Influence of Fall and Spring Tillage on Soil CO_2 Efflux from a Loamy Sand Soil in Alabama

S.A. Prior*, B.G. Dorman, R.L. Raper, and E.B. Schwab, National Soil Dynamics Laboratory, USDA-Agriculture Research Service, 411 South Donahue Drive, Auburn, AL, USA, 36832. sprior@acesag.auburn.edu

ABSTRACT

Management decisions that affect tillage intensity and the amount and placement of residues can influence soil C storage, thereby representing a viable strategy to help mitigate the rise in atmospheric CO_2. However, information on seasonal CO_2 flux patterns as affected by degree of soil disturbance/residue mixing and time of tillage operations are lacking. A experiment was conducted following a grain sorghum [*Sorghum bicolor*] (L.) Moench.] crop on a Norfolk loamy sand (Typic Kandiudults; FAO classification Luxic Ferralsols) in east-central Alabama (USA) to characterize soil CO_2 flux patterns as affected by tillage tool type [disk (DK), high residue field cultivator (FC), and no-till (NT)] and time of soil disturbance (i.e., fall and spring). Soil CO_2 efflux was assessed immediately following fall tillage and periodically up to and including planting operations; likewise, these measures were also taken in the spring after imposing tillage treatments on another set of undisturbed plots. Concurrent measures were also made on NT plots. Increased CO_2 efflux was related to degree of soil disturbance attributed to fall tillage; losses were similar for the FC and NT treatment and the highest loss occurred for DK treatment; cumulative flux estimates also reflected such differences. With spring tillage, loss of CO_2 for the NT and DK treatment was similar, while the FC treatment exhibited a slightly lower loss. Results suggest that selection of fall tillage equipment that maintains surface residue and minimizes soil disturbance could help reduce CO_2 loss. However, such considerations for spring tillage operations would not result in a substantial reduction in CO_2 loss.

INTRODUCTION

The chemical climate is changing and increases in trace gases such as atmospheric CO_2 are well-documented (Keeling and Whorf, 1994). Since CO_2 is the principal mobile form of carbon (C) in the atmosphere and is a key player in the biosphere, geosphere, and hydrosphere, the dynamics of C in terrestrial ecosystems has become a major issue. Agroecosystems are typically viewed as CO_2 sources due to the impact of long-term cultivation on reducing soil C content (Houghton et al., 1983). Currently there is interest in the potential of highly managed agricultural soils to store surplus atmospheric CO_2 as an amelioration measure since management decisions concerning tillage intensity and the amount and placement of residues (e.g., conservation tillage) can influence soil C storage (Lal et al., 1999). The rate of residue decomposition in conjunction with the rate of evolution of stored soil C as a decomposition product (mainly CO_2) are important aspects of net storage both in the short and long run. Short-term CO_2 flux from tillage operations have recently been studied (e.g., Reicosky and Lindstrom, 1993; Reicosky et al., 1999). However, information on long-term seasonal CO_2 flux patterns as affected by degree of soil disturbance/residue mixing and time of tillage operations are lacking.

The objective of this work was to determine seasonal CO_2 flux patterns and cumulative CO_2 efflux associated with different tillage implements and operations in fall vs. spring. Such data are needed to formulate recommendations which may lead to adoption of optimum management methods and times of operation which can increase soil C sequestration and ensure improvements in soil quality and crop productivity.

MATERIALS AND METHODS

The study was conducted on a Norfolk loamy sand (fine-loamy, siliceous thermic, Typic Kandiudults) at the E.V. Smith Research Center of the Alabama Agriculture Experiment Station in east central Alabama, U.S.A. (N 32E25.467', W 85E 53.403'). The study area has a long-term history of being under fallow or conventionally cropped conditions. In 1998, grain sorghum seed (Dekalb 55)[1] were sown on 9 Jun 1998; the final stand density was 37 plants m^{2}. Fertilizer application rates were based on standard soil test. Plots were harvested at maturity (24 Sept 1998) for determination of top dry mass production (minus grain mass) and grain yield. In the off season, weed control was done using glyphosate (N-[phosphonomethyl] glycine).

Characterization of soil CO_2 efflux patterns were initiated about 2 months after the harvest (see Fig. 1). Equipment-induced soil gas fluxes were measured at midday immediately following implement operations and periodically thereafter using a LI-COR 6200 gas exchange system equipped with a soil respiration chamber (Model 6000-09, LI-COR, Inc., Lincoln, NE)[1] using procedures described by Prior et al. (1997); triplicate readings were taken in all plots.

