.8-cm diam. by 10.2 cm high) attached to a photosynthesis meter (Model CI 301 PS, CID, Inc., Camas, WA). The system was closed (air outside the chamber was not allowed to enter during RESP measurements), air was circulated inside the chamber and photosynthesis meter by two circulating fans and one small pump, respectively. Soil respiration was measured in situ on both ends of each lysimeter by manually placing the open end of the respiration module on the soil surface. To prevent outside air contamination entering the photosynthesis meter, the module was gently pressed into the soil to a depth of 1 cm. After each module positioning in the lysimeters, a computer program in the respiration instrument was manually activated, and a single CO_2 concentration was automatically calculated after a 30-s stabilization period and recorded to a data logger. Data collected included CO_2 evolution rate.

Microbial biomass C was determined by the fumigation extraction method of Wu et al. (1990). For each extraction, 5 g of soil plus 20 mL of extractant (0.5 *M* K_2SO_4) were used. Soil samples were shaken for 1 h and the extractant before and after chloroform fumigation was analyzed for organic C by high-temperature combustion (Dohrmann Model DC 190, Rosemount Analytical, Inc., Santa Clara, CA) (USEPA, 1987). Organic C in the extraction before fumigation was used to estimate SOC. Soluble organic C was monitored because it is a readily available energy source for microorganisms.

Statistical Analysis

The three replications of the four water table treatments (12 lysimeters) were arranged in a randomized complete block design. All statistical analyses were performed with PROC MIXED with the SAS statistical software package (SAS Institute, 1999). Data were analyzed as a split-plot design with cycles as repeated measures. The split plot was measurement day. On the basis of procedures described by Tao et al. (2002), the compound symmetry model (type = CS) was used to describe repeated measures covariance in all analyses. Correlations among BO, RESP, MBC, SOC, SM, and T7 were determined on sample means (days after drainage for each water table treatment). Significant and highly significant differences were identified at $P \leq 0.05$ and $P \leq 0.01$, respectively.

RESULTS

Oxidation Potential

Analysis of variance of BO indicated that water table depth, cycle, and the water table depth × day interaction were statistically significant ($P < 0.05$) (Table 1). Effect of day and water table depth × cycle, day × cycle, and water table depth × day × cycle interactions were not significant. Our discussion for BO as well as RESP, MBC, SOC, SM, and T7 will focus only on water table depth × day interaction. Because cycle effects were due to uncontrolled weather patterns and/or plant growth during the summer, we were unable to partition their individual effects. Consequently, all figures show the water table treatment at each sampling day averaged across cycles.

The effects of water table levels and days of drainage on BO is illustrated in Fig. 1A. The −1 d represents the last day of flooding. The drain cycle started on Day 0. For the continuously drained treatment, no sample was taken on the last day of flooding. The continuously drained treatment had a mean BO rate of 415 nmol CO_2 kg^{-1} soil h^{-1} averaged across the 14 d of drain. The

Table 1. Sources of variation and probabilities of >*F* from ANOVA for nine parameters.†

Source of variation	Probability > *F*					
	BO	RESP	MBC	SOC	SM	T7
Water (W)	0.04	0.02	0.05	0.18	0.14	0.19
Day (D)	0.13	<0.01	<0.01	<0.01	<0.01	<0.01
W × D	0.04	0.02	0.41	<0.01	<0.01	0.62
Cycle (C)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.00
W × C	0.53	0.43	0.03	0.41	0.25	0.23
D × C	0.20	0.01	<0.01	<0.01	<0.01	<0.01
W × D × C	0.52	0.60	0.84	0.81	0.88	0.03

† BO, benzoate C oxidation; MBC, microbial biomass carbon; RESP, soil respiration; SM, soil moisture; SOC, soluble organic carbon; T7, temperature at the 7-cm soil depth.

flood and drain 50-cm water table treatment had rates of BO greater than the continuously drained treatment, up to 3 d of drain (Fig. 1A). The BO in this treatment reached a maximum steady state of 482 nmol CO_2 kg^{-1} soil h^{-1} at about 3 d of drainage. The BO at the 16-cm water table declined from 346 to 297 nmol CO_2 kg^{-1} soil h^{-1} from −1 to 14 d of drainage, while the 33-cm water table rose slightly from 339 to 354 nmol CO_2 kg^{-1} soil h^{-1} from −1 to 14 d of drain. On sample Days 3, 7, and 14, the treatment that was periodically flooded and drained to a 50-cm water table had the highest BO, followed by the treatment continuously drained to 50 cm, followed by the treatment that was periodically flooded and drained to 33 cm (Fig. 1A). Also, the treatment periodically flooded and drained to 16 cm had the lowest BO.

