Agricultural Practices and Policies for Carbon Sequestration in Soil

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CHAPTER 8

Long-Term Effect of Moldboard Plowing on Tillage-Induced CO_2 Loss

D. C. Reicosky

CONTENTS

ABSTRACT

The possibility of global greenhouse warming due to rapid increase in carbon dioxide (CO_2) is receiving attention. Agriculture's role in sequestering carbon (C) is not clearly understood. Intensive tillage reportedly has caused between a 30 to 50% decrease in soil C since many soils were brought into cultivation; recent studies have shown a large short-term pulse of CO_2 released immediately following tillage, which partially explains C loss from soils. The objective of this work was to evaluate the long-term effects (3 months) of moldboard plowing on CO_2 loss from a Barnes loam (Udic Haploborolls, fine-loamy, mixed) in west central Minnesota (45°41′14″ N latitude and 95°47′57″ W longitude).

Treatments were weed-free replicated plots that were moldboard plowed and not tilled. Tillage-induced CO_2 loss was periodically measured using a large portable chamber for 87 days during summer of 1998. The soil CO_2 concentration was measured at 5-, 10-, 20-, 30-, 50-, and 70-cm depths in the not-tilled plots and 30-, 50-, and 70-cm depths in plowed plots. Soil gas samples were drawn once or twice weekly throughout the growing season from stainless-steel mesh sampling tubes; they were drawn with gas-tight syringes and run through an infrared gas analyzer using a computer-controlled data system and numerical integration techniques to determine the concentration. The initial flush of CO_2 immediately after moldboard plowing was nearly 100 g CO_2 m^{-2} h^{-1}, while that from the not-tilled treatment was less than 0.9 g CO_2 m^{-2} h^{-1}. The flux from the plowed

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plots declined rapidly during the first 4 hours to 7 g CO_2 m^{-2} h^{-1} and yielded a cumulative CO_2 flux from the moldboard plow treatment 14 times that from not-tilled plots. For the 85-day period following tillage, the cumulative CO_2 flux from the plowed treatment was 2.4 times higher that from not tilled.

Both treatments showed a seasonal trend as soil temperature cooled and fluctuations occurred associated with rainfall events.

Soil gas samples showed a similar trend with an increase in the CO_2 concentration with depth on the not-tilled plots until day 200, then gradually declined as soil C resources were used and temperatures decreased. Carbon dioxide concentrations were highest at the 30-, 50-, 70-cm depths. The decline in soil CO_2 concentration on the moldboard plow treatment was more dramatic than on the not-tilled treatment suggesting that higher air permeability in the tilled layer resulted in the higher gas exchange.

Results support previous short-term fluxes and confirm the role of intensive tillage in long-term soil C decline. The large differences in CO_2 loss between moldboard plow and not-tilled treatments reflect the need for improved soil management and conservation policies that favor conservation tillage to enable C sequestration in agricultural production systems.

INTRODUCTION

The possibility of global greenhouse warming due to rapid increase in CO_2 is receiving increased attention (Wood, 1990; Post et al., 1990); concern is warranted because potential climate change could result in increased temperature and drought over present agricultural production areas. Agriculture and intensive tillage have caused a 30 to 50% decrease in soil organic carbon (SOC) since many soils were brought into cultivation more than 100 years ago (Schlesinger, 1985). Examples of how intensive tillage has impacted agricultural production systems and SOC are illustrated by the long-term soil C trends in the Morrow plots in Champaign, IL, (Odel et al., 1984; Peck, 1989) and in Sanborn Field at the experiment station of the University of Missouri, Columbia (Wagner, 1989). Both locations show similar decreases in SOC over the last 100 years; thus, it is necessary to understand better the tillage processes in agricultural production and the mechanisms leading to C loss. Carbon loss can be linked to soil production, soil quality, C sequestration, and, ultimately, crop production (Paustian et al., 1997).

