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SOIL CO_2 EFFLUXES IN CONVENTIONAL AND CONSERVATION TILLAGE SYSTEMS WITH POULTRY LITTER APPLICATION

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Abstract

Increased levels of carbon dioxide (CO_2) in the atmosphere could cause major changes in our global climate which could have a detrimental effect on world agriculture. More carbon (C) is contained in the soil than in the world's atmosphere and vegetation combined, therefore soil organic matter (SOM) plays a vital role in the world carbon balance. A field study is being conducted using existing plots and treatments established in the Fall of 1996 in a cotton [*Gossypium hirsutum* (L.)] and corn (*Zea mays*) rotated field at the Alabama Agricultural Experiment Station, Belle Mina, AL. The objectives of this study are to measure, model, and document carbon sequestration and CO_2 loss in tilled and non-tilled cotton plots receiving poultry litter as a nutrient. In 2003, plots that received 100 kg poultry litter N ha^{-1} had total carbon values in conventional-till (CT) which averaged 22 g/kg C. No significant differences due to treatments were found in the total carbon levels in the 0-5, and 60-90 cm layers of soil. Carbon dioxide efflux values in CT which averaged 5.6 $um/m^{-2}/s^{-1}$ were 9% higher than those in mulch till (MT), 83% higher than those in no-till (NT), and 307% higher than CO_2 efflux values in bare fallow (BF) plots. So far, this study demonstrates that no-till and mulch-till conservation tillage systems will sequester carbon by reducing the amount of CO_2 released from soils under cotton production. This will increase soil carbon, which will in turn increase soil productivity for sustainable agriculture.

Introduction

Agricultural ecosystems play an important role in the storage and release of C within the terrestrial carbon cycle (Lal et al., 1995). Soil organic carbon is recognized as an indicator of soil quality (Reeves, 1997). Carbon dioxide is a greenhouse gas released from soil through microbial degradation. Carbon dioxide allows short wave solar radiation into the atmosphere, but traps most of the long wave radiation going out in a process known as the greenhouse effect (Brady and Weil, 2002). 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, 6.3 million ha of cotton [*Gossypium hirsutum* (L.)] were planted in 2001 (Agricultural Statistics Board, 2002), and 126.4 kg per ha were harvested at a value of 4.26 million dollars (Agricultural Statistics Board, 2002). In Alabama 247,050 ha of cotton were planted in 2001 (Agricultural Statistics Board, 2002), and 90.3 kg per ha were harvested (Agricultural Statistics Board, 2002).

Despite being a valuable and important crop, cotton can be a greater soil erosion hazard than other widely grown annual crops (Triplett et al, 1996) if produced using conventional tillage systems which leave the soil susceptible to erosion (Burgess et al., 1996; Lopez-Bellido et al., 1996). Conservation tillage systems such as mulch-till and no-till can reduce soil erosion (Nyakatawa et al., 2001a, 2001b), replenish soil organic matter, conserve soil moisture, and improve cotton productivity (Nyakatawa et al., 2001b). Cover crops provide needed organic material which improves SOM (Schertz and Kemper, 1994). Cover crops also reduce nitrate leaching to groundwater by scavenging residual nutrients (Kelley et al., 1992; Nyakatawa et al., 2001c). 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 soil nutrient. Poultry litter can increase soil organic nitrogen, soil carbon content, soil porosity, and enhance microbial activity (Nyakatawa et al., 2001b). Methods need to be developed in order to quantify and reduce agricultural contributions to atmospheric CO_2. The CQESTR model (Rickman, et al., 2001), a model which utilizes information about tillage practices, crop rotations, and crop production will be used in this study to predict gain or loss of soil organic matter. The objectives of this study are to measure, model, and document carbon sequestration and CO_2 loss in tilled and non-tilled cotton plots receiving poultry litter as a nutrient.