Soil Respiration

For RESP, the water table depth, day, and water table depth × day interaction were statistically significant (Table 1). Among the flood and drain treatments within 3 d after drain, there generally were no significant differences in CO_2 evolution responses (Fig. 1B). The RESP from the continuously drained treatment remained constant at 24 μmol CO_2 m^{-2} s^{-1} throughout the 14-d drain period. On the day of drainage (0 d), there was a spike in CO_2 production from all of the flood and drain treatments that was greater than the continuously drained treatment. The peak reached a mean flux of 60 μmol CO_2 m^{-2} s^{-1}. By 1 wk after flooding, all treatments had similar rates of CO_2 evolution with a mean of 26 μmol CO_2 m^{-2} s^{-1}. After 7 d of flood (−1 d), the rate of CO_2 evolution from the soil was not completely eliminated; a mean flux of 2 μmol CO_2 m^{-2} s^{-1} was observed.

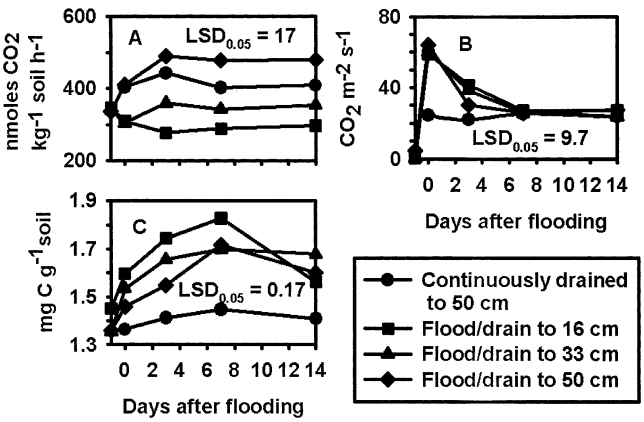

Fig. 1. Mean benzoate C oxidation (A), soil respiration (B), and microbial biomass (C) averaged across the drainage period as influenced by water table treatments. The least square difference of the mean (LSD) was calculated from the day × water table interaction.

Microbial Biomass Carbon

The effect of water table depth and day were significant on MBC, while water table depth × day interaction was not significant (Table 1). After drainage, MBC increased with lower water table depths (Fig. 1C). The MBC increased to a maximum at Day 7 in all flood and drain water table treatments, then declined slightly during the remaining 7 d. The continuously drained treatment had the lowest MBC with a mean of 1.41 mg C g^{-1} soil averaged across the drainage cycle.

Soil Environment Parameters

Soluble Organic Carbon

Soluble organic C was affected by day and water table depth × day interaction (Table 1). Among the flood and drain treatments, increasing the height of the water table tended to increase the SOC (Fig. 2A). After 3 d, the treatment that was continuously drained to a 50-cm water table and the flood followed by drainage to 50-cm water table treatment had similar SOC contents with a mean of 732 μg C g^{-1} soil. Soluble organic C in the flood and drain treatments peaked on the last day of flood (−1 d) with a mean of 927 μg C g^{-1} soil. Soil SOC

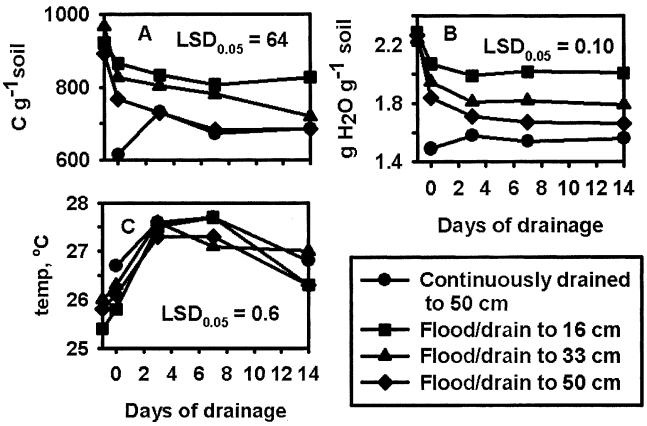

Fig. 2. Mean soluble organic C (A), soil moisture (B), and soil temperatures at the 7-cm depth (C) averaged across the drainage period as influenced by water table treatments. The least square difference of the mean (LSD) was calculated from the day × water table interaction.

