Carbon Dioxide Efflux from Soil with Poultry Litter Applications in Conventional and Conservation Tillage Systems in Northern Alabama

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Increased CO_2 release from soils resulting from agricultural practices such as tillage has generated concerns about contributions to global warming. Maintaining current levels of soil C and/or sequestering additional C in soils are important mechanisms to reduce CO_2 in the atmosphere through production agriculture. We conducted a study in northern Alabama from 2003 to 2006 to measure CO_2 efflux and C storage in long-term tilled and non-tilled cotton (*Gossypium hirsutum* L.) plots receiving poultry litter or ammonium nitrate (AN). Treatments were established in 1996 on a Decatur silt loam (clayey, kaolinitic thermic, Typic Paleudults) and consisted of conventional-tillage (CT), mulch-tillage (MT), and no-tillage (NT) systems with winter rye [*Secale cereale* (L.)] cover cropping and AN and poultry litter (PL) as nitrogen sources. Cotton was planted in 2003, 2004, and 2006. Corn was planted in 2005 as a rotation crop using a no-till planter in all plots, and no fertilizer was applied. Poultry litter application resulted in higher CO_2 emission from soil compared with AN application regardless of tillage system. In 2003 and 2006, CT (4.39 and 3.40 μmol m^{-2} s^{-1}, respectively) and MT (4.17 and 3.39 μmol m^{-2} s^{-1}, respectively) with PL at 100 kg N ha^{-1} (100 PLN) recorded significantly higher CO_2 efflux compared with NT with 100 PLN (2.84 and 2.47 μmol m^{-2} s^{-1}, respectively). Total soil C at 0- to 15-cm depth was not affected by tillage but significantly increased with PL application and winter rye cover cropping. In general, cotton produced with NT conservation tillage in conjunction with PL and winter rye cover cropping reduced CO_2 emissions and sequestered more soil C compared with control treatments.

Growing public concern over environmental issues and increasing scientific proof of human interference with the earth's climate has pushed climate change into the political arena in the past 30 yr. The Kyoto Protocol, which resulted from the United Nations Framework Convention on Climate Change, advises developed nations to reduce greenhouse gas emissions to 5% below their 1990 levels and allows them to meet their reduction limits by C sequestration in terrestrial sinks (United Nations, 1998). Although the USA has indicated that it will not participate in the agreement, the US government has taken efforts to target C sequestration in forests and croplands in the USA (USDA, 2003).

Agricultural ecosystems play an important role in the storage and release of C within the terrestrial C cycle (Lal et al., 1999). These systems are important in the global context because of their large CO_2 flux to the atmosphere and because C storage in these systems can be sensitive to management practices such as tillage and cropping systems (West and Post, 2002). Soil conservation practices that increase soil organic C levels include conservation tillage, planting cover crops such as winter rye [*Secale cereale* (L.)], and applying manures such as poultry litter (PL) (Reeves, 1997; USDA, 2003). Worldwide restoration of soil C levels is important for reducing atmospheric CO_2 concentrations (Lal, 2004; Lal et al., 2004). Although US agriculture has seen a 17% increase in no-tillage (NT) practice and an 11% decrease in conventional tillage (CT) practice from 1990 to 2004 (CTIC, 2004), there is still major potential for reducing CO_2 efflux through greater adoption of soil conservation tillage practices to sequester C.

Soil CO_2 emission is affected by agricultural practices such as tillage and residue management and varies with climatic conditions (Yavitt et al., 1995). Intensive tillage can lead to C loss from agricultural soils due to exposure and subsequent oxidation of previously protected organic matter (Reicosky et al., 1995). Cover crops provide needed organic material that increases soil

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Abbreviations: AN, ammonium nitrate; CF, cotton-fallow; CR, cotton-rye; CT, conventional tillage; MT, mulch tillage; NT, no tillage; PL, poultry litter; 100 ANN, ammonium nitrate at 100 kg N ha^{-1}; 100 PLN, poultry litter at 100 kg N ha^{-1}.

Table 1. Cropping scheme, varieties, planting and harvest dates of cotton, winter rye and corn crops, Belle Mina, AL, 2003–2006.