Agriculture's role in sequestering C is not clearly understood; there is a definite need for direct measurements to quantify CO_2 fluxes influenced by agricultural management practices (Houghton et al., 1983). Understanding these processes will lead to enhanced soil management techniques and new technology for increased food production efficiency with a minimum impact on environmental quality and greenhouse gas emissions. Soil disturbance by tillage may alter environmental conditions and soil structure to enhance production of CO_2.

Work using small static chambers showed that tillage influenced soil respiration in a small way compared to other variables such as crop species, growth stage, soil temperature, and soil water (Hendrix et al., 1988; Franzlubbers et al., 1995a,b). Results from simulated tillage led Roberts and Chan (1990) to conclude that a tillage-induced increase in microbial activity was not a major cause of soil C loss. More recently, Reicosky et al. (1997) reported differences as large as tenfold in tillage-induced flushes of CO_2 measured with a large chamber vs. a small soil respiration chamber. Flux differences from the different chambers were not resolved; however, the larger mixing rate in the large canopy chamber may have been partly responsible for the higher tillage-induced fluxes. Both chambers gave essentially the same low flux for the undisturbed soil (not tilled) in three cropping systems. Concern for pressure fluctuations associated with turbulent mixing required for sampling uniformity, and the tillage-induced change in soil air permeability bring uncertainty to the meaning of soil gas fluxes measured with dynamic chambers (Conen and Smith, 1998; Lund et al., 1999).

As the need for soil gas emission data increases, understanding chamber effects and interpreting data from static and dynamic chambers requires careful analysis. While chambers are convenient and relatively inexpensive, their use requires an appreciation of methodological limitations that may permit only qualitative assessment and limited quantitative data. Recent studies involving a dynamic chamber and tillage methods and the associated incorporation of the residue in the field indicate major gaseous loss of C immediately following tillage (Reicosky and Lindstrom, 1993). Immediately following tillage, a pulse of CO_2 was measured using a large portable dynamic chamber technique. Short-term impact of various tillage methods on loss of CO_2 from the soil surface was measured using a portable chamber designed to measure canopy photosynthesis.

Reicosky and Lindstrom (1993) found that the moldboard plow had the roughest soil surface and the highest initial CO_2 flux and maintained the highest flux throughout the 19-day study. High initial CO_2 fluxes correlated to deep soil disturbance and resulted in a rougher surface and larger voids. Lower CO_2 resulted from less soil disturbance and small voids with not tilled showing the least CO_2 loss during the 19-day study. Ellert and Janzen (1999) used a single pass with a heavy-duty cultivator (0.075 m deep) and a smaller dynamic chamber to show CO_2 fluxes 0.6 h after tillage were 2- to 4-fold above pretillage fluxes and rapidly declined to similar values within 24 h of cultivation. They concluded that short-term influence of tillage on soil C loss was small under semiarid conditions. On the other hand, Reicosky and Lindstrom (1993) concluded that tillage methods, especially moldboard plowing to 0.25 m deep in humid climates, affected the initial CO_2 flux differently and suggested that improved soil management techniques can minimize agriculture's impact on global CO_2.

The impact of broad area tillage on soil C and CO_2 loss suggests possible improvements with mulch between the rows and less intensive strip tillage to prepare a narrow seedbed. Reicosky (1998) quantified the short-term, tillage-induced CO_2 loss caused by several strip tillage tools and a moldboard plow. Not tilled had the lowest CO_2 flux during the study and moldboard plow had the highest immediately after tillage, which declined as the soil dried. Forms of strip tillage had initial flushes related to tillage intensity and were intermediate between moldboard plow and not-tilled extremes with both 5-h and 24-h cumulative losses related to disturbed soil volume. These results suggested that a direct interaction of the disturbed volume and amount of shattering of the soil were related to gas exchange, i.e., CO_2 loss and oxygen entry into soil enhances short-term microbial activity while energy resources are available. Reducing the volume of the soil disturbed by tillage should enhance soil and air quality by increasing soil C, therefore enhancing the overall environmental quality.

