Continuous corn with moldboard tillage: Residue and fertility effects on soil carbon

D.C. Reicosky, S.D. Evans, C.A. Cambardella, R.R. Allmaras, A.R. Wilts, and D.R. Huggins

ABSTRACT: Greenhouse gas emissions from soil depend on land use, cropping systems, and tillage methods. The impact of 30 years of continuous corn (*Zea mays* L.) with moldboard plow tillage was evaluated from four treatments and a control: silage removal versus grain removal, each with low [83 kg N ha^{-1} (74 lb N ac^{-1})] and high [166 kg N ha^{-1} (148 lb N ac^{-1})] fertility, and no added fertilizer with grain removal. Soil organic carbon (SOC) changes over a 30-yr period were measured, as well as tillage-induced CO_2 loss immediately after moldboard plowing, in the spring of 1996. The 24 h cumulative tillage-induced CO_2 loss was not significantly different among treatments (excluding the control). Total C, total N, and C:N ratio in the soil remained virtually unchanged after 30 yr in fertilized treatments. All four treatments produced the same SOC content [21.9 g kg^{-1} (2.2%)] in the 0 - 20 cm (0 - 8 in) depth. The cumulative total input of 241 Mg ha^{-1} (107 t ac^{-1}) of aboveground stover from the high fertility grain treatment, compared to none from the high fertility silage treatment, yielded no differences in SOC. Fertilizer N rates of 83 and 166 kg ha^{-1} (74 and 148 lb ac^{-1}) produced no difference in SOC or associated C:N ratios. Moldboard plow tillage caused rapid soil degassing that masked fertilizer and stover removal and/or return effects on SOC. This uncontrolled SOC decline agreed with other studies in this region, indicating that the soils were sources of CO_2 regardless of other agronomic practices, as long as moldboard plow tillage was used.

Keywords: Biomass removal, carbon dioxide, plow tillage, soil organic carbon

The management of crop residues and soil organic carbon (SOC) is of primary importance in maintaining soil fertility and productivity and for minimizing agriculture's impact on environmental change. The possibility of global greenhouse warming due to rapidly increasing carbon dioxide (CO_2) has received increased attention (Wood 1990; Post et al. 1990). Management practices are needed to optimize net primary production in order to improve soil carbon (C) sequestration (Paustian et al. 1997; Robinson et al. 1996). Determining agriculture's role in the overall global C balance requires direct measurements of CO_2 flux as impacted by agricultural management practices (Houghton et al. 1983; Post et al. 1990). More detailed information on the interaction between tillage, residue management, and SOC sequestration is required in order to

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minimize the negative impact of agricultural practices on global climate change (Kern and Johnson 1993).

The magnitude of greenhouse gas emissions from soil depends on land use, cropping system, and tillage method. Prior to 1950, the annual flux of C from biological processes in soils, primarily associated with the conversion of grassland and forests to farmland, was larger than the flux contributed by the burning of fossil fuels (Houghton et al. 1983). As a result of conversion to agricultural production, U.S. soils have lost between 30 and 50% of their SOC in the last 100 years (Schlesinger 1985). There are 118 million ha (292 million ac) of cropland in the United States, which, with improved management, could sequester near pre-agricultural levels of SOC and partially offset fossil fuel sources of CO_2 (Lal et al. 1998).

Reicosky et al. (1995) reviewed tillage and biomass production impacts on SOC in agricultural systems. They concluded that SOC was controlled by crop residue input that was largely determined by crop choice, fertilization, and climate. Crop residue returns or removal, biological oxidation rates, and soil erosion controlled the SOC losses from systems. The contributions from the latter two mechanisms of SOC loss were substantially lessened under reduced tillage or no-till (Dao 1998; Doran et al. 1998). Recently identified gaseous losses of soil CO_2 after moldboard plowing, compared with relatively small losses from no-till, demonstrated that SOC oxidation rates were higher under conventional tillage and partially explained why crop production systems using the plow have decreased soil organic matter (SOM) and why no-till systems are halting or reversing that trend (Reicosky and Lindstrom 1993; 1995). Similar results, though lower in magnitude, have been observed with chisel plowing in semi-arid soils (Ellert and Janzen 1999) and moldboard plowing in sandy loam (Rochette and Angers 1999).

A few studies have shown surprisingly little response of SOC to differences in C inputs. These results suggest an upper limit on C sequestration in mineral soils independent of the input rate, as demonstrated by Campbell et al. (1991a; 1991b) and Soon (1998), who showed no effect of varying C inputs on soil organic matter. Campbell et al. (1991b) reported no difference in SOC content for conventionally tilled plots from which the wheat (*Triticum aestivum* L.) straw was removed, compared with plots where the straw was retained, after 30 yr of spring wheat. These results suggest that roots may contribute more to the maintenance and accumulation of SOM than aboveground crop residue.

Robinson et al. (1996) studied the effect of long-term (12-36 yr) cropping systems and fertility treatments on SOC at three locations in Iowa. An evaluation of the first 35 yr of a 75 yr continuous corn study (at a fourth location) showed that about 30% of SOC was lost from manure and lime treatments when no commercial fertilizer was added. The various treatments at all locations included continuous grain corn and silage corn at high and low N levels. Corn silage treatments with no fertilizer had the lowest SOC at each location. Soil organic C changes were linearly related to the amount of residue returned. Converting row crop systems to 4 yr rotations could sequester as much as 30% of the C released since cropping began in Iowa.