Commercial implements evaluated were a John Deere 210 Disk (Deere & Company, Moline, IL) and a Tiger-Mate II High Residue Field Cultivator (DMI, Inc., Goodfield, IL) operated at a depth of 7.6-10.2 cm. In the treatment descriptions these implements will be referred to as DK and FC, respectively. The experimental design was a randomized complete block with four replications. The treatments were: (1) Fall DK; (2) Fall FC; (3) Spring DK; (4) Spring FC and 1) No-till (NT). In the fall, CO_2 flux measurements were initiated immediately following tillage (2 Dec 1998) and monitored periodically up to and including planting operations (see Fig. 1). The same tillage treatments were imposed (6 April 1999) on another set

---

[1]Trade names and products are mentioned solely for information. No endorsement by the USDA is implied.

of plots (undisturbed since harvest) and flux patterns were monitored as described above. Soil CO_2 efflux was concurrently measured on NT plots from fall to spring. It is important to note that NT does not imply a long-term history of no-till, but rather indicates that plots were left undisturbed until 25 May 1999; on this date these plots and others (i.e., fall and spring tillage plots) were disked for seed bed preparation followed by a simulated planting event (28 May 1999) using a Marliss Grain Drill (Marliss Ind., Inc., Jonesboro, AR). Flux measures were made immediately after and following these events. Termination of the flux study occurred on 3 Jun 1999. This study did not assess CO_2 losses associated with the actual growing season due to the difficulty of separating root respiration from microbial respiration. All operations used a John Deere 8300**7** tractor (8402 kg, 149 kW).

In addition, estimates of cumulative fluxes were calculated using a basic numerical integration technique (i.e., trapezoidal rule). For the fall treatments, cumulative fluxes were determined for the following time intervals: (1) fall tillage to spring disk; (2) spring disk to planting; (3) planting to end of study; (4) spring disk to end of study; (5) fall tillage to end of study (total cumulative flux). Intervals for the spring treatments were: (1) spring tillage to spring disk; (2) spring disk to planting; (3) planting to end of study; (4) spring disk to end of study; (5) fall to end of study (total cumulative flux). Total cumulative flux for the spring treatments were estimated by adding the NT flux values from fall to spring tillage interval to the values of the Aspring tillage to end of study @values. For the NT treatment, the cumulative fluxes for appropriate time interval comparisons were also determined.

Statistical analyses of data were performed using the General Linear Model (GLM) procedure of SAS (Statistical Analysis Systems, 1982). Fisher's protected least significant difference was used for mean comparisons. A significance level of $P \leq 0.10$ was established *a priori*.

RESULTS AND CONCLUSIONS

Upon introducing implement operations on residue covered plots, flux rates increased due to soil disturbance (Fig. 2), a finding in support of previous reports on short-term CO_2 flux patterns (Ellert and Janzen, 1999; Prior et al., 2000; Reicosky and Lindstrom, 1993; Reicosky et al., 1999). Of the two implements tested, the FC plots exhibited less soil disturbance and residue incorporation (compared to the DK treatment), but had the highest initial flux rate; the DK treatment exhibited an intermediate value followed by the NT treatment, which had the lowest rate. Flux rates decreased over the following few days. However, during this period the DK treatment now exhibited greater flux compared to the other two treatments. A subsequent increase in flux rates was related to a rainfall event, but rates were similar across treatments. Other reports have also indicated stimulation of short-term CO_2 flux associated with increases in soil water content in different cropping systems (Prior et al., 1997; Reicosky et al., 1999). This was followed by a sharp drop and leveling off of flux rates; the initial portions of this period generally showed that the DK treatment had the highest flux rates. From DAT (days after tillage) 28 to 117, no treatment differences were observed except on DAT 86 where the DK treatment was highest. In general, during the period of DAT 127 to 147, the DK treatment again usually exhibited the highest flux rates. Following this period up to the spring disk operation on DAT 174 (i.e., seedbed preparation), no differences in flux rates were observed across treatments. Immediately following the spring disk operation, flux rates were similar for the two implement treatments and were higher than the NT treatment. No treatment differences were observed on the day of planting operations (DAT 177). Flux rates dropped dramatically over the following few days and some treatment effects were observed, but differences were small.

