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Intensive tillage as a mechanism for CO_2 emission from soils

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Summary

Tillage effects the mechanism and magnitude of carbon dioxide (CO_2) gas generation and emission from agricultural soils. This research evaluated the impact of different tillage methods on the short-term CO_2 flux from a loam soil. Tillage-induced CO_2 loss after strip tillage tools, spaced at 76 cm, was measured with a large portable chamber. No-till had the lowest CO_2 flux during the study and moldboard plow had the highest immediately after tillage. Other forms of strip tillage had an initial flush between these extremes, with both the 5- and 24-hour cumulative losses related to soil volume disturbed. The CO_2 release immediately following moldboard plow tillage increased with increasing plow depth, and was substantially higher than that from the no-till treatment. Reducing the volume of soil disturbed by tillage and direct seeding should enhance soil and air quality by increasing soil carbon content for enhanced environmental quality.

Key Words: *strip tillage, tillage depth, soil carbon, tillage-induced CO_2 loss*

Introduction

The possibility of global greenhouse warming due to a rapid increase of carbon dioxide (CO_2), is receiving increased attention (Wood, 1990; Post et al., 1990). This concern is warranted because potential climatic changes could result in increased temperature and drought over present agricultural production areas (Wood, 1990). Thus, agriculture's role in the overall global carbon (C) balance must be understood. We need direct measurements to quantify CO_2 flux as impacted by agricultural management practices (Houghton et al., 1983; and Post et al., 1990). The crop root system can be used to sequester and redistribute C deeper in the soil profile where the carbon can become less susceptible to conversion to CO_2. Management practices need to be developed to optimize CO_2 utilization from soil and plants in photosynthesis to increase crop yields. Understanding the environmental impacts of tillage on CO_2 loss from soil and how farming practices can be managed to minimize impact on global climate change will enable sustainable production systems.

Recent studies involving a dynamic chamber, various tillage methods and associated incorporation of residue in the field indicated major carbon (C) losses immediately following tillage (Reicosky and Lindstrom, 1993). They found that the moldboard plow had the roughest soil surface, the highest initial CO_2 flux and maintained the highest flux throughout the 19-day study. High initial CO_2 fluxes were more related to the depth of soil disturbance that resulted in a rougher surface and larger voids than to residue incorporation. Lower CO_2 fluxes were caused by tillage associated with low soil disturbance and small voids with no-till having the least amount of CO_2 loss during 19 days. Reicosky and Lindstrom (1993) concluded that intensive tillage methods, especially moldboard plowing to 0.25 m deep, affected this initial soil flux differently and suggest that improved soil management techniques can minimize agricultural impact on global CO_2 increase. The average cumulative short-term CO_2 loss (5 hours) for four conservation tillage tools was only 31% of the moldboard plow. The moldboard plow treatment lost 13.8 times as much CO_2 as the soil area not tilled, compared to the average of four different conservation tillage tools that lost only 4.3 times (Reicosky, 1997).

This report evaluates the short-term impacts of various tillage methods on C flow within an agricultural production system. Several experiments dealing with short-term tillage-induced CO_2 release were conducted. The research objectives were: to evaluate the effect of strip tillage methods and depth of moldboard plowing on short-term CO_2 emissions.

Strip Tillage Study

The study was conducted on a Barnes loam (Udic Haploborolls, fine loamy, mixed) in spring wheat residue (*Triticum aestivum* L. cv. Marshall) and weed mix that had been killed with Roundup* (glyphosate 0.8 kg a.i. ha^{-1}) 2 weeks before tillage as described by Reicosky (1998). The study evaluated several strip tillage tools common to the Midwest USA. The CO_2 flux from the tilled soil surfaces was measured using a large portable chamber described by Reicosky (1990), Reicosky, Wagner & Devine (1990) and Reicosky and Lindstrom (1993). Measurements of CO_2 flux were initiated within 60 s of the last tillage pass. Briefly, the chamber (volume of 3.25 m^3 covering a horizontal land area of 2.67 m^2) with mixing fans running was moved over the tilled surface until the chamber reference points aligned with plot reference stakes, lowered and data rapidly collected at 1-s intervals for a period of 60 s to determine the rate of CO_2 and water vapor increase. After the appropriate lag times, data for a 30-s period was used to convert the volume concentration of water vapor and CO_2 to a mass basis then linearly regressed as a function of time as described by Reicosky, Wagner & Devine (1990). The slopes of these regression lines that

