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COVER CROP AND SOIL AMENDMENT EFFECTS ON CARBON SEQUESTRATION IN A SILAGE CORN - SOYBEAN CROPPING SYSTEM

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COVER CROP AND SOIL AMENDMENT EFFECTS ON CARBON SEQUESTRATION IN A SILAGE CORN - SOYBEAN CROPPING SYSTEM

By

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ABSTRACT

COVER CROP AND SOIL AMENDMENT EFFECTS ON CARBON SEQUESTRATION IN A SOYBEAN – CORN SILAGE CROPPING SYSTEM

By

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Decline of soil organic carbon (SOC) in agricultural systems combined with increased awareness of the importance of the terrestrial ecosystem in a global carbon budgets has stimulated evaluations of land management effects on soil C dynamics and storage. Past and present farming practices have led to an estimated loss of 4 ± 1 Mg of carbon from soils of the United States. In this project we investigated the effectiveness of winter rye as a cover crop, fresh manure, and composted manure as potential methods to sequester atmospheric carbon in the soil. This research was repeated over three years at two locations; East Lansing (N 42.43, W 84.28) and Chatham (N 46.29, W 86.76). The two locations allowed for analysis of latitude effects. Compost treatments increased SOC the most at East Lansing followed by manure treatments. There were no differences in SOC accumulation at Chatham. Compost had a lower annual flux of greenhouse gases from the soil under both rotations at East Lansing, compost was also the lowest at Chatham when applied to continuous corn. Compost, manure, compost + rye, and manure + rye all had negative global warming potential (GWP) while rye alone and the untreated were net emitters of GHG at East Lansing. Continuous corn – compost was the only treatment at Chatham that had a negative GWP.

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CHAPTER 1

COVER CROP AND SOIL AMENDMENT EFFECTS ON SOIL ORGANIC CARBON IN SILAGE CORN – SOYBEAN CROPPING SYSTEMS

INTRODUCTION

Decline of soil organic carbon (SOC) in agricultural systems combined with increased awareness of the importance of the terrestrial ecosystem in global corn budgets has stimulated evaluations of land management effects on soil C dynamics and storage (Lal et al. 1995). Past and present short sighted farming practices have resulted in loss of an estimated 4±1 x 10^9 Mg of carbon from soils of the United States, and 78±12 x 10^9 Mg from the world's soils, a large fraction of which ended up in the atmosphere (Lal 1999). Soils play a major role in the global carbon budget not only because of the large amount of carbon stored in soil, with estimates ranging from 1395 to 1636x10^8 Mg (Post et al. 1992 in Torbert et al. 1999; Schlesinger 1984) but also because the annual flux of CO_2 to the atmosphere from soil is 10 times the amount of CO_2 contributed by fossil fuel usage (Post et al. 1990). Soil serves as both a source and sink for atmospheric CO_2, therefore soil and crop management significantly affect the global balance of CO_2.

There is increasing evidence when soil management or land use is changed to reduce SOC loss or increase input carbon to the soil, loss of SOC can be reversed (Janzen et al. 1998b). Approximately one-third of the atmospheric CO_2 that has accumulated since pre-industrial times is derived from land use practices that involve soil disturbance and removal of vegetation (Grant et al. 2001). These losses indicate widespread soil degradation. Currently there is much interest in reducing these losses through land use practices that increase the sequestration of carbon in soils. Land use practices that may increase carbon sequestration include a switch to no-tillage (NT), greater cropping frequency (Bremer et al. 1994; Campbell et al. 1995), and application of organic amendments such as manure (Sommerfeldt et al. 1988) although Janzen et al. (1998a) regarded applications of carbon amendments as a carbon transfer rather than a gain. Many of these practices (manure, forage production, and reduced harvest removal) that favor carbon storage appear to interact synergistically with each other, so that increases in SOC under one practice are greater when combined with other practices (Grant et al. 2001).

SOC storage is a balance between carbon additions from non-harvested portions of crops and organic amendments, and carbon losses primarily through organic matter decomposition and release of respired CO_2 to the atmosphere (Huggins et al. 1998). Additions and losses of carbon are regulated by agricultural practices such as crop rotation (Janzen et al. 1992), residue and tillage management (Havlin et al 1990), and fertilization (Bloom 1982; Paustian et al. 1992). SOC changes can be attributed to crop species grown, cropping systems (including rotations), residue management practices, fertilizer applications, tillage practices, and other management factors (Havlin et al. 1990). Additional input of organic substances containing high amounts of carbon such as farmyard manure or the incorporation of crop residues will increase SOC content (Dersch and Bohm 2001). Root contributions are important to conserving or increasing SOC (Balesdent and Balabane 1996; Campbell et al. 1991; Solberg et al. 1998). Changes in SOC following implementation of a new management practice are dependent on climate, soil parent material, topography, biotic factors, and time.