Huggins and Fuchs (1997) summarized the long-term effect of N management on corn yield and SOC levels. Annual returns of crop residue were estimated based on grain yield data, and SOC changes were interpreted using climate and soil information. Soil organic C did not vary significantly with N rates after 19 yr of continuous corn, but there was a trend of less SOC with low N treatment [16 kg N ha^{-1} (14 lb N ac^{-1})] compared to high N treatment [195 kg N ha^{-1} (174 lb N ac^{-1})]. There was 2.45 Mg ha^{-1} (1.1 t ac^{-1}) less stover returned annually to the soil in the low N treatment than to the high N treatment. Green et al. (1995) showed that the addition of inorganic N stimulated the mineralization of C from corn stover and suppressed the mineralization of C from SOM.

Under continuous corn, the removal of stover plus grain had a negative effect on SOC of Mollisols in Iowa (Larson et al. 1972; Robinson et al. 1996), Indiana (Barber 1979), Michigan (Vitosh et al. 1997), Wisconsin (Vanotti et al. 1997), and Minnesota (Huggins et al. 1998a; Bloom et al. 1982). Bloom et al. (1982) reported the stover-fertility management effects on SOC for the first 13 yr of the continuous corn study that is the subject of this report.

The crop was either harvested as silage or grain. The stover remaining after the grain harvest was incorporated by tillage. Both residue treatments were conducted at high and low fertility levels. Except for the low fertility silage treatment, which had about 15% less SOC than the others, there were only minor changes in SOM after 13 yr. They concluded that longer treatment times were needed for precise estimates of treatment effects on organic C loss in Mollisols. The experiment was thus maintained for a total of 30 yr to evaluate the impact of continuous corn silage removal versus grain removal at low and high fertility. The specific objective of this study was to evaluate the long-term treatment effects on tillage-induced CO_2 emission loss, SOC, and N levels.

Methods and Materials

The experimental site, located at the West Central Research and Outreach Center near Morris, Minnesota (N 45° 36" 5' and W 95° 54" 11', elevation = 344 m), had been in continuous corn (*Zea mays* L.) for 30 seasons as described in detail by Bloom et al. (1982). The surrounding topography is a gently rolling glacial till plain. The local climate is continental with a mean annual rainfall of about 610 mm (24 in) [406 mm (16 in) during the growing season] and a mean annual temperature of 5.7°C (42.3°F). The growing season is characterized by warm, humid conditions during the summer months, and winters are cold enough to maintain frozen soil for an extended period. The experimental area extended over three soil series: Hamerly clay loam (Aeric Calciaquoll), McIntosh silt loam (Aeric Calciaquoll), and Winger silty clay loam (Typic Calciaquoll). These had minor textural differences and similar surface properties of water holding capacity, color, and C content.

The experimental land area was virgin prairie until it was first tilled in 1875; since then it has been farmed with conventional tillage methods. The primary crops in rotations prior to the experiment were corn, wheat (*Triticum aestivum* L.), alfalfa (*Medicago sativa* L.), and oats (*Avena sativa* L.) in various combinations up to 1965. This experiment was established to study the effects of silage removal versus moldboard plow incorporation of corn stover on the yield and soil properties under conditions of both high and low fertility (Bloom et al. 1982). The annual low fertility treatment was 83, 23, and 45 kg ha^{-1} (74, 20, and 40 lb ac^{-1}) of N, phosphorus (P), and potassium (K), respectively. The high fertility treatment was 166, 46, and 90 kg ha^{-1} yr^{-1} (148, 41, and 80 lb ac^{-1} yr^{-1}) of N, P, and K, respectively. Nitrogen was fall-applied prior to tillage as ammonium nitrate or urea. The experimental design was a 4 x 4 Latin square, using 15 x 15 m (50 x 50 ft) plots. The main treatments were arranged as a 2 x 2 factorial: two levels of residue returned by two levels of fertilization. Measurements were also made on adjacent areas (unfertilized check plots with only grain removed), which were moldboard plowed and planted, but did not receive fertilizer over the 30 yr period.

Hybrids (suitable to the local environs) were planted at various times from mid-April to mid-May [55,000 plants ha^{-1} (135,850 plants ac^{-1}) in early years and 75,000 plants ha^{-1} (185,250 plants ac^{-1}) in later years]. Treatments were generally fall moldboard plowed to 20 cm (8 in) after the grain harvest, followed by spring disking or cultivation. Silage was typically harvested before 15 September (late dough, early dent stage, before the grain had completely dried), while the grain was harvested about three weeks later. Thus, there was a short growth period between silage removal and the killing frost prior to grain harvest, but it presumably did not contribute much additional SOC input on the grain plots since the corn was no longer accumulating significant biomass. The cobs of the grain plots were returned to the soil. The silage was cut 15-20 cm (6-8 in) above the soil surface, leaving the corn stalk with brace roots as the only aboveground non-harvested biomass. Silage yields were also measured on the grain plots to identify differences in aboveground biomass, and thus C input. No silage or grain yield data were obtained in fall of 1993 due to an extremely wet period that prevented harvest.