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* Names of products are included for the benefit of the reader and do not imply endorsement or preferential treatment by USDA.

reflect the rate of CO_2 and water vapor increase within the chamber were expressed on a unit horizontal land area basis.

The CO_2 flux as a function of time for each tillage method for the first 5 hours showed the moldboard plow (MP) had the highest flux that was as large as 35 g CO_2 m^{-2} h^{-1} then rapidly declined to 6 g CO_2 m^{-2} h^{-1} five hours after tillage (data not shown). The second largest CO_2 flux was 16 g CO_2 m^{-2} h^{-1} following the subsoil shanks (SS) also slowly declined. The least CO_2 flux was measured from the no-till treatment with an average flux of 0.2 g CO_2 m^{-2} h^{-1} for the five-hour period. The other forms of strip tillage were intermediate and only a small amount of CO_2 was detected immediately after tillage with the Residue Manager[1] (RM = residue cleaning and 13-wave coulter). The Mole Knife (MK) started as high as 8 g CO_2 m^{-2} h^{-1} and gradually declined to approach no-till (NT) values within five hours. The Yetter L-128 fertilizer knife (YK) had 3 g CO_2 m^{-2} h^{-1} immediately after tillage and declined as the soil dried toward no-till values. These results suggest a direct relationship between the magnitudes of the CO_2 flux that appeared to be related to the volume of soil disturbed.

The cumulative CO_2 evolved after tillage was calculated using a simple numerical integration (trapezoid rule) of the flux data. This method assumes linear interpolation between the measured fluxes over the time interval which area was summed to give a total CO_2 evolved as a first approximation. Figure 1 shows cumulative losses for 5 and 24 h after various tillage methods. The values for 24 hours may be subject to slight error due to the long time between the last two measurements and tillage-induced drying that may have caused the tilled treatments to dry out faster than the no-till treatments. The cumulative flux for the first five hours after tillage for the moldboard plow was 59.8 g CO_2 m^{-2} decreasing to 31.7 g CO_2 m^{-2} for the subsoil shank to a low of 1.4 g CO_2 m^{-2} for the no-till treatment. The Residue Manager had slightly more CO_2 loss than no-till, but slightly less than the Yetter fertilizer knife and Mole Knife. Similarly, the cumulative data for the 24-h period reflects the same trend. The maximum release by the moldboard plow was 159.7 g CO_2 m^{-2} decreasing to 7.2 g CO_2 m^{-2} for no-till. The other forms of strip tillage were intermediate between these that paralleled the five-hour data. The results suggest cumulative CO_2 loss was directly related to the soil volume disturbed by the tillage tool. The narrower and shallower soil disturbance caused less CO_2 loss (Reicosky, 1998). These data showed seasonal variation directly related to a given set of soil water and temperature conditions.