Upon introducing the spring tillage treatments on residue covered plots (left undisturbed since the fall; see Fig. 1) flux differences as seen in the fall tillage plots (Fig. 2) were not observed (Fig. 3). Although measurements were taken immediately after tillage, no dramatic increase in flux rates was attributed to tillage operations. In fact, the FC treatment exhibited a decrease in flux rate relative to NT and DK treatments, which were similar to each other. Flux rates decreased over the next few days (DAT 1 and 2); during this period both the DK and FC treatments had lower rates compared to NT. On DAT 7, the FC treatment again exhibited the lowest flux rate; similar trends were observed in the following two sample periods. On DAT 17, the DK treatment had a higher flux rate compared to the other treatments that were similar to each other. From DAT 22 to 42, the general pattern was for the FC treatment to have the lower flux rate. On the day before the spring disk operation, the DK treatment had the highest flux rate, but the other two treatments were similar to each other. On the day of the spring disk operations, treatment differences were small; however, on the next two sampling periods, flux rates increased dramatically. On these days (DAT 49 and 50), both the DK and FC treatments had the highest flux rates compared to NT. No treatment differences could be attributed to planting operations and although subsequent flux rates dropped dramatically, no treatment effects were observed during the remainder of study.

To facilitate comparison of treatment trends as a function of time, estimates of cumulative CO_2 flux were calculated using a basic numerical integration technique (i.e., trapezoidal rule). Cumulative fluxes were estimated for various time intervals (see Fig. 1) to evaluate contribution of fluxes attributable to implement operations over the course of the experiment.

In the fall treatment, the greatest CO_2 loss (from fall to spring disk operations) occurred with the DK treatment while the FC treatment showed an intermediate value relative to NT conditions (Fig. 4). At the next time interval (spring disk to planting), both tillage tool treatments (FC and DK) exhibited higher losses compared to NT, however, no significant treatment effects were noted at the last interval (planting to study termination). Although the cumulative loss of CO_2 attributed to seedbed preparation/planting operations (i.e., spring disk to end of study) was higher for the tillage tool treatments, this amount was relatively small compared to losses during the longer time interval of fall to spring disk.

In the spring treatment, the tillage tool treatments were imposed on plots that had remained fallow since the fall. Figure 5 shows the cumulative flux of CO_2 which occurred during the time interval of fall to spring tillage for the NT treatment; it was assumed that this value was representative of CO_2 losses from undisturbed DK and FC plots over the same time interval. Cumulative flux from this period represented the greatest loss compared to all other time intervals evaluated. From spring tillage to spring disk, cumulative loss of CO_2 from the NT and DK treatments were similar to each other; however, the FC treatment exhibited a slightly lower value. At the next time interval (spring disk to planting), both tillage tool treatments (FC AND DK) exhibited higher losses compare to NT, however, no significant treatment effects were noted at the last interval (planting to study termination). The cumulative loss of CO_2 attributed to seedbed preparation/planting operations (i.e., spring disk to end of study) for the NT and DK treatment were similar, while the FC treatment exhibited a slightly lower loss. Losses during this time period were substantial, however, the cumulative CO_2 loss attributable to the longer time interval of fall to spring disk was much greater.

Figure 6 illustrates total cumulative CO_2 flux for all treatment conditions. With fall tillage, the FC caused less soil disturbance and residue mixing which probably accounts for its cumulative flux being similar to that observed under NT conditions. In comparison, the DK treatment had the highest total loss, which was reflective of a greater degree of soil disturbance/residue mixing. With spring tillage, total loss of CO_2 for the NT and DK treatments were similar, while the FC treatment exhibit a trend for a slight reduction in total CO_2 loss.

This work demonstrates that tillage tool type can influence long-term loss of C from soil, but this was contingent on time of year that tillage was conducted. Results suggest that selection of fall tillage equipment that maintains surface residue and minimizes soil disturbance could help reduce CO_2 losses. For spring tillage operations, however, reductions in CO_2 loss would be small. Findings also underscore the importance of assessing CO_2 efflux during the overwintering period since the greatest proportion of total loss occurred over this time period.

ACKNOWLEDGMENTS

The authors acknowledge H. Eric Hall (Department of Biosystems Engineering, Auburn University, Auburn, AL), Tammy K. Dorman (School of Forestry and Wildlife Sciences, Auburn University), Robert M. Durbin (Superintendent, E.V. Smith Research Farm), and his support staff for their assistance.

REFERENCES

Ellert, B.H., Janzen, H.H., 1999. Short-term influence of tillage on CO_2 fluxes from a semi-arid soil on the Candadian Prairies. Soil Tillage Res. 50, 21-32.

Houghton, R.A., Hobbie, J.E., Melillo, J.M., More, B., Peterson, B.J., Shaver, G.R., Woodwell, G.M., 1983. Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: A net release of CO_2 to the atmosphere. Ecol. Monographs 53, 235-262.