Materials and Methods

A field study is being conducted using existing plots and treatments established in the Fall of 1996 in a cotton [*Gossypium hirsutum* (L.)] and corn (*Zea mays*) rotated field 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 is a randomized complete block. Plot size is 8m by 9m with eight rows of crops. This experiment includes three tillage methods, two sources of nitrogen, three levels of nitrogen, and two cropping systems. The three tillage methods are conventional-till, no-till, and mulch-till. The two sources of nitrogen are poultry litter and ammonium nitrate. Three rates of N application are used: 0 kg N ha^{-1}, 100 kg N ha^{-1}, and 200 kg N ha $^{-1}$. The two cropping systems are cotton winter-fallow, which means cotton in the summer and fallow in the winter and cotton-rye [*Secale cereale* (L.)] sequential cropping which means cotton in summer and rye in winter. However, a select twelve treatments (Table 1.) were included in the study 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, and killed by Glyphosphate herbicide in the spring. Conventional tillage included 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 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. Sure Grow cotton was planted in all plots except in bare fallow treatment using a no-till planter. A herbicide mixture of Fluometuren (3.5L/ha), Pendimehalin (2.3L/ha), and Gramoxone extra (1.7L/ha) was applied to all plots before planting. 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. Soil and rye tissue samples were collected prior to planting in spring 2003. Soil CO_2 efflux measurements were taken using the LI-COR 6400 IRGA (LI-COR, inc. 1997) system attached to a LI-09 soil chamber (LI-COR, inc. 1997). 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 2003 season. Chemical measurements include soil organic matter, soil carbon and soil nitrogen using the LECO carbon and nitrogen analyzer, (Leco Corporation, 2000).

Data Analysis

Data was analyzed using analysis of variance (ANOVA), regression analysis (PROC REG), and correlation procedures in the SAS Statistical Analysis System (SAS Version 8.2, 1999). Treatment means were compared using LSD mean separation and contrast analysis.

Results and Discussion

Carbon Dioxide Efflux

Carbon dioxide (CO_2) efflux values in *u*m/m^{-2}/s^{-1} sampled at weekly intervals during the summer 2003 growing season are displayed in Figure 1. In general, amounts of CO_2 released from convention-till plots were higher than that released from no-till, mulch-till, and bare-fallow plots (Figure1.). Exceptions to this occurred on 05-02-03, before tillage and on 05-09-03 after tillage treatments were imposed on soils for the 2003 growing season. On 05-09-03, although conventional-till still released more CO_2 than mulch-till, no-till, and bare-fallow treatments, no-till released more CO_2 than mulch-till and bare-fallow treatments (Figure 1.). Soil CO_2 efflux values in plots prior to tillage on this particular date is likely a reflection of soil treatment effects from previous years. Conventional-till and mulch-till plots run out of residues before no-till plots due to increased oxidation and biological degradation of residues. After tillage treatments were imposed, on the dates of 06-06-03, 06-13-03, and 07-04-03, CO_2 values for mulch-till plots were higher than conventional-till plots. This variation is likely due to impaired CO_2 release from plots due to heavy rainfall which occurred before measurements thus high soil moisture content. Overall means for CO_2 efflux in *u*m/m^{-2}/s^{-1} by tillage at 100 kg poultry litter N ha^{-1} are displayed in Figure 2. Plots under conventional till had 9%, 83% and 307% significantly higher CO_2 efflux values than those under mulch till, no-till, and bare fallow soils for the summer 2003 growing season by 9%, 83%, and 307% respectively (Figure 2.). Mulch-till plots had 67% and 271% significantly higher values of CO_2 efflux than no till and bare-fallow plots respectively (Figure 2.). This is likely due to increased microbial decomposition and oxidation of residue due to high levels of CO_2 in mulch-till plots. When tillage treatments are initially imposed on mulch-till plots, the combination of increased oxygen levels along with an abundant source of nutrients for microbe consumption in the form of crop residues makes conditions suitable for increased soil microbial growth. Conventional tillage leaves less than 30% of residue cover on the soil surface. Therefore, plots under conventional-till have more soil oxygen in comparison to mulch-till, no-till, and bare fallow. Due to higher soil oxygen levels and carbon availability, the process of microbial degradation is likely to peak then later plateau to soil CO_2 levels similar to surrounding soils first in the conventional-till plots, then mulch-till, non-till soils, and lastly bare fallowed plots. In a study conducted by Wuest et al. (2003), carbon dioxide flux measurement during simulated tillage soils also produced large peaks of CO_2 flux immediately after tillage followed by a steady rate of decay.