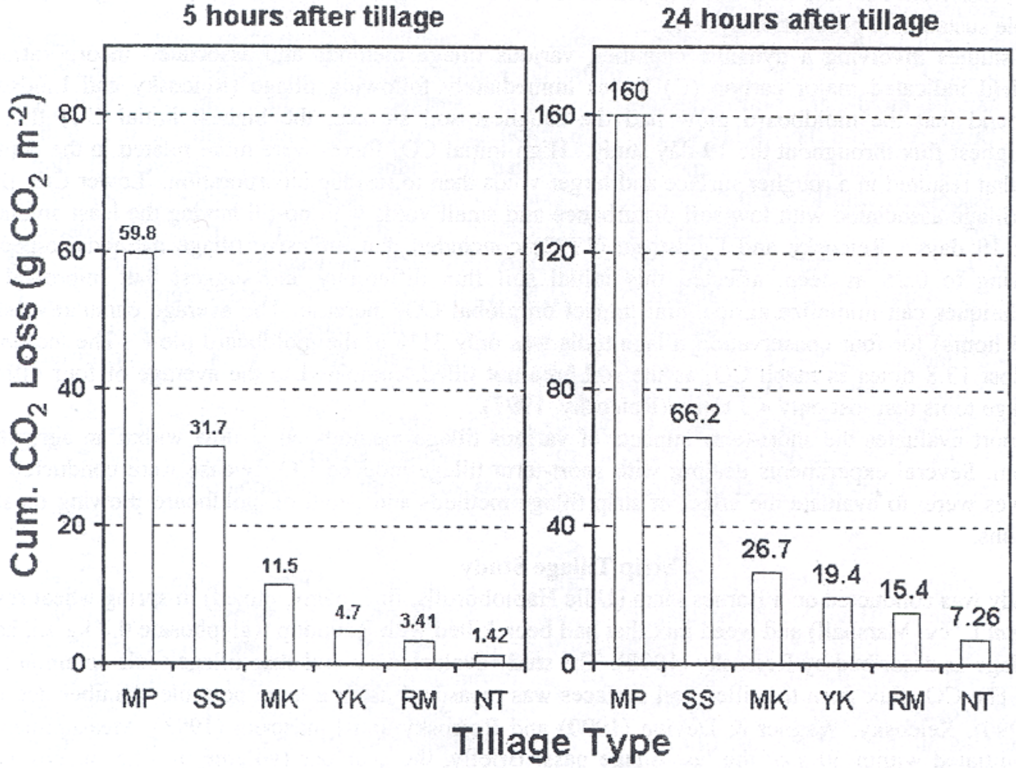

Figure 1. Cumulative CO_2 lost from various strip tillage methods in 5 and 24 hours.

The strip tillage study suggests that to minimize the impact of tillage on soil and air quality, the volume of soil disturbed must be minimized. Intensive tillage fractured a larger depth and volume of soil and increased aggregate surface area available for gas exchange. The increased area for gas exchange contributed to the vertical gas flux that was largest following moldboard plow. Tilling the soil volume necessary to get an effective seedbed and leaving the remainder of the soil undisturbed is required to conserve water and store C to minimize soil erosion and CO_2 loss. Limited tillage can be beneficial and do much to improve soil and air quality, minimize runoff to enhance water quality and minimize the greenhouse effect. The energy savings represent an additional economic benefit associated with less disturbance of the soil. Soil management decisions need to consider environmental benefits and C storage of strip tillage over broad area tillage.

Moldboard Plow Depth Study

This study was conducted on the same soil type and using the same methods as described above in late summer of 1998. Moldboard plow (MP) tillage was accomplished with a conventional 46-cm wide four-bottom Case[1] plow (Model 500) pulled at preset depths of 102, 152, 203, and 280 mm below the untilled soil surface. These depths are approximate but represent substantial differences in the depth of tillage as could be adjusted on the moldboard plow. The plow was pulled with an 80-kW tractor at about 7-8 km h^{-1}. The shallowest depth was that at which the plow operation resulted in complete inversion and nearly complete incorporation of the crop residue. All measurement areas for the four replicates were in the same soil type and located within 30 m of each other to reflect the same soil conditions. With only one chamber for flux measurements, replicates were selected as different days to evaluate all four MP tillage depths each day.

The moldboard plow treatment was accomplished with two passes that resulted in a total width of 5.1 m wide using the four bottom plows: The first pass enabled the second pass to get a more uniform depth of tillage as a result of having the depth control plow wheel in the furrow on the second pass. All the measurements were made with the chamber covering most of the second pass for soil depth considerations and for timing of the measurements to make them as rapid as possible after tillage.