Conservation of SOC should be a goal in production agriculture to improve soil quality and decrease agricultural CO_2 emissions. It is possible to conserve SOC through appropriate choices of cropping, tillage, fertility, and residue management systems. Such management of SOC would decrease agricultural CO_2 emissions through reduced SOC decomposition, increased sequestering of atmospheric C, and reduced fossil fuel consumption (Robinson et al. 1996).

TILLAGE EFFECTS ON SOC

Tillage is used to mix and aerate the soil, and to incorporate soil amendments, cover crops, and crop residues into the soil. Soil incorporation of organic carbon has been associated with improvements in many soil physical, chemical, and biological properties, including improved porosity, microbial activity, and availability of plant nutrients (Logan et al. 1991). However, tillage exposes organic carbon in inter- and intraaggregate zones and that immobilized in microbial cellular tissues to rapid oxidation because of the improved availability of O_2 and exposure of more decomposition surfaces (Crasswell and Waring 1972; Reicosky and Lindstrom 1993; Beare et al. 1994; Jastrow et al.1996).

Losses of 40% or more of the SOC during a 60 yr period were realized with conventional tillage (Tiessen and Stewart 1983). Several researchers have shown increases in organic matter content, especially in NT systems as larger amounts of residue associated with increased crop yields are returned to the soil (Havlin et al. 1990; Rasmussen et al. 1980). NT cropping system accumulated on average 0.3 Mg/ha carbon annually in the Midwest United States (Franzluebbers and Steiner 2002). Increased carbon storage has frequently been observed in soils under conservation tillage, particularly with NT (Lamb et al. 1985; Unger 1991). Widespread adoption of conservation tillage could result in net increases in carbon sequestration in agricultural lands, reversing the decline caused by intensive tillage practices used for decades (Kern and Johnson 1993). Conversion of land from plow tillage to long-term NT management has a positive influence on the quality of agricultural soil (McCarty and Meisinger 1997; McCarty et al. 1995). Soil properties rapidly change during transition from plow- to NT management with much of the character of NT soil developed within the first 3 yr of NT treatment (McCarty et al. 1998).

Soil under long-term NT is stratified in composition and amount of soil organic matter (SOM). The carbon nitrogen ratio of SOM increased substantially toward the surface of soil under NT management (McCarty and Meisinger, 1997). Various long-term field studies have demonstrated marked stratification of soil organic matter with depth that occurs in soils under NT management as well as the apparent increase in the amount of organic matter in the surface profile of soil. (Blevins et al. 1984). Increased amounts of soil nitrogen and carbon in the top soil under NT was with little doubt due to surface deposition of crop residue, whereas losses of nitrogen and carbon in the 12.5 to 20 cm interval may be attributed to net loss through mineralization (McCarty et al. 1998).

NT agriculture, together with leaving crop residue in fields, does have costs. The yield may be lower in poorly drained and compacted soils and in places whre springtime soil warming is slow. Initially, more fertilizer may be required, but as SOC increases, the soil becomes more productive, requiring the same or even less fertilizer. Crop residue left in the fields would not be available for animal feed, energy production, biofuels, or other uses and may increase incidence of pests and pathogens (Lal et al. 2004).

Tillage is the most important controlling factor for carbon sequestration in soil; and carbon sequestration will be very slow as long as surface tillage is a part of the management system (Torbert et al. 1999). Increasing conservation tillage to 76% of planted cropland would change agricultural systems from carbon sources to carbon sinks (Kern and Johnson 1993). Of all cultivated land (1379 Mha globally), NT is currently practiced on only 5% of the worlds cropland (Derpsch and Benites 2003 in Lal et al 2004). Concomitant conversion to cropping systems that conserve, or increase, SOC could also help move agriculture from carbon source to carbon sink (Robinson et al. 1996).

ROTATION EFFECTS ON SOC

Crop rotations usually increase SOC, when compared with monocultures (Havlin et al. 1990). Generally, SOC and nitrogen concentrations have decreased for continuous cropping, while rotations maintained or increased SOC and nitrogen concentrations in the surface layer (Varvel 1994).

The prevalent cropping system in the Corn Belt is an alternating 2 yr rotation of corn and soybean. Although more above ground carbon was returned to the soil with corn (1.4 times more than soybean), total SOC did not differ with crop sequence or depth. Using a two pool model, Huggins et al. (1998) determined the half lives of C4 (corn) and C3 (soybean) carbon in the fast pool were less than 1 yr, while in the slow pool the half life of C3 derived carbon was 34 yr longer than C4 derived carbon.