Historically, intensive tillage of agricultural soils has led to substantial losses of soil C as indicated by long-term and short-term analyses. Even though atmospheric CO_2 enrichment has occurred due to C emissions from soil, a potential to reverse the trend and sequester C in the world's soils exists. Adoption of best management practices that include modifying tillage techniques can lead to increasing soil reserve at the expense of decreasing the atmospheric C pool. Long-term studies show continued decline in SOC with intensive agriculture, but few suggest when the major C loss takes place. The objective of this work was to characterize the long-term impact of intensive tillage (moldboard plowing) on cumulative CO_2 loss. An experiment was designed to characterize the short-term, tillage-induced CO_2 fluxes and determine the impact duration by comparing not tilled (no soil disturbance in the recent past) and moldboard plow for a 3-month period without plant growth. It was hoped that these results would contribute to understanding using appropriate land usage to sequester more C in agricultural production systems.

METHODS AND MATERIALS

This work was conducted on a Barnes loam (Udic Haploboroll, fine-loamy, mixed) at the Barnes–Aastad Swan Lake Research Farm in west central Minnesota (45°41′14″ N latitude and

95°47′57″ W longitude). The surface horizon is generally dark colored with typically 28 to 32 g kg^{-1} C and developed over subsoil high in free calcium carbonate. The cropping history for the last 80 years has been corn (*Zea mays* L.), soybean (*Glycine max* L.), and spring wheat (*Triticum aestivum* L.) with conventional tillage.

The long-term study began July 14 (day 195) and ended October 9, 1998 (day 285) and was conducted on an area planted to soybeans on May 6 (day 126). Two weeks before tillage, soybeans were killed with glyphosate and then mowed to minimize the effect of residue decomposition on surface CO_2 fluxes. On July 14 (day 195), four replicate plots were plowed (0.25 m deep) with a commercially available, four-bottom moldboard plow (each bottom was 46-cm wide) to establish alternating plots of moldboard plow and not tilled. Plots had no prior soil disturbance other than the initial spring tillage and soybean planting. The plot size was 20 m long by 3.7 m wide as a result of two passes with the four-bottom plow. The moldboard plowing resulted in a complete inversion of the surface and nearly 100% incorporation of the residue. Both plowed and adjacent not-tilled plots had negligible surface residue from the previously killed soybean crop. Throughout the remainder of the experiment, the moldboard plow and not-tilled plots were kept weed-free by routine bi-weekly applications of herbicide.

The short-term, tillage-induced CO_2 release was measured with a large portable chamber (area = 2.71 m^2) designed to measure canopy photosynthesis and mounted on a four-wheel drive, rough-terrain forklift for portability. Details of the chamber and operations used to measure CO_2 flux from the soil surface are presented by Reicosky and Lindstrom (1993) with further modifications and improvements described by Wagner et al. (1997).

Immediately (within 1 min) after tillage of the first plot, four measurements were taken to obtain initial CO_2 fluxes followed by measurements at the corresponding not-tilled plot. Measurements were then repeated on the next plowed plot and the adjacent not-tilled plot for all four replicates. The cycle was repeated six times over 7 hours the first day. Subsequent measurements were delayed 48 hours due to intense rainfall (49 mm), which caused some reconsolidation of the plowed soil. Under these conditions, the moldboard plow CO_2 flux was still substantially larger than that from not tilled. Measurements were then made periodically once or twice a week throughout the remainder of the season until termination on October 9 (day 282) prior to a killing frost.

Soil CO_2 concentrations were measured periodically throughout the growing season to quantify the relation of soil CO_2 to CO_2 loss through the surface. Sampling tubes, plumbed with nylon tubing, were installed in the not-tilled and plowed plots on days 161 and 195, respectively. Glass gas-tight syringes were used to draw gas from the stainless steel screen sampling tubes installed at 5-, 10-, 20-, 30-, 50-, and 70-cm depths from the soil surface in the not-tilled plots. Because of the rough, porous nature of the plowed layer, gas-sampling tubes were only installed at 30-, 50-, and 70-cm depths in the plowed plots shortly after tillage. Samples were taken and analyzed with an infrared gas analyzer flow-through system. Generally 1-cc samples were drawn to provide adequate sensitivity for concentrations at all depths. Soil CO_2 concentrations in the not-tilled plots were monitored 3 weeks previous to plowing.