Keeling, C.D, Whorf, T.P., 1994. Atmospheric CO_2 records from sites in the SIO air sampling network. In: Boden, T.A., Kaiser, D.P., Sepanski, R.J. and Stoss, F.W. (Eds), Trends 1993: A Compendium of Data on Global Change. CDIC, ORNL, Oak Ridge, TN, pp. 16-26.

Lal, R., Follett, R.F., Kimble, J., Cole, C.V., 1999. Managing U.S. cropland to sequester carbon in soil. J. Soil & Water Conserv. 54, 374-381.

Prior, S.A., Rogers, H.H., Runion, G.B., Torbert, H.A., Reicosky, D.C., 1997. Carbon dioxide-enriched agro-ecosystems: Influence of tillage on short-term soil carbon dioxide efflux. J. Environ. Qual. 26, 244-252.

Prior, S.A., Reicosky, D.C., Reeves, D.W., Runion, G.B., Raper, R.L., 2000. Residue and tillage effects on planting implement-induced short-term CO_2 and water loss from a loamy sand soil in Alabama. Soil Tillage Res. 54, 197-199.

Reicosky, D.C., Lindstrom, M.J., 1993. Fall tillage method: The effect of short-term carbon dioxide flux from soil. Agron. J. 85, 1237-1243.

Reicosky, D.C., Reeves, D.W., Prior, S.A., Runion, G.B., Rogers, H.H., Raper, R.L., 1999. Effects of residue management and controlled traffic on carbon dioxide and water loss. Soil Tillage Res. 52, 153-165.

