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Tillage-induced soil carbon dioxide loss from different cropping systems

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Abstract

Tillage of soils often decreases soil organic matter content and increases the flux of carbon dioxide (CO_2) from soils. Our objectives were (1) to measure short-term, tillage-induced soil CO_2 flux from different cropping systems using two instruments, a soil chamber (about $10^{-3}\,m^3$) and a canopy chamber ($3.25\,m^3$), and (2) to examine the interactions between cumulative short-term soil CO_2 flux and soil N transformations. Measurements were made on 6 and 7 May 1994 for three cropping systems (coastal bermudagrass (*Cynodon dactylon* (L.) Pers.), continuously cultivated sorghum (*Sorghum bicolor* (L.) Moench), and no-till sorghum) that had three different tillage practices (moldboard plow, chisel plow, and untilled as the control) imposed on a vertisol at the Blackland Research Center, Temple, Texas, USA. The soil CO_2 flux was calculated from the rate of CO_2 concentration increase inside each chamber. Soil inorganic N content (NO_2-N, NO_3-N, and NH_4-N) was measured from soil cores collected immediately preceding tillage and at 8, 24, and 102 h thereafter. The CO_2 flux over a 24 h period measured by both methods was greatest immediately after tillage, but maximum soil chamber fluxes were only about 10% of those measured by the canopy chamber. The large differences between chambers are a concern, and probably were related to the inability of the soil chamber to make a representative measurement for tilled surfaces and to the increased turbulence and possible associated pressure effects inside the canopy chamber. Increased soil surface area under the canopy chamber caused by increased soil surface roughness may also explain observed chamber differences. Fluxes were greatest in the bermudagrass and least in the continuously cultivated sorghum. Fluxes in the moldboard plow treatment were usually the greatest, and fluxes in the untilled treatment were considerably smaller than fluxes from either tillage treatment. For the first 24 h after tillage, there was no relationship between cumulative CO_2 flux and the change of inorganic N. Thus, to the extent that these inorganic N content changes reflect microbial activity, the short-term CO_2 flux from tilled soils is

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controlled more by mass flow processes related to a tillage-induced change in porosity than to immediate microbial activity.

Keywords: Tillage; Soil carbon; Soil nitrogen; Soil respiration; Soil chamber; Canopy chamber

1. Introduction

Increasing soil organic matter is important because soils could be a large global carbon sink (Gifford, 1980, Gifford, 1994) that could ameliorate the increasing concentration of atmospheric CO_2 (Raynaud and Barnola, 1985; Neftel et al., 1985). Low soil organic matter also can have a deleterious effect on the environment because it often results in reduced fertility, increased erosion, and decreased tilth, water infiltration, and water-holding capacity of soils. Tillage often decreases soil organic matter (Gebhart et al., 1994) and increases the flux of CO_2 from soils (Reicosky and Lindstrom, 1993) through enhanced biological oxidation of soil carbon by increasing subsequent microbial activity as a result of residue incorporation (Reicosky et al., 1995).

Measurements of soil CO_2 flux for different tillage treatments and cropping systems are important for identifying management practices that may increase this flux and thus affect the global C balance (Houghton et al., 1983; Post et al., 1990). This flux, also referred to as soil respiration, is a function of microbial decomposition of organic C and is often measured using chambers of various types that are placed directly on the soil for periods of seconds to months (e.g. Mosier, 1989; Nakayama, 1990; Norman et al., 1992; Dugas, 1993; Hutchinson and Livingston, 1993). Soil CO_2 flux may have large spatial variability, both within a homogeneous field (Rochette et al., 1991; Dugas, 1993) and for different cropping systems and landscape positions (DeJong, 1981).

The microbial-controlled decomposition of soil organic C that affects soil CO_2 flux is dependent on several plant, soil, and climatic conditions that also are affected by tillage. Plant factors include age, amount, and the C:N ratio of plant residue (Parr and Papendick, 1978; Ghidey and Alberts, 1993). Soil and climate factors include soil water content, soil temperature, soil aeration, and available nutrients, e.g. soil N. The microbial-controlled decomposition of organic C also controls soil N transformations, e.g. mineralization and immobilization (Jansson and Persson, 1982). This suggests that a strong relationship may exist between soil N transformations and soil CO_2 flux.