To reflect initial conditions, soil samples [0-20 cm (0-8 in) depth] from the plots were collected in the fall of 1965 and analyzed for C and N in 1996. These samples had been air-dried and stored in a heated building. The plots were also sampled [0-20 cm (0-8 in) depth] for organic C analysis after 13 cropping seasons (Bloom et al. 1982). On 28 May 1996, the plots were sampled at the 0-10, 10-20, 20-35, 35-50, 50-76, and 76-100 cm (0-4, 4-8, 8-14, 14-20, 20-30, and 30-40 in) depths for organic and inorganic C, total N, organic and inorganic N (NO_3^- and NH_4^+), and pH in 0.01 M $CaCl_2$ analyses. All samples were air-dried, ground, and sieved to pass 2 mm (0.08 in) before analysis. Routine analytical methods were used (LECO 1994a; 1994b; Mulvaney 1996; Nelson 1982; Bremner 1996). Inorganic C was determined by a method developed by Wagner et al. (1998).

Throughout all 30 yr of the study, moldboard plow tillage was generally done after harvest in the fall, using a standard three-bottom plow that rotated so that all the plots were plowed in one direction. However, in 1995, due to a relatively wet fall, moldboard plowing was postponed until 30 May 1996. The CO_2 flux from the plowed surfaces (spring 1996 only) was measured using a portable chamber (Reicosky and Lindstrom 1993). The chamber, with a volume of 3.25 m^3 (115 ft^3), covered a land area of 2.67 m^2 (29 ft^2). Briefly, the chamber, with mixing fans running, was lowered over the plot surface (referenced for repeat measurements) within 1 min after tillage, and data were collected at 1 s intervals for 60 s to determine the rate of CO_2 and water vapor increase (Reicosky and Lindstrom 1993). The chamber was then raised, calculations completed, and the results stored on a computer diskette. In addition to the analog output of a LI-COR 6262[1] infrared gas analyzer that measured CO_2 and water vapor concentration, time, plot identification, solar radiation, photosynthetically active radiation, air temperature, and wet bulb temperature were also recorded. After the appropriate lag time, data for a 30 s calculation window was used to convert the volume concentrations to a mass basis and then regressed as a function of time (Wagner et al. 1997). The parameters from these regression lines, which reflect the rate of CO_2 and water vapor increase within a chamber, were then used to calculate the fluxes expressed on a unit horizontal land area basis. The total time for a single measurement, including data collection and computation, was about 2 min. Triplicate measurements were made on each of the plots immediately after tillage as part of a routine measurement cycle before moving to the next plot. The cycle was repeated on all treatments and continued for 8 h after the initial tillage event, followed by another set of measurements at 24 h. The instantaneous CO_2 fluxes as a function of time were accumulated using a simple numerical integration (trapezoid rule) technique to give the total CO_2 loss.

An ANOVA (SAS Institute 1988) was used to determine significant treatment effects and to estimate means and variances in the Latin square field experiment, with a 2 x 2 factorial combination of treatments. Precision of the biomass means in the unfertilized treatment adjacent to the Latin square was estimated from the variances computed in the ANOVA. Whenever means were combined over treatment and their associated standard errors reduced, a "t" test ($p>0.05$) was used to determine statistical significance.