Cumulative CO_2 efflux values in summer 2003 under 100 kg poultry litter N ha^{-1} in conventional-till, mulch-till, no-till, and bare-fallow treatments were 332 *u*m/m^{-2}/s^{-1}, 286 *u*m/m^{-2}/s^{-1}, 184 *u*m/m^{-2}/s^{-1}, 87 *u*m/m^{-2}/s^{-1} respectively. The above results indicate that use of conservation tillage systems no-till and mulch-till in cotton production systems will sequester carbon by reducing the amount of CO_2 released from the soils thus improving soil productivity for sustainable agriculture.

Addition of poultry litter to soil provides an immediate food source to soil microbes and results in increased microbial respiration and carbon CO_2 release. In a study conducted about mineralizable carbon, nitrogen, and water extractable phosphorus release from stockpiled and composted manure and manure amended soils Dao and Cavigelli (2003) observed that adding manures to soils significantly increased CO_2 flux densities compared to soils with no manures added. Overall means for CO_2 efflux (*u*m/m^{-2}/s^{-1}) by nitrogen (N) source and rate using no-till and cotton/rye cropping systems are given in Figure 3. Although higher means of CO_2 efflux values were found for plots receiving 200 kg poultry litter N ha^{-1} compared to 100 kg poultry litter N ha^{-1}, no significant differences were found between those two treatments. However, plots receiving 200 kg poultry litter N ha^{-1} and plots receiving 100 kg poultry litter N ha^{-1} both had significantly higher efflux values than soils receiving 100 kg ammonium nitrate N ha^{-1} by 30% and 17% respectively (Figure 3.). Microbial growth and decay are logarithmic in nature. It is therefore expected that CO_2 efflux following poultry litter application will peak early in the season compared to later in summer during the experiment.

Means for overall CO_2 efflux (*u*m/m^{-2}/s^{-1}) by cropping system using conventional-till and 100 kg ammonium nitrate N ha^{-1} are displayed in Figure 4. Cotton-fallow and cotton-rye cropping systems had overall efflux values of 4.8 *u*m/m^{-2}/s^{-1} and 4.5 *u*m/m^{-2}/s^{-1} (Figure 4.). Overall, significantly higher CO_2 efflux values (7%) were found in the cotton-fallow cropping systems in comparison to the cotton-rye cropping systems under conventional tillage. Overall means for carbon dioxide (CO_2) efflux (*u*m/m^{-2}/s^{-1}) by cropping system using no-till and 100 kg ammonium nitrate N ha^{-1} are given in Figure 4. In this tillage system, the overall mean efflux values for cotton-fallow and cotton-rye were 2.1 *u*m/m^{-2}/s^{-1} and 2.6 *u*m/m^{-2}/s^{-1} respectively. Although higher CO_2 efflux values were found in the cotton-rye cropping system than in the cotton-fallow cropping system, no significant differences were found in CO_2 efflux levels due to these cropping systems under no-till practices.

Soil CO_2 efflux under cotton-fallow and cotton-rye in conventional-till was greater than that under cotton-fallow and cotton-rye in no-till (Figure 4.). There was a significant tillage and cropping system interaction. This may imply that carbon storage under no-till plots will be higher than that under conventional-till. Buyanovsky et al. (1986) and Wuest (2003) observed that cropping systems involving tillage may produce less soil carbon storage than non-tilled soils. Buyanovsky and Wagner (1983) observe that tillage affects convection and diffusivity at the soil-atmosphere surface which in turn mediates the flux of CO_2 from the soil atmosphere to the aboveground atmosphere. The findings from our study show that in conventionally tilled soils, significantly more CO_2 was released in the cotton-fallow cropping systems than the cotton-rye cropping system. Thus, conservation tillage practices using a winter rye cover crop reduce the levels of CO_2 released from soils thus promote carbon sequestration and soil productivity.

Total Soil Carbon

There were no significant differences in total carbon levels among conventional-till, mulch-till, no-till, and bare fallow plots in the 0-5 and 60-90 cm depth (Table 2.). The lack of significant differences in total soil carbon in the top 0-5 cm among treatments can be attributed to crop residues which accumulate at the soil surface. This indicates that the tillage treatments may not show benefit of carbon sequestration close to the soil surface. However no-till plots had significantly higher amounts (20%) of total soil carbon than bare fallowed soils at the 5-15 cm depth (Table 2.). Mulch-tilled and non-tilled soils had significantly higher amounts of total soil carbon (17% and 23% respectively) than bare fallowed soils in the 15-30 cm depth. Conventionally-tilled soils had significantly higher amounts (30%) of total soil carbon than bare fallowed plots in the 30-60 cm depth.