Information is needed on the variation and magnitude of the CO_2 flux and N transformations caused by tillage of different soil types and cropping systems. The objectives of this study were to compare measurements of the soil CO_2 flux using a soil chamber and canopy chamber and to examine the interactions between short-term soil CO_2 flux and soil N transformations from three cropping systems on a vertisol that had three different tillage practices imposed.

2. Materials and methods

2.1. Cropping systems

Measurements of soil CO_2 flux were made on 6 and 7 May 1994, at the Blackland Research Center, Temple, Texas, (31°6′N, 97°20′W, elevation 219 m) on three fields, all within 1 km of each other, each having a Houston Black clay (fine montmorillonitic thermic Udic Pellusterts) and a different cropping history. On 11 April 1994, glyphosate was applied to the areas that were to be tilled in each field so there was no live vegetation in any field on the day of tillage. The fertility history was similar for all three fields and is considered typical for the area. The recommended long-term N fertilizer application rates were based on experiment station recommendations and ranged from 63 to 108 kg N ha^{-1} $year^{-1}$ over the last 5 years. The N fertilizer applied in the spring for the 1994 season was 72 kg N ha^{-1}, 108 kg N ha^{-1}, and 108 kg N ha^{-1} for the bermudagrass, continuously cultivated sorghum, and no-till sorghum, respectively. The cropping systems were single fields in place for decades and as a result did not allow complete randomization and replication. Further details for the three cropping systems were as follows:

1. Coastal bermudagrass. This field was in bermudagrass and had not been tilled for more than 30 years. The grass was cut for hay about two times per year and the field was fertilized annually. On 25 April and 3 May 1994 the dead grass was cut in this field.
2. Continuously cultivated sorghum. This field had been in continuous row crops or, occasionally, small grains for more than 30 years. Crop residues were shredded and incorporated into the soil. Annual tillage practices usually included three passes with a disk of 0.2 m depth and one pass with a chisel plow, a typical central Texas tillage intensity. Sorghum was seeded in April 1994.
3. No-till sorghum. This field was under a no-till system since 1991, during which there had been no tillage and shredded crop residues had been left on the soil surface. Grain sorghum was planted in April 1994. Before initiating the no-till system, this field was managed in a manner similar to that of the continuously cultivated sorghum. Thus, the tillage intensity for this field is intermediate between the bermudagrass and continuously cultivated sorghum fields.

2.2. Tillage methods

Two primary tillage treatments and a control (untilled) were used in each cropping system on 6 May 1994. The control treatment had no soil disturbance by tillage. Tillage treatments were adjacent to each other separated by alleys for traffic and were 20 m long. Within each tillage strip, three measurement sites were identified for replication of soil CO_2 flux measurements. Primary tillage implements used sequentially were moldboard plow and chisel plow. The moldboard plow consisted of three bottoms of 0.41 m width that plowed to about 0.2 m depth. Two adjacent passes were required to achieve the necessary width for the canopy chamber measurements. The chisel plow was of 3 m width, with shanks spaced 0.3 m apart and penetrating to about 0.2 m depth. Each primary tillage was followed by a secondary tillage with two passes of a disk harrow about 5 h after the primary tillage.

In each field, soil CO_2 flux measurements were made initially in the untilled treatment, followed by tillage with the moldboard plow and soil CO_2 flux measurements on that treatment, and finally chisel plow tillage and flux measurements on that treatment. This sequence took about 45 min for each field. Measurements and tillage were initiated in the no-till sorghum field at 07:15 h Central Standard Time (CST) on 6 May 1994, followed by measurements in the bermudagrass and continuously cultivated sorghum fields. These sequences of soil CO_2 flux measurements were repeated in each tillage treatment and cropping system throughout the day on 6 May until about 17:00 h CST. Each sequence of CO_2 flux measurements took about 2.25 h to complete measurements in all fields. The disk harrow tillage treatment was imposed in the same order in these fields. One final set of soil CO_2 flux measurements was made in each field beginning at about 08:00 h CST on 7 May 1994 to give a total of eight measurements on each treatment.

2.3. Soil CO_2 flux

Soil CO_2 flux was measured in all cropping systems and tillage treatments using two types of instrumentation, a soil chamber and a canopy chamber. The soil chamber CO_2 flux was measured using a small, cylindrical, vented soil chamber (volume 0.75×10^{-3} m^3; diameter 0.1 m) that had a Li-Cor (Li-Cor, Inc., Lincoln, NE) Model 9960-035 sensor head and a Li-Cor Model 6200 Photosynthesis System attached. The soil chamber was placed on polyvinyl chloride collars randomly located in each treatment and buried to a depth of 40 mm. The rate of CO_2 increase inside the soil chamber was measured for about 15–30 s. Concurrent measurements of soil temperature at 5 mm depth were made at the time of each soil CO_2 flux measurement. Further details on this method have been presented by Dugas (1993).

