EFFECTS OF RESIDUE PLACEMENT ON CO_2 LOSS IN AN IRRIGATED, NO-TILL CORN SYSTEM

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ABSTRACT

It is well known that residue management practices that leave crop residue on the surface, such as no-till agriculture, promote soil fertility. However, the effects of such practices on carbon sequestration can be highly variable. To better understand how residue management impacts the loss of carbon through mineralization, we investigated the effects of residue location and addition on CO_2 produced from residue decomposition under no-till irrigated continuous corn in Northern Colorado. Over a period of two years, we monitored the CO_2 fluxes of ^{13}C labeled residue treatments (i.e., incorporated vs surface applied) and their respective unlabeled residue controls. In the first year of the experiment, the incorporated residue treatment had greater residue-derived CO_2 loss during the non-growing season, while the surface applied residue treatments lost more residue-derived CO_2 during the growing season. In the second year, surface applied residue had greater residue-derived CO_2 loss than the incorporated residue in both the non-growing and growing season. Ultimately, our surface applied treatment lost more residue carbon as CO_2 (38.06%) than did our incorporated treatment (20.39%) over this two-year period, but still only represented a fraction of the added residue. Our results suggest that there may be more residue lost as CO_2 in irrigated systems practicing no-till agriculture, compared to those that are conventionally tilled, over the long term. However, CO_2 is only one piece of the carbon puzzle and therefore, the efficiency of carbon stock formation in the soil profile must be investigated as well.

INTRODUCTION

As atmospheric CO_2 levels continue to warm our planet at unprecedented rates, it is imperative that we reduce CO_2 emissions as well as draw down atmospheric CO_2. One way this can be accomplished is through soil carbon sequestration. Due to their large global land coverage and depleted carbon pools, croplands have high potential to be used as a soil carbon sink if we alter agricultural management practices (Paustian et al., 2016). Recently, residue management practices that leave residue on the soil surface have been highly advocated to promote soil fertility and soil health (Derpsch et al., 2010). However, the impact of surface placement on residue carbon stabilization is unclear.

When organic matter, such as crop residue or manure, is deposited on or within the soil, it gets broken down and decomposed by soil faunal and microbial communities. Throughout this process, the carbon from the organic matter can become stabilized as soil organic carbon (through microbial assimilation or physical/chemical protection), be lost through leaching, or be lost as CO_2 during microbial respiration (Trumbore, 2009). By monitoring the amount of CO_2 respired from crop residues, we can gage how efficiently the residue carbon is stabilized in soil versus lost into the atmosphere.

Soil CO_2 emissions stem from several different abiotic and biotic sources, including carbonate dissolution, root respiration, rhizomicrobial respiration, microbial decomposition of plant residues, microbial respiration from the priming effect, and basal microbial respiration (Kuzyakov, 2006). By labeling our plant residue with ^{13}C, a carbon isotope rarely found in nature, we are able to trace the portion of CO_2 that was specifically derived from this residue (Soong et al., 2014).

The objective of this research study was to analyze the effects of ^{13}C labeled residue placement (surface applied versus incorporated) on labeled residue-derived CO_2 fluxes in an irrigated, no-till cornfield in Northern Colorado over two years. After one year, unlabeled residue was added to assess the effects of a fresh carbon source on ^{13}C labeled residue carbon loss. We hypothesized that the incorporated residue would have greater CO_2 fluxes than our surface applied residues. This is due to more consistently favorable climatic conditions for the microbes within the incorporated treatment soil, which would allow for more decomposition and microbial respiration. We also hypothesized that fresh residue addition would result in greater ^{13}C labeled CO_2 fluxes due to priming.

MATERIALS AND METHODS

The field experiment was conducted at Colorado State University's Agricultural Research, Development and Education Center (ARDEC) in Northern Colorado. Our research plot was located within an irrigated, historically continuous no-till cornfield, where the soil is classified as a Fort Collins clay loam (fine-loamy, mixed, mesic Aridic Haplustalf).

In November of 2017, PVC collars (15 cm height, 10 cm diameter) were pounded 10 cm into the ground of our research plot, each positioned 0.7 meters apart and within one of four rows. Treatments consisted of surface applied or incorporated (10 cm into the soil profile) residue within the PVC collar. The experiment was a randomized block design with four replicates and described in detail by Leichty et al. (2018).