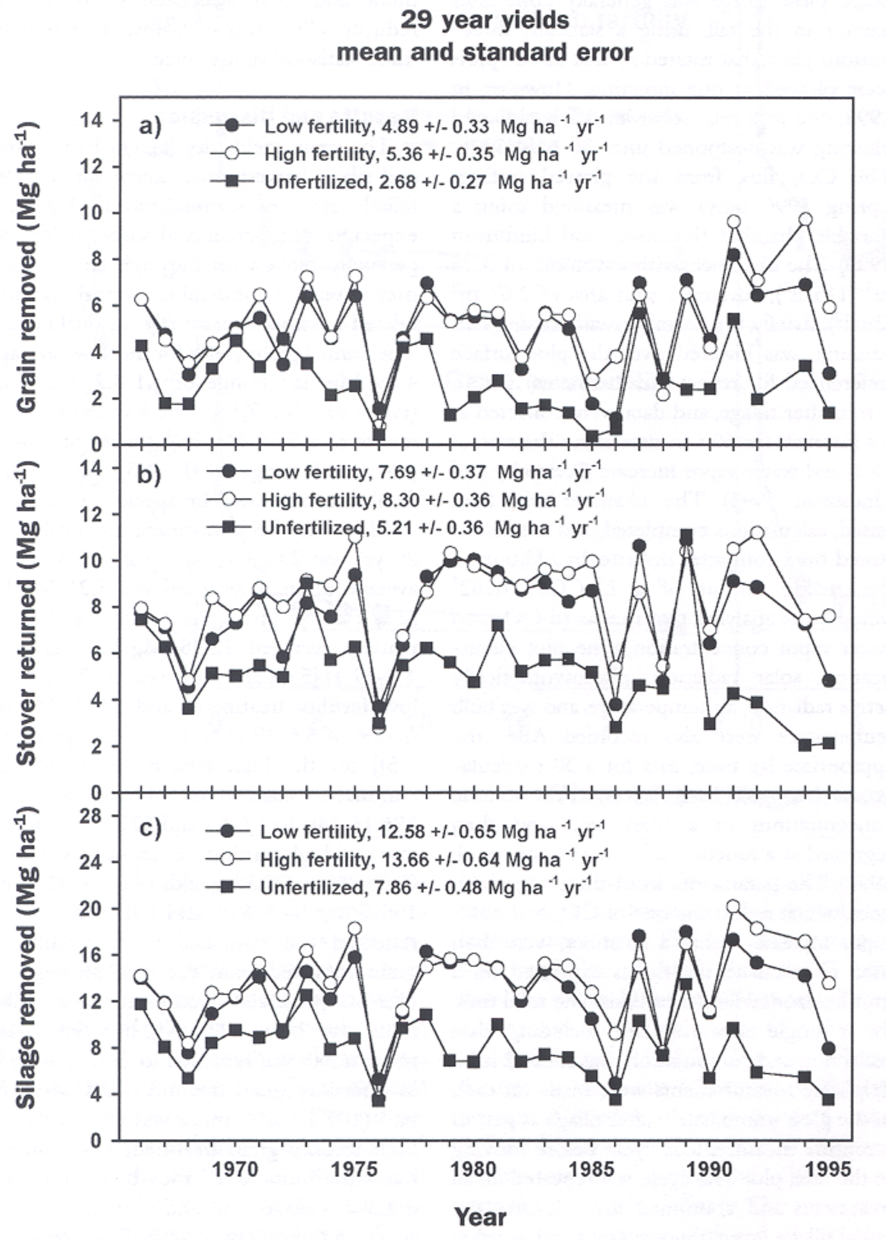
Results and Discussion

The grain yield (dry weight basis), stover, and silage harvest data, except for the 1993 failed crop, are summarized in Fig. 1. As expected, both grain and silage yields were generally highest on the high fertility treatment, with considerable annual variation related to climate (primarily seasonal rainfall). The annual grain yields for the 29 yr averaged 4.89 Mg ha^{-1} (range of 1.1-8.2) [2.2 t ac^{-1} (range of 0.5-3.7)] for the low fertility treatments and 5.36 Mg ha^{-1} (range of 0.8-9.7) [2.4 t ac^{-1} (range of 0.4-4.3)] for the high fertility treatments. The average annual grain yield for the check treatment (no fertilizer for 29 yr) was 2.68 Mg ha^{-1} (1.2 t ac^{-1}) and the average biomass returned was 5.21 Mg ha^{-1} (2.3 t ac^{-1}). The annual silage yields (dry matter) averaged 12.58 Mg ha^{-1} (range of 4.4-17.1) [5.6 t ac^{-1} (range of 2.0-7.6)] for the low fertility treatments and 13.66 Mg ha^{-1} (range of 5.6-19.1) [6.1 t ac^{-1} (range of 2.5-8.5)] for the high fertility treatments. The cumulative silage removed was 364.85 and 396.16 Mg ha^{-1} (163 and 177 t ac^{-1}) for the low and high fertility treatments, respectively. Cumulative grain yields were 141.9 and 155.4 Mg ha^{-1} (63.3 and 69.3 t ac^{-1}). Stover returned was estimated by subtracting the grain removed from the total aboveground biomass produced. Compared to the silage plots over 29 yr, 222.9 Mg ha^{-1} (99.4 t ac^{-1}) more stover was returned to the soil with the low fertility grain treatment and 240.8 Mg ha^{-1} (107.4 t ac^{-1}) more was returned to the high fertility grain treatment soil. Assuming the same amount of root biomass in both grain and silage plots and a stover C content of 410 g C kg^{-1} (183 t ac^{-1}) (Buyanovsky and Wagner 1986), 91.4 and 98.7 Mg ha^{-1} (40.8 and 44.0 t ac^{-1}) more C was returned to the grain plots than silage plots for low and high fertility, respectively.

Biomass production data from silage versus grain plots showed a strong 1:1 linear relationship for both low and high fertility treatments (data not shown). Total shoot biomass affects root biomass, thus any variation in above ground biomass should be reflected in the roots through a similar root:shoot ratio

Figure 1

Biomass yields versus time: (a) corn grain yield removed, (b) stover returned, and (c) silage removed (grain + stover) from low and high fertility treatments compared with unfertilized. Data from 1966-1995 (crop failure in 1993). (n = 4 from low and high fertility treatments, n = 1 from unfertilized check.)



(Buyanovsky and Wagner 1986).

