Influence of Tillage and Poultry Litter Application on Carbon Dioxide Efflux and Carbon Storage in Soil under Cotton Production System

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Abstract

Agricultural ecosystems play an important role in the storage and release of C within the terrestrial carbon cycle. A study was conducted in north Alabama in 2003-2006 to measure CO_2 efflux and carbon storage in long-term tilled and non-tilled cotton plots receiving poultry litter and ammonium nitrate as N sources. Treatments were established in 1996 and consisted of conventional-tillage (CT), mulch-tillage (MT), and no-tillage (NT) systems with winter rye [*Secale cereale* (L.)] cover cropping and ammonium nitrate (AN) and poultry litter (PL) as nitrogen sources. In 2003, 2004 and 2006 cotton was planted and in 2005 corn was planted as a rotation crop using a no till planter in all plots and did not receive any fertilizer. All tillages with PL application recorded higher CO_2 emission from soil compared to AN application. 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 @ 100 kg ha^{-1} N (100 PLN) recorded significantly higher CO_2 efflux compared to NT with 100 PLN (2.84 and 2.47 µmol m^{-2} s^{-1}, respectively). On average, CT and MT with 100 PLN emitted 37 and 25%, respectively higher CO_2 compared to NT with 100 PLN. In all years cotton–rye cropping system (CR) recorded higher CO_2 efflux compared to cotton-fallow (CF). CT and MT with CR released higher CO_2 from soil compared to NT with CR in 2003 and 2006. Total carbon in soil (0-15cm) did not differ significantly with tillage. Our study suggests that NT conservation tillage systems along with application of poultry litter @ 100 kg N ha^{-1} and winter rye cover cropping emits lower CO_2 in to the atmosphere compared to conventional and mulch till. Further it helps in safe disposal of poultry litter which is a major problem in southeastern US.

Introduction

Agricultural ecosystems play an important role in the storage and release of C within the terrestrial carbon cycle. Soil organic carbon is recognized as an indicator of soil quality. Carbon dioxide is a greenhouse gas which allows short wave solar radiation into the atmosphere, but traps most of the long wave radiation going out, the process is better known as the greenhouse effect. There is a major potential for increasing soil carbon through restoration of degraded soils and widespread adoption of soil conservation practices. In the United States, 5.6 million ha of cotton [*Gossypium hirsutum* (L.)] were planted in 2005 (Agricultural Statistics Board, 2005); it was 226,720 ha in Alabama. Despite being a valuable and important crop, cotton creates a greater soil erosion hazard than other widely grown annual crops (Triplett et al, 1996). Most cotton is produced using conventional tillage systems which leave the soil susceptible to erosion. However, conservation tillage systems such as mulch-till and no-till can reduce soil erosion, replenish soil organic matter (SOM), conserve soil moisture, and improve cotton productivity (Nyakatawa et al., 2001a, 2001b). Cover crops provide needed organic material which improves SOM (Schertz and Kemper, 1994). Major cotton producing states also produce large amounts of poultry litter (Agricultural Statistics Board, 2002). A novel approach to dispose of poultry litter is to use it as a nutrient source for cotton (Reddy et al., 2007). Poultry litter can increase soil organic nitrogen, soil carbon content, and soil porosity (Nyakatawa et al., 2001b). Hence a study was conducted for four years to quantify the CO_2 efflux and carbon storage under different tillage systems using poultry litter as a nutrient source for cotton.

Materials and Methods

A four year field study (2003-06) was conducted using existing plots and treatments established in the Fall of 1996 in a cotton [*Gossypium hirsutum* (L.)] and corn (*Zea mays*) rotation system at the Alabama Agricultural Experiment Station, Belle Mina, AL (34° 41' N, 86° 52'W) on a Decatur silt loam (clayey, kaolinitic thermic, Typic Paleudults). The experimental design was a randomized complete block. Plot size was 8m by 9m with eight rows of crops. This experiment included three tillage methods, two sources of nitrogen, three levels of nitrogen, and two cropping systems. The three tillage methods were conventional-till, no-till, and mulch-till. The two sources of nitrogen were poultry litter and ammonium nitrate. Three rates of N application were used: 0 kg N ha^{-1}, 100 kg N ha^{-1}, and 200 kg N ha^{-1}. The two cropping systems were cotton-fallow (cotton in the summer and fallow in the winter) and cotton-rye [*Secale cereale* (L.)] sequential cropping (cotton in summer and rye in winter). However, only twelve treatments were included in the study due to paucity of space and resources in an incomplete factorial randomized block design .