The climate during the experiment was characterized at a weather station (200 m away) that recorded daily measurements of solar radiation, soil and air temperature, and rainfall. The daily minimum and maximum air temperature and rainfall during the study are summarized in Figure 8.1. Air temperature followed a typical seasonal trend. While the air temperatures at the weather station might not have truly reflected soil temperatures at the site, they did represent relative temperature trends. Gas exchange measurement sensitivity to solar radiation and air temperature at the time of measurement and tillage was reflected in the magnitude of the fluxes. This suggests that CO_2 loss as an indicator of biological activity is highly dependent on water content and temperature. Tillage was completed on July 14 (day 195), one of the warmest days of the year with maximum air temperature of 32.3°C and minimum of 17.5°C. Some cooler weather in which daily maximum and minimum air temperature was 23.1°C and 8.6°C, respectively, preceded the end of the study.

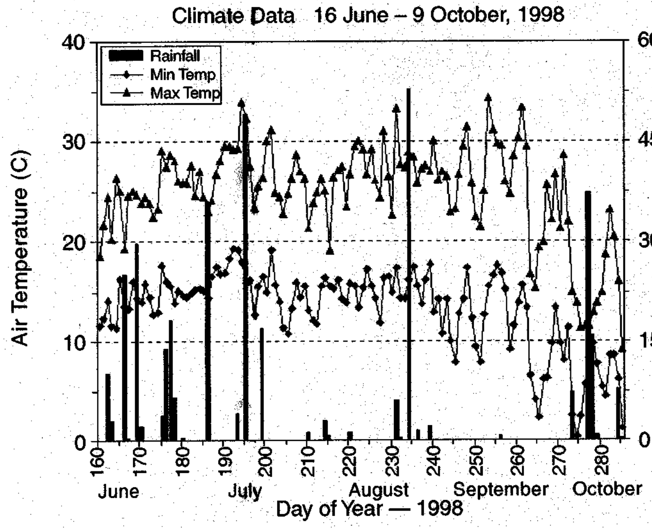

Figure 8.1 Daily minimum and maximum air temperatures and rainfall amounts from June through October, 1998.

Rainfall intensities were expressed only on an hourly basis. Presumably the short-term intensity could have been larger, but these data reflect the relative impact of rainfall events on the magnitude of the CO_2 fluxes and the amount of soil reconsolidation and surface crusting that took place. A heavy rain of 49 mm (42 mm h^{-1} max. intensity) occurred the night following tillage, effectively sealing and consolidating the soil surface of the plowed plots. Another substantial rain of 17 mm (7 mm h^{-1} max. intensity) occurred on day 199, followed by a heavy rain of 53 mm (39 mm h^{-1} max. intensity) on day 234. The major rainfall events partially leveled the plowed surfaces and consolidated the soil. After a few days of drying, both plowed and not-tilled plots showed essentially the same extent of surface soil cracking and drying.

RESULTS AND DISCUSSION

The daily max and min air temperatures and rainfall distribution in Figure 8.1 show typical seasonal trends with a gradual decline in air temperatures towards the end of period. From days 160 to 180 significant rainfall was fairly well distributed prior to tillage. The last significant rainfall (36 mm) prior to tillage occurred on day 186. After tillage, there were five major rainfalls with more than 15 mm. Three of these had 40 mm or more rainfall in 24 h; the rainfall intensity during these times was as high as 39 mm h^{-1} on day 235. This energy reconsolidated the moldboard plowed surface to the extent that both plowed and not-tilled surfaces appeared similar at season's end. The only visible difference was that the moldboard plow had a few larger clumps of soil that were higher compared to the relatively smooth not-till surface. The extent of cracking as a result of drying later in the study was nearly the same in both treatments.