Residue was ^{13}C labeled *Andropogon gerardii* (Soong et al., 2014), a native C4 grass, and was used to create our three treatments (**Table 1**): incorporated labeled residue (INC), surface applied labeled residue (SA), and surface applied labeled residue without new residue (SA-NR). Our two controls, incorporated control (C-INC) and surface applied control (C-SA), were established without labeled residue; therefore, C-INC was disturbed to mimic the incorporated treatment and C-SA was left undisturbed. In the fall, one year after establishment, unlabeled corn (*Zea mays* L.) stover was collected from the field and added to all treatments, except for SA-NR, to simulate fresh inputs following annual harvest. We only report residue-derived CO_2 data from the ^{13}C labeled treatments (INC, SA, and SA-NR).

Treatment Name	Residue Placement	First Year Residue Addition	Second Year Residue Addition
INC	Incorporated	^{13}C labeled Andropogon gerardii	Unlabeled corn stover
SA	Surface applied	^{13}C labeled Andropogon gerardii	Unlabeled corn stover
SA-NR	Surface applied	^{13}C labeled Andropogon gerardii	No residue
C-INC	Incorporated	No residue	Unlabeled corn stover
C-SA	Surface applied	No residue	Unlabeled corn stover

Table 1. Experimental design and treatments.

Every year in April/May, corn (*Zea mays* L.) was planted along the edge of each row of PVC collars. SuperU, a slow-release fertilizer (polymer-coated urea), was then surface-band applied near the corn row at emergence in May at a rate of 120.5 lb N acre^{-1}. Throughout the growing season, the corn received approximately 35 mm of sprinkler-applied irrigation water once a week. Following the growing season, the corn was harvested annually.

Gas samples of treatments were taken continuously throughout the two years of our study, with the frequency of sampling depending on season. During the non-growing season, treatments were sampled once a week to once a month. During the growing season, treatments were sampled twice a week, once before the weekly irrigation and once following the weekly irrigation. To obtain gas samples, we sealed each treatment collar with a cap and used a syringe to extract 50 mL gas samples from within the sealed collar at 0, 15, 30, and 45 minutes. Each gas sample was then injected into two separate 12 mL Exetainer vials, each vial receiving approximately 25 mL of the gas sample. Back at the laboratory, one of the vials was analyzed on a gas chromatograph to obtain CO_2 concentration and the other vial was run on an isotope ratio mass spectrometer to measure $\delta^{13}C$ values. These two measurements, along with the initial $\delta^{13}C$ of the labeled residue and the $\delta^{13}C$ of the unlabeled controls, were used to construct Keeling plots (a linear regression of $\delta^{13}C$ versus $1/CO_2$ concentration) for each 45 minute sampling period for each field replicate (Pataki et al., 2003). A two end-member mixing model was used to partition the total CO_2 flux into residue-derived and soil-derived CO_2 flux. By interpolating between sample points, we calculated cumulative fluxes to understand how much residue carbon was lost as CO_2 over time and between treatments.

RESULTS AND DISCUSSION

First year residue-derived CO_2 fluxes

During the non-growing season of the first year, INC had a higher residue-derived CO_2 flux than both SA and SA-NR (**Figure 1, a**). However, during the growing season, SA and SA-NR had higher residue-derived fluxes than INC (**Figure 1, b**). Overall, fluxes of all treatments were greater during the growing season than during the non-growing season, resulting in SA and SA-NR having greater cumulative residue-derived CO_2 fluxes in the first year, compared to INC (**Figure 1, c**). There were no significant differences between residue-derived CO_2 fluxes of SA and SA-NR at any point during the first year.

