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ScienceDirect

Soil & Tillage Research 92 (2007) 156–166

Soil & Tillage Research

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Influence of tillage and plant residue management on respiration of a Florida Everglades Histosol

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Received 7 June 2005; received in revised form 20 January 2006; accepted 22 February 2006

Abstract

Subsidence of drained, high organic matter Histosols in the Everglades Agricultural Area (EAA) is a concern for the sustainability of crop production in southern Florida. Histosol subsidence is primarily due to oxidation of organic matter by aerobic microorganisms, but far less is known about the influence of agricultural practices. The use of shallow tillage, as opposed to deep tillage, combined with proper plant residue management, may help to reduce the present rate of subsidence and soil CO_2 emissions. The present study was conducted on a Lauderhill soil (euic, hyperthermic, Lithic Haplosaprist) previously cropped in sugarcane (*Saccharum* spp.). The objectives were to (1) determine the effects of tillage depth on short-term CO_2 losses in a herbicide-killed weedy residue covered field and another field kept fallow without residue cover, and (2) compare soil respiration measurements made with two different dynamic closed-system portable chamber techniques. Four tillage practices common to the EAA were used to produce soil disturbance ranging in depth from approximately 20 to 300 mm. These practices included switch plowing, disk harrowing, and single and multiple tine cultivation. Twenty-four hours after tillage, cumulative CO_2 loss from the deepest tillage treatment (switch plow; 300 mm deep) was as much as 33 times greater than that from the no-till (control) treatment. Cumulative CO_2 loss following intermediate tillage (disk harrow; 78–145 mm deep) was as much as 2.3-fold greater than the no-till treatment, but shallower tillage (tine cultivation; 20–41 mm deep) was generally not different. Short-term tillage-induced CO_2 loss was primarily related to soil moisture content and soil porosity. Soil respiration measurements made with the two chamber techniques agreed well with each other except for the deepest tillage treatment, where the larger chamber measured CO_2 flux that was approximately 10 times greater than for the smaller chamber. Results indicate that minimum or no-tillage may reduce short-term tillage-induced CO_2 emissions on organic soils, thus minimizing soil subsidence.

Keywords: Histosol; Soil respiration; Tillage; Residue management

1. Introduction

The Everglades Agricultural Area (EAA), located in southern Florida, USA, is an area of the Everglades watershed that was drained in the early 1900s for agricultural production (Stephens and Johnson, 1951; Shih et al., 1998). Sugarcane (*Saccharum* spp.) is the most valued crop in the EAA and is grown on approximately 180,000 ha annually (Glaz and Vonderwell, 2004). Additionally, the EAA produces a large portion of the nation's winter vegetable crops (Ingebritsen et al., 1999). The soils in the EAA are Histosols with organic matter content as high as 80–90% (Snyder et al., 1978). Since the draining and establishment of the EAA, soil subsidence has become an ongoing problem.

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0167-1987/$ – see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.still.2006.02.004

Presently, in most areas of the EAA the soil depth above limestone bedrock is only 30–150 cm, varying with location (Shih et al., 1998; Ingebritsen et al., 1999). Soil subsidence in Histosols is believed to be primarily due to aerobic microbial oxidation of organic carbon (Tate, 1980). Recent evidence indicates that microbial oxidation of Histosols in the EAA results in soil subsidence of about 1.4 cm year^{-1} (Shih et al., 1998), which is a decline from about 2.5 cm year^{-1} reported earlier by Stephens and Johnson (1951). However, later studies addressing the relationship between Everglades Histosol subsidence and organic matter oxidation have involved laboratory measurements (Knipling et al., 1970; Tate, 1980). Far less attention has been given to field measurements and evaluating influences of agricultural practices on soil subsidence (Morris et al., 2004).

In the later part of the 20th century research focused on studying greenhouse gas emissions, particularly CO_2, have indicated that agriculture can act both as a sink and a source (Houghton et al., 1983; Schlesinger, 1985; Paustian et al., 1997; Lal et al., 1998). Agricultural tillage practices may be a significant contributor of CO_2 to the atmosphere (Houghton et al., 1983), but perhaps even more importantly can lead to the loss of soil carbon (Reicosky and Lindstrom, 1993) thus reducing soil quality and productivity. Reicosky and Lindstrom (1993, 1995) showed that short-term CO_2 loss from mineral soils resulting from deep tillage with a moldboard plow can be substantial when compared to losses from no-till or minimally tilled (shallow tillage) soils. Deep tillage causes an immediate loss of trapped CO_2 when the soil is inverted and fractured, but also incorporates plant residues and aerates the soil thus enhancing microbial oxidation (Reicosky and Lindstrom, 1995). Short-term tillage-induced soil CO_2 loss is likely to be greater for Histosols than that for mineral soils (Lohila et al., 2003). However, the influence of tillage depth on CO_2 loss from organic soils has not been well investigated.

Sugarcane producers in the EAA often use deep tillage prior to planting to promote water drainage in the field (Matherne et al., 1972) and break up plow pans. When practiced, deep tillage is performed approximately every three years between sugarcane crops. Additionally, shallower tillage (~5–10 cm) is often used early in the growing season to control weeds. Modification of agricultural practices may reduce soil subsidence and CO_2 emissions to the atmosphere.