Three cropping systems (fertilizer based-N, manure based-N, and legume based-N) were evaluated over a corn-soybean rotation by Drinkwater et al. (1998). Corn, the only C4 crop present, accounted for 74, 48 and 22% of the returned residues in the conventional, legume and manure systems respectively. Maize derived carbon replaced the original SOC deposited by the C3 temperate forests that preceded agriculture in this region. Net carbon levels did not change because the loss of C3 derived carbon was nearly equivalent to the gain of C4 derived carbon. Net gains in soil carbon seen in the legume and manure systems were due to significant increases in C3 derived carbon.

Plant species composition and litter quality influenced SOC turnover markedly (Drinkwater et al. 1998). Greater retention for both carbon and nitrogen suggest that use of low carbon-to-nitrogen residues to maintain soil fertility combined with increased temporal diversity restores the biological linkage between carbon and nitrogen cycling in these systems and could lead to improved global carbon and nitrogen balances.

Application of these practices in the major maize/soybean growing region in the USA would increase SOC sequestration by $0.13\text{-}0.30 \times 10^{14}$ g yr^{-1}. This is equal to 1-2% of the estimated annual carbon released into the atmosphere from fossil fuel combustion in the USA (Marland and Boden 1997 in Lal et al 2004) and is a significant contribution.

MANURE EFFECTS ON SOC

Beef cattle feedlot manure contains essential nutrients in addition to approximately 15% carbon that can be used to improve soil physical and chemical properties (Eghball 2002). Carbon in manure is likely to have far greater value than the nutrients it contains if applied to a low organic matter or eroded soil. A long-term study in Germany found that more than 100 yr of manure applications increased soil organic matter fractions associated with the fine and medium silt fractions while clay associated fragments were higher in the unfertilized treatment (Schulten and Leinwever 1991). Cattle feedlot manure application increased SOC, total nitrogen (TN), potentially mineralizable nitrogen, soluble phosphorous, and soil microbial biomass, compared with soils receiving no manure (Fraser et al. 1988).

Rate of SOC change was directly related to carbon input from crop residues and amendments (Rasmussen and Parton 1994). Additional input of organic substances containing high amounts of carbon, such as farmyard manure or the incorporation of crop residues will increase organic carbon content in soil (Dersch and Bohm 2001).

Despite increased oxidative losses it was estimated that approximately half of the added manure-carbon was retained in the soil at the end of the season (Rochette and Gregorich 1998). Iazurralde et al. (2001) determined that addition of farmyard manure was a key management component leading to SOC increases. Increasing the amount of plant residue carbon returned as manure reduces the level of carbon productivity needed for a fixed carbon input to soil. SOC, phosphorous, and potassium increased with increasing rate of composted beef cattle feedlot manure applied form 1987 to 1990, while increasing rates of synthetic N fertilizer application decreased soil phosphorous and potassium, but had no effect on SOC (Schlegel 1992). Drinkwater et al. (1998) compared manure and conventional systems and found that even though both systems received equal amounts of carbon, the manure system showed a significant increase in carbon stored in soil. Compared with senescent-crop residues, a larger proportion of manure-derived carbon is retained in soil, probably because manure is already partly decomposed and contains a larger proportion of chemically recalcitrant organic compounds (Paustian et al. 1992; Hassink 1992). Manure has the ability to increase SOC even with high-intensity conventional tillage (Anderson et al. 1990).

Composting manure is a useful method of producing a stabilized product that can be stored or spread with little odor or fly-breeding potential. The other advantages of composting include killing pathogens and weed seeds, and improving handling characteristics of manure by reducing manure volume and weight (Eghball 2002). Approximately 25 and 36% more carbon remained in the soil after 4 yr of application of manure and compost respectively than the fertilizer treatment. A greater fraction of applied carbon remained in the soil from compost application even though cumulative carbon application rate was less for compost 7.78 Mg/ha then for manure 10.42 Mg/ha when averaged across treatments indicating more stable carbon compounds in compost than in manure. Composting has some disadvantages that include nutrient and C loss during composting, the cost of land, equipment, and labor required for composting, and odor associated with composting (Eghball 2002)

Total carbon concentration in the surface soil was generally greater for nitrogen (N) than phosphorous (P) based manure and compost applications, and the differences became greater with years of application, indicating the cumulative effects of manure and compost application (Eghball 2002). Biennial N-based compost treatment resulted in greater soil surface (0-15) carbon and nitrogen concentrations than annual N-based compost in the fourth year, even though similar total amounts of compost were applied for both treatments in 4 yr. This indicates that heavy application of compost every other year may protect the carbon and nitrogen from mineralization, as compared with smaller annual rates (Eghball 2002). All N-based treatments significantly increased SOC in the 0-15 cm soil profile compared to the check while, the only P-based system that increased SOC was the biennial P-based manure system. These results indicate that manure and compost can increase carbon sequestration in the soil, which may have implications for global climate change (Eghball 2002).