The instantaneous CO_2 flux after the initial tillage, averaged for four measurements on four reps, is shown in Figure 8.2. Error bars represent +/- one standard error of the mean. Prior to tillage, the CO_2 fluxes were low for both treatments. However, in the moldboard plow treatment, the initial flux after tillage was nearly 100 g CO_2 m^{-2} h^{-1}, rapidly declined to about 25 g CO_2 m^{-2} h^{-1} within the first 15 minutes, then continued to decline to about 15 g CO_2 m^{-2} h^{-1} 1 hour after tillage. The gradual decline continued and the CO_2 flux was 7 g CO_2 m^{-2} h^{-1} 4 hours after tillage. During this 4-hour period, the cumulative CO_2 flux for the not-tilled treatment was 3.7 g CO_2 m^{-2}

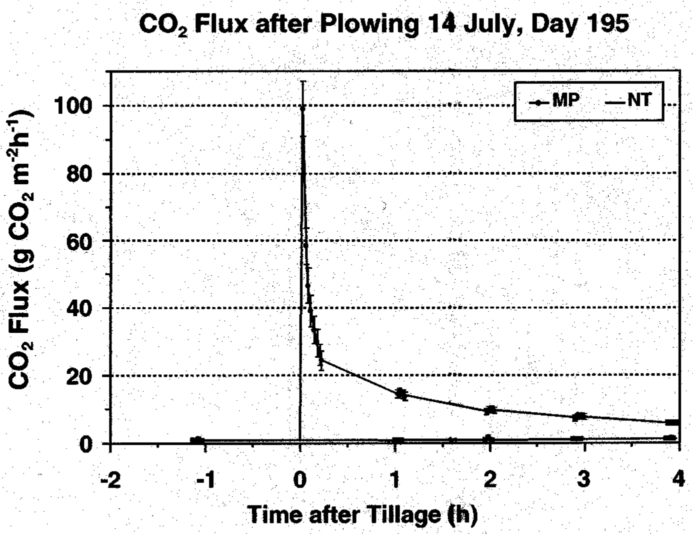

Figure 8.2 Short-term CO_2 flux as a function of time after tillage. Each data point is the average of four replicates at the same time in each measurement sequence.

while the corresponding cumulative flux for the moldboard plow treatment was 51.0 g CO_2 m^{-2}, a 14-fold difference.

This short-term high flux of CO_2 immediately following a tillage event agreed with the earlier results of Reicosky and Lindstrom (1993 and 1995). The same pretillage flux on both treatments demonstrates the impact of moldboard plowing on tillage-induced CO_2 loss that showed a rapid decline as a function of time. The change in tillage-induced soil properties allows more gas exchange initially, which is moderated as the soil reconsolidates and C reserves are used up by microbial activity.

The flux measurements on the not tilled and moldboard plow plots were continued throughout the season at weekly to twice-weekly intervals after tillage. The CO_2 fluxes from days 197 to 282 for both moldboard plow and not-tilled treatments are summarized in Figure 8.3. Note the change in the scale of the y-axis with a maximum span of 0 to 3 g CO_2 m^{-2} h^{-1} for the long-term trends as opposed to 0 to 100 g CO_2 m^{-2} h^{-1} for the short-term burst in Figure 8.2. The moldboard plow treatment showed a consistently higher, more erratic trend that appeared to be related to rainfall events and temperature fluctuations. Both treatments tended to show a gradual decline with time as soil and air temperatures decreased.

The similar temporal trends suggest that the CO_2 fluxes measured on moldboard plow and not-tilled treatments were biologically controlled because of the strong dependence of the CO_2 flux on water content and temperature. The seasonal decline could also be related to decreased C resources as a result of microbial activity with no C replenishment. The gradual decline continued through the end of the season; the soil CO_2 concentration differences between the two treatments grew smaller.