Fertilizer treatments and residue removal by corn silage harvest (the 2 x 2 factorial) in this study showed little effect on SOC. The SOC content for 1965 and 1996 is summarized in Fig. 2. The initial organic C in 1965 in the 0-20 cm (0-8 in) depth ranged from 24.4-28.2 g kg^{-1} (2.4-2.8%), with a mean of 25.73 g kg^{-1} (standard deviation of 1.43 g kg^{-1}) [2.6% (standard deviation of 0.14%)]. After 13 cropping seasons, Bloom et al. (1982) reported a SOC range of 22.5-25.8 g kg^{-1} (2.2-2.6%). In 1996, SOC in fertilized plots ranged from 21.3-22.0 g kg^{-1} (2.1-2.2%) [average values for 0-10 and 10-20 cm (0-4 and 4-8 in.) depths], with a mean of 21.57 (standard deviation of 0.141 g kg^{-1}) [2.1 (standard deviation of 0.01%)], and showed no treatment difference. This suggests that fertility level and the C removed by silage had no effect on SOC content in the top 20 cm (8 in) after 30 yr. There was a significant (at p = 0.01) SOC decrease from 1965 to 1996: about 4.3 g kg^{-1} (0.4%) averaged across all four treatments; that decrease is in agreement with the findings of Angers et al. (1995) on silage plots. There was a larger loss in the silage corn treatment than in the grain corn after 30 yr, for which there are several explanations. One is the difference in initial SOC content, another is the difference in the C input from aboveground stover, and a third is possibly the negative impact of moldboard plowing or some combination of the three.

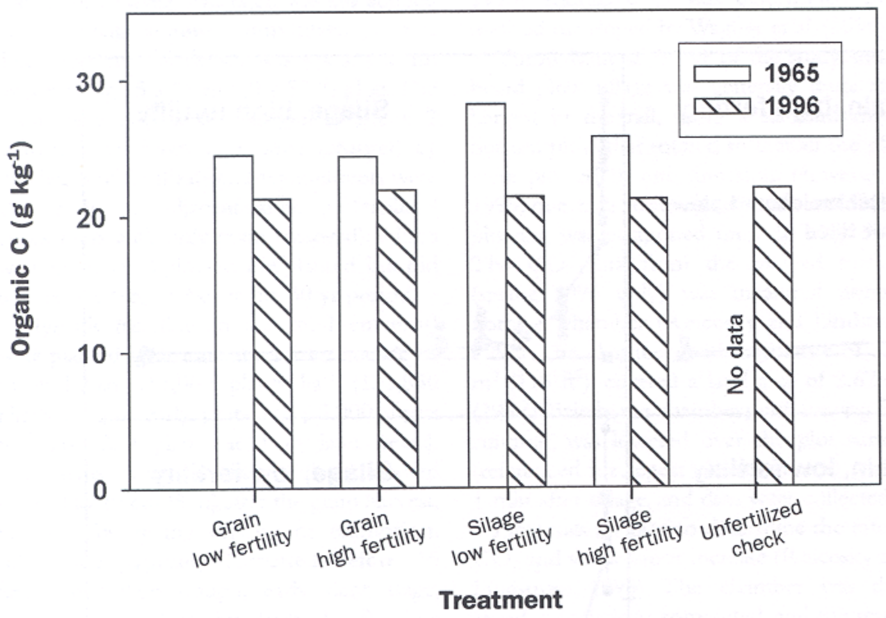
Undisturbed soil bulk density was not measured at the start of the study in 1965, but measured values in 1995 averaged 1.28, 1.31, and 1.39 Mg m^{-3} for 0-15, 15-30, and 30-45 cm (79.92, 81.80, and 86.79 lbs ft^{-3} for 0-6, 6-12, and 12-18 in) depths, respectively. Treatment differences were not discernable (data not shown). Bulk densities for the subsoil [below 45 cm (18 in.)] were variable and ranged from 1.4-1.5 Mg m^{-3} (87-94 lb ft^{-3}). Measured pH (in 0.01 M $CaCl_2$) increased from an average of 7.55 to 7.75 in the Ap layer over the 30 yr of this study (data not shown).

There was little difference in total C and N between the top 10 cm and 10-20 cm (4 in and 4-8 in) in all of the treatments (Fig. 3). There was a tendency for total soil N to decrease with depth, while total C increased slightly between 40 and 60 cm (18 and 24 in), primarily due to high inorganic C levels that are characteristic of the Calciaquolls in this landscape and may be expected, based on soil classification (Fig. 3). The predominant organic component of the total C in the surface soil decreased with depth (Fig. 3). The total C declined slightly at 80-100 cm (32-40 in), relative to 60-80 cm (24-32 in). Only the check treatment (no fertilizer for 30 yr) indicated a slight decrease in total C, descending in the top 35 cm (14 in) (data not shown). In all other treatments, the total C and N in the top 35 cm (14 in) did not change significantly with depth. The value of the C:N ratio was consistently 11.2 in the top 35 cm (14 in) of all four treatments, suggesting that residue removal or addition had little effect and that even with the best aboveground stover management practices, intensive tillage deters SOC buildup.

Not only did the high and low fertility levels show no significant SOC difference in the 0-20 cm (0-8 in) depth for either silage

Figure 2

Soil organic carbon concentrations measured in 1965 and 1996 (0-20 cm depth) (n = 4).



removal or grain removal treatments, the SOC content for the check plots was essentially the same, though there was less biomass and grain yield (Fig. 1). These results differ from Gregorich et al. (1996) who evaluated over 31 yr of soil tests in eastern Canada and found that fertilization on continuous corn resulted in 13% more SOC.