Chamber techniques are often used for measuring soil respiration (Reicosky, 1990; Pumpanen et al., 2004). All chamber techniques have their limitations, and anytime a device is placed over the soil to measure surface gas exchange the physical characteristics affecting gas flux are altered (Livingston and Hutchinson, 1995; Davidson et al., 2002). Differences in soil respiration measurements among chambers can develop because of how different chamber designs and measurement techniques affect the CO_2 diffusion gradient within the soil and the pressure differential between the inside and outside of the device (Davidson et al., 2002; Pumpanen et al., 2004). Objectives of this study were to (1) determine and characterize the effects of tillage depth and residue management on short-term CO_2 flux in a Histosol previously cropped in sugarcane and (2) compare respiration measurements made with two different dynamic closed-system portable chamber devices to identify potential limitations to making measurements on organic soils. Potential reasons for differences in measurements between chamber techniques and potential limitations of each method are discussed.

2. Materials and methods

2.1. Field sites

The study was conducted on 22–25 January 2002 at the Everglades Research and Extension Center, University of Florida, Belle Glade, FL (26°39′N, 80°38′W, 4.5-m elevation). Two field sites situated within 1100 m of each other were chosen for the experiment. Both fields consisted of a Lauderhill soil (euic, hyperthermic, Lithic Haplosaprist) where sugarcane (interspecific hybrids of *Saccharum* spp.) had been grown from December 1997 to December 2000. After removing the final sugarcane crop, fields were disk harrowed and left fallow. In 2001, fields were managed so that the effects of plant residue and tillage method on soil respiration could be studied. One of the fields was maintained by tillage fallow (henceforth referred to as the ‘‘bare fallow’’ field). This field was kept weed free by multiple disk harrowing operations (150–200 mm tillage depth) performed on 8 and 21 November, 6 and 21 December 2001, and 2 January 2002. On 8 and 16 January 2002, application of *N*-phosphono-methylglycine (1.1 kg a.i. ha^{-1}) was made to kill any weeds that may have germinated prior to the experiment. The other field was kept as a plant residue fallow (henceforth referred to as the ‘‘residue covered’’ field). Sugarcane producers in the EAA commonly disk harrow fields prior to planting, rather than allow plant residue to remain on the surface. No-tillage was performed on the residue covered field after the summer of 2001, but weeds were controlled by periodic mowing to maintain plant height to 10 cm. The primary weed species in the residue covered field were dayflower (*Commelina diffusa* Burm. f.) and goosegrass [*Eleusine indica* (L.) Gaertn.]. Prior to making experimental measurements, weeds in the residue field were killed with two applications of *N*-phosphono-methylglycine made on the same dates and at the same rate as the bare fallow field. No green plant material was visible at the time the experiment began. The amount of plant surface residue was determined by sampling four 0.09 m^2 randomly chosen areas from two locations within the residue field on 22 January 2002. The average surface residue cover was 3179 ± 439 kg ha^{-1}.

2.2. Tillage treatments

Both field sites had uniformly flat topography. Tillage treatments were randomized into blocks that were 61 m × 4.3 m for the residue and 76 m × 4.3 m for the bare fallow fields. However, because of the size of our field-scale tillage equipment, and in order to minimize temporal variability of CO_2 measurements, randomization within blocks was not possible. Thus, each block was devoted to a single tillage treatment, but divided into four plots for replicated time-series measurements of soil respiration. Each replicated plot was 15.2 m × 4.3 m for the residue and 19 m × 4.3 m for the bare fallow fields. Treatments consisted of (a) no-till control; (b) switch plow (Model 3608, LMC Bainbridge Equip. Co., Bainbridge, GA); (c) disk harrow (Model 425, Deere and Company, Moline, IL); (d) spring tine cultivation done one time (custom built); and (e) spring tine cultivation done twice. The switch plow consisted of eight curved blades 0.60 m wide × 0.56 m high spaced 0.50 m apart on a tool bar, resulting in similar soil disturbance of a moldboard plow. The disk harrow consisted of 16 coulter and 16 round disks (0.35 m radius) that were spaced 0.25 m apart. The spring tine cultivator, used for scratching the surface to control weeds, consisted of five rows of tines (0.27 m long) spaced 0.19 m apart on the implement. For each tillage practice, depth of tillage in each replicated plot was measured in the outermost furrow in the center of the plot and taken from the soil surface to the bottom of the furrow.

Because of limited equipment availability, tillage operations could not be performed in both fields on the same day. The bare fallow field was tilled on 22 January and the residue field was tilled on 24 January. Tillage began at 08:30 h Eastern Standard Time on 22 January and 08:00 h on 24 January. On both days, all tillage operations were completed within approximately 2 h. Weather was similar on each day of the experiment. Skies were clear to partly overcast, no precipitation occurred, and diurnal air and dewpoint temperature patterns were similar for those days that CO_2 flux measurements were taken.

2.3. Soil respiration

CO_2 flux from the soil surface was measured with two types of dynamic closed-system portable chamber devices (one large and one small) that varied considerably in surface area covered and chamber volume. The large portable chamber has been described by Reicosky (1990), and the data acquisition and methods used to determine CO_2 flux have been reported by Wagner and Reicosky (1996) and Wagner et al. (1997). In brief, the chamber covered a surface area of 2.67 m^2 and had a volume of 3.25 m^3. With the mixing fans running, the chamber was lowered over the treatment surface with its bottom support frame inserted into the soil approximately 10–20 mm. CO_2 and water vapor concentrations were measured with a LI-6262 gas analyzer interfaced with an LI-670 flow control unit (LI-COR, Lincoln, NE). Data, which included solar radiation, photosynthetically active radiation, air temperature, and wet bulb temperature were collected at 1-s intervals over a 60-s period and stored on a laptop computer. Following an appropriate lag and mixing time, data for a 30-s calculation window were selected to convert the volume concentrations of water vapor and CO_2 to a mass basis, then regressed as a function of time using linear and quadratic equations to estimate gas fluxes (Wagner et al., 1997). For each replicated plot within a treatment, three measurements in the same area (approximately 2 min each) were made and averaged.