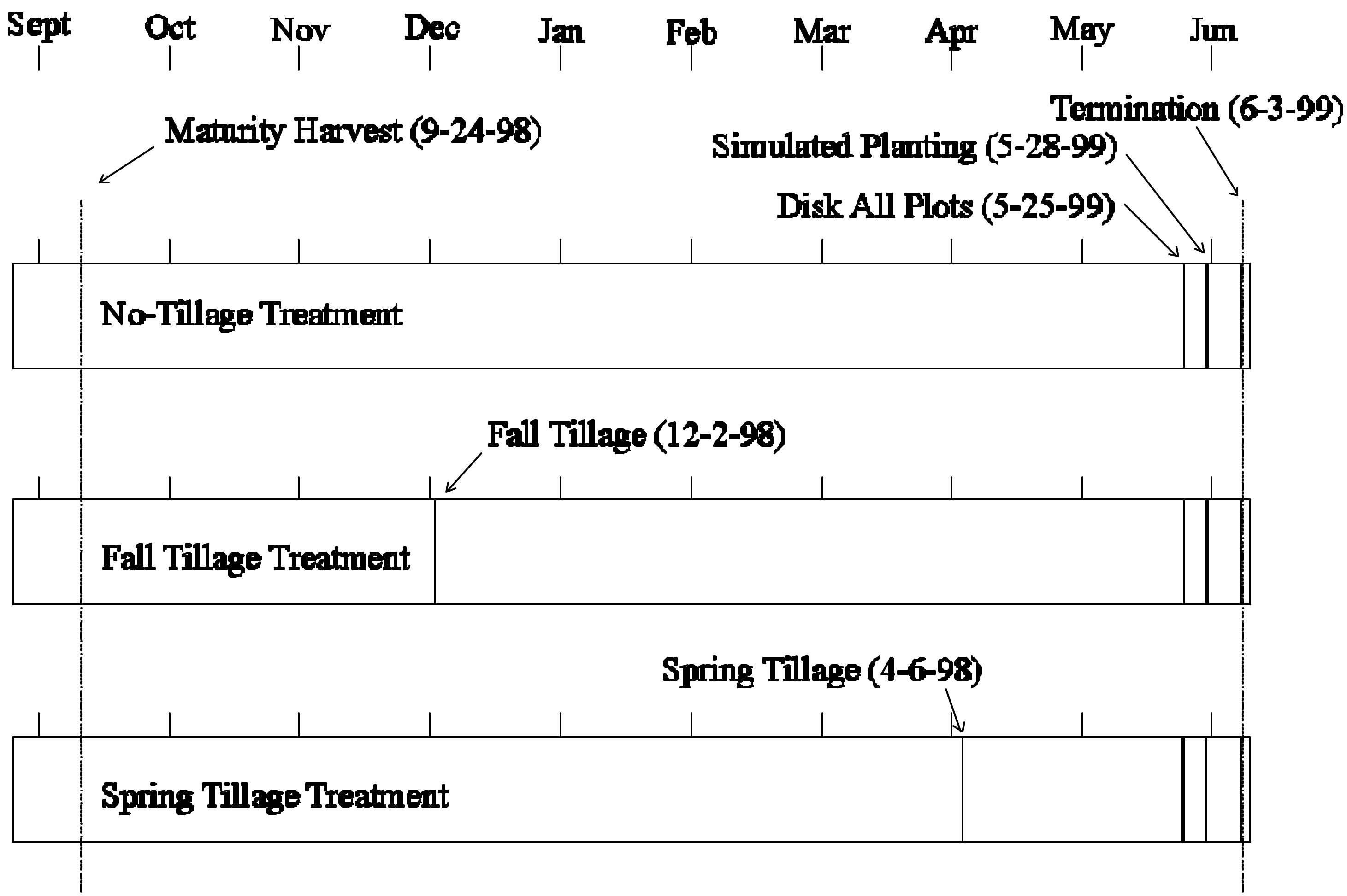


Figure 1. Time line of major operational events.