A study about tillage systems and crop rotation effects on dryland crop yields and carbon in the Central Great Plains conducted by Halvorson et al. (2002) observed increasing soil carbon with decreasing tillage. Results from this research show that there is 423% more total carbon in the top 0-5 cm depth of soil than in the 60-90 cm depth of soil (Table 2.) So far, our study shows that differences in carbon storage among tillage systems can be expected in the 5-30 cm soil profile. Most tillage operations are performed on the top 0-15 cm of soil where the bulk of the total carbon is stored. Therefore, conservation tillage practices mulch-till and no-till which promote carbon sequestration serve a vital role in the storage of carbon in the soil plough layer.

Conclusions

Practicing conservation tillage methods such as mulch-till and no-till in addition to using poultry litter as a nutrient source in cotton production systems helps to sequester carbon by reducing CO_2 release to the atmosphere thus improving agricultural sustainability. Cropping systems cotton-fallow and cotton-rye under no-till had lower CO_2 efflux values than cropping systems under conventional-till. Therefore, conservation tillage practices mulch-till and no-till are beneficial to carbon storage in soil.

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Table 1. List of treatments.Alabama Agricultural Experiment Station, Belle Mina, AL.

		Cropping System			
		Summer	**Winter**		
1	Conventional-till	Cotton	Rye	None	0
2	Conventional-till	Cotton	Cotton	Ammonium Nitrate	100
3	No-till	Cotton	Cotton	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	Cotton	None	0
11	No-till	Cotton	Rye	Poultry Litter	200
12 (Control)	None	Fallow	Fallow	None	0

Table 2. Soil total carbon levels by depth as influenced by tillage. Alabama Agricultural Experiment Station, Belle Mina, AL April, 2003.

	Tillage Systems			
Depth	**Conventional-till**	**Mulch-till**	**No-till**	**Bare-fallow**
	------------------------------g/kg†---------------------------			
0-5	22.0a‡	16.6a	19.6a	17.9a
5-15	12.0ab	11.8ab	12.7a	10.6b
15-30	9.6ab	10.3a	10.8a	8.8b
30-60	5.6a	4.7ab	5.3ab	4.3b
60-90	4.2a	3.7a	4.0a	3.8a

† Values within each column group followed by the same letter are not significantly different at the 0.05 probability level.