The winter rye cover crop was planted in sequential cropping plots using a no-till grain drill in the fall. Conventional tillage includes fall plowing with moldboard followed by a spring disk harrow. To prepare a smooth seedbed after disking, a disk cultivator was used. Mulch-till plots were tilled with a cultivator to shallowly incorporate crop residues to a depth around 5 cm before planting. The ammonium nitrate was measured and applied by hand. The poultry litter was incorporated to a depth of 5 cm by pre-plant cultivation in the mulch-till and conventional-till plots. The poultry litter was not incorporated in the no-till system. In 2003, 2004 and 2006 Sure Grow cotton was planted in all plots using a no-till planter except in bare fallow treatment. Fallow plots are kept weed free by the use of herbicides. Weeds are controlled by both tillage and herbicides in the conventional tillage systems and by applying herbicides only in the mulch-till and no-till systems. In 2005 corn was planted as a rotation crop using a no-till planter in all plots. No fertilizer was applied for corn. Soil samples were collected prior to planting. Soil CO_2 efflux measurements were taken using the LI-COR 6400 IRGA system attached to a LI-09 soil chamber. Soil CO_2 efflux measurements were collected once before tillage and thereafter at seven day intervals following application of treatments for the duration of the summer season. Chemical measurements include soil organic matter (Walkey and Black, 1934), soil carbon and soil nitrogen using the LECO carbon and nitrogen analyzer, (Leco Corporation, 2000).

Data Analysis

Data was analyzed using mixed models in Statistical Analysis System (SAS Version 9.1). Treatment means were compared using LSD mean separation.

Conventional Tillage

Mulch Tillage

No Tillage

LICOR 6400

Results and Discussion

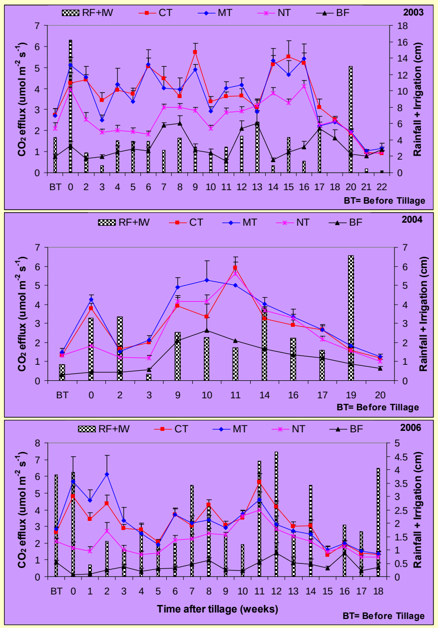

Figure 1. Soil CO_2 efflux in conventional-tillage (CT), mulch-till (MT), no-till (NT) and bare-fallow (BF) cotton production systems during growing season and amount of rain fall (RF) + irrigation water (IW) received a week before the day of CO_2 efflux measurement, Belle Mina, AL, 2003, 2004 and 2006 (vertical bars= S. E.).

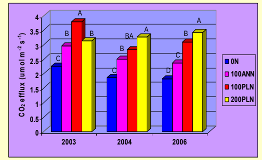

Figure 2. Influence of N sources on soil CO_2 efflux, 2003, 2004 and 2006 (100 ANN= Ammonium Nitrate @100 kg N ha^{-1}, 100PLN= Poultry Litter @100 kg N ha^{-1}, 200PLN= Poultry Litter @100 kg N ha^{-1}).

Table 1. List of treatments used in the study at Belle Mina, AL.