Season	Year	Crop	Variety	Planting date	Harvest date
Summer	2003	cotton	SG 215 BR	27 May 2003	23 Oct. 2003
Fall/spring	2003/2004	winter rye	Elbon	11 Nov. 2003	10 Apr. 2004
Summer	2004	cotton	STN 4892 BR	18 May 2004	25 Oct. 2004
Fall/spring	2004/2005	fallow	–	–	–
Summer	2005	corn	Pioneer 31G98	5 Apr. 2005	21 Sept. 2005
Fall/spring	2005/2006	winter rye	Elbon	11 Oct. 2005	12 Apr. 2006
Summer	2006	cotton	DPL 445 BR	17 May 2006	2 Oct. 2006

organic matter (Schertz and Kemper, 1994; Reeves 1997). Reddy et al. (2004) found that winter rye [*Secale cereale* (L.)] cover cropping increased surface residue cover by up to 35, 70, and 100% in CT, mulch-tillage (MT), and no-tillage (NT) systems, respectively. Furthermore, Al-Kaisi and Yin (2005) found that cumulative soil CO_2 emission was 24% less for NT systems with residue than without residue during their 480-h measurement period. Reicosky et al. (1999) found higher fluxes of CO_2 in CT treatments than NT treatments on a short-term and cumulative CO_2 flux basis.

Application of PL can also be used to increase soil C (Nyakatawa et al., 2001). In the USA, over 10 billion kg of broiler litter is produced annually (Reddy et al., 2007). An economical and environmentally beneficial way to dispose of this PL would be to apply it as a nutrient source in crop production. Reddy et al. (2004) found that PL provided adequate nitrogen fertilization in NT and MT conservation systems with winter rye cover cropping and was ideal for cotton production in the southeast USA. Cotton is a low-residue crop that does not supply adequate C levels necessary to improve soil tilth in the seed zone or to increase soil organic matter (Reeves, 1997). There are limited studies that document and quantify the effects of tillage system on soil CO_2 emission and C storage with PL vs. commercial inorganic N applications.

The objective of this study was to measure and document CO_2 loss and C storage in tilled and non-tilled cotton receiving PL and ammonium nitrate (AN) as a nutrient source and rye as winter cover crop.

Table 2. List of treatments used in the study, Belle Mina, AL, 2003–2006.

Treatment	Tillage	Cropping system		N source	N rate
		Summer	Winter		
					kg ha^{-1}
1	conventional till	cotton	rye	none	0
2	conventional till	cotton	fallow	ammonium nitrate	100
3	no till	cotton	fallow	ammonium nitrate	100
4	conventional till	cotton	rye	ammonium nitrate	100
5	conventional till	cotton	rye	poultry litter	100
6	mulch till	cotton	rye	ammonium nitrate	100
7	mulch till	cotton	rye	poultry litter	100
8	no till	cotton	rye	ammonium nitrate	100
9	no till	cotton	rye	poultry litter	100
10	no till	cotton	fallow	none	0
11	no till	cotton	rye	poultry litter	200
12 (control)	none	fallow	fallow	none	0

Materials and Methods

Site Description

A field study was conducted at the Tennessee Valley Research and Extension Center, Belle Mina, AL (34° 41′ N, 86° 52′ W) on a Decatur silt loam (clayey, kaolinitic thermic, Typic Paleudults) soil from 2003 to 2006. Soil temperatures for Belle Mina averaged monthly from 1950 to 2006 were 20.4, 24.3, 26.2, 25.6, 25.6, and 22.3°C for April, May, June, July, August, and September, respectively. Monthly precipitation averages from 1950 to 2006 were 117, 113, 101, 111, 85, and 98 mm for the same months, respectively.

Carbon dioxide measurements for this study were taken during summers in 2003 to 2006, but treatments have been imposed since 1996 in this long-term study. Crop rotation pattern starting in 1996 has been two continuous years of cotton followed by 1 yr corn (cotton-cotton-corn). Cropping scheme followed, varieties, and planting and harvest dates during 2003 to 2006 are presented in Table 1.