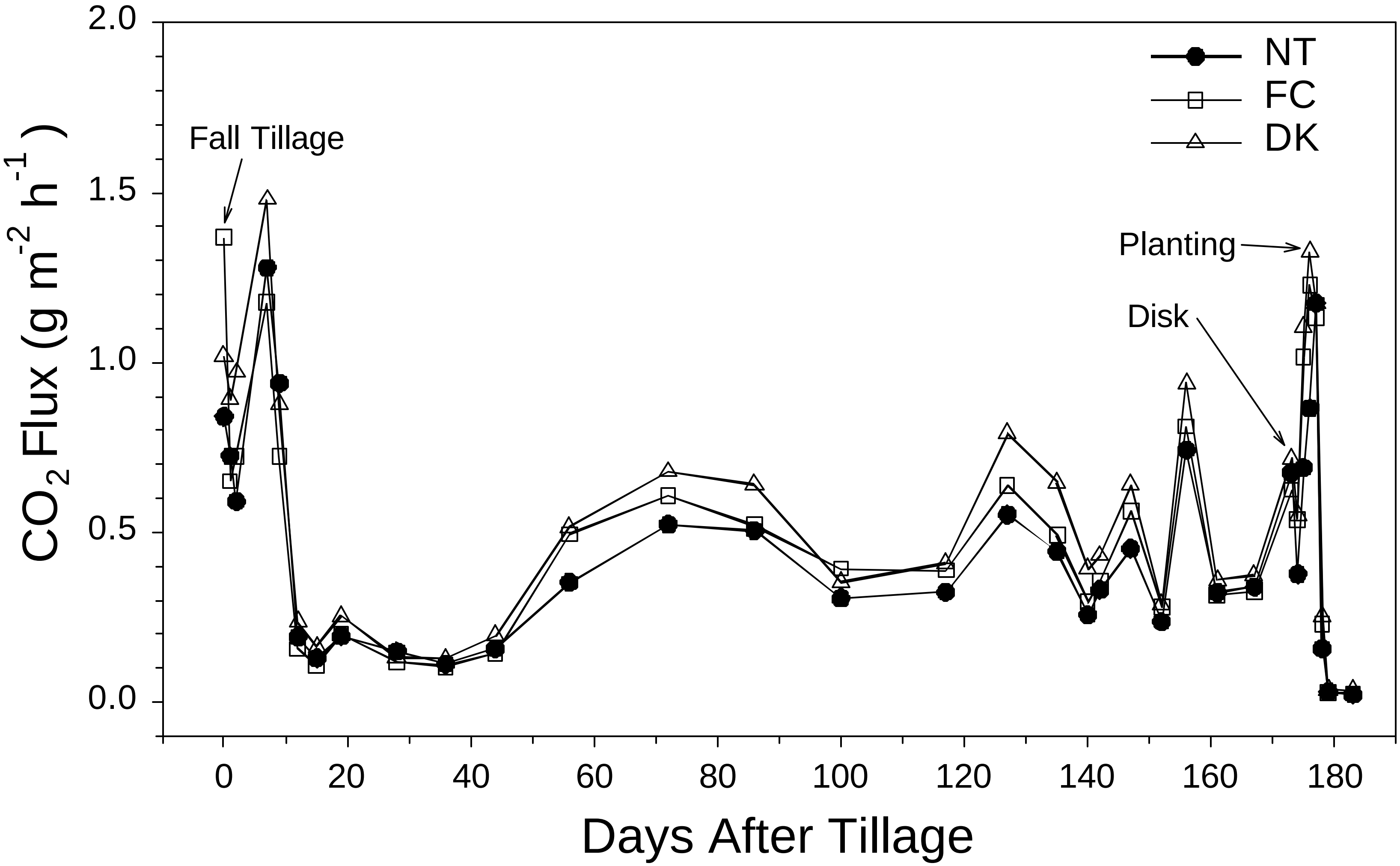


Figure 2. Soil CO_2 flux as a function of time for the fall tillage treatments. Values represent means of four replicates. Abbreviations: NT, DK, and FC denote no-till, disk, and high residue field cultivator, respectively.

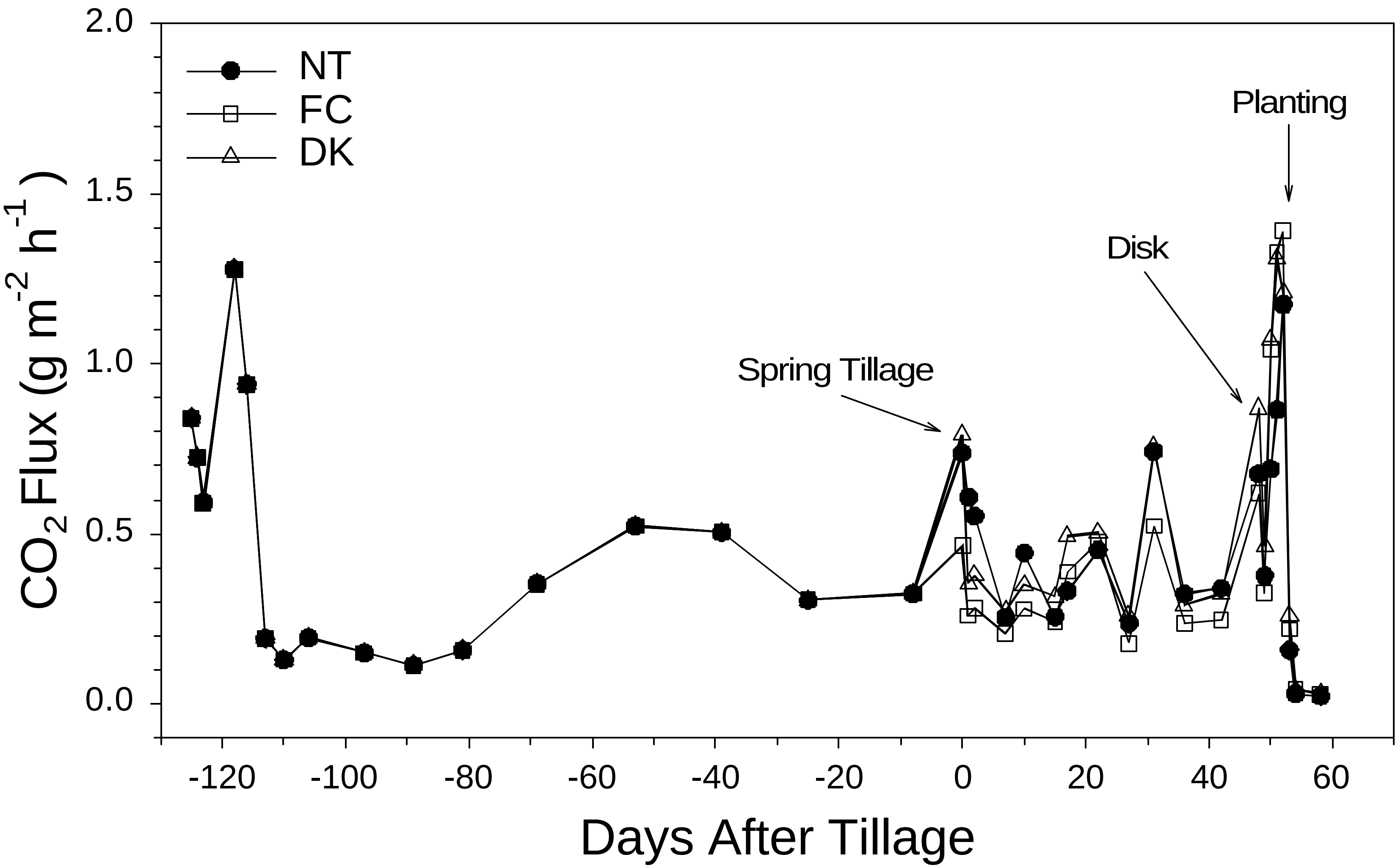


Figure 3. Soil CO_2 flux as a function of time for the spring tillage treatments. Values represent means of four replicates. Abbreviations: NT, DK, and FC denote no-till, disk, and high residue field cultivator, respectively