The first post-tillage soil chamber flux measurement was usually made within 20 s after completion of tillage. Measurements were made on three collars at these locations within each tillage treatment. Collars were adjacent to the areas used for canopy chamber measurements. Once collars were placed in a tillage treatment, they were only removed briefly for the disk harrow tillage. The three measurements for each tillage treatment were averaged and individual measurements were used as replicates. The CO_2 fluxes (positive upward) were expressed on a land area basis, which, for tilled surfaces, is less than the exposed soil surface area, owing to the surface roughness (Reicosky and Lindstrom, 1993).

The canopy chamber soil CO_2 flux was measured using a canopy chamber (Reicosky, 1990; Reicosky et al., 1990; Reicosky and Lindstrom, 1993) that had a volume of 3.25 m^3 and covered a soil area of 2.71 m^2. The soil CO_2 flux, per unit ground area, was calculated from the rate of increase of CO_2 inside the chamber for a 30 s calculation window, corrected for appropriate lag time after placement on the surface, as measured by a Li-Cor Model 6262 IR gas analyzer (Reicosky, 1990; Wagner et al., 1997). (Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.) Concentrations were regressed as a function of time. Each measurement took about 2 min to complete. Three measurements were sequentially made for each tillage treatment, each at a predetermined distance (approximately 3, 6, and 9 m) from the end of the tilled area. Each canopy chamber measurement was used as a replicate. The canopy chamber measurements were made at the same time as soil chamber measurements.

2.4. Soil temperature

In addition to the instantaneous soil temperature measurements made with the soil chamber, soil temperatures were measured in the continuously cultivated sorghum field from 5 May (Day 125) to 11 May 1994 (Day 131), i.e. from 1 day before to 5 days after implementation of tillage treatments. The 15 min averages of soil temperature were measured using thermocouples at 0.1 and 0.3 m inserted on wooden dowels at four locations, equally spaced across the width of the tilled area, in the moldboard plow and chisel plow treatments, and at two locations in the untilled treatment. Thermocouples were removed for about 15 min during the time of tillage.

2.5. Soil carbon, nitrogen, and water

Three soil cores (57 mm diameter) to a depth of 0.3 m were collected immediately before implementation of the primary tillage and 8, 24, and 102 h after tillage in each cropping system and tillage treatment. Cores were sectioned into 0–0.05, 0.05–0.1, 0.1–0.2, and 0.2–0.3 m depth increments. Immediately after collection, samples were frozen until they were analyzed in the laboratory.

Soil samples were extracted with 2 M KCl (soil:solution ratio 1:5) and extracts were colorimetrically analyzed for NO_2-N, NO_3-N, and NH_4-N concentrations using a Technicon Autoanalyzer (Technicon Industrial Systems, 1973). Inorganic N content was calculated as the sum of these three concentrations. Increases of inorganic N content in tilled soils relative to untilled were attributed to net N mineralization, and decreases in inorganic N content in tilled soils were attributed to net N immobilization. Soil organic C and inorganic C contents were determined with a LECO CR12 Carbon Determinator (Chichester and Chaison, 1992). Soil bulk density used in calculation of soil inorganic N content, and soil water content were determined for each sample depth increment in each cropping system from three additional soil cores of 0.3 m depth. The N data were analyzed as a split plot with cropping system as the main plot and tillage as the subplot. Treatment means were separated using LSD (least significant difference) at 10% probability level.

3. Results and discussion

In each field, surface residue was measured in the control (untilled) treatment on 7 May 1994 using six, randomly positioned 0.25 m^2 quadrants. The average (and standard deviation) residue dry weight was 223 (66) g m^{-2}, 77 (38) g m^{-2}, and 148 (49) g m^{-2} for the bermudagrass, continuously cultivated sorghum, and no-till sorghum, respectively.