Treatments and Experimental Design

Treatments included three tillage systems (CT, MT, and NT), two cropping systems (cotton in the summer and fallow in the winter [CF] and cotton in the summer and cereal rye cover crop in winter [CR]), and two sources of nitrogen (AN at 100 kg N ha^{-1} and PL at 100 and 200 kg N ha^{-1}). A control treatment with no N application was also included. A bare fallow (BF) treatment was maintained without any crop, tillage, and fertilizer application.

The experimental design was a randomized complete block with an incomplete factorial treatment arrangement due to constraints on land availability. Out of all combinations, only 12 important treatments were selected and replicated four times. All 12 treatments used in the study are presented in Table 2.

Conventional tillage included chisel plowing followed by disking before cotton seeding. Mulch-till included only chisel plowing to partially incorporate crop residues to a depth of 5 to 7 cm before planting. A field cultivator was used to prepare a smooth seed bed in the CT and MT plots. No-tillage was implemented by planting cotton directly into untilled soil using a John Deere 1700 planter. Bare fallow plots were managed using multiple applications of glyphosphate as needed throughout the growing season.

Poultry litter was applied at two rates to supply 100 and 200 kg N ha^{-1}, calculated for application each year based on the N content of the PL. Poultry litter was analyzed for total N on a LECO CN 2000 (LECO Corporation, St. Joseph, MI). Total N content of PL was 4.3, 3.7, and 1.8% in 2003, 2004, and 2006, respectively. Poultry litter applications were calculated assuming 60% of N availability from PL during the first year (Keeling et al., 1995). Approximately 3.9, 4.5, and 9.3 t ha^{-1} of PL was added to supply 100 kg N in 2003, 2004, and 2006, respectively. Poultry litter and AN were broadcasted by hand and incorporated to a depth of 5 to 8 cm by pre-plant cultivation in the CT and NT systems and left unincorporated in the NT system. The entire amount of ammonium nitrate and PL were applied to the plots on the day of planting.

The inorganic N control of ammonium nitrate was applied at a rate of 100 kg N ha^{-1}, which is the extension recommendation for cotton in the region. Two rates of PL were used in the NT treatments (100 and 200 kg N ha^{-1}) due to variability in N release associated with PL and to determine if higher rates of PL could be safely and sustainably used. The 200 kg N ha^{-1} litter treatment was applied in the NT system because NT with a cereal crop has become the standard in the region. Plots were 8 m wide and 9 m long, which resulted in eight rows of cotton spaced 1 m apart. Irrigation was applied as necessary on discretion of research station staff. Weed control, cotton defoliation, and other cultural practices were performed as per the recommendation of the local extension service.

Cover Crop and Soil Sampling

The winter rye cover crop (cv. Elbon) was seeded at 60 kg ha^{-1} in fall with a NT grain drill and killed with glyphosphate herbicide about 7 d after flowering in the spring of 2004 and 2006. Because corn in the summer of 2005 was going to add sufficient crop residue, winter rye was not planted in 2004, and all plots were kept fallow. The time between killing of winter rye and cotton planting was about 4 wk each year to allow for total drying of residues. No fertilizer was applied to the cover crop. Above ground biomass of winter rye was estimated for all years by sampling in 1 m^2 area in each plot. In spring of 2003, 2004, and 2005, before cotton/corn planting, soil samples were collected from each plot at 0- to 5-, 5- to 15-, 15- to 30-, 30- to 60-, and 60- to 90-cm depths using a hydraulic soil probe attached to a tractor before treatments were imposed. Soil, PL, and rye samples were analyzed for total C and N concentrations. Samples were ground to pass through a 2-mm mesh screen on a Wiley mill (A.H. Thomas Co., Philadelphia, PA) and analyzed for total C and N on the LECO CN 2000 analyzer (LECO Corporation, St. Joseph, MI).