The tillage-induced CO_2 flux data, which represents gas exchange as a function of time for all treatments, are summarized in Fig. 4. The CO_2 flux just prior to tillage averaged 0.29 g CO_2 m^{-2} h^{-1} (2.6 lb CO_2 ac^{-1} h^{-1}) for the high fertility plots. The largest flux, immediately after tillage, was 45 g CO_2 m^{-2} h^{-1} (401.4 lb CO_2 ac^{-1} h^{-1}) on a low fertility grain plot. Soil loosened by tillage should increase the CO_2 flux due to degassing and better accessibility of oxygen necessary for organic matter decomposition and microbial respiration, whereas other consequences of tillage that may affect soil water and temperature are not easy to predict (Reicosky and Lindstrom 1993). There were large initial CO_2 fluxes immediately after tillage, probably reflecting "outgassing" of the soil, which rapidly decreased within 4-5 h of tillage. The decrease in CO_2 flux continued throughout the 24 h measurement period. However, CO_2 flux measurements remained higher than those found before tillage. The flux 24 h after tillage was around 3 g CO_2 m^{-2} h^{-1} (27 lb CO_2 ac^{-1} h^{-1}), an order of magnitude higher than the pre-tillage value. The temporal trend was similar for all treatments, suggesting that soil loosening controlled the flux rather than the imposed experimental treatments.

The initial flux was lower than that meas-

Figure 3

Total and organic carbon and total nitrogen contents for four treatments with depth (0-100 cm deep) in 1996 (n = 4, standard error shown).

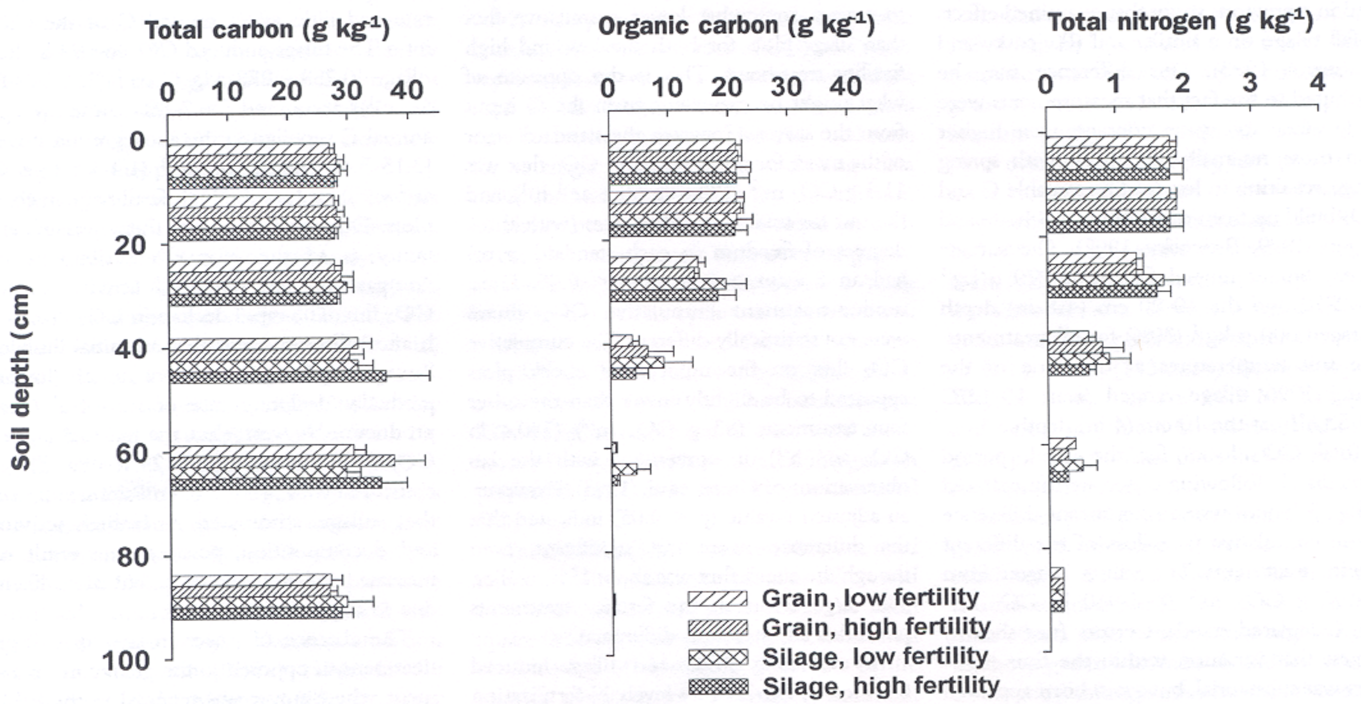
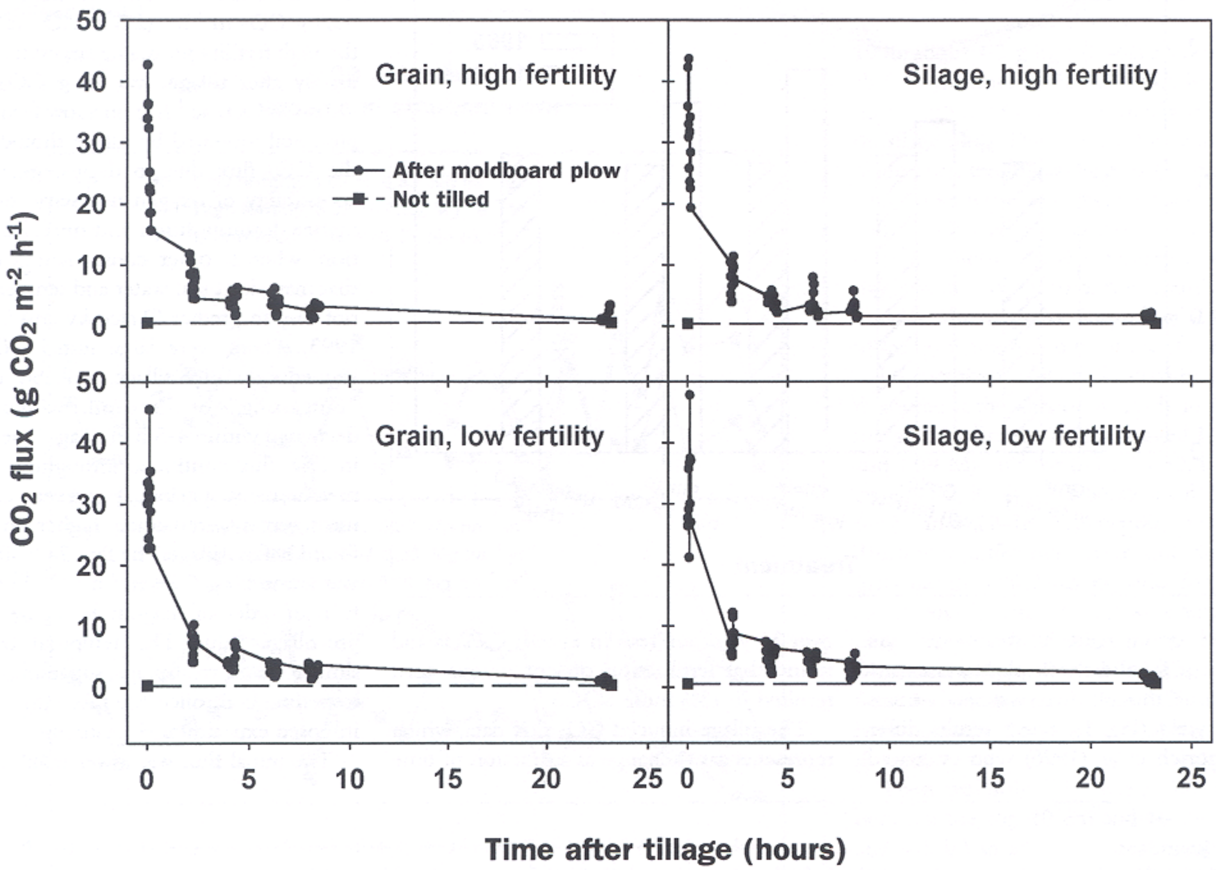