The small portable chamber was a LI-6400-09 Soil CO_2 Flux Chamber (LI-COR,) with a surface area of 0.0072 m^2 and a volume of 0.001 m^3. Immediately following tillage, three polyvinyl chloride (PVC) support collars (102 mm diameter × 45 mm high) were installed within a randomly selected 1 m^2 area within 2 m of the large chamber measurements. Collars were kept approximately 0.5 m apart and installed to a depth of 35 mm. Because of the physical nature of the soil (i.e., soil looseness related to low bulk density and dry surface layer), wooden slats (2 mm thick × 25 mm wide × 300 mm long) were attached with epoxy to opposite exterior sides of the PVC collars to add support for the CO_2 flux chamber. The PVC support collars were installed immediately following the tillage event and allowed to equilibrate for approximately 5 min before taking the first measurement. The CO_2 flux chamber was flushed with ambient air before placing on a collar for data collection. The mean of three measurements (20–30 s per measurement) per collar was averaged per treatment replication. Because CO_2 efflux was so great immediately following switch plow tillage, the ‘‘buffered autolog’’ mode of the LI-6400-09 was used to collect data for this treatment. Using this mode, CO_2 concentrations were collected at 1-s intervals for a 25-s period per measurement and three measurements were made per collar. CO_2 concentration was then regressed against time to determine the flux.

The treatment measurement sequence was (1) no-till, (2) switch plow, (3) disk harrow, (4) 1 × tine cultivation, and (5) 2 × tine cultivation. The sequence was performed the same in both fields for both chamber techniques. Base-line soil CO_2 flux measurements for the treatments were taken prior to commencement of the tillage operations. Within 1–2 min after the tillage implement passed through a plot, the large chamber was lowered onto the center of the plot to make the first measurement. For the small chamber the first measurement was made within 5–10 min following the tillage pass. All four replications within a treatment were measured in the same manner before switching tillage implements and moving to the next treatment. CO_2 flux measurements were repeated on a regular cycle so that each of the treatments was visited at least once every 2 h for up to 8 h after the initial tillage. Additional measurements were made at 24–25 h after tillage to characterize the longer-term impact of various tillage methods.

2.4. Soil water content

Prior to tillage and before measuring soil respiration on no-till plots, soil cores (20-mm diameter) were sampled from all four replications of each tillage treatment and separated into 0–50, 50–100, 100–200, and 200–325-mm depths. The soil cores were weighed, dried at 105 °C for 48 h, and weighed again to determine gravimetric water content ($kg\,kg^{-1}$). Soil cores were sampled with PVC cylinders (50 mm high × 38 mm i.d.) at the same depths as for water content from the no-till plots of both fields after the experiment to determine bulk density ($Mg\,m^{-3}$). Soil volumetric water content ($m^3\,m^{-3}$) was calculated assuming the density of water equals 1 $Mg\,m^{-3}$ and total soil porosity and air-filled porosity ($m^3\,m^{-3}$) were also determined. For porosity calculations, a particle density of 1.74 $Mg\,m^{-3}$ was used for the upper 300 mm of the Lauderhill soil (Grigg, unpublished data) and it was assumed that the pre-tillage bulk density was the same as that measured in the no-till plots.

2.5. Soil temperature

Soil temperature was measured continuously at 10, 50, 200, and 300 mm in each of the treatments in the bare fallow field only, because of limited equipment. Copper–constantan thermocouples were attached to a length of 15-mm o.d. PVC tube. Two thermocouple arrays were randomly placed in each tillage treatment block in the bare fallow field. The arrays in the no-till treatment were installed the day before tillage, whereas those in the tilled treatments were installed within 20 min after tillage. Temperature measurements were taken every 60 s and 15-min averages recorded and stored with either a Campbell Scientific 10× or 23× data logger (Campbell Scientific, Logan, UT). Air and dewpoint temperatures at a height of 2 m (15-min averages) were obtained from a weather station located 850 m from the field sites. In the residue covered field, soil temperature was measured at 150-mm depth with the small chamber at the same time as CO_2 flux measurements.

2.6. Statistical analysis

Soil CO_2 flux was expressed on a mass basis (g of $CO_2\,m^{-2}\,h^{-1}$) and plotted as a function of time after tillage (TAT). For comparisons among treatments, fields, and chamber techniques, soil CO_2 flux data were used to calculate cumulative CO_2 flux ($g\,m^{-2}$) using the trapezoid rule as previously reported by Reicosky et al. (1997). Cumulative CO_2 flux plotted against TAT was fit with a non-linear + linear equation of the form: $y = a(1 - e^{-bx}) + cx$, where y is cumulative CO_2 flux and x is TAT. Equation solutions were then used to calculate 24 h cumulative CO_2 loss. For cumulative CO_2 loss and other comparisons, factorial ANOVA was performed using the GLM procedure of SAS. Least significant differences (LSD) at the $P = 0.05$ level were used to detect differences among means for the main effects of tillage, residue management, and chamber technique. Because of the large CO_2 flux in the switch plow treatment, statistical comparisons were first performed with all tillage treatments to determine differences between the switch plow and other tillages and then without the switch plow (i.e., treating as an ‘‘outlier’’) to determine differences among other treatments.