Soil CO_2 Efflux Measurements

Soil CO_2 efflux was measured during summers in 2003 to 2006 using a LI-COR 6400 Infrared Gas Analyzer (LI-COR, Lincoln, NE) system attached to a LI-09 soil chamber (LI-COR, Lincoln, NE) and polyvinyl chloride soil collars. The LI-6400, in conjunction with the LI-09 system, uses gas exchange principles to measure soil CO_2 efflux. Two polyvinyl chloride collars, 10 cm in diameter and 5 cm in length, were installed in the center of each plot to avoid border effects from neighboring treatments. Collars were inserted 4 cm into the soil to serve as an interface between the chamber and soil. They were installed before the treatments were imposed to measure initial CO_2 efflux and removed to avoid interference with tillage operations and reinstalled after treatments were imposed. Collars were left in place undisturbed for CO_2 efflux measurements to be taken throughout the growing season. Measurements were taken at three stages: once before tillage treatments were applied, once immediately after tillage operations, and thereafter at 7-d intervals until harvest. Soil temperature at the 5-cm depth was measured by using a built-in thermometer attached to the LI-6400 IRGA. Soil CO_2 efflux was measured in $\mu mol\ m^{-2}\ s^{-1}$. Solely for the purpose of making an estimate of soil CO_2 emission, soil CO_2 efflux in $\mu mol\ m^{-2}\ s^{-1}$ was converted to Mg $ha^{-1}d^{-1}$ by using the formula $1\ \mu mol\ m^{-2}\ s^{-1} = 0.038\ Mg\ ha^{-1}\ d^{-1}\ [(44 \times 10^{-12}) \times (10^4) \times (24 \times 60 \times 60)]$ and calculated for the 165 d of the cotton-growing period. Rainfall data were collected from a weather station at the Tennessee Valley Research and Extension Center, Belle Mina, AL.

Statistical Analysis

Using mixed model procedures of the Statistical Analysis System (Version 9.1; SAS Inst., Cary, NC), data were analyzed to test the effect of year and treatment factors. Treatment means were compared using the LSD at $\alpha = 0.05$ within these sets of analyses. There were numerous year-by-treatment interactions; therefore, data were analyzed and presented by year. Pearson correlation analyses were performed between CO_2 efflux values and amount of rain fall + irrigation water applied 1 wk before the CO_2 emission readings were taken. In 2005, corn was planted as a rotation crop uniformly without applying any treatment in all plots using a no-till planter. Because corn did not receive any treatments, CO_2 efflux values were generally similar in all plots in 2005 (2.89–3.07 $\mu mol\ m^{-2}\ s^{-1}$). Hence, CO_2 efflux data for 2003, 2004, and 2006 under cotton cropping system are discussed here.

Results and Discussion

Tillage

Soil CO_2 efflux values sampled at weekly intervals during the summer of 2003, 2004, and 2006 are given in Fig. 1. In all years before tillage treatments were imposed on soils, NT released lower CO_2 than MT and CT (Fig. 1). Of all tillage treatments, BF plots continuously released the lowest amount of CO_2 throughout the growing season in all years (Fig. 1). The day tillage treatments were imposed (week 0) had an immediate dramatic increase in soil CO_2 efflux compared with the CO_2 efflux levels of the previous week. Similar results occurred in a study conducted by Calderon and Jackson (2002) where tillage was followed by immediate and significant increases in CO_2 efflux in roto-tilled and disked soils. Tillage causes a temporary increase in CO_2 efflux as soil pores equilibrate with a new concentration gradient (Wuest et al., 2003). A sharp increase in CO_2 emission immediately after the tillage operations may be due to the rapid increase in microbial activities in the decomposing labile soil organic pool (Al-Kaisi and Yin, 2005). In another study, Roberts and Chan (1990) and Jackson et al. (2003) observed that the increase in soil CO_2 emission is not due to microbial respiration but to increased soil aeration induced by tillage disturbance to the soil. Calderon and Jackson (2002) showed bursts of CO_2 caused by tillage and attributed this to the physical degassing of dissolved CO_2 from the soil solution because the soil microbial rate found in their data did not increase simultaneously.