Figure 4

CO_2 flux versus time after tillage from four treatments. Dashed line and two data points represent fluxes prior to tillage. Time of tillage ranged from 0800-1000 hours on May 30, 1996.



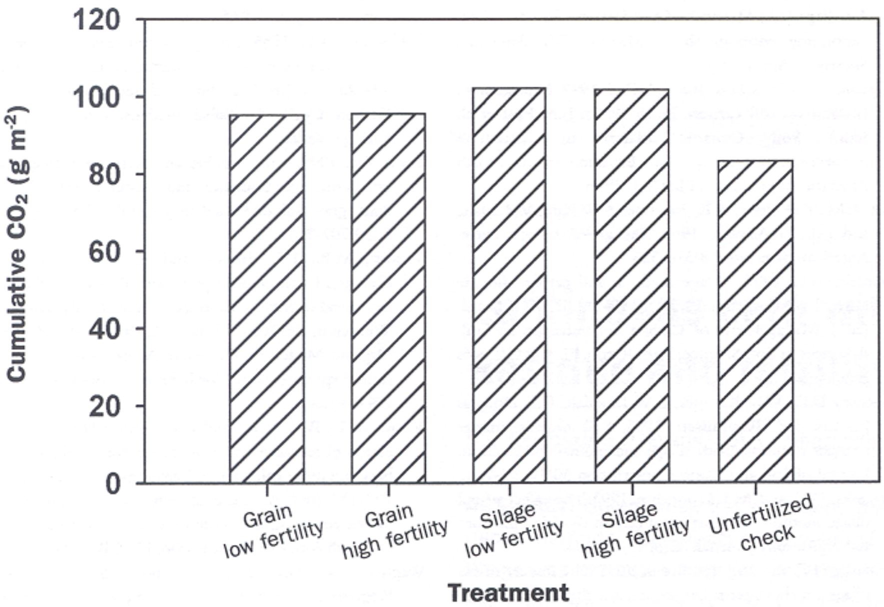
ured in a previous study that examined effects of fall tillage on a similar soil (Reicosky and Lindstrom 1993). This difference may be attributed to the fact that measurements were made when soil water contents were higher than those normally associated with spring tillage, resulting in less readily available C and CO_2 build up from respiration (Rochette and Angers 1999; Reicosky 1997). The surface water content ranged from 260-270 g kg^{-1} (26-27%) and the 10-20 cm (4-8 in) depth averaged 300 g kg^{-1} (30%) for all treatments. The soil temperatures at the time of the spring 1996 tillage ranged from 10-12°C (50-53.6°F) at the 10 cm (4 in) depth.