The CO_2 fluxes as a function of time for the first day after tillage are summarized in Figure2. Note the rapid decline in the flux during the first few minutes after tillage reflecting the degassing of the soil, followed by a more gradual decline over the first five hours. The data shows that the initial flux was the largest with the deepest depth of tillage on this day. The maximum initial flux for the deepest depth was 85 g CO_2 m^{-2} h^{-1}. For the shallowest plow depth, the initial CO_2 flux ranged from 10 g CO_2 m^{-2} h^{-1} to as high as 22 CO_2 m^{-2} h^{-1}. In all cases there was a rapid initial decline followed by a more gradual decline in the CO_2 flux out to five hours after tillage. Although the variability expanded with depth of tillage, the relative differences between the fluxes for each plow depth remained the same with the deepest depth showing the largest CO_2 loss at the end of five hours and the shallowest depth showing the least. All plow depths showed more CO_2 loss than from the areas not tilled on both a relative and an absolute basis.

Soil CO_2 fluxes at each plow depth were integrated to estimate cumulative soil respiration during the entire measurement period. The cumulative loss was calculated from the area under each of the fitted curves for 24-h (Figure 3). The total soil C emissions during the first 24-h interval ranged from 10.2 g CO2 m-2 with no tillage and 47.7 g CO2 m-2 with plow tillage to 102 mm to a high of 229 g CO2 m-2 for plow tillage at 280 mm. The deepest tillage depth always had the highest 24-h cumulative flux compared to the other depths. The no-till plots always had the smallest amount of CO2 lost as a result of no soil disturbance.

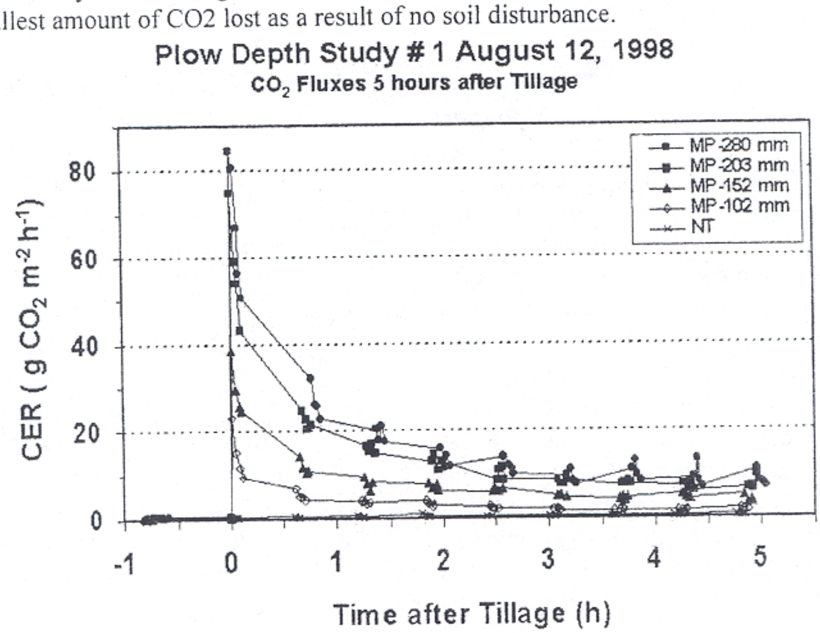

Figure 2. Short-term CO_2 flux versus time after no till (NT) and moldboard plow (MP) tillage at four depths.

This trend continued for 25 days after tillage with nearly 2 kg CO_2 m^2 lost from the 280 mm MP depth. The relationship shows the gradual decline as the tillage depth decreased from 280 mm to 102 mm, which was the shallowest depth that could be plowed. The decline the cumulative CO_2 loss as a function of tillage depth agreed with the earlier observations of Reicosky (1998) which showed that the tillage-induced CO_2 loss was linearly related to the volume of soil disturbed. Expressing the data on a soil volume basis suggests that the same phenomenon was observed because the CO_2 loss from moldboard-plow tillage was proportional to the tillage depth or volume of soil disturbed.