An increase in CO_2 efflux was observed in all years when there was a rainfall and or irrigation (Fig. 1) throughout the growing season except for a few weeks before harvest. Positive correlations were observed between CO_2 efflux and amount of rainfall + irriga-

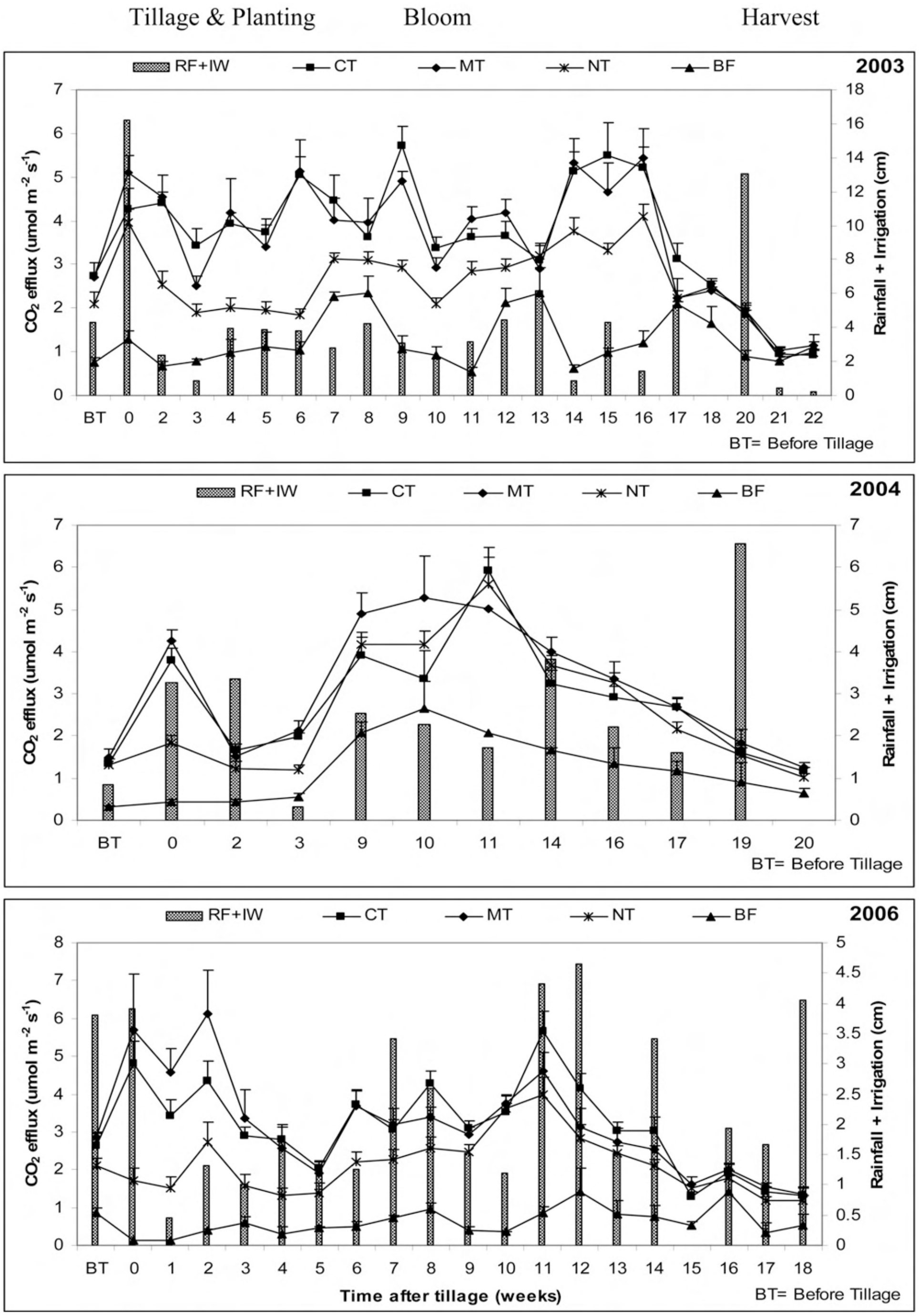

Fig. 1. Soil CO$_2$ efflux in conventional tillage (CT), mulch till (MT), no till (NT), and bare fallow (BF) cotton production systems during a growing season and amount of rain fall (RF) + irrigation water (IW) received 1 wk before the day of CO$_2$ efflux measurement, Belle Mina, AL, 2003, 2004, and 2006 (vertical bars = SE).