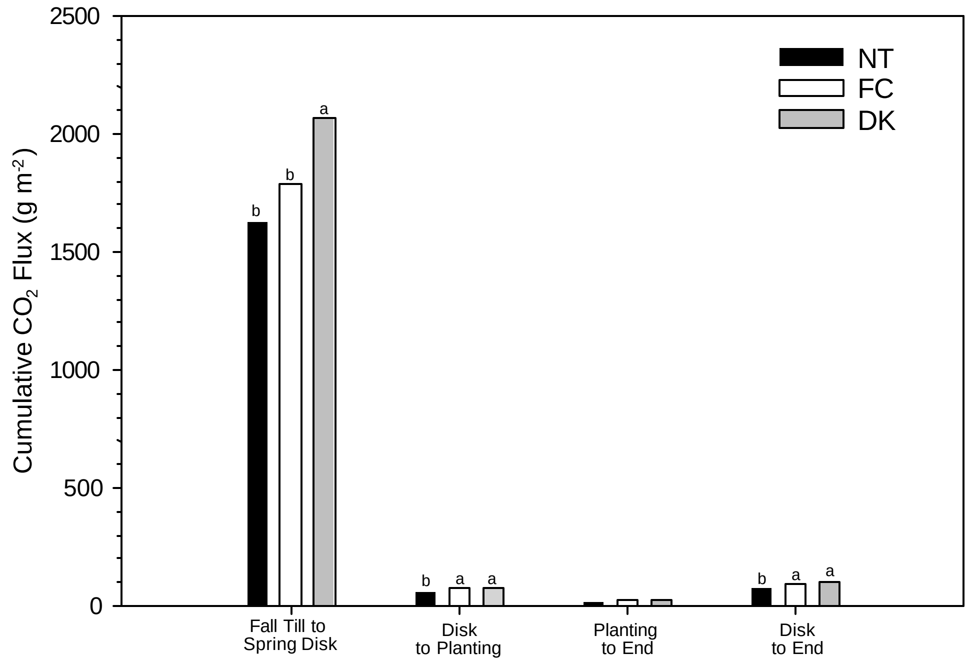
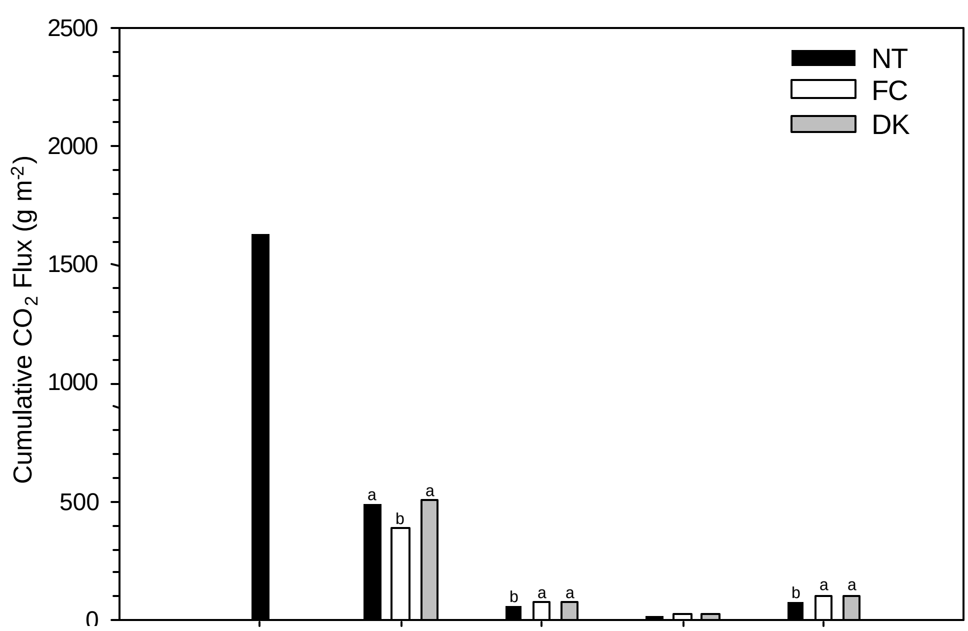


Figure 4. Cumulative CO_2 flux for different time intervals associated with operational events for fall (top) and spring (bottom) tillage treatments. Bars represent means of four replicates. Bars within an interval grouping with the same letter do not differ significantly. Abbreviations: NT, DK, and FC denote no-till, disk, and high residue field cultivator, respectively. The single NT bar in the bottom graph denotes that flux values were similar across treatments since spring tillage plots remained undisturbed from fall up to spring tillage.