3. Results

Depth of tillage was greatest for the switch plow treatment, followed by disk harrowing, and the 1 and 2 × tine cultivation (Table 1). Impeded penetration of the tillage implements in the residue covered field was likely caused by surface residue and roots imparted by the herbicide-killed plants and perhaps a different soil structure due to lack of previous tillage as compared to the bare fallow field (Table 1). Total depth of soil from the surface to the limestone bedrock was similar in both fields, averaging 647 ± 31 mm (S.E.) and 697 ± 21 mm in the bare fallow and residue covered fields, respectively.

Soil water content within 325 mm of the surface varied among treatments and fields prior to initiation of tillage (Table 1). Across all treatments, volumetric water content was significantly greater in the residue covered field than the bare fallow field.

Immediately following tillage, soil CO_2 flux dramatically increased for the switch plow treatment in the bare fallow and residue covered fields (Fig. 1). Mean CO_2 flux values measured with the small chamber within 5–10 min after plow tillage were 34 and 9 times greater than those for no-till in the bare fallow and residue fields, respectively (Fig. 1). Mean CO_2 flux values with the large chamber within 2–4 min after plow tillage were 717 and 86 times greater than those for no-till in the fallow and residue fields, respectively (Fig. 1). Within about 3 h after tillage, CO_2 flux sharply declined in plow tillage on both fields, but tended to remain greater than no-till and other treatments for the remainder of the experiment (Fig. 1). When compared to no-till, spring tine cultivation had little effect on CO_2 flux in either the fallow or residue fields (data not shown). However, disk tillage caused an increase in CO_2 flux in the residue field (Fig. 1), but fell to rates similar to those of the no-till treatment within approximately 3 h. The CO_2 flux measured with both chamber techniques was similar for no-till and shallow tillage treatments, but differed considerably for the switch plow, particularly immediately following tillage, where values for the large chamber were approximately 10-fold higher than the small chamber (Fig. 1). However, after 3 h, CO_2 flux values measured with both chambers for the switch plow treatment were more similar in magnitude.

Instantaneous rates of CO_2 flux were used to calculate cumulative CO_2 flux as a function of time after tillage (Fig. 2). For both field sites, cumulative CO_2 flux was linearly related to time after tillage in no-till, disk, and spring tine cultivation treatments with r^2 values ranging from 0.91 to 0.99 (Fig. 2C–F). The response for both 1 and 2 × tine cultivation was similar to that of no-till for both chamber techniques and thus, data not shown. Variability of CO_2 flux tended to be greater for the large than small chamber and increased with tillage depth. The pattern of cumulative CO_2 flux from plow tillage differed from other treatments in that it followed an initial logarithmic increase (Fig. 2A and B) associated with a tillage-induced flush. However, the initial dramatic increase was short-lived, occurring within 3 h after tillage, followed by a similar linear trend as the other tillage treatments. A similar response was observed for disk tillage, albeit to a much lesser degree (Fig. 2C and D).

For both fields, 24-h cumulative CO_2 loss measured with either the small or large chamber was greatest for plow tillage (Table 2). As compared to the no-till, the 1 and 2 × tine cultivations had little impact on cumulative CO_2 loss (Table 2). In the residue covered field, disk tillage resulted in greater 24-h CO_2 loss than the no-till and tine cultivations (Table 2). Comparing between fields, 24-h CO_2 loss measured with the small chamber was greater for the disk, 1 × tine cultivation, and no-till treatments in the residue covered field (Table 2).

Table 1
Tillage depth and volumetric water content for the tillage treatments in the bare fallow and plant residue covered systems

Tillage	Tillage depth		Volumetric water content	
	Bare fallow (mm)	Residue (mm)	Bare fallow[a] ($m^3 m^{-3}$)	Residue ($m^3 m^{-3}$)
Switch plow	300 ± 19 a	283 ± 41 a	0.43 c	0.55 b
Disk	145 ± 4 b	78 ± 11 b	0.54 b	0.62 a
1× Tine cultivation	38 ± 4 c	18 ± 1 c	0.51 b	0.55 b
2× Tine cultivation	41 ± 4 c	20 ± 3 c	0.61 a	0.59 ab
No till	NA	NA	0.50 b	0.62 a

Soil water content was measured within 1 h prior to tillage. Values for tillage depth are means ± S.E. Values for volumetric water content are the overall means for the 0–325-mm soil depth, which when followed by the same letters (a–c) within columns are not significantly different at the $P < 0.05$ level.

[a] Across all tillages, volumetric water content was significantly lower in the bare fallow system (51.7%) than the residue system (58.4%).