Conclusions

A clearer understanding of the residual soil organic matter and how it is maintained and/or increased is unfolding. Intensive tillage, particularly moldboard plowing, can cause large gaseous losses of C. No-till had the lowest CO_2 flux during the first study and MP had the highest immediately after tillage. Other forms of strip tillage had an initial flush between these extremes, with both the 5- and 24-hour cumulative losses related to soil volume disturbed. The CO_2 release immediately following MP tillage increased with increasing plow depth, and in every case was substantially higher than that from the no-tillage treatment.

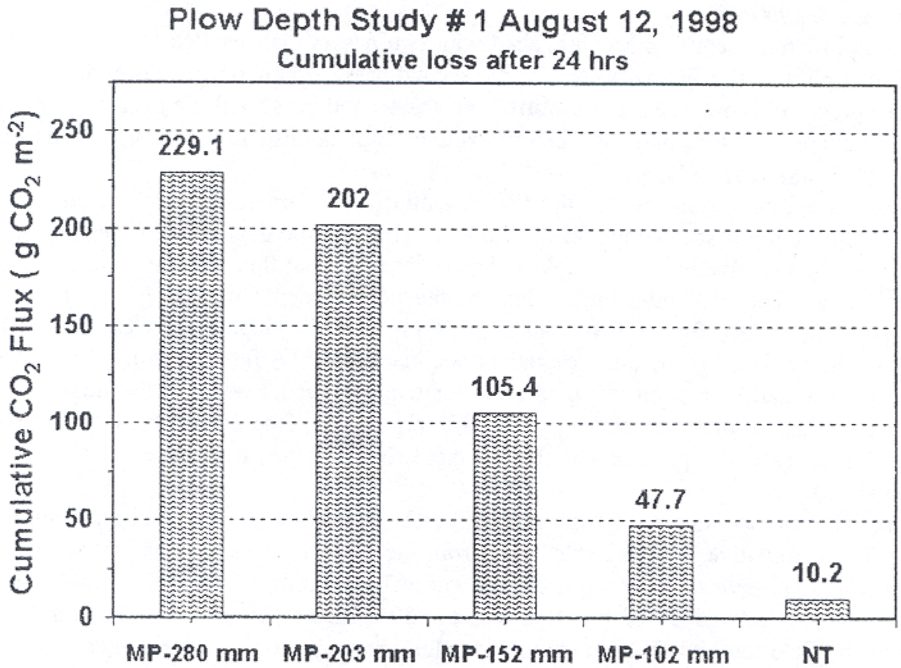

Figure 3. Cumulative CO_2 loss for 24 hours after no till (NT) and moldboard plow (MP) tillage at four depths.

The large losses of CO_2 following moldboard plowing compared to the relatively small losses with no-till or conservation tillage systems illustrates why crop production systems involving moldboard plowing have decreased soil C and why no-till systems are reversing this trend. These results demonstrate that tillage-induced changes in soil properties with plow depth resulted in substantial CO_2 loss that ultimately leads to a net C loss from the soil. Soil CO_2 was lost to the atmosphere and presumably oxygen entered the soil through large voids to enhance microbial activity. This effect was exacerbated with MP tillage depth with more CO_2 lost with deeper tillage, at least to 280 mm in this study. Intensive tillage also breaks up the soil aggregates to expose fresh surfaces for enhanced gas exchange from the interior where the aggregate interior may have a higher CO_2 concentration. This effect is amplified with the depth of tillage. Changing the surface soil properties by MP tillage depth combined with aerodynamic forces associated with natural wind movement over the soil can result in substantial CO_2 loss and oxygen entry. Differences in CO_2 flux among tillage methods suggested potential for improved soil management to minimize agriculture's contribution to global CO_2 increase. Tillage methods that minimize depth and extent of soil disturbances will have the least impact. Any effort to decrease MP tillage depth should result in improved management practices for sustainable production and enhanced environmental quality.

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