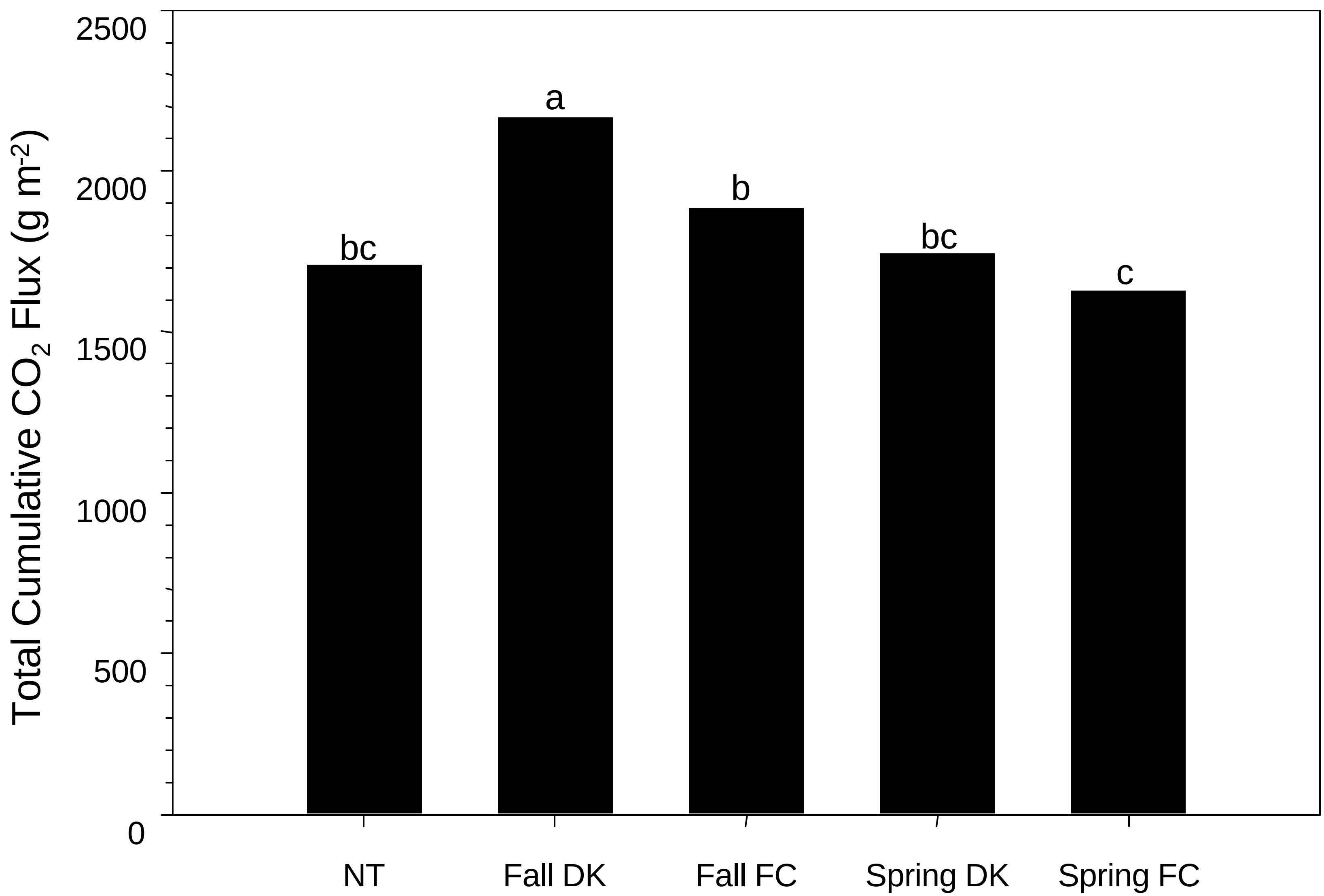


Figure 6. Total cumulative CO_2 flux for all treatments. Bars with the same letter do not differ significantly. Abbreviations: NT, DK, and FC denote no-till, disk, and high residue field cultivator, respectively.