Table 2. Linear correlation coefficients (r) between soil benzoate C oxidation (BO), respiration (RESP), microbial biomass carbon (MBC), soluble organic carbon (SOC), soil moisture (SM), and temperature at the 7-cm depth (T7).†

Parameter	RESP	MBC	SOC	SM	T7
BO	−0.11ns‡	−0.22ns	−0.65**	−0.65**	0.19ns
RESP	–	0.26ns	−0.19ns	−0.22ns	−0.14ns
MBC		–	−0.06ns	<−0.01ns	0.47*
SOC			–	0.95**	−0.53*
SM				–	−0.62**

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.
† The means (n = 19) are calculated from the day × water table treatment data as shown in Fig. 1 and 2.
‡ ns, not significant at the 0.05 level of probability.

then declined during the next 7 d. The SOC response of the drain treatment during the 14-d drain period was one that fluctuated about a mean of 676 μg C g^{-1} soil.

Soil Moisture

Soil moisture content was affected by day and water table depth × day interaction (Table 1). All flood treatments had similar SM on Day −1 with a mean of 2.3 g H_2O g^{-1} soil (Fig. 2B). The SM content in the continuously drained treatment (averaging 1.6 g H_2O g^{-1} soil across the 14-d drain cycle) were the lowest of all treatments. Soil moisture contents of the flood and drain treatments declined after 3 d of drainage to a steady state with means of 2.0, 1.8, and 1.7 g H_2O g^{-1} soil for the 16-, 33-, and 50-cm water table treatments, respectively.

Soil Temperature

The T7 was affected by day (Table 1), with the responses among water table treatments being similar across the 14-d drain period (Fig. 2C). Temperature averaged across all water table treatments tended to increase up to 3 d after drainage followed by a decline. Ranges of temperatures were 25.4 to 27.7°C.

Correlations

Analyses indicated no correlations among BO, RESP, and MBC. However, BO was negatively correlated with SOC and SM (Table 2). Microbial biomass C was positively correlated with T7. Soluble organic C was influenced by water table since it was positively correlated with SM.

DISCUSSION

Significant correlations among BO, RESP, and MBC were expected. These indicators of microbial activities and populations were anticipated to increase or decrease in unison according to increase or decrease of O_2 diffusion into the soil because of water table treatments (Volk, 1973; Tate, 1979a; Reddy, 1987; Robert and Chenu, 1995). Higher water tables decrease O_2 diffusion, while the reverse is true for lower water tables. However, our data did not validate these expected relationships among microbial activities and populations (Table 2). Apparently, BO and RESP represent activities from different parts of the overall microbial population. Furthermore, our results show that MBC, which reflects the total microbial mass, cannot be used as an indicator of either BO or RESP.

To detect differences in oxidation potential due to water table treatment, BO was preferable to RESP and MBC because BO tended to decrease as the depth to water table was reduced (Fig. 1A). This is the known response based on field measurements across long periods of time. Stephens et al. (1984) reported on long-term soil subsidence mostly from microbial oxidation in cropped Histosols from several countries around the world. Their study indicated that when soil loss was plotted against water table depth (32–82 cm), positive linear prediction equations resulted from data analysis. Our data in the time period between 3 and 14 d of drain corroborate those of Tate (1979a, 1979b) suggesting that short-term measurements by BO depicts significant differences of soil OM oxidation potential because of water table treatment.

The flood followed by drainage to 50-cm water table tended to have greater BO than the continuous 50-cm water table treatment (Fig. 1A). This is also explainable in that alternate wetting and drying increases the rate of mineralization. Terry (1980) and Diaz et al. (1993) incubated organic soils under wetting and drying conditions in the laboratory. Terry (1980) indicated that N mineralization was doubled after 84 d of alternate wet and dry cycles compared with soil at 0.03 MPa SM. Diaz et al. (1993) showed that as much as 1.2 to 6.4 times more total P was released after flooding compared with continuously drained soils.