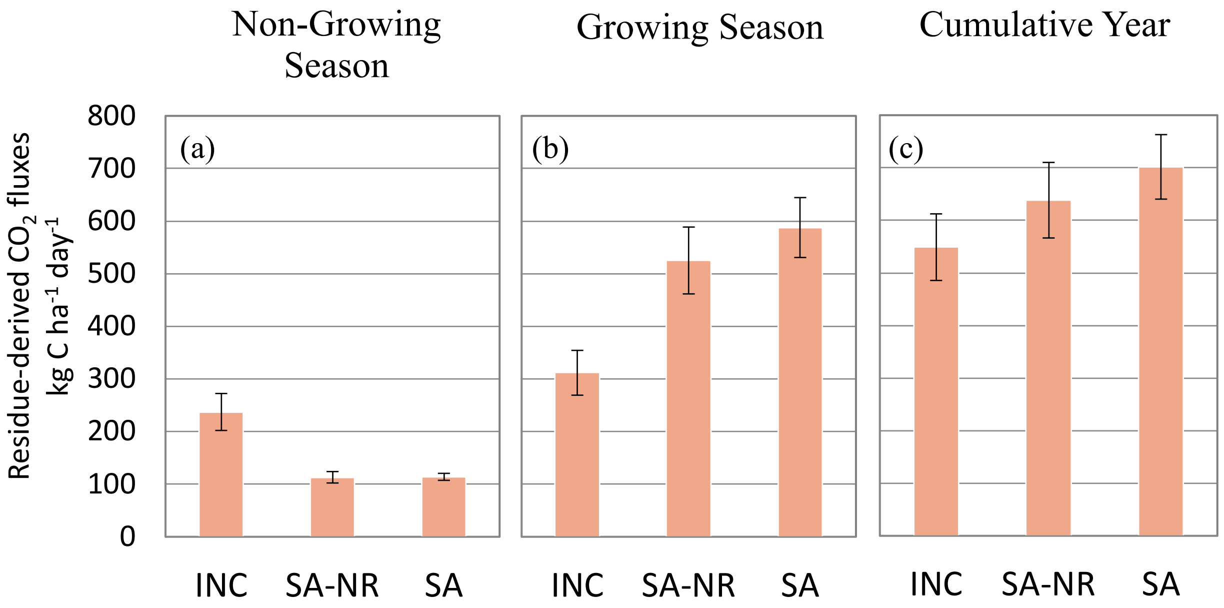

Figure 1. First year residue-derived CO_2 fluxes (kg C ha^{-1} day^{-1}) of incorporated (INC), surface applied without new residue (SA-NR), and surface applied (SA) treatments from the non-growing season (a), growing season (b), and cumulative year (c). Redrawn from Leichty et al. (2018).

Second year residue-derived CO_2 fluxes

Compared to the first year, the second year residue-derived CO_2 fluxes followed a similar pattern during the growing season and cumulatively. There were no significant differences between residue-derived CO_2 fluxes of SA and SA-NR at any point during the second year. The residue-derived CO_2 fluxes of the second year, however, were much lower than those of the first year. During the non-growing season of the second year, SA and SA-NR had greater residue-derived CO_2 fluxes than INC. While the CO_2 fluxes of INC were significantly different from those of SA, they were not significantly different from those of SA-NR (**Figure 2, a**). SA and SA-NR continued to have greater residue-derived CO_2 fluxes than INC through the growing season, although during this period, the difference between CO_2 fluxes of both surface applied and incorporated residue treatments was significant (**Figure 2, b**). Cumulatively, SA and SA-NR had greater residue-derived CO_2 fluxes than INC during the second year (**Figure 2, c**).