Skies were mostly cloudy, air temperature ranged from 20 to 30°C, half-hour averages of wind speeds were less than 4.3 m s^{-1}, and relative humidities varied from 60 to 100% on both days of soil CO_2 flux measurements. There were 17 mm and 19 mm of precipitation on 29 April and 2 May, respectively. Thus surface soils were moist (gravimetric water contents approximately 0.3 g g^{-1}). There were, however, only small soil water content differences (0.01–0.02 $g\,g^{-1}$) across cropping systems. Soil organic C concentrations were essentially equal in the continuously cultivated sorghum and no-till sorghum, but as expected (Gebhart et al., 1994), about twice as large in the bermudagrass. They were greater near the surface in all cropping systems (Table 1). The lack of a large difference in soil organic C for the two sorghum fields may be because crop residue was incorporated in the continuous cultivated sorghum, and suggests that 3 years of no-till management are not sufficient to influence total soil organic C in soils with inherently high organic C levels. Soil organic C concentrations were not greatly different from those reported for cropped fields and native pastures by Gebhart et al. (1994) and from those previously measured in the continuously cultivated sorghum field (D.L. Gebhart, unpublished data).

3.1. Soil CO_2 flux

The soil CO_2 flux measured by both the soil chamber and canopy chamber was greatest immediately after tillage in all cropping systems (Fig. 1). This result is similar to that reported by Reicosky and Lindstrom (1993). The considerably smaller flux from untilled treatments represents the flux that originates within the soil and from surface residue decomposition owing to microbial activity on the moist soil surface. The much greater flux from the tilled treatments was due to physical CO_2 release from soil pores and solution (Reicosky and Lindstrom, 1993).

Fluxes from the untilled treatment were slightly greater than zero for the entire period for both chambers (Fig. 1). For the two tilled treatments, fluxes immediately after tillage were greatest in the bermudagrass for both the soil chamber and canopy chamber, probably owing to higher CO_2 concentrations in soil pores from increased organic C (Table 1) and surface residue. The next highest post-tillage flux was measured in no-till sorghum, probably owing to the greater amount of surface residue in this system relative to the continuously cultivated sorghum, which had the lowest flux immediately after tillage.

Two hours after tillage, fluxes from all fields decreased rapidly to a value about 20% of the maximum. Thus, a large percentage of the CO_2 loss occurred immediately after primary tillage; this suggests that physical release is the primary controlling mechanism. The disk harrow tillage approximately 5 h after primary tillage caused only a slight flux increase in all cropping systems (Fig. 1). The fluxes measured with the canopy chamber

Table 1
Average soil organic carbon concentrations ($g\,kg^{-1}$) for three cropping systems

Depth (m)	Cropping system		
	Coastal bermudagrass	Continuously cultivated sorghum	No-till sorghum
0–0.05	48.3	20.7	20.2
0.05–0.1	34.2	19.9	17.6
0.1–0.2	26.8	15.4	16.1
0.2–0.3	23.6	13.4	15.8
Average	33.2 ± (3.4)	17.3 ± (1.2)	17.4 ± (0.9)