Application of compost or manure appear to be effective methods to increase SOC however, Schlesinger (1999) argued that manuring is not a valid method for soil carbon sequestration because of the extra land required to produce the manure.

COVER CROPS

Winter cover crops have shown some potential to reduce soil bulk density, increase water infiltration properties, and change the distribution of soil aggregate-size classes relatively quickly after their introduction into cropping systems (McVay et al.1989; Kuo et al 1997). There were trends for both TOC and TKN levels to be lower in soil from the cereal treatment plots, which indicates that the use of triticale as a cover crop may promote mineralization of SOM (Mendes et al. 1999).

Multiple factors influence sequestration of carbon in soils; tillage practices, types of crops produced, productivity of the soil, proper use of soil amendments such as manure and compost, cropping frequency, and latitude. The objectives of this research were to 1) determine the effect of cover crops, manure, and compost on carbon sequestration rates in a silage corn – soybean rotation; 2) evaluate the effect of latitude on carbon sequestration; and 3) develop best management practices to increase carbon sequestration in Michigan soils.

MATERIAL AND METHODS

Field experiments were conducted near East Lansing (N 42.43, W 84.28) and Chatham (N 46.29, W 86.76), MI over a three year period beginning in the fall of 2001. Soil at East Lansing was a mixture of Aubbeenaubbee-Capac sandy loams (Fine-loamy, mixed, mesic Aeric Ochraqualfs) and Colwood-Brookston loams (Fine-loamy, mixed mesic Typic Argiaquolls and Typic Haplaquolls). Chatham soil was a Trenary fine sandy loam (Coarse-loamy, mixed frigid Alfic Fragiorthods). Experimental design was a randomized complete block with four replications at each location. Treatments were arranged as a 2x3 factorial at East Lansing. Factors consisted of rye vs. no rye, and compost amendment vs manure amendment vs no amendment.

Prior to experiment establishment at East Lansing the site was under a corn-soybean rotation with conventional tillage. Corn was planted in 2001, harvested as silage and no-till production practices were implemented when the winter rye cover crop was planted. The site was split into two rotations, corn-soybean-corn (CSC) and soybean-corn-soybean (SCS). Treatments at East Lansing were; winter rye cover crop (R) alone or in combination with either composted manure (R+C), or fresh manure (R+M), composted manure (C) alone, fresh manure (M) alone, and an untreated check (U) applied to both rotations.

The Chatham site was an alfalfa field prior to experiment establishment. The experiment at Chatham consisted of two rotations, continuous silage corn (CC) and a forage soybean–silage corn rotation (SC). A winter rye cover crop was planted after removal of forage soybean in 2002. Treatments consisted of composted manure (C), liquid dairy manure (M), and an untreated check (U) applied to both rotations.

Plot size varied between locations with plots at East Lansing 6.1 x 12.2 m with 76 cm wide rows of corn or 38 cm wide rows of soybean and plots at Chatham were 18.3 x 18.3 m wide with 76 cm wide rows of corn or soybean in 19 cm wide rows. Planting dates, and harvest dates can be found in Table 1.

Winter rye was terminated approximately two weeks prior to planting with glyphosate (840 g ae/ha) at East Lansing and glufosinate (140 g ai/ha) at Chatham.

Biomass samples were collected by harvesting four 0.25m^2 quadrats in 2002 per plot and six quadrats in 2003-04 prior to planting. Samples were dried and ground to pass through a 1 m screen and analyzed for total carbon and total nitrogen (TN) content using a Carlo-Erba CN analyzer (Carlo Erba Strumentazione, Milano, Italy). Winter rye kill and harvest dates are located in Table 1.

Solid dairy/beef manure and composted manure were applied in the spring and fall of each year through the spring of 2004 at East Lansing. Liquid dairy slurry and solid composted manure were applied in the spring of each year at Chatham. Tables 2 and 3 include the date of application, rates of manure or compost application, and nutrient analyses of manure and compost.