tion water applied 1 wk before CO$_2$ observations were taken in 2003 ($r = 0.05$; $p \leq 0.14$), 2004 ($r = 0.12$; $p \leq 0.01$), and 2006 ($r = 0.17$; $p \leq 0.001$). Increased CO$_2$ emissions from soil after irrigation have been reported (Curtin et al., 2000; Calderon and Jackson, 2002; Sainju et al., 2008). This was attributed to increased microbial activity and root respiration. Soil CO$_2$ efflux values were higher in 2003 and 2006 than in 2004. This was probably due to higher soil C levels observed in 2003 and 2006 due to the previous year's corn residue, a rotation crop, in this experiment (data not shown). Increased residue availability leads to increased microbial activity and consequently increased CO$_2$ efflux (see Soil Organic Carbon section for additional discussion). In all years, interactions for tillage × N source and tillage × cropping system were significant.

Tillage × N source

Conventional tillage with PL at 100 kg N ha^{-1} (100 PLN) showed the highest CO$_2$ efflux, and NT with AN at 100 kg N ha^{-1} (100 ANN) recorded the lowest CO$_2$ efflux (Table 3). In 2003 and 2006, all types of tillages with 100 PLN recorded higher CO$_2$ efflux (averaged over the season) compared with application of AN at the same rate (Table 3). This was expected because application of PL resulted in large input of additional C to the soil. Approximately 1.2, 1.4, and 3.2 t ha^{-1} of organic C was added through PL at 100 kg N ha^{-1} in 2003, 2004, and 2006, respectively. The CT and MT with 100 PLN resulted in significantly higher mean CO$_2$ emission during the growing season compared with NT with 100 PLN (Table 3) in 2003 and 2006. These results can be attributed to the intensity of soil disturbance, which was highest in CT, followed by MT and NT. Increased disturbance promotes increased aeration of the soil and increased exposure of soil microbes to soil C (Angers et al., 1993)and thus promotes rapid oxidation (Reicosky and Lindstrom, 1993). Ginting et al. (2003) found most CO$_2$ effluxes to be attributed to soil microbial and invertebrate activities. Al-Kaisi and Yin (2005) found that cumulative soil CO$_2$ emission was 19 to 41% lower for less intensive tillage treatments than moldboard plow during their 480-h measurement period. Averaged over the 3 yr, CT and MT with 100 PLN released 27 and 25% higher CO$_2$ into the atmosphere compared with NT with 100 PLN. No-tillage treatments had lower soil CO$_2$ emissions by 6.1 and 5.4 Mg ha^{-1} during the cotton growing season of about 165 d compared with CT and MT, respectively.

Table 3. Interaction effect of tillage and nitrogen sources on soil CO_2 efflux, Tennessee Valley Research and Extension Center, Belle Mina, AL 2003, 2004, and 2006.

	Nitrogen source							
	2003		2004		2006		Average	
Tillage	100PLN	100AN	100PLN	100AN	100PLN	100AN	100PLN	100AN
	μmol m^{-2} s^{-1}							
CT‡	4.39a†	3.65b	3.00a	2.74ab	3.40a	2.98ab	3.60	3.12
MT	4.17a	3.09c	2.90ab	2.95a	3.39a	2.70bc	3.49	2.91
NT	2.84c	2.25d	2.57ab	2.04b	2.47c	1.58d	2.63	1.96

† Treatment means in each year followed by the same lowercase letter are not significantly different from each other at $P \leq 0.05$.

‡ CT, conventional tillage; MT, mulch tillage; NT, no tillage; 100 ANN, 100 kg N ha^{-1} as ammonium nitrate; 100 PLN, 100 kg N ha^{-1} as poultry litter.

Tillage × Cropping System

There was a significant interaction between tillage and cropping system on soil CO_2 efflux. Means for CO_2 efflux during the measurement period as affected by tillage and cropping system are presented in Table 4. Inclusion of rye cover crop during winter significantly increased CO_2 emission from soil compared with keeping the land fallow in winter under NT system. Similar results were observed in CT only in 2006. This was attributed to the addition of organic C through rye residue. The amount of residue added through rye cover cropping in 2003/04 and 2005/06 is presented in Table 5. Nitrogen and C concentrations of rye residue ranged from 1.3 to 1.5% and from 42 to 47%, respectively. The NT under CF cropping system resulted in significantly lower CO_2 efflux in all years. Conventional tillage and MT with CR cropping system released significantly more CO_2 than NT with the same cropping system. On average, under rye cover cropping, CT and MT released 23 and 20%, respectively, higher CO_2 compared with NT. Higher-intensity soil disturbance in CT and MT plots is likely the reason for this.