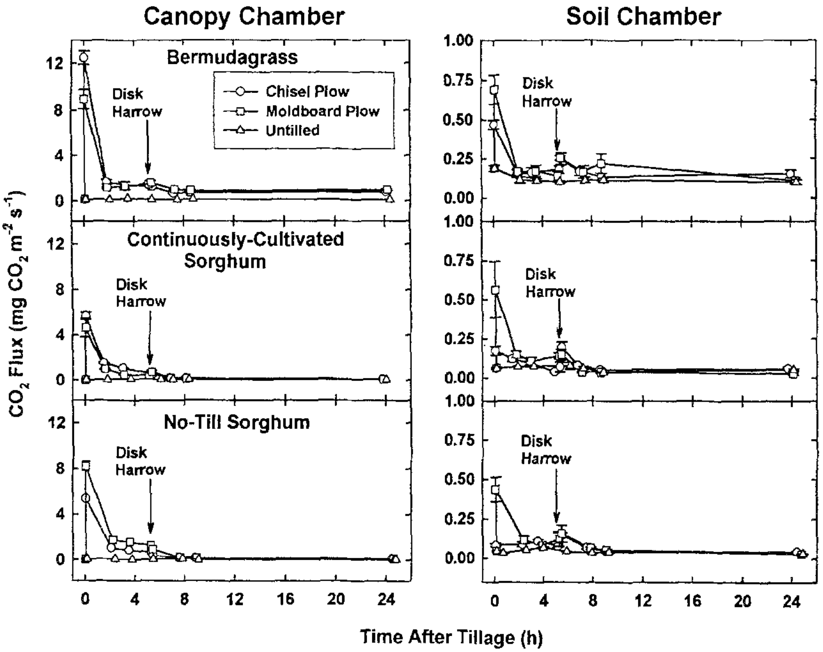

Fig. 1. Average soil CO_2 flux from three cropping systems and three tillage treatments as measured at selected times after tillage by a canopy chamber (left) and soil chamber (right). (Note change of scale.) Tillage was imposed at 08:00h, 08:45h, and 07:15h Central Standard Time on 6 May 1994 in the bermudagrass, continuously cultivated sorghum, and no-till sorghum, respectively. A disk harrow was used in the moldboard and chisel plow treatments at the times denoted.

were not affected whereas the percentage increase for the soil chamber was larger. The breakdown of the large soil aggregates following secondary tillage was noticeable on the bermudagrass, but caused only minor surface mixing and breakdown of large aggregates on both sorghum plots, resulting in little effect on CO_2 flux.

The CO_2 fluxes 24h after tillage (i.e. on the following morning) measured by the canopy chamber were essentially equal in the tilled and untilled treatments for the continuously cultivated sorghum and no-till sorghum. However, fluxes remained about ten times greater in the bermudagrass tilled treatments (Fig. 1), presumably owing to higher soil C concentrations and root decomposition rates. The soil chamber also measured a greater flux in the bermudagrass, although the soil chamber flux from the bermudagrass was considerably smaller relative to the canopy chamber flux.

Fluxes immediately after tillage in the tilled treatments measured by the soil chamber were only about 10% of those measured by the canopy chamber (Fig. 1). This flux difference is considerably larger than the difference measured by Dugas et al. (1997) using the same instrumentation for two untilled bare soil treatments. The larger flux difference between methods in the current tillage study is probably related to the following: (1) the small diameter of the soil chamber precluded a representative measurement in these tilled soils where the size of soil clods and air gaps (approximately 0.3 m) was about three times greater than chamber diameter; (2) increased turbulence and dynamic pressure differences inside the canopy chamber caused by the mixing fans may have biased the flux measurement from this instrumentation (Kanamasu et al., 1974; Nakayama and Kimble, 1988; Dugas et al., 1997); (3) the surface area and porosity of soil under the canopy chamber after tillage was considerably greater than that under the soil chamber, owing to increased soil roughness. Reicosky and Lindstrom (1993) calculated a 50% increase in soil surface area for plots that were tilled with a moldboard plow. Hendrix et al. (1988) also failed to detect a large increase in soil CO_2 flux after tillage using chambers of 0.1 m diameter. Breakage of large soil aggregates or clods is probably an important process affecting soil CO_2 flux after tillage (Rovira and Greacen, 1957) and the small diameter of the soil chamber probably precludes a representative measurement for very rough soil surfaces.

There were no consistent patterns among CO_2 fluxes from the different tillage treatments. Fluxes from the moldboard plow treatment were greatest in all cropping systems as measured by the soil chamber, but only in no-till sorghum for canopy chamber measurements. Reicosky and Lindstrom (1993) reported significantly and consistently greater fluxes from fields tilled with a moldboard plow than from fields where a chisel plow was used, primarily owing to depth and extent of soil disturbance. In this work, tillage depth for the moldboard and chisel plow was the same (about 0.2 m). In the moldboard plow treatment for bermudagrass, it was difficult to seal the canopy chamber bottom to the soil surface because the soil turned over as 'slabs' that were held together by a mat of dense bermudagrass roots. There was little breakdown of soil clods. Air leaking out of the chamber owing to these gaps would have biased canopy chamber measurements low.

Cumulative fluxes for the 24 h period after tillage, calculated using the trapezoid rule on the data in Fig. 1, were about five times greater for the canopy chamber than for the soil chamber (Fig. 2). For treatments with tillage, cumulative canopy chamber measurements ranged from a high of 116 g CO_2 m^{-2} day^{-1} for coastal bermudagrass to a low of 32 g CO_2 m^{-2} day^{-1} for continuously cultivated sorghum. Absolute differences between cropping systems were less for fluxes measured by the soil chamber. Relative differences between cropping systems were smaller than the effect of tillage for both chambers. For both chamber methods, cumulative fluxes for each tillage method were greatest for the bermudagrass, and were similar for the no-till and continuously cultivated sorghum. Fluxes were least from the untilled treatment in all cropping systems and for both methods. The bermudagrass flux, which was largest even under the untilled treatment, was probably enhanced owing to root decomposition.