Soil Sampling

Soil samples were collected using a regular hand soil probe in 2002 and a GeoProbe (Salina, KS 67401) slide hammer type probe in 2003 and 2004. Six soil cores 1.8 cm in diameter were collected from each plot and divided into 0-5 and 5-25 cm deep samples in the spring of 2002. Three soil cores 3.9 cm in diameter were taken per plot in the spring of 2003 and spring and fall of 2004. Samples within a plot were composited to make one bulk sample each for the 0-5 and 5-25 cm depths per plot per sampling. Soil moisture, bulk density, nitrate-nitrogen, phosphorous, SOC, TN, and particulate organic matter carbon (POM-C) content were determined from these samples. Sampling dates can be found in Table 1.

Soil samples were weighed before being sieved through a 4 mm screen to remove large rocks and pieces of organic material. A sub-sample of the sieved soil was dried at 65° C to determine soil moisture. Bulk density was calculated by subtracting the weight of the rocks from each sample and multiplying by the percent dry soil then dividing by the total volume of soil collected minus the volume of the rocks.

Michigan State University Soil and Plant Tissue testing laboratory protocols were used to determine nitrate-nitrogen and phosphorous concentrations (Frank et al. 1998 and Gelderman and Beegle, 1998). A 1 *N* KCl solution was used to extract the nitrate-nitrogen from wet soil. Bray P-1 methodology was used on air dried samples to determine phosphorous concentrations.

A ball mill was used to finely grind a subsample of soil before analysis with a Carlo-Erba CN analyzer for SOC and TN concentration. Carbon in the soil was considered 100% organic since the soil pH was below 7.0 at both locations. SOC and TN data is presented on a mass per unit area basis by multiplying the fraction of SOC by respective measurements of soil bulk density and depth of soil sampled.

Particulate organic matter carbon (POM-C) concentration was determined using a modified version of a procedure described by Camberdella et al (1992). 10 g of soil was shaken for 15 hours in a 5 g/L solution of sodium hexametaphosphate. After shaking, the mixture was washed through a 53 μm screen with distilled water to separate the soil into two parts, mineral and particulate matter. The mineral portion was collected, dried, and ground using a mortar and pestle and then analyzed for carbon content using a Carlo Erba CN analyzer. POM-C was calculated by subtracting the mineral associated carbon from the total carbon.

Deep core samples to a depth of 0.9 m were collected to monitor nitrate and phosphorous leaching and loading. A Giddings hydraulic probe (Ft. Collins, CO 80522) was used to extract the cores. Two cores were collected per plot and divided into four depths (0-15, 15-30, 30-60, and 60-90 cm). These samples were subjected to the same protocols as described earlier for nitrate-nitrogen and phosphorous concentration determination.

Tissue sampling

Rye and soybean aboveground residues were harvested and analyzed to determine how much total carbon and nitrogen was being returned to the soil. Root residue contributions were estimated for corn and soybean using published values from the literature (Buyanovsky and Wagner 1986; Bolinder et al. 1999).

RESULTS AND DISCUSSION

East Lansing

Soil bulk density

Soil bulk density is an important factor in determining carbon sequestration in soil. Soil organic carbon (SOC) and total nitrogen (TN) levels are easily manipulated with bulk density (McCarty et al. 1998). An increase in SOC or TN percentage doesn't necessarily mean that SOC or TN increased, if the bulk density decreased the total amount of carbon or nitrogen might have remained the same.

Bulk densities were similar among treatments in both the CSC and SCS rotation areas in the spring of 2002 (Table 4). Main effect of rye resulted in lower bulk density of the 0-5cm profile in the CSC rotation in the spring of 2003 than those treatments without rye (Table 5). Treatments containing either compost or manure soil amendments had lower bulk densities than those without in the spring of 2003 and the fall of 2004 in the 0-5 cm profile of the CSC rotation. Rye decreased the bulk density of the 0-5 cm profile of the SCS rotation by 25% while non-rye treatments decreased bulk density by 18%.

Cover crop and soil amendments did not affect soil bulk density in the 5-25 cm profile in either rotation; however the interaction of the two main effects did influence the bulk density in the fall of 2004 in the CSC rotation (Tables 4 and 6). The untreated resulted in a lower bulk density than R and M but was not significantly lower than the other treatments.