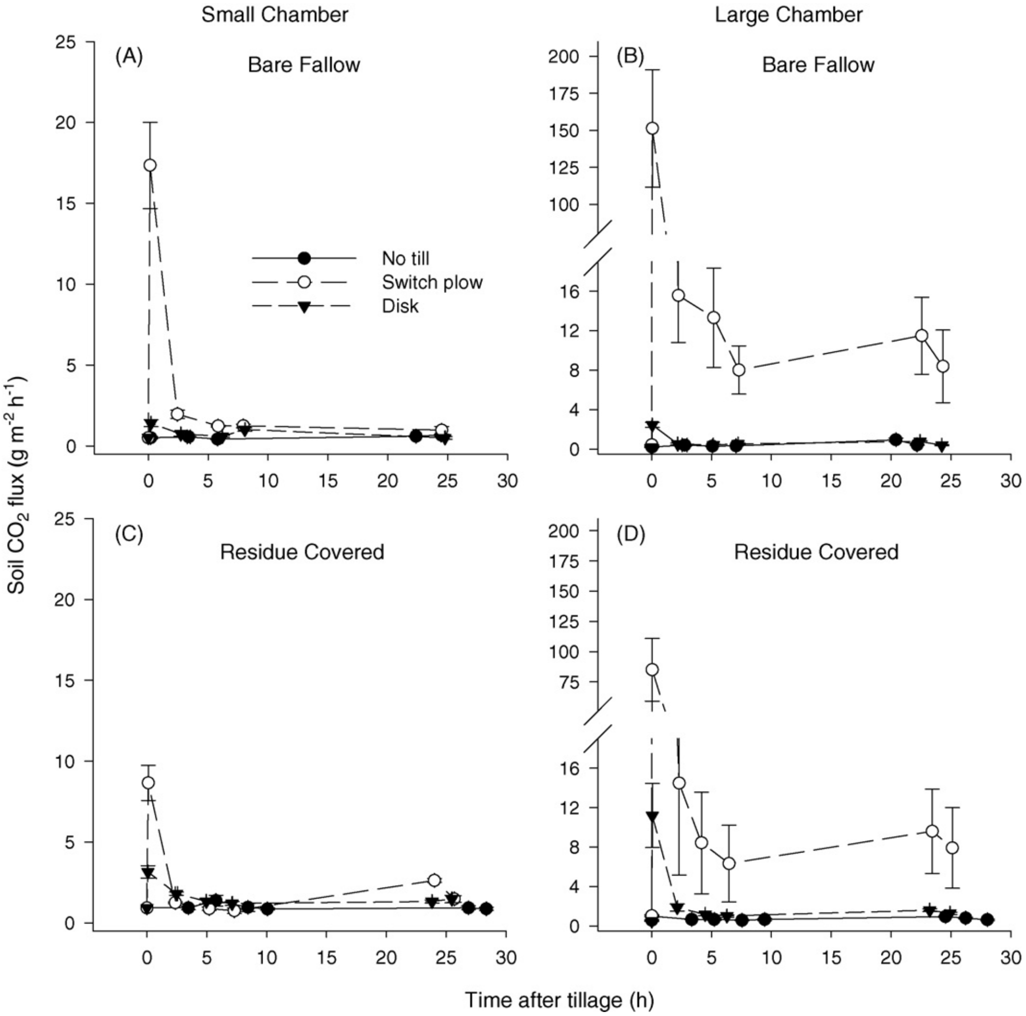

Fig. 1. The effect of tillage on soil CO_2 flux measured with the small and large chambers as a function of time after tillage for the bare fallow field (A and B) and the residue covered field (C and D). Values are means ± S.E., $n = 4$. Plots of the 1 and 2 × tine cultivation, which responded similarly to the no-till treatment, are not included for clarity of the graph. Note the y-axis scale difference between the small and large chamber.

Except for disk tillage, there was no difference in 24-h CO_2 loss between fields measured with the large chamber (Table 2). No differences were found between the chamber techniques except for plow tillage in both fields. Twenty-four hour cumulative CO_2 loss measured with the large chamber for plow tillage was 8.5 and 6.5 times greater than that measured with the small chamber on the fallow and residue covered fields, respectively (Table 2).

For both fields, bulk density in the no-till plots ranged from 0.27 to 0.46 Mg m^{-3} (data not shown). Within the 0–325-mm soil profile, air-filled porosity was significantly greater in the bare fallow than the residue covered field primarily due to drier soil (Fig. 3). This may be one reason that CO_2 flux immediately following plow tillage tended to be greater in the bare fallow field. For plow tillage in the residue covered field, air-filled porosity in the 0–50 and 100–200-mm layers was 53 and 67% less, respectively, than in the bare fallow field (Fig. 3). However, in the 200–300-mm layer, air-filled porosity was greater for the residue field.

Soil temperature at 10 mm mirrored that of air temperature, and around midday was typically 1–3 °C warmer than the air in the least disturbed treatments (Fig. 4). There were no large differences in soil temperature among the various treatments. As might have been expected, 10-mm soil temperature was initially slightly lower in plow tillage due to inversion of soil. In the residue field, soil temperature was not different among treatments (Fig. 4).