Carbon dioxide efflux was significantly influenced by N sources. Application of PL at 100 or 200 kg N ha^{-1} released higher CO_2 compared with AN at 100 kg N ha^{-1} (Fig. 2). On average, 24 and 26% higher CO_2 was emitted from plots receiving PL at 100 and 200 kg N ha^{-1}, respectively, compared with AN at 100 kg N ha^{-1}. These results are in agreement with findings of Dao and Cavigelli (2003).

Table 4. Interaction effect of tillage and cropping systems on soil CO_2 efflux, Tennessee Valley Research and Extension Center, Belle Mina, AL 2003–2006.

	Cropping system							
	2003		2004		2006		Average	
Tillage	CR	CF	CR	CF	CR	CF	CR	CF
	μmol m^{-2} s^{-1}							
CT‡	3.74a†	3.61a	2.86a	2.51a	3.25a	2.63b	3.28	2.92
NT	2.82b	2.16c	2.66a	1.89b	2.50b	1.57c	2.66	2.59
MT	3.64a	–§	2.93a	–	3.04a	–	3.20	–

† Treatment means in each year followed by the same lowercase letter are not significantly different from each other at $P \leq 0.05$.

‡ CF, cotton–fallow; CR, cotton–rye; CT, conventional tillage; MT, mulch tillage; NT, no tillage.

§ MT–CF interaction does not exist in the experiment.

Table 5. Rye residue dry matter added in 2003/04 and 2005/06, Belle Mina, AL.

	Treatments											
Year	1	2	3	4	5	6	7	8	9	10	11	12
	t ha^{-1}											
2003/04	0.5	0	0	0.5	0.6	0.8	0.5	0.7	0	0	0.8	0
2005/06	1.2	0	0	1.8	1.4	1.5	1.3	1.8	0	0	1.7	0

Total Soil Carbon

Total soil C concentrations (0–15 cm) differed significantly among years. Overall, soil C was significantly higher in 2003 than in 2004 and 2005 at all depths (Table 6). This temporal change in C was likely due to the corn-cotton-cotton crop rotation. Corn was planted as a rotation crop in 2002 before cotton in 2003, and its residue was left in the field in their respective plots. Decomposition of corn residue likely influenced 2003 soil C data. In 2003, cotton, a low-residue crop that slowly decomposes, was planted leaving little residue on the soil surface for the 2004 growing season. Soil C concentrations decreased with depth, most notably below 30 cm (Table 6). Torbert et al. (2004) found that soil organic C content was stratified in the soil profile with much higher organic C levels in the top of the profile as compared with the deeper soil depths.

Total soil C was not significantly influenced by tillage (Table 7) in all years. Intensity of soil disturbance in different tillages was in the order of CT > MT > NT. This resulted in higher CO_2 emission in CT and MT compared with NT in all years (Fig. 1), but it did not reflect significant change in total C. Furthermore, there was a difference in method of PL application in these tillages. In CT and MT plots, PL was incorporated into soil to a depth of 5 to 8 cm, and in NT it was unincorporated. Even this difference in method of application did not influence total C significantly. Among tillages, MT recorded slightly higher C followed by NT. Motta et al. (2002) found that soil C was affected by the interaction of soil type, tillage, and depth and was inversely related to soil disturbance at the 2.5-cm depth. Application of PL or AN recorded significantly higher total soil C compared with 0-N control in 2004 and 2005. Although there was no significant difference, PL at 100 or 200 kg N ha^{-1} showed slightly higher soil C compared with AN at 100 kg N ha^{-1}. Winter cover cropping influenced the total C in 2004. A cotton-rye cropping system showed significantly higher