Treatment	Tillage	Cropping System: Summer	Cropping System: Winter	Nitrogen Source	*Nitrogen Rate kg/ha*
1	Conven.-till	Cotton	Rye	None	0
2	Conven.-till	Cotton	Fallow	Ammonium Nitrate	100
3	No-till	Cotton	Fallow	Ammonium Nitrate	100
4	Conven.-till	Cotton	Rye	Ammonium Nitrate	100
5	Conven.-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

Carbon Dioxide (CO_2) Efflux:

Effect of Tillage

- On the day of application of treatments, week 0, a significant increase in soil CO_2 efflux was observed in all plots that received one or other type of tillage (Fig. 1).
- 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 @ 100 kg N ha^{-1} (100 PLN) recorded significantly higher CO_2 efflux compared to NT with 100 PLN (2.84 and 2.47 µmol m^{-2} s^{-1}, respectively).
- On average NT with poultry litter @ 100 kg N ha^{-1} can reduce soil CO_2 emissions by 37 and 25%, respectively compared to CT and MT during a cotton growing season of about 165 days.
- Bare fallow plots had least amount of carbon efflux throughout the sampling period (Fig. 1).
- No treatment differences in carbon efflux were noted In 2005 since corn was planted uniformly with a no-till planter in all plots.
- A careful analyses of the carbon efflux data indicate that the efflux was proportional to the level of soil tillage (bare fallow being completely undisturbed vs. conventional tillage being the maximum disturbance of soil) and the effect is tapered off from the date of application of tillage.

Table 2. 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

Tillage	2003 100PLN	2003 100AN	2004 100PLN	2004 100AN	2006 100PLN	2006 100AN	Average 100PLN	Average 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 with in each year followed by the same lowercase letter are not significantly different from each other at P ≤ 0.05.

‡ CT= Conventional Tillage, MT= Mulch Tillage, NT= No Tillage, 100 PLN= 100 kg N ha^{-1} as poultry litter, 100 ANN= 100 kg N ha^{-1} as ammonium nitrate.

Table 3. Interaction effect of tillage and cropping systems on soil CO_2 efflux, Tennessee Valley Research and Extension Center, Belle Mina, AL 2003-2006

Tillage	2003 CR	2003 CF	2004 CR	2004 CF	2006 CR	2006 CF	Average CR	Average 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 within each year followed by the same lowercase letter are not Significantly different from each other at P ≤ 0.05.

‡ CT= Conventional Tillage, NT= No Tillage, MT= Mulch Tillage, CR= Cotton – Rye, CF= Cotton – Fallow. *MT-CF interaction does not exist in the experiment

Table 4. Soil carbon concentrations by depth (pooled treatments) as influenced by year, Tennessee Valley Research and Extension Center, Belle Mina, AL, 2003-2005 (Before planting summer crop)

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

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

‡ Treatment means (in rows) within each soil depth followed by the same uppercase letter are not significantly different from each other at the 5% level.

Table 5. Total soil carbon concentrations (0-15cm) as influenced by tillage, cropping systems and N sources, Tennessee Valley Research and Extension Center, Belle Mina, AL, 2003-2005 (Before planting summer crop)

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 ≤ 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 ≤ 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 ≤ 0.05)	NS	2.81	2.13

† 100 ANN= 100 kg N ha^{-1} as ammonium nitrate, 100 PLN= Poultry litter @ 100 kg N ha^{-1}, 200 PLN= Poultry litter @200 kg N ha^{-1}.

Carbon Dioxide (CO_2) Efflux:

Effect of Cropping System

- CT and MT with cotton- rye cropping system (CR) released significantly more CO_2 than NT with same cropping system. On average, under rye cover cropping CT and MT released 23 and 20%, respectively higher CO_2 compared to NT (Table 3).

Effect of Nitrogen Source

- Poultry litter application resulted in higher CO_2 emission from soil compared to AN application, regardless of tillage system (Table 2).
- On average 24 and 26% higher CO_2 was emitted from plots receiving poultry litter @ 100 and 200 kg N ha^{-1}, respectively compared to ammonium nitrate @ 100 kg N ha^{-1}.

Total Soil Carbon:

- Total soil C at 0-15 cm depth was not affected by tillage but significantly increased with poultry litter application and winter rye cover cropping (Table 5).
- Overall, soil C was significantly higher in 2003 than in 2004 and 2005 at all depths (Table 5). This temporal change in C was likely due to the corn-cotton-cotton crop rotation. Corn was planted as a rotation crop in 2002 prior to cotton in 2003 and its residue was left in the field in their respective plots.

Conclusion

Application of poultry litter at 100 or 200 kg N ha^{-1} under no-tillage 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 poultry litter to soils is an environmentally friendly practice which reduces the accumulation of waste material generated by the poultry industry in the southeastern US.

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