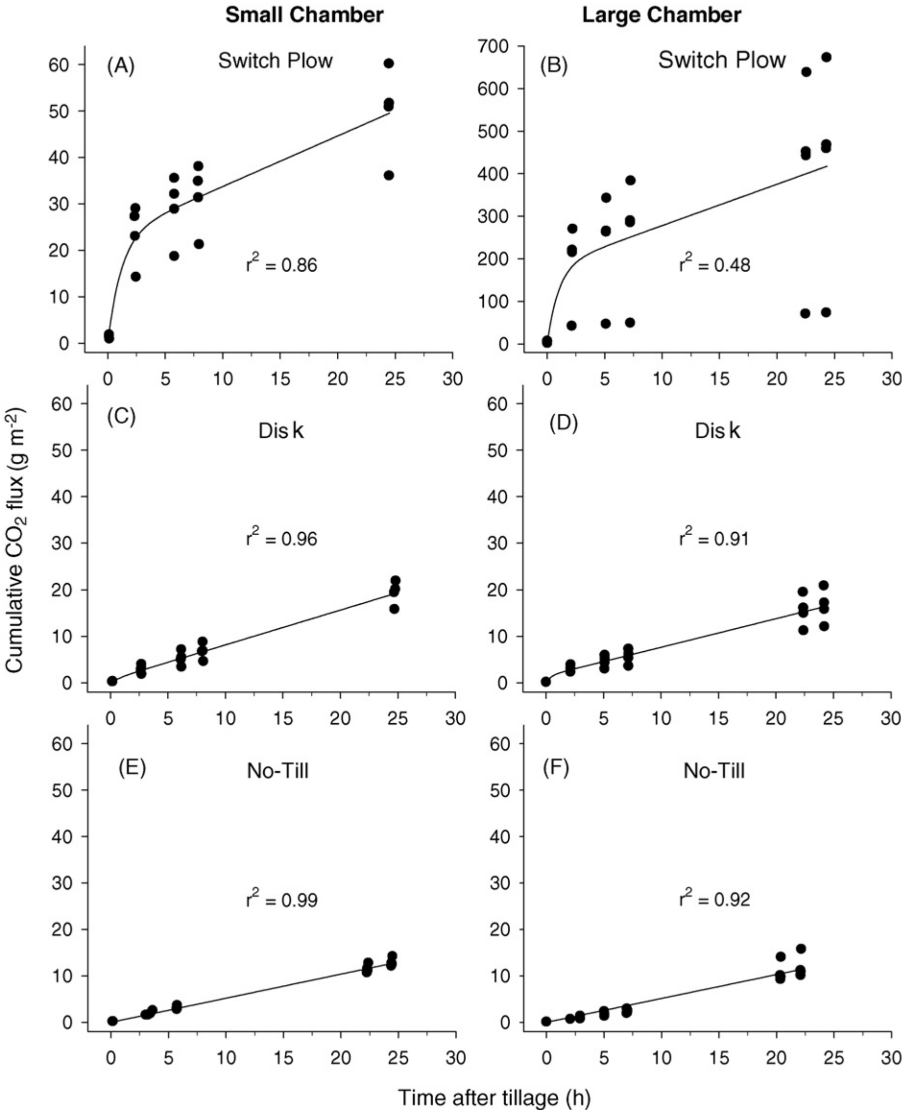

Fig. 2. The effect of tillage on cumulative CO_2 flux measured with the small and large chambers as a function of time after tillage for the bare fallow field. Graphs 'A' and 'B' are for the switch plow, 'C' and 'D' for the disk harrow, and 'E' and 'F' for the no-till treatments. Values represent individual measurements and lines represent regressions of the data with corresponding r^2 values. The 1 and 2 × tine cultivation, which responded similarly to the no-till treatment, are not shown. Data were fit to a non-linear + linear function of the form: $y = a(1 - e^{-bx}) + cx$, where y is cumulative CO_2 flux and x is TAT. Note the y-axis scale difference in graph B.

4. Discussion

Soil respiration for the bare fallow and residue covered soils were generally two to three times greater than measured on mineral soils in the northern Corn Belt of the USA that contain up to 10% organic matter content (Reicosky and Lindstrom, 1993; Reicosky, 1997). Lohila et al. (2003) also found soil respiration of an agriculturally managed Histosol (Terric Histosol) in Finland to be two to three-fold greater as compared to two similarly managed mineral soils. Soil CO_2 flux of the Histosol in their study ranged from 0.40 to 1.30 g CO_2 m^{-2} h^{-1} over the period of May–September at a mean soil temperature of 18 °C at a depth of 40 mm. In comparison, CO_2 flux for no-till and intermediate depth tillage treatments in our study ranged from 0.40 to 0.79 g CO_2 m^{-2} h^{-1} in the bare fallow field and from 0.74 to 2.67 g CO_2 m^{-2} h^{-1} in the residue covered field.

Soil CO_2 loss measured by both chambers was generally greater for deep and intermediate tillage (i.e., switch plow and disk harrow) than less disturbed

Table 2
Cumulative CO_2 loss as affected by tillage and residue management for the two field sites measured with both the small (SC) and large (LC) chambers

Tillage	Bare fallow		Residue covered		Comparison between fields	
	SC (g CO_2 m^{-2})	LC (g CO_2 m^{-2})	SC (g CO_2 m^{-2})	LC (g CO_2 m^{-2})	SC	LC
Switch plow	49.0 A	413.9[a] a	44.9 A	292.4 a	NS	NS
Disk	18.6 BC	16.3 B	34.1 B	42.9 B	***	***
1 × Tine cultivation	18.5 BC	9.6 C	27.5 C	15.2 C	**	NS
2 × Tine cultivation	20.0 B	13.4 BC	19.5 D	13.1 C	NS	NS
No-till	12.4 C	12.4 BC	23.0 CD	18.6 C	**	NS

Cumulative CO_2 was estimated from the regression of cumulative CO_2 loss as a function of time after tillage. Values are the mean of four replications per treatment. Within columns and time interval, values followed by the same letters (a, A–D) are not significantly different at the $P < 0.05$ level. NS denotes non-significant differences.