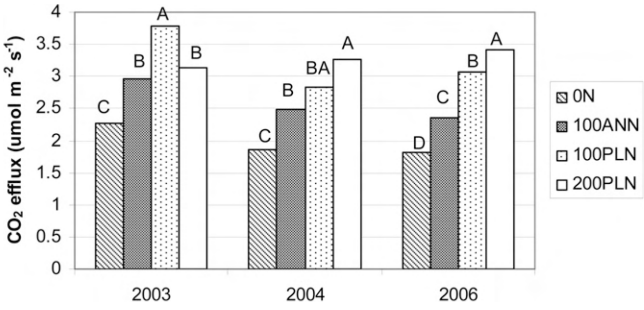

Fig. 2. Influence of N sources on soil CO_2 efflux, Belle Mina, AL, 2003, 2004, and 2006. Treatment means under each year followed by the same uppercase letter are not significantly different from each other at $P \leq 0.05$. 100 ANN, ammonium nitrate at 100 kg N ha^{-1}; 100 PLN, poultry litter at 100 kg N ha^{-1}; 200 PLN, poultry litter at 100 kg N ha^{-1}.

Table 6. Pooled treatments soil carbon concentrations by depth as influenced by year, Tennessee Valley Research and Extension Center, Belle Mina, AL, 2003–2005 (before planting summer crop).

	Year		
Soil depth	2003	2004	2005
cm		g kg^{-1}	
0–5	19.0a†A‡	15.7aB	13.7aB
5–15	11.9bA	10.0bB	10.3bB
15–30	9.8cA	8.3cB	9.2cB
30–60	5.1dA	3.8dB	5.0dB
60–90	4.4dA	2.6eB	4.2eB

† Treatment means (in columns) for each year followed by the same lowercase letter are not significantly different from each other at $P \leq 0.05$.

‡ Treatment means (in rows) for each tillage system in different years followed by the same uppercase letter are not significantly different from each other at the $P \leq 0.05$.

total C in the soil at 0- to 15-cm depth compared with cotton-fallow in 2004. It was attributed to addition of rye residue to the soil, which was planted as a winter cover crop (Table 7). The general elevated and nonsignificant nature of C data in 2003 could be attributed to residue of rotation crop corn grown in 2002.

Conclusions

Our study suggests that NT with PL at 100 kg N ha^{-1} can reduce soil CO_2 emissions by 27 and 25%, respectively, compared with CT and MT during a cotton growing season of about 165 d. Poultry litter applications at 100 or 200 kg N ha^{-1} caused an increase in CO_2 efflux compared with AN at 100 kg N ha^{-1}. However, soil C concentrations were increased with applications of PL compared with a 0-N control. Total soil C was not affected by tillage during the three seasons studied. A winter rye cover crop increased soil C significantly. Application of PL at 100 or 200 kg N ha^{-1} under NT systems with a winter rye cover crop is an effective way to mitigate CO_2 emissions and to sequester C in the soil. Furthermore, the safe application of PL to soils is an environmentally friendly practice which reduces the accumulation of waste material generated by the poultry industry in the southeastern USA.

Table 7. Total soil carbon concentrations (0–15 cm) as influenced by tillage, cropping systems, and N sources, Tennessee Valley Research and Extension Center, Belle Mina, AL, 2003–2005 (before planting summer crop).

	Year		
Treatment	2003	2004	2005
		g kg^{-1}	
Tillage			
Conventional till	15.6	13.0	11.8
Mulch till	16.4	14.0	12.9
No till	15.2	13.1	12.1
LSD ($P \leq 0.05$)	NS	NS	NS
Cropping system			
Cotton–rye	15.8	13.8	12.4
Cotton–fallow	14.8	11.7	11.2
LSD ($P \leq 0.05$)	NS	1.89	NS
N source			
0 N	13.7	11.4	10.9
100 ANN†	15.8	13.0	12.5
100 PLN	15.8	14.4	12.5
200 PLN	17.2	14.5	13.5
LSD ($P \leq 0.05$)	NS	2.81	2.13

† 100 ANN, 100 kg N ha^{-1} as ammonium nitrate; 100 PLN, poultry litter at 100 kg N ha^{-1}; 200 PLN, poultry litter at 200 kg N ha^{-1}.

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