For the soil chamber, cumulative fluxes from the moldboard plow treatments were consistently higher in all three cropping systems, whereas for the canopy chamber measurements the moldboard plow value was greatest only for no-till sorghum. Differences in cumulative flux owing to primary tillage method were small, but differences between cropping systems were substantial, as indicated by the error bars (Fig. 2). For all tillage treatments, daily cumulative CO_2 fluxes are near the upper end of the range of those calculated by Gliński and Stępniewski (1985). As also shown by Dugas et al. (1997), CO_2 fluxes from the canopy chamber were consistently about 30% greater than those from the soil chamber for the untilled treatment in each cropping system.

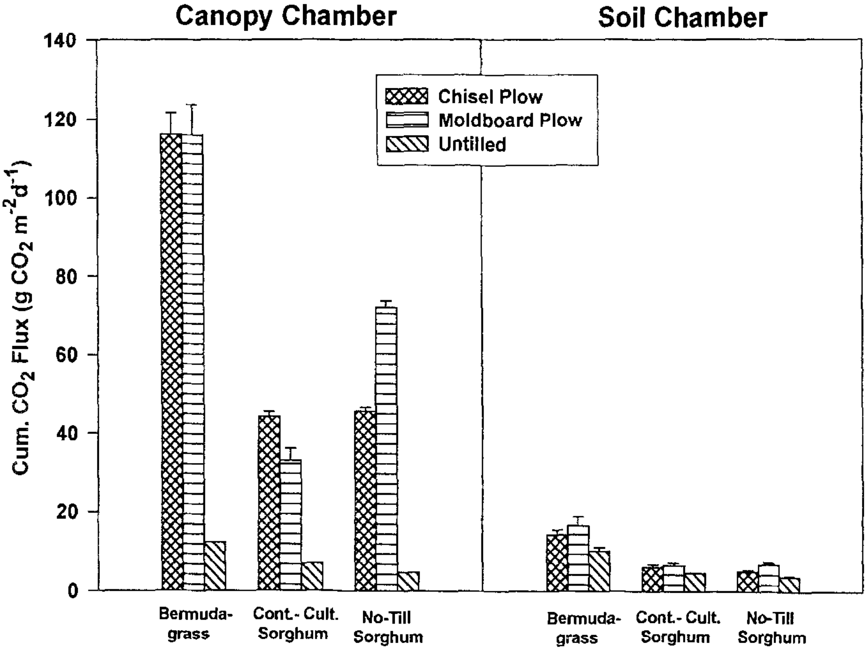

Fig. 2. Cumulative soil CO_2 flux for 24 h after tillage from three cropping systems and three tillage treatments as measured by a canopy chamber (left) and soil chamber (right). Each cumulative flux represents the mean of three replicates, and error bars represent ± 1 SE.

3.2. Soil temperature

Soil temperatures measured at 5 mm in conjunction with soil chamber measurements increased, as expected, throughout the day on 6 May, but were consistently lower in the tilled treatments (Fig. 3), probably owing to increased soil evaporation following soil inversion and placement of deeper, cooler soil near the surface for the moldboard plow treatment. Temperatures were lowest in the moldboard plow treatment. The rapid decrease in soil temperature about 6 h after primary tillage was due to the disk harrow tillage, which probably resulted in increased evaporation and a cooler soil at the surface.

Results were similar for the continuous soil temperature measurements in the continuously cultivated sorghum (data not shown). For the first 3 days after tillage, maximum daily temperatures at 0.1 m in the untilled treatment were about 2°C greater than temperatures in the moldboard plow treatment and were about 1°C greater for the following 2 days. At 0.3 m, temperatures in the untilled treatment were consistently about 1°C greater for the 5 days of measurements after tillage. Temperature differences between the untilled and chisel plow treatments were approximately half of the difference between the not tilled and moldboard plow treatments. Temperature differences were least (approximately 0.5–1°C) at time of minimum temperatures. These relatively small temperature differences probably had less influence on soil CO_2 flux than tillage-induced soil disruption.