[a] The plow was analyzed with all treatments, whereas the other four treatments were compared without the plow treatment, treating it as an ''outlier'' in the analysis.

** Significant differences at the $P < 0.01$ for comparisons of tillage treatments between fields for the small and large chambers.

*** Significant differences at the $P < 0.001$ for comparisons of tillage treatments between fields for the small and large chambers.

systems. Although CO_2 flux for both plow and disk tillage declined rapidly (Fig. 1), CO_2 loss generally remained greater than that of shallower tillage and no-till for up to 24 h after tillage (Table 2). Variability in CO_2 flux was large after tillage, likely in response to variability in depth of soil disturbance caused by the tillage implements. It has been suggested that large chambers, because of the greater surface area that they integrate over for measuring CO_2 flux, should have less variability than smaller chambers (Davidson et al., 2002). This was not the case in our study, at least for plow tillage, where the larger chamber tended to have more variability among measurements at the same time than the small chamber.

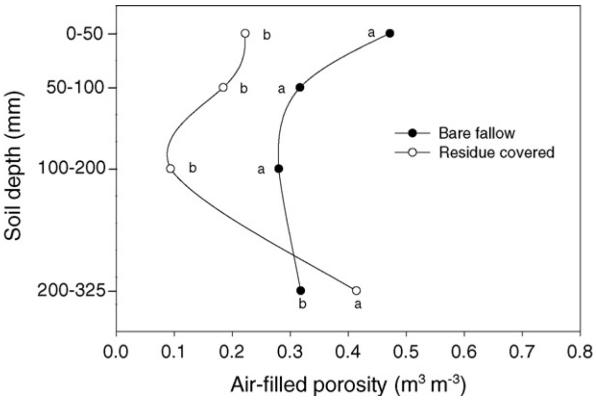

Fig. 3. Air-filled porosity for the switch plow treatment of the bare fallow and residue covered field as a function of the soil profile. Values are means, $n = 4$. Values in each profile layer followed by the same letter are not significantly different at the $P < 0.05$ level.

Alternatively, another reason for large variability in CO_2 flux, especially with plow tillage, may have been caused by wind effects. Reicosky et al. (2002) showed that $[CO_2]$ at a 0.3 m depth after plow tillage of the bare fallow field declined with increasing wind speed and stabilized or slightly increased as wind speed decreased. This same effect was not as evident in the no-till treatment. Their results suggest that soil re-distribution and mixing caused by deep plowing led to increased soil permeability and aeration thus enhancing wind-induced gas exchange. Takle et al. (2004) showed that wind blowing across an agricultural mineral soil can create pressure fluctuations that penetrate to 0.5 m in the soil, thus providing a ''pressure-pumping'' type mechanism for bulk transport of gases. They concluded that this phenomenon could lead to large spatial variability in vertical CO_2 flux measurements from the soil.

In the present study, short-term (~24 h) effects of tillage and residue on CO_2 flux were determined. However, using the same fields and treatments as the present study, Morris et al. (2004) found that oxidation potential was greatest over a 42-day period for plow tillage. They also showed that greater soil respiration (measured with a small closed dynamic chamber) in plow tillage persisted for up to 20 days in the bare fallow field and up to 42 days in the residue covered field. In our study, within 24 h, cumulative CO_2 loss after plowing was as great as 414 g CO_2 m^{-2} from the bare fallow field and 292 g m^{-2} from the residue covered field, as measured with the large chamber. Results clearly indicate that within one day after deep tillage of a drained Everglades Histosol a significant amount of carbon is lost via soil CO_2 emission.

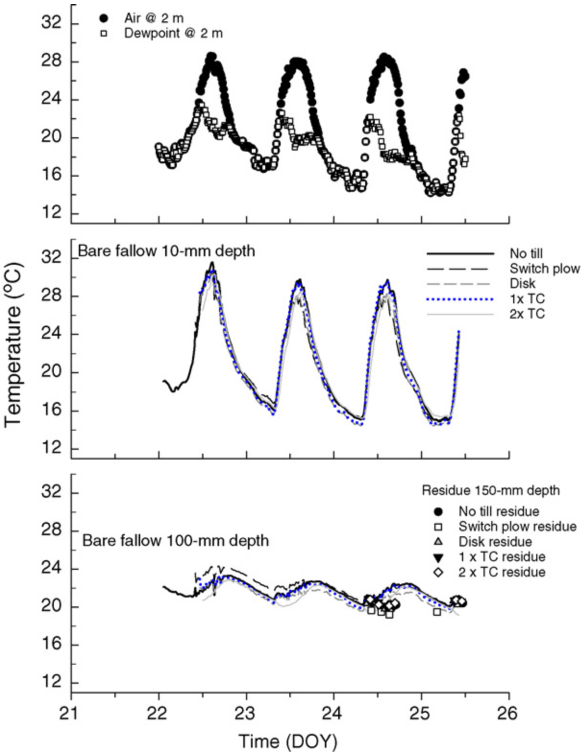

Fig. 4. Air and soil temperatures during the tillage experiment. For the residue covered field, only point measurements at a 150-mm depth were taken at the same time soil respiration was sampled with the LI-COR 6400-09 (small chamber). Air and dewpoint temperatures at a height of 2 m were measured at a weather station located 850 m from the experiment site.