At the 16-cm water table, the BO tended to decrease during the drain period compared with the flooded state (Fig. 1A). This lowering of BO may have been because of sugarcane plants exerting a negative influence on BO by roots reducing O_2 levels in the soil through respiration or excretion of toxic substances (Drew, 1997; Bowen and Rovira, 1999). Other research has shown that plants can exert a negative influence on OM oxidation. Tate (1980b) collected soil samples from fallow, sugarcane, and St. Augustinegrass fields and reported that there was greater oxidation of ^{14}C-labeled salicylate under St. Augustinegrass compared with sugarcane or fallow. On the basis of a 7-yr field experiment with marker posts, Shih et al. (1978) showed there was about 30% less soil subsidence in sugarcane fields compared with pasture and truck crops. The influence of sugarcane on reducing BO in high water tables will require further investigation.

Another aspect of BO under the flooded condition was that the microbial activity was not zero (Fig. 1A). Broadbent (1960) showed that organic soil decomposition was only 20% less with 0.1% O_2 in soil air compared with decomposition at 21% O_2. Knipling et al. (1970) measured nonlabeled CO_2 evolution from flooded soil in the laboratory, and also did not obtain a zero rate of flux. In a field study with ^{14}C-labeled salicylate, Tate (1979a) did not obtain zero activity in a flooded soil. This result corresponds to research by Snyder et al. (2002), who measured CH_4 generation in flooded rice fields in the EAA; CH_4 production in soil is associated

with anaerobic conditions. They could not detect significant amounts of CH_4 evolution because O_2 was carried by water that percolated through the soils at rates of 5 to 7 cm d^{-1}. Even if it were assumed that there were anaerobic pockets in the soil, oxidation of OM may not be stopped completely.

Unlike the BO response, RESP showed a large increase in CO_2 flux within 24 h after drainage (Fig 1B). A similar response was reported within a few hours after tillage of drained mineral soils (Reicosky et al., 1997). The spike in CO_2 after tillage was attributed to a rapid physical release from soil pores and solution. Since all the soil pore space in our flooded treatments was filled with water, the rapid increase of CO_2 flux after drainage was due to increased aerobic microbial activity and/or increased sugarcane root respiration. When the stress from excess water was lessened immediately after drainage and O_2 entered the pore spaces, facultative anaerobic or dormant aerobic microorganisms were revived so that there was a rapid increase in aerobic respiration without a corresponding increase in MBC. Root respiration would also increase after O_2 entered the pore spaces because root cell metabolism is greater under aerobic than anaerobic soil conditions (Drew, 1997).

The rapid loss in SOC within 24 h after drainage (Fig. 2A) could have been due to microbial utilization. However, another mechanism for loss of carbohydrates is direct uptake by plant roots. This can be illustrated in the experiment of Sparling et al. (1982), where soils were amended with ^{14}C OM, and barley was grown. Of the total labeled C that was lost from the soil, about half was incorporated in the plant roots. They surmised that uptake of organic compounds by plant roots could impact plant growth.

By 7 d after flooding, RESP of the flood and drain treatments had declined to a rate similar to that of the drained treatment (Fig. 1B). Since RESP in our study did not correspond to field measurements reported in the literature of OM oxidation potentials as related to water table depths (Stephens et al., 1984; and Shih et al., 1978), RESP was not a good method for monitoring OM oxidation potential under sugarcane. But we cannot eliminate the possibility that RESP measured in a soil without plants could provide adequate estimates of OM oxidation potential because amounts of plant root respiration in a mineral soil can represent a significant quantity of the total RESP. Cheng et al. (1993) used ^{14}C labeling of wheat (*Triticum aestivum* L.) and estimated that 40% of the total respiration in the rhizosphere was due to roots with the remaining contribution from microorganisms.

Contrary to expectations, MBC tended to increase as water tables approached the soil surface (Fig. 1C). Robert and Chenu (1995) reported that bacterial, actinomycete, and fungal numbers decreased as SM increased. However, they used plate counts, which measured only active microbes that grew on the selective media used in their study. Our experiment was different in that we measured the total MBC (active and dormant microbes). Perhaps estimating MBC of both active and dormant microorganisms would provide the reasons for the increase in MBC with increasing water table levels (Horwath and Paul, 1994). Because of the uncertainty of what MBC represents and because MBC did not follow expected responses due to water table treatment, MBC does not appear to be a good method to estimate oxidation potential of Histosols under sugarcane. Even though there was greater mass of microbes with higher water tables, there was less microbial activity (BO). Future research should strive to partition the active from the dormant soil microbial populations.