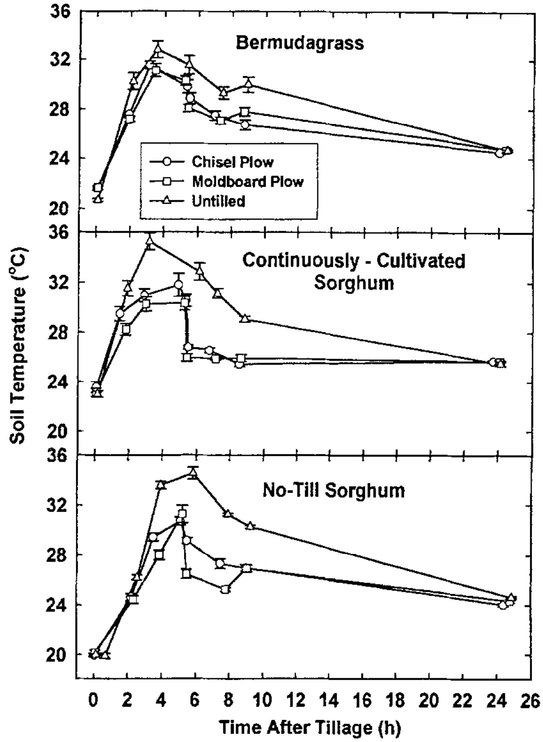

Fig. 3. Average soil temperature ($n = 3$) at 5 mm of three cropping systems and three tillage treatments measured by the soil chamber. Error bars represent ± 1 SE. Tillage was imposed at 08:00h, 08:45h, and 07:15h Central Standard Time in the bermudagrass, continuously cultivated sorghum, and no-till sorghum, respectively.

3.3. Soil nitrogen

There was a significant amount of variability in the inorganic N content as a function of time after tillage for each cropping system and tillage method (Table 2). For example, in the untilled treatments there were large increases (implying potential net N mineralization) and some decreases (implying potential net N immobilization) of inorganic N content across the three cropping systems from the time immediately before to 102 h after tillage. This indicated that large levels of N turnover (immobilization or mineralization) owing to microbial activity were occurring in this soil without tillage during the sampling period.

Averaged across the three cropping systems for each time of measurement, there were no significant differences in inorganic N content for the three tillage treatments or significant tillage × cropping system interaction, except at 8 h after tillage when the N content in the moldboard plow treatment was lower. Some of the changes of inorganic N contents between 24 and 102 h after tillage may have been related to the 50.7 mm of precipitation that occurred on the morning of 8 May (Day 128).

Table 2
Average inorganic N content (NO_2-N + NO_3-N + NH_4-N, in kg ha^{-1}) for three cropping systems, three tillage treatments, and different times after tillage

Tillage treatment	Time after tillage (h)	Cropping systems			
		Coastal bermudagrass	Continuously cultivated sorghum	No-till sorghum	Average of three cropping systems
	0	35.1	69.6	74.4	59.7
Chisel plow	8	49.7	120.0	88.3	86.0a
Moldboard plow	8	29.4	88.0	73.7	63.7b
Untilled	8	62.7	117.4	73.4	84.5a
Chisel plow	24	58.4	156.0	86.4	100.2a
Moldboard plow	24	48.9	120.9	76.8	82.2a
Untilled	24	85.9	106.4	65.0	85.7a
Chisel plow	102	58.1	140.0	82.1	93.4a
Moldboard plow	102	51.8	95.0	89.6	78.8a
Untilled	102	68.1	121.9	62.0	84.0a

For each time after tillage, averages in a column followed by the same letter do not differ significantly.

There were more consistent differences between inorganic N contents when they were averaged for all tillage methods (Table 3). Inorganic N contents were always significantly lower for the bermudagrass compared with the continuously cultivated sorghum, with no-till sorghum intermediate between the other two treatments. These inorganic N contents are consistent with surface residues for the three locations. The surface with the highest residue had the lowest inorganic N content. The higher residue levels reduced the rate of net N mineralization. Changes in crop residue composition (e.g. C:N ratio) and the previous N fertility history for the three different fields may have also contributed to these results.

There was no clear relationship between cumulative CO_2 flux and the increase of

Table 3
Average inorganic N content (NO_2-N + NO_3-N + NH_4-N, in kg ha^{-1}) for three cropping systems averaged across three tillage treatments at different times after tillage

Time after tillage (h)	Cropping systems		
	Coastal bermudagrass	Continuously cultivated sorghum	No-till sorghum
0 [1]	35.1	69.6	74.4
8	47.2c	108.5a	78.5b
24	64.4b	127.7a	76.1ab
102	59.3b	119.0a	77.9ab

For each time after tillage, averages followed by the same letter do not differ significantly.
[1] At time zero, split plots did not exist because tillage had not been implemented.