Carbon

Crop residues can be a significant tool to increase SOC; this study investigated silage corn and soybean which generally return little carbon back to the soil since the majority (95%) of the corn stover is removed during harvest and soybean residue is relatively low in quantity and decomposes quickly. Several studies have noted that carbon inputs from roots are probably underestimated due to the difficulty of measuring rhizodeposition of carbon and turnover of root biomass before maturity (Barber 1979; Buyanovsky et al. 1987). There were few differences observed in the amount of carbon from crop residues returned to the soil (Table 7). Treatments including either compost or rye returned more crop residue to the soil than other treatments (Table 8). Total crop residue returned over three growing seasons was similar among all treatments. The SCS rotation returned 26.7 Mg/ha compared to 22.0 Mg/ha from the CSC rotation when averaged across treatments.

Total carbon inputs were significantly affected by both the soil amendment and rye cover crop factors. Total carbon input over three growing seasons was greatest with manure followed by compost and rye treatments. Manure application at East Lansing resulted in 21.6 Mg/ha of carbon being added to the soil surface in both rotations over the three years (Table 2). The majority of that carbon was added in 2002 (59%) when beef feedlot manure with woodchip bedding was used (43% C). Compost treatments added 16.29 Mg/ha of carbon at East Lansing (Table 2).

Rye did not affect total carbon levels in the 0-5 or 5-25 cm profiles in either rotation (Table 9). Mendes et al. (1999) realized a trend for SOC levels to be consistently lower in soil removed from a cereal crop, indicating the use of triticale as a cover crop may promote mineralization of organic matter. Rye is a cereal crop so it is possible that it may also promote organic matter mineralization.

Application of soil amendments did influence total carbon levels in the 0-5 and 0-25 cm profiles of the CSC rotation (Table 9). Compost increased total SOC more than manure which increased SOC more than no amendment in the 0-5 cm profile of the CSC rotation (Table 10). Total profile SOC increased by 43% with compost compared to 26% with manure and a 3% loss with no amendment.

Soil amendments had a significant impact on SOC in the 0-5 and 0-25 cm profiles of the SCS rotation in the spring and fall of 2004 (Table 9). Compost increased SOC more than manure or no amendment in the 0-5 cm profile in the spring of 2004 (Table 10). This disagrees with work done by Rochette and Gregorich (1998) who found that stockpiled manure increased SOC more than rotted (partially composted) manure when incorporated to a depth of 20 cm. However, Eghball (2002) reported a greater fraction of carbon remained in the soil after compost application than manure. Compost and manure both increased SOC more than no amendment in the 0-25 cm profile in the spring and fall of 2004.

The interaction of the two factors was significant for some sampling dates in the 0-5 cm profile in the SCS rotation (Table 9). R+C had significantly more SOC in the spring of 2003 than all other treatments (Table 11). R and U both resulted in less SOC in the fall of 2004 than all other treatments. Since these treatments had the smallest amounts of carbon returned back to the surface it makes sense that they would have the smallest increase in SOC.

The lack of significance among treatments in the 5-25 cm profile is not surprising. No differences in SOC in the 5-15 cm profile were evident after 4 and 8 yr of NT (Wood et al. 1991; Ortega et al. 2002). Wright and Hons (2004) did observe differences in the 5-15 cm profile for some treatments after 20 yr. Rate of soil carbon sequestration will reach a peak in 5 to 10 yr, then decline to near zero in 15 to 20 yr after a change to NT practices (West and Post 2002). Little to no increase in SOC in the first 2 to 5 yr after changing management practices will be observed but will be followed by a large increase in the next 5 to 10 yr (Franzluebbers and Arshad 1996; Lal et al. 1998) Global analysis of soil organic carbon sequestration rates by West and Post (2002) found that little or no change occurred between 20 and 30 cm.

Particulate organic matter

POM is the most reactive fraction of organic matter to production practices (Koutika et al. 2001). This fraction of organic matter is the easiest to detect changes in carbon content in over a short period of time which was essential for this research since it was conducted over a three year period. Substantial changes to other organic matter fractions would be hard to measure in such a short time period.

Data is reported in kg/ha of POM-C. Cover crop did not affect POM-C in either rotation (Table 12). Soil amendment had a significant effect on POM-C in the 0-5 and 0-25 cm profiles of the CSC rotation in the fall of 2004, on the change in POM-C for the 0-

5 cm profile and on the 0-25 cm profile of the SCS rotation. The same trend was present for both rotations with POM-C being influenced most by compost then manure then no amendment (Table 13). There was a significant interaction between the main effects in the fall of 2004 in the SCS rotation (Table 12). R+C had the highest amount of POM-C followed by C, R and U had the lowest levels of POM-C (Table 14).