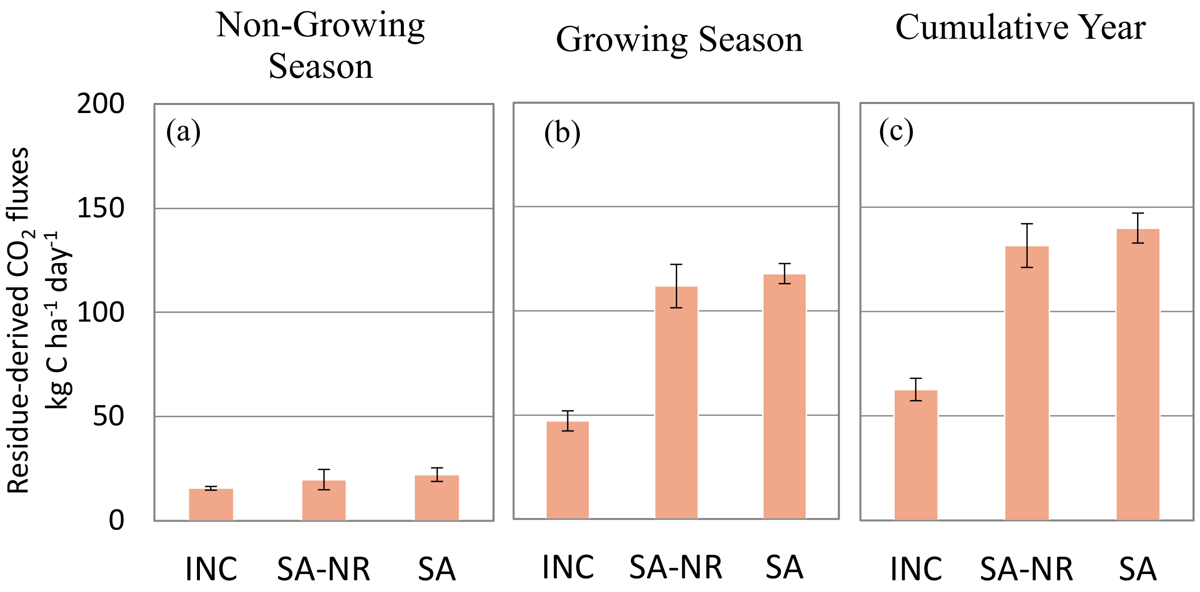

Figure 2. Second year residue-derived CO_2 fluxes (kg C ha^{-1} day^{-1}) of incorporated (INC), surface applied without new residue (SA-NR), and surface applied (SA) treatments from the non-growing season (a), growing season (b), and cumulative year (c).

Two-year cumulative residue-derived CO_2 fluxes

Combined over the two years, SA had the greatest residue-derived CO_2 flux, followed by SA-NR and then INC (**Figure 3**). Accordingly, SA lost 38.06% of residue to CO_2, SA-NR lost 25.67% of residue to CO_2, and INC lost 20.39% of residue to CO_2 (data not shown).

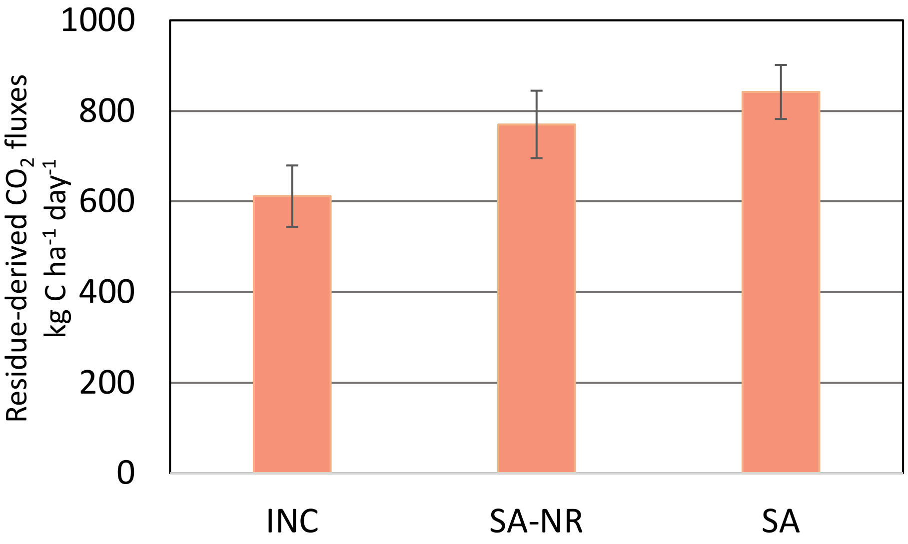

Figure 3. Two-year cumulative residue-derived CO_2 fluxes (kg C ha^{-1} day^{-1}) of incorporated (INC), surface applied without new residue (SA-NR), and surface applied (SA) treatments.

Our results indicate that residue placement has a significant effect on residue carbon mineralization. Contrary to our hypothesis, surface applied residue treatments lost more residue-carbon as CO_2 than did incorporated residue treatments. Additionally, due to the lack of differences found in the SA and SA-NR treatments, our study indicates that priming does not play a large role in the decomposition of residue. Together, our results suggest that, at least in an irrigated, no-till cornfield in Northern Colorado, agricultural practices that incorporate residue may be more efficient in stabilizing residue carbon. Agricultural management practices that promote soil health may not necessarily efficiently store residue carbon.

Our study uses carbon loss as CO_2 as a proxy for carbon stabilization efficiency; however, it is important to also consider the stability of the residue carbon that remains within the soil profile. According to Cotrufo et al. (2015), residue carbon can be transformed into either particulate organic matter (POM) or mineral-associated matter (MAOM). Essentially, MAOM is mostly formed of microbial cell debris and POM is mostly formed of partly decomposed and fragmented plant debris (Miltner et al., 2011). Due to the chemically stabilizing interactions that MAOM forms with minerals, it is considered the most stable pool of organic matter (Mikutta et al., 2006); therefore, it is an important pool to consider for long-term carbon sequestration. In order to more wholly understand the effects of residue placement on our system's ability to stabilize carbon, it would be helpful to additionally analyze the differences between treatments in terms of the allocation of residue carbon between POM and MAOM pools.

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