Monitoring SOC may also provide a means to indicate the potential for OM oxidation. Soluble organic C tended to increase as water tables were raised (Fig. 2A), and there was a negative correlation with BO. The increase in SOC was likely due to exudation of carbohydrates by sugarcane and solubilization of soil OM.

Sugarcane plants were under varying degrees of high water stress at our water tables. A previous report showed that nine cultivars had average yield reductions of 8% when grown in an organic soil with a 15-cm compared with a 38-cm water table level, and one of those cultivars had a yield reduction of 25% (Glaz et al., 2002). Therefore, flooding induces stress in nontolerant plants, causing them to exude increased levels of carbohydrates in the rhizosphere compared with nonstressed plants (Drew, 1997). Amounts of exudation can be large because under nonstressed conditions, some plant roots excrete as much as 25% of their dry matter in the rhizosphere (Barber and Martin, 1976; Haller and Stolp, 1985).

It has also been reported that flooding fallow organic soils may also increase SOC. Reddy (1982) collected five organic soils in 7.5-cm plastic cylinders and incubated them in a greenhouse without plants for 5 wk. When he flooded the soils, SOC increases ranged from 18 to 144 mg C kg^{-1} soil wk^{-1}. The exact contribution of SOC from plants and soils could not be determined in our study. But, regardless of the source, SOC would need to be included in the calibration with BO across a wide range of soil types and water table levels to use SOC to indicate OM oxidation potential. Even though there are detectable quantities of SOC that increase with flooding, research on Histosols in California has shown that soil loss due to dissolution of C from soil OM is small (<1%) compared with larger gaseous C losses (60 to 76%) due to microbial oxidation of OM (Deverel and Rojstaczer, 1996).

Another parameter that appears to have potential to monitor soil OM oxidation is SM (Fig. 2B). There was a significant negative correlation between SM and BO (Table 2). The most probable reason for this negative correlation is because there is generally less O_2 in the soil with increasing moisture content (Reddy, 1987). Thus, lower O_2 levels reduced microbial activity that was responsible for OM oxidation. As with SOC, SM would need to be calibrated against BO across a range of soils and water table levels in the field, as Histosols have different types and quantities of OM that affects water holding capacity and capillary rise, which in turn influences soil O_2 contents.

The T7 could not be used as an indicator for OM oxidation potential in our study because neither BO nor RESP were correlated with T7 (Table 2). One contributing reason is probably related to the relatively narrow temperature range encountered (Fig. 2C). In addition, Reddy (1982) incubated EAA soils in a greenhouse for 1 yr and reported little effect due to seasonal temperatures (between 5 and 35°C) on N mineralization (Reddy, 1982).

CONCLUSIONS

The BO method compared with RESP and MBC to measure OM oxidation potential provided the best results in this study. Organic matter oxidation potential (BO) was reduced with reduced water table depths, which follows the reports of field experiments whereby there is reduced soil loss as water tables approach the soil surface. Also, when comparing drainage to the same water table level, there was greater BO in soil with alternate flooding and draining than in soil that was continuously drained, which conforms to reports in the literature. Since higher water tables produced higher SM contents, sugarcane plants likely experienced increasing stress from excess water and excreted SOC. Along with solubilization of soil SOC under flooded conditions, increased SOC was related to lower BO. The exact relationship between BO and SOC will require further investigation. However, because of the significant correlation of BO with both SM and SOC, SM and SOC may offer alternative methods to monitor potential for soil OM oxidation in Histosols.

Microbial biomass C method was not a good indicator of oxidation potential because even though MBC tended to increase at higher water table levels, there was no relationship with BO, suggesting that microorganisms responsible for soil oxidation are only a portion of the total microbial population in the soil. Similarly, the RESP method reflects respiration from both microorganisms and plant roots and appears not to be valid for monitoring soil OM oxidation potential in sugarcane fields. Neither MBC nor RESP were related to SOC, which suggests that not all of the SOC was available for microbial utilization.

ACKNOWLEDGMENTS

The authors acknowledge Brian Maxwell and Jennifer Vondewell for their technical assistance in management of the lysimeters and data collection.

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