Total nitrogen

Total nitrogen (TN) in the 0-5, 5-25, and 0-25 cm profiles in the CSC rotation was affected by soil amendments (Table 15). Compost generally resulted in higher TN than manure or no amendement in the 0-5 and 0-25 cm profiles (Table 16). Soil amendments affected TN in the 0-5 cm profile of the SCS rotation in the spring of 2004 and in the 0-25 cm profile in the spring and fall of 2004. Compost increased TN more than the other treatments in most instances.

There was a significant interaction between the cover crop and soil amendment factors in 2003, fall of 2004, and in the change in TN in the 0-5 cm profile in the SCS rotation (Table 15). R+C had more TN than all treatments in 2003, while R and U had less TN than all other treatments (Table 17). All treatments except U were similar to R+C in the fall of 2004 and in percent change of TN.

Nitrate and phosphorous

Application of manure and compost not only is a viable method of increasing SOC but also provides nutrients such as nitrogen, phosphorous, and potassium (Eghball 2002). Nitrogen and phosphorous are nutrients essential for plant growth and development but can also be considered pollutants. Nitrates can leach through the soil profile and into the groundwater where they can accumulate to potentially dangerous levels (El-Hout and Blackmer 1990). Phosphorous is more of a surface water concern where it can cause eutrophication (Carpenter et al. 1998). Phosphorous generally doesn't leach through the soil profile unless the soil becomes saturated with phosphorous. With the high application rates of manure and compost in these studies it was important to monitor nitrate and phosphorous levels throughout the soil profile.

Nitrate-N levels were monitored in the 0-5, 5-25, and 0-25 cm profiles similar to SOC and TN. Cover crop and soil amendment factors were significant in both rotations (Table 18). Rye significantly reduced the amount of nitrate in all of the soil profiles in 2002 in both the CSC and SCS rotations (Table 19). Rye also decreased nitrate-N levels in 2003 in the SCS rotation. An interesting observation was that nitrate-N levels increased by 27 and 34% over the three growing seasons in the rye treatments and decreased by 22 and 33% in the non-rye treatments in the CSC and SCS rotations respectively.

Soil amendments affected nitrate-N levels in the 0-5 and 0-25 cm profiles of the SCS rotation (Table 18). Manure resulted in the highest nitrate-N levels in the spring of 2004 in both the 0-5 and 0-25 cm profiles (Table 19). In 2003 compost had higher nitrate-N than the other treatments.

A significant interaction between the cover crop and soil amendment occurred in 2003 for all profiles in the CSC rotation (Table 18). Compost alone had the highest level of nitrate-N in all three profiles followed by U (Table 20). The compost applied April 8, 2003 had a C:N ratio of 13.9 which was the lowest of any compost applied. This may have led to more nitrate-N being transported into the soil solution and away from the compost. Rye cover crop also had approximately 50% of the nitrate-N has the treatments that did not include rye.

Soil samples were taken before the manure and compost was applied in the spring of 2002; also the rye cover crop was planted in October of 2001 so there was a lot of fresh vegetative growth before soil sampling was completed. This would explain the lower nitrate-N levels under rye treatments in 2002. Soybean were grown in 2003 in the CSC rotation and being a legume they have the ability to 'fix' nitrogen in the root nodules which may be lost to the soil through exudation or decomposition. However if nitrogen is available soybean will utilize that nitrogen first before 'fixing' nitrogen. This may explain why there was a significant interaction in the spring of 2004 in the CSC rotation. Why the manure treatments were so high in the spring of 2004 under the SCS rotation is not known. The observation that rye treatments increased nitrate-N over the three growing seasons is more difficult to explain. This could be explained by the fact that the spring 2002 samples were collected after allowing the rye cover crop to grow for approximately 6 months after harvesting silage corn; the fall 2004 samples were collected shortly after soybean harvest. Therefore, in 2002 rye had the chance to use any available nitrate in the soil while in the fall of 2004 there would not have been a sink for the nitrate left in the soil or that being released by the decomposition of soybean residues. These results are similar to those of Sanchez et al. (2004) who found that wheat reduced nitrate leaching after soybean by drying the soil and immobilizing the nitrogen from the soybean residue.

Soil amendments significantly affected soil phosphorous levels in the 0-5 and 0-25 cm profiles of the CSC rotation and the 0-25 cm profile of the SCS rotation every year except for 2002 (Table 21). Compost resulted in higher phosphorous levels than the other treatments every year (Table 22). Rye had minimal effect on the accumulation of phosphorous in either the 0-5 or 5-25 cm profiles (Table 22).

There was a significant interaction between the cover crop and soil amendment factors in 2003, fall of 2004, and in the percent change of phosphorous in the 0-5 cm profile of the SCS rotation (Table 21). R+C and C had the highest levels of phosphorous in 2003 and fall of 2004 (Table 23). Phosphorous levels in the 0-5 cm profile increased by 35% with R+C between the spring of 2002 and fall of 2004.