The large cumulative soil CO_2 loss immediately following switch plowing may have been due to the interaction of physical and biological factors. Slightly greater bulk density and higher soil water content in the 100–200-mm profile depth, reflected by lower air-filled porosity (Fig. 3), likely enhanced microbial respiration in this zone, while creating a barrier to prevent rapid CO_2 loss prior to tillage. Upon plowing, this deeper, moist soil was re-distributed to the surface, allowing the CO_2 trapped there to be quickly released. This deeper, wetter soil was not disturbed by intermediate tillage and no-till, except for partial disturbance by disk harrow in the fallow field, which went as deep as 145 mm (Table 1).

Although temperature is an important determinant of soil respiration (Nakadai et al., 2002), it did not appear to be an important factor in the present experiment as temperature differences among treatments were generally small. Residue management did influence initial plow tillage-induced CO_2 flux, where flux was greater in the bare fallow than the residue covered field (Fig. 1). This difference in CO_2 flux was likely caused by differences in soil moisture and air-filled porosity between fields. Soil air-filled porosity between 0 and 200 mm was greater in the bare fallow field and thus, it may have contained more trapped gaseous CO_2 than the residue field. If this were so, then its potential for short-term CO_2 loss following plowing was inherently greater. Diffusion rates for gases in soil substantially decrease with increasing soil water content and decreasing air-filled porosity (Moldrup et al., 2000). The greater water content and lower air-filled porosity, especially in the 100–200-mm layer of the soil profile of the residue covered field, when inverted upon plowing, may also have impeded immediate diffusion of CO_2 as compared to the bare fallow field where the soil was drier and more porous.

Soil CO_2 flux measured with the small and large chambers tended to agree well with each other when CO_2 fluxes were generally low (e.g. no-till and intermediate tillage). However, the two differed in magnitude immediately following plow tillage, when fluxes were high. The large chamber consistently measured greater CO_2 flux than the small chamber, in agreement with Reicosky et al. (1997). One reason for this may have been due to a negative pressure created near the soil surface resulting from air mixing by fans in the large chamber acting as a vacuum to extract CO_2, thus leading to an overestimation CO_2 efflux. This air mixing pressure-induced effect has been recently described for the large chamber by Denmead and Reicosky (2003). Similar phenomena have been described in the field and in small chambers (Takle et al., 2004). Conversely, the small chamber may have underestimated CO_2 flux in part due to its smaller volume-to-surface area ratio, which was approximately nine times less than that of the large chamber. If CO_2 builds up too rapidly in the chamber headspace it can change the natural CO_2-gradient between soil and atmosphere resulting in slower CO_2 diffusion from the soil (Nay et al., 1994; Livingston and Hutchinson, 1995; Davidson et al., 2002). For closed dynamic chambers, this effect becomes more pronounced as the measurement time increases (Pumpanen et al., 2004). In our study, the time taken to make flux measurements with the small chamber in plow tillage was intentionally kept as brief as possible to minimize this effect. Another contributing factor to chamber differences in plow tillage is that initial flux measurements were made sooner with the large chamber. Reicosky and Lindstrom (1993) have shown that the initial ''burst'' of CO_2 following deep tillage occurs quickly (i.e., within seconds to minutes) and then CO_2 flux declines.

Having allowed time to equilibrate the soil support collars for the small chamber, flux rates might have begun to decline by the time measurements commenced. Soil disturbance caused by insertion of the large chamber without allowing equilibration might have also caused greater flux. However, previous tests have indicated that this effect is minimal for the large chamber, especially on soils that have been disturbed by deep tillage.

The above and below ground plant material recently killed by herbicide treatment prior to commencement of tillage in the residue field did not appear to have greatly affected soil respiration. Although the intermediate tillage and no-till treatments on the residue field tended to evolve slightly more CO_2 than those of the bare fallow field, the differences were not significant and were probably influenced more by soil water content than recently killed plant residue.

5. Conclusions

Our study concurs with Morris et al. (2004) that minimum or no-tillage may reduce soil CO_2 flux and soil oxidation potential of organic soils, thus reducing soil subsidence rates. Presently, in the EAA the most common practices used for sugarcane production involve disk harrowing fields prior to planting, followed by multiple disking or shallow tillage events between rows to control weeds prior to sugarcane canopy closure. Deep tillage and no-till are less commonly practiced in this region. A challenge to implementing minimum or no-till in this region is the need to maintain adequate drainage on organic soils, particularly early in the growing season when sugarcane is susceptible to flood damage. Further research on the interactions of tillage and residue management with water infiltration during the growing season would be useful in elucidating recommended practices for reducing soil CO_2 flux while maintaining high sugarcane yields. Additionally, research is needed to determine longer-term effects of deep tillage on annual CO_2 emissions and the soil–carbon balance in Everglades Histosols.

Our study found that CO_2 fluxes measured with the small and large dynamic closed-system chambers agreed relatively well with shallow tillage depth of <145 mm. However, with deep tillage (i.e., switch plow), the large chamber may have overestimated CO_2 flux due to the negative pressure created at the surface caused by its mixing fans, while the small chamber may have underestimated fluxes due to its low volume-to-surface area ratio. Large variability encountered with both chamber techniques in the deep tillage treatment may have been related to wind-induced soil pressure changes.

Acknowledgements

The authors wish to thank Steven Wagner, Christopher Wente, and Brian Maxwell for expert technical field assistance and Ron Gosa and Lee Liang for obtaining soil water content data. We would also like to acknowledge financial support from Monsanto and thank the University of Florida EREC for providing the weather data and housing facilities.

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