The cumulative CO_2 flux for the not-tilled plots from days 197 to 282, not including the first 4 hours after tillage, was 1035 g CO_2 m^{-2}, while the corresponding value for the moldboard plow was 2468 g CO_2 m^{-2}. The difference indicates 2.38 times as much CO_2 loss from the moldboard plow treatment as from the not-tilled treatment. This is only slightly different from the 2.48 times as much CO_2 from the moldboard plow when the first 4 hours after tillage are included. For the long term (87 days), the moldboard plow caused more than 2.4 times as much CO_2 loss as that from not-tilled treatment. To minimize complications in the CO_2 exchange rates, both treatments were maintained weed-free by spraying every 2 weeks so that there was no additional C input during the study.

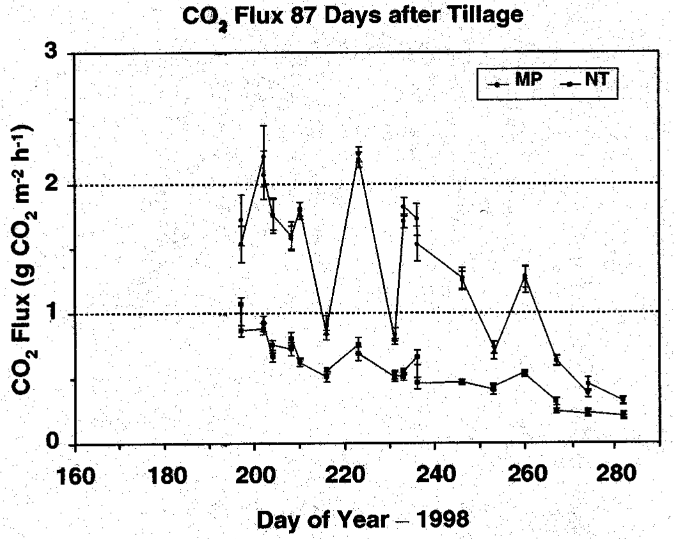

Figure 8.3 The average CO$_2$ flux from moldboard plow and not-tilled treatments as a function of time during the 1998 season. Note the scale change on the y-axis relative to Figure 8.2.

The mean soil CO$_2$ concentrations at the six depths sampled in the not-tilled plots are summarized in Figure 8.4a and for three depths in moldboard plow plots in Figure 8.4b. The error bars for each data point represent +/- one standard error of the mean. The data in Figure 8.4a show that, at 5- and 10-cm depths, the CO$_2$ concentrations never exceeded 15 mL L^{-1} during any time in the summer; but show a gradual decline with time as air temperatures cooled. The CO$_2$ concentrations at 30-, 50-, and 70-cm of the not-tilled plots showed a peak around day 200, then a gradual decline related to seasonal trends in soil temperature and water content. Some of the variation in CO$_2$ concentration was apparently related to the rainfall events, but it was very difficult to make a definitive statement because the times between rainfall and actual soil CO$_2$ measurement were not consistent.

The CO$_2$ concentration at 50 cm in the moldboard plow plots was nearly 35 mL L^{-1} on Day 200 shortly after tillage, and then showed a rapid decline apparently related to the tillage event. This apparent short-term negative gradient at the 50-cm depth likely reflects the interaction of the plow event 5 days earlier and the combined effect of 49 mm rainfall following tillage and 17 mm one day before the gas measurement on day 200. Intensity and amounts of rainfall acted to "seal" the soil surface and slow loss of CO$_2$ from the deeper depths. As the plowed and soil surface dried, the soil air permeability increased and CO$_2$ concentrations at the lower depths decreased below those of not-tilled plots. The decline in soil CO$_2$ concentration was more dramatic on the moldboard plow plots, decreasing to less than 20 mL L^{-1} at the 70-cm depth between days 220 and 240 and suggesting that the air permeability of the plowed surface layer was higher than the same thickness of the not-tilled treatment. The CO$_2$ concentrations in the plowed plots were substantially lower than in the not-tilled plots. The gradual decline in both treatments was most likely related to soil temperature and water content decline, as well as to possibly depleted C resources due to microbial activity similar to results of Buyanovsky and Wagner (1983).