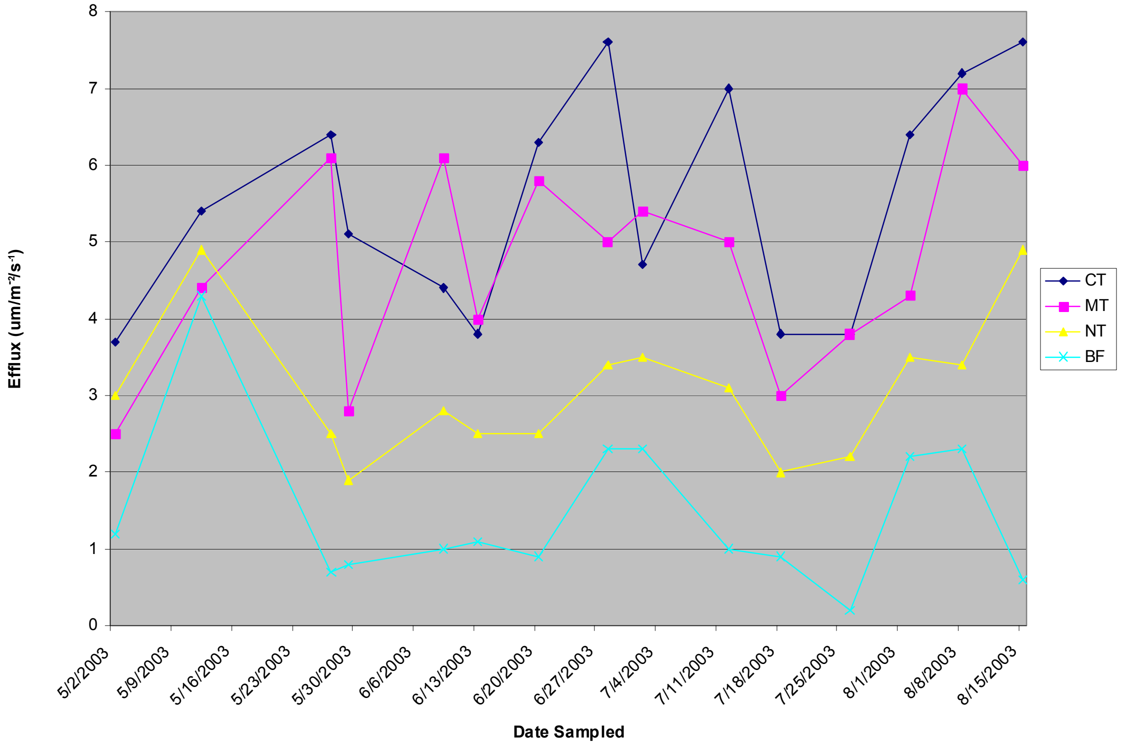

Figure 1. Carbon dioxide (CO_2) efflux by tillage using 100 kg poultry litter N ha^{-1}. Alabama Agricultural Experiment Station, Belle Mina, AL, 2003.

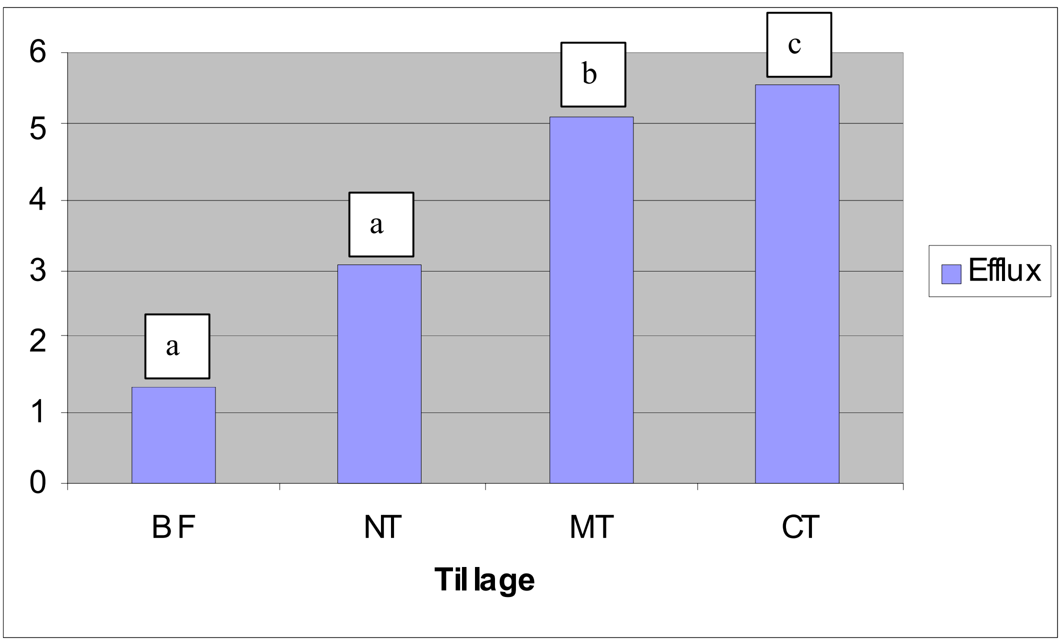

Figure 2. Overall means for carbon dioxide (CO_2) efflux (um/m^{-2}/s^{-1}) by tillage using 100 kg poultry litter N ha^{-1}. Alabama Agricultural Experiment Station, Belle Mina, AL 2003.