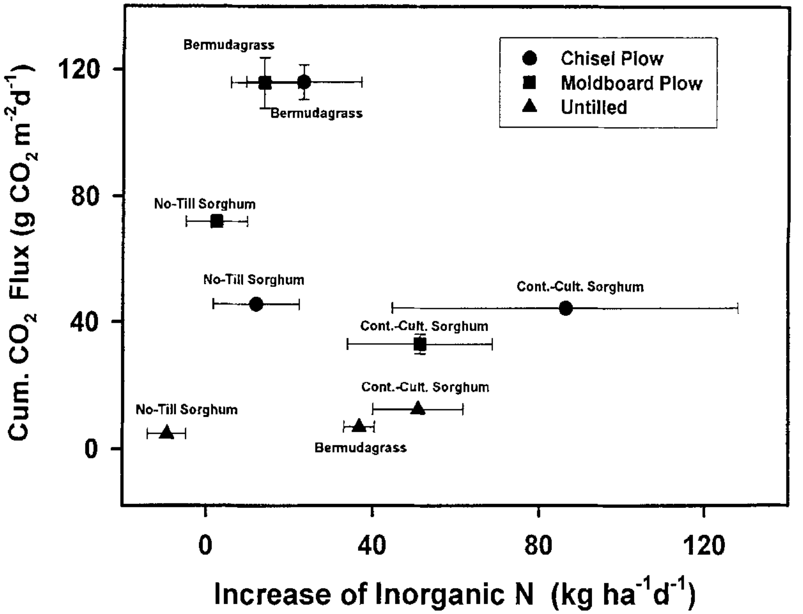

Fig. 4. Average cumulative CO_2 flux and average increase of inorganic N content for the first 24h after imposition of three tillage treatments in three cropping systems.

inorganic N for the first 24h after tillage (Fig. 4). For the untilled treatment, where cumulative CO_2 fluxes were less than $14\,g\,m^{-2}\,day^{-1}$, there was a range of increases of inorganic N from -9 to $51\,kg\,ha^{-1}\,day^{-1}$. This lack of a consistent relationship between short-term CO_2 flux and increase of inorganic N suggests that the total CO_2 flux from these three cropping systems and tillage treatments for the first 24h after tillage was independent of the change of inorganic N content. To the extent that these inorganic N changes reflect microbial activity, the short-term CO_2 flux from tilled soils was controlled more by mass flow processes related to a change in porosity and not microbial activity. This is not likely to be true for longer periods.

4. Conclusions

Two methods, a soil chamber with a volume of about $10^{-3}\,m^3$ and a canopy chamber with a volume of $3.25\,m^3$, were compared for measuring soil CO_2 flux from three cropping systems and three tillage treatments. For tilled surfaces, flux differences between methods were very large, although both showed similar temporal trends. The small surface area of the soil chamber, relative to the large spatial variation of soil clods and air gaps in the tilled surfaces, suggests that the soil chamber was unable to make a representative and accurate measurement. There is some uncertainty about the dynamic pressure phenomena associated with turbulent mixing in the canopy chamber interacting with the tillage-induced change in soil porosity and how these contribute to subsequent soil CO_2 flux. The disparity between the chamber methods suggests a critical need for a reference or standard method for quantitative comparison of CO_2 fluxes, especially for tilled soils.

Cumulative CO_2 flux for 24 h from the three cropping systems after tillage with either a moldboard plow or a chisel plow was considerably greater from an established bermudagrass pasture than from a no-till sorghum field or a continuously cultivated sorghum field. Differences were related to previous tillage history, soil organic C concentration, and surface residue. Fluxes from the tilled treatments, either with a moldboard or chisel plow, were considerably greater than from the untilled treatment. The soil chamber and canopy chamber showed similar qualitative temporal and treatment trends.

There was no clear relationship between short-term changes in inorganic N content of soil and cumulative CO_2 flux. Thus, tillage, with either moldboard plow or chisel plow, increased short-term CO_2 fluxes more as a result of the physical release from soil pores and solution that accumulated from previous microbial activity than as a result of increased current microbial activity.

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