Soil CO$_2$ concentration profiles with depth at selected times in the season are summarized in Figure 8.5. The first (day 197) was shortly after tillage (2 days); then the second and third occurred on days 216 and 274, midway and at the end of the experiment, respectively. The highest CO$_2$ concentrations during the season were related to the highest soil temperatures and presumably highest microbial activity. The differences between the moldboard plow and the not-tilled treatments from the 30- to 70-cm depth were very small early in the season, but grew larger; on day 216, the not-tilled treatment concentrations were nearly twice as high as moldboard plow. On day 274, both

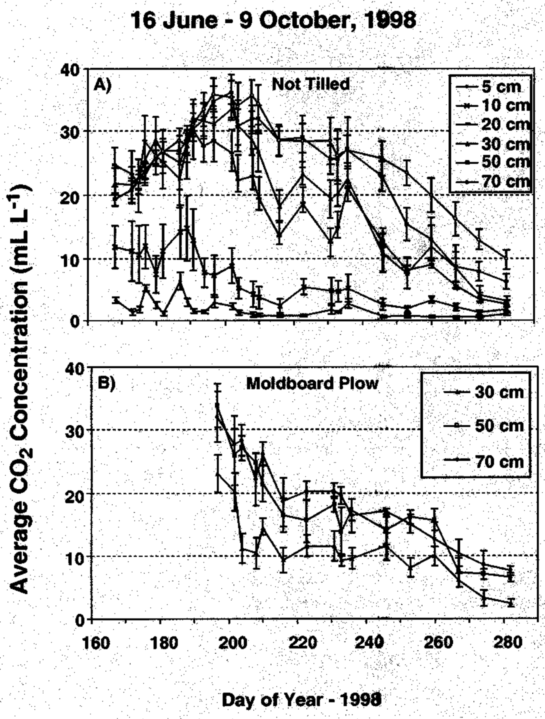

Figure 8.4 (a) Soil CO_2 concentration at six depths as a function of time during the growing season in the not-tilled plots; (b) soil CO_2 concentration as a function of time in the moldboard plow plots at 30-, 50-, and 70-cm depths.

magnitudes were generally lower than 10 mL L^{-1} with small differences between the moldboard plow and not-tilled. These results suggest that a change in soil air permeability of the plowed layer above the 30- to 70-cm depth resulted in higher CO_2 fluxes and lower soil CO_2 concentrations compared to the not-tilled treatment. This trend continued throughout the season and the differences between the two treatments grew smaller as the source of CO_2 decreased related to declining temperature.

In general, the soil gas concentrations in plowed plots after tillage were lower than the corresponding depths of not-tilled plots. At the end of the experiment, soil gas concentrations were essentially the same low value as microbial activity declined with temperature. While there was considerable variation in the CO_2 flux measurements in Figure 8.3, there appeared to be a general correspondence in the soil CO_2 flux decline in moldboard plow and not-tilled treatments, with the gradual decline in soil CO_2 concentrations similar to results of Buyanovsky and Wagner (1983) under wheat.

The results suggest that CO_2 loss was a result of a combination of a change in soil properties and current biological activity. If one assumes that the microbial respiration generating CO_2 was similar in both treatments, then the CO_2 concentrations in the not-tilled treatment would build up to a higher concentration than that in the plowed plots. Gas flow by diffusion and convection through the not-tilled surface was slower than that in the moldboard plow treatment; the loose open soil in the plowed plots allowed better gas exchange and resulted in lower CO_2 concentrations. While these observations may seem contradictory, CO_2 concentration with depth and the surface flux were both affected by plow tillage. The lower CO_2 concentration possibly also suggests higher oxygen concentration (not measured) that might result in higher aerobic decomposition of the soil organic matter.