Total CO_2 losses for the 24 h period immediately following tillage are summarized in Fig. 5. There was no significant difference in the cumulative CO_2 loss of the different fertility treatments. The values ranged from 95-102 g CO_2 m^{-2} (847-910 lb CO_2 ac^{-1} h^{-1}). Calculated standard errors (not shown) suggest that variation within the four replicates was substantial, but grain corn appeared to have a somewhat lower cumulative flux than silage plots for both the low and high fertility treatments. This is the opposite of what might be expected, given the C input from the stover. However, the standard error of the mean for the cumulative CO_2 flux was 11.3 g CO_2 m^{-2} (100.8 lb CO_2 ac^{-1} h^{-1}), and the test for treatment differences (with three degrees of freedom in each standard error) had an F ratio > 9.28 at $p < 0.05$. Thus, residue-treatment cumulative CO_2 fluxes were not statistically different. The cumulative CO_2 flux on the unfertilized check plots appeared to be slightly lower than the other four treatments (83 g CO_2 m^{-2}) (740.4 lb CO_2 ac^{-1} h^{-1}), in agreement with the lab observations of Green et al. (1995). However, an adjusted t-value ($p < 0.05$) indicated that the differences were not significant, even though the check flux was about 15% smaller. The large errors in the fertility treatments precluded any statistical difference.

In evaluating SOC and tillage-induced CO_2 loss at two fertility levels, N fertilization rate had little effect on soil C or the C:N ratio. The tillage-induced CO_2 loss 24 h after tillage [0.259-0.278 Mg C ha^{-1} (231-248 lb C ac^{-1})] accounted for 7-8% of the average annual C supplied in the aboveground stover [3.15-3.40 Mg C ha^{-1} yr^{-1} (1.4-1.5 tons C ac^{-1} yr^{-1})] on low and high fertility grain corn plots. During this period, there was uncertainty as to the relative contributions of "outgassing" and microbial activity to the CO_2 flux. The rapid decline in CO_2 flux 1-2 h after tillage suggests that an initial flush of "outgassing" tapers into a much lower, gradually declining rate of microbial CO_2 production. Nevertheless, the ten-fold higher CO_2 flux of plowed plots 24 h after tillage, compared with pre-tillage emissions, indicates that tillage stimulated microbial activity and decomposition, possibly as a result of increased soil-stover contact, but more likely due to oxygen entry.

The absence of stover in the corn silage treatment, as opposed to the grain corn treatment where stover was retained in the field,

Figure 5
Cumulative carbon dioxide loss 24 hours after tillage (n = 4). Data from May 30 and 31, 1996.



had no effect on surface layer SOC after 30 yr. There was a slight decline in total SOC during the 30 yr study in all treatments. Campbell et al. (1991a; b) found similar results from varying C inputs that had no effect on SOC after 30 yr of spring wheat with intensive tillage. While we did not determine the contribution of roots to SOC in this study, root density should have been similar in all four treatments and may have been the main contributor to soil C maintenance (Balesdent and Balabane 1996). The lack of treatment differences in short-term tillage-induced CO_2 losses suggests little effect from stover returned and tilled into the soil.

Summary and Conclusion

Other work on large annual crop stover additions and removal—in Iowa by Larson et al. (1972) and Robinson et al. (1996), in Indiana by Barber (1979), and in Minnesota by Huggins and Fuchs (1997) and Huggins et al. (1998b)—has shown small increases in soil C with continued large inputs of residue C. Our study supports the theory that gains in SOC in cropping systems that employ intensive tillage will be limited, a finding similarly observed by Huggins et al. (1998a). Based on this work, any attempt to improve C sequestration in soil by way of corn stover management will require plants with more biomass (roots and shoots as discussed by Buyanovsky and Wagner 1986), and/or less intensive tillage if it is to be successful (Huggins et al. 1998a).

Results demonstrated the immediate impact of intensive surface tillage of soils on gaseous C loss and the lack of impact of residue removal or addition. Vitosh et al. (1997) reported that the addition of organic C and N as manure increased SOC even when corn silage was removed. In contrast, our study, an evaluation of 30 years of the same stover treatments and fertility levels with moldboard plow as the common element, suggests that the potential beneficial effects of C input through aboveground stover management were negated by intensive tillage. These results illustrate the complex C interactions in continuous corn systems and the importance of improved residue management to maximize retention of soil C and minimize tillage impact on the environment.

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Endnote

[1]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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