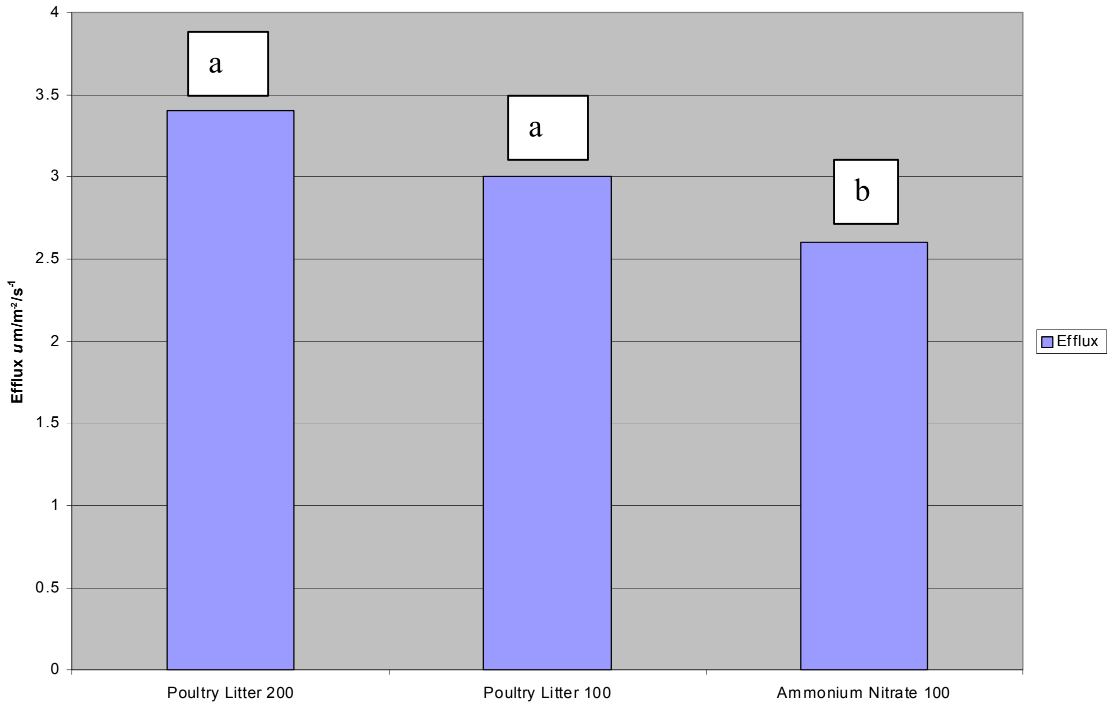

Figure 3. Overall means for carbon dioxide (CO_2) efflux (um/m^{-2}/s^{-1}) by nitrogen source and rate using no-till and cotton/rye cropping system 2003. Alabama Agricultural Experiment Station, Belle Mina, AL.

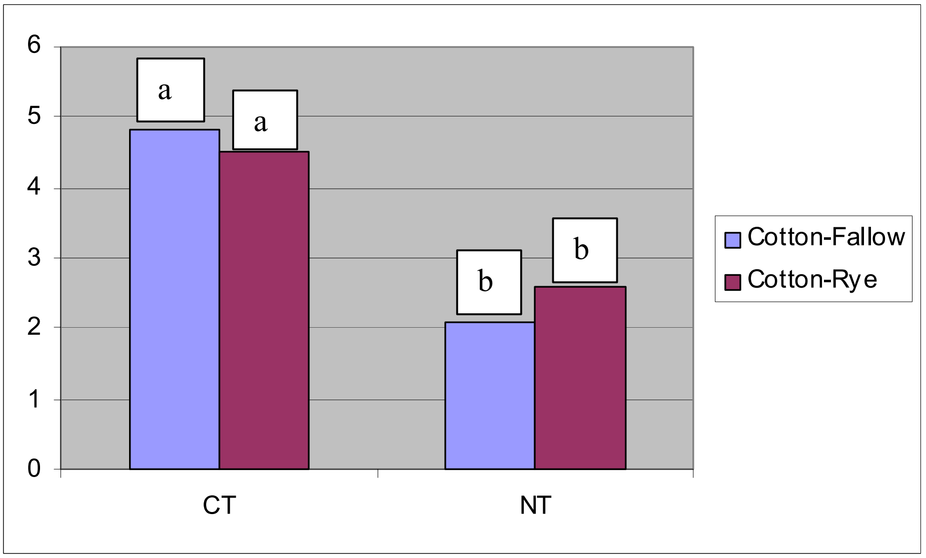

Figure 4. Tillage and cropping system interaction for carbon dioxide (CO_2) efflux (um/m^{-2}/s^{-1}) using 100 kg ammonium nitrate N ha^{-1}. Alabama Agricultural Experiment Station, Belle Mina, AL, 2003.