The consistent differences in CO_2 fluxes from the plowed and not-tilled surfaces suggest that tillage-induced soil changes can cause different CO_2 fluxes. These results differ with those of

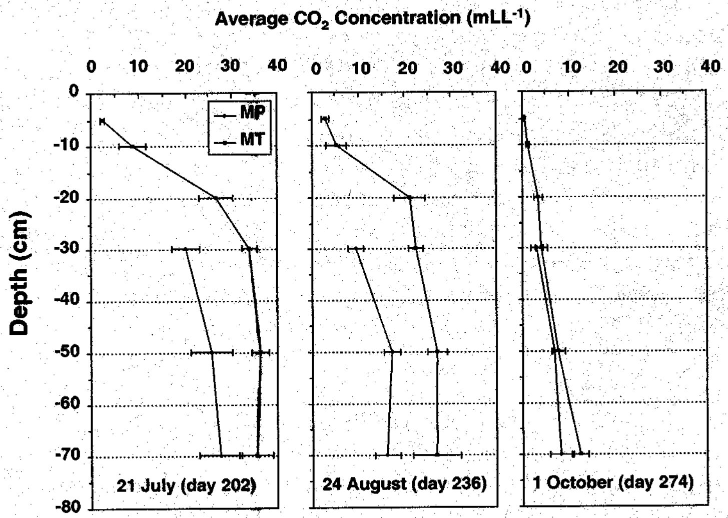

Figure 8.5 Soil CO_2 concentration profiles on the not-tilled and moldboard plow plots early-, mid-, and late season during 1998.

Hendrix et al. (1988) and Franzlubbers et al. (1995a,b) using small soil chambers. Results from simulated tillage led Roberts and Chan (1990) to conclude that a tillage-induced increase in microbial activity was not a major cause of soil C loss. While the absolute magnitudes of the fluxes in this work may be open to question due to the turbulent mixing inside the chamber that creates small negative pressures (Conen and Smith, 1998; Lund et. al., 1999), the relative difference between the plowed and not-tilled treatments should remain the same.

The role of natural wind in the magnitude of gas fluxes is not clear, but presumably the natural turbulence outside the chamber can affect the natural flux similarly. The changes in soil air permeability with tillage would impact the convective component of the total gas flux more than the diffusive component and partially explain the observed treatment differences. The dramatic change in soil properties following the plow are likely related to the large short-term flux differences and to the smaller long-term flux differences for 87 days after tillage. These data differ from Ellert and Janzen (1999), who showed that CO_2 fluxes 0.6 h after shallow cultivation were two- to four-fold above pretillage fluxes and rapidly declined to similar values within 24 h of cultivation.

This longer-term study shows that the moldboard plow treatment with no plants growing on the soil maintains a significantly higher CO_2 flux than plots not tilled throughout the growing season. While this may be an artificial situation, differences between the moldboard plowing and not-tilled plots were maintained for 87 days, even though the appearance of surface sealing from rainfall may have had some affect. The magnitude of the CO_2 fluxes did not reflect any differences in surface sealing or crusting that appeared similar on both treatments in the latter part of the study. The data suggest that soil air permeability and gas exchange from the moldboard plow system were higher supporting the lower CO_2 concentrations with soil depth. Possibly higher oxygen concentrations may be responsible for higher aerobic microbial activity that results in higher respiration and loss of CO_2.

CONCLUSIONS

In summary, results support earlier work on short-term, tillage-induced CO_2 loss that the impact of moldboard plow tillage on CO_2 loss continues to affect soil and air quality for nearly 3 months. To minimize the environmental impact, one must minimize the volume of soil disturbed, till only the soil volume necessary to get an effective seedbed, and leave the remainder of the soil undisturbed to conserve water and C, as well as to minimize erosion and CO_2 loss.

Conservation tillage can be beneficial by improving soil and air quality, minimizing runoff, enhancing water quality, and minimizing contributions to the greenhouse effect. Decreased CO_2 released from the soil to the atmosphere will require less intensive tillage than the moldboard plow. The associated fossil fuel energy savings represent an additional economic benefit connected with less disturbance of the soil. The combination of short- and long-term environmental benefits of conservation tillage and the economic benefits relative to broad area tillage need to be considered when making soil management decisions. These technical considerations need to be identified and placed into policy decisions used for developing and evaluating methods for C sequestration in agricultural systems.

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