Chatham

Soil bulk density

Bulk densities at Chatham were not different among treatments in the 0-5 or 5-25 cm profiles at any sampling (Table 24). All treatments resulted in increased bulk densities in the 0-5 cm profile and there were no differences in the percent change between 2002 and fall 2004. Bulk density of the 5-25 cm profile appears to be affected by rotation, CC-M and CC-C decreased bulk density while SC-M and SC-C increased bulk density.

Carbon

Total crop residue carbon returned ranged from 1.46 to 3.39 Mg/ha. SC-C returned more crop residue carbon than all other treatments except SC-M (Table 25). Significantly more carbon was returned in the SC than the CC rotation. Rye cover crop added approximately 0.13 Mg/ha of carbon in 2003 to the system (Table 25). However, it is difficult to determine the impact the winter rye cover crop had on SOC since it was used in conjunction with forage soybeans. Liquid dairy slurry manure added 8.73 Mg C/ha and compost added 6.04 Mg C/ha to the soil surface (Table 25).

SOC levels at Chatham were not different at any sampling date or any portion of the profile (Table 26). CC-U was the only treatment that did not result in increased SOC in the 0-5 cm profile. Rates of change of SOC were also similar among treatments for both depths and the total soil profile.

Though there were no differences there were some interesting results. SOC in the 0-5 cm profile of the CC increased by 6.06 Mg C/ha more than SC between 2002 and 2004 even though SC-M added1.39 Mg C/ha more to the system than CC-M. CC-C and SC-C resulted in 64% and 79% increases in SOC. A surprising result occurred between CC-U and SC-U, CC-U loss 0.71 Mg C/ha while SC-U gained 9.27 Mg/ha. Total carbon additions for these treatments were 1.55 Mg C/ha for CC-U and 3.17 Mg C/ha for SC-U so the large difference is not accounted for there (Table 25). Crop rotation does increase carbon sequestration rates compared to monocultures however, it is hard to believe that it could have this big of an impact.

An interesting observation in the 5-25 and 0-25 profile was that SC-M and SC-C increased soil carbon more than CC-M and CC-U. This supports previous research that crop rotations are better than monocultures at sequestering carbon.

Total nitrogen

No differences in TN were evident at any time in any profile (Table 26). CC-U loss 3% of the original total N during the course of the experiment. This result is not very surprising considering that the only N added to this system was in the form of 28% UAN during sidedressing.

Particulate organic matter

POM-C was initially 20 to 27% of the total SOC in the 0-5 cm profile at Chatham (Table 27). In the fall of 2004 that had increased to 29 to 46% of the SOC was associated with the POM fraction. However, there were no differences among treatments. In the 5-25 cm profile POM-C ranged from 4 to 14% and 28 to 32% in 2002 and the fall of 2004, respectively. Similar to the 0-5 cm profile there were no differences among treatments.

Nitrate and phosphorous

Nitrate-N levels in both the 0-5 and 5-25 cm profiles at Chatham were generally stable throughout the experiment (Table 28). Differences among treatments were observed in the fall of 2004 for the 0-5 cm profile and in the spring and fall of 2004 for the 5-25 cm profile. Addition of compost resulted in higher nitrate-N levels than all other treatments in the fall of 2004. All treatments resulted in increased nitrate-N levels over the three growing seasons for both the 0-5 and 5-25 cm profiles.

Phosphorous levels in the 0-5 cm profile were similar among treatments until the fall of 2004 when SC-C and CC-C had higher phosphorous levels than all other treatments (Table 28). CC-C and SC-C increased phosphorous levels by 859% and 693%, respectively. SC-M had more initial phosphorous than CC-C in 2002 but in the fall of 2004 they had similar levels. SC-C had the highest level of phosphorous in the fall of 2004 and was similar to CC-C and SC-M. Total phosphorous levels and percent change of phosphorous were highest with SC-C and CC-C. All other treatments were similar to each other.

Latitude effects

SOC levels are often related to climatic patterns, generally increasing from south to north due to cooler temperatures and lower decomposition rates, and from west to east due to precipitation (Kern and Johnson 1993; and Paustian et al. 1997). Chatham (N 46.29, W 86.76) is significantly farther north than East Lansing (N 42.43, W 84.28), so the expectation would be that carbon would be sequestered at a faster rate in Chatham than East Lansing.

Average monthly temperatures and total monthly precipitation for East Lansing and Chatham can be found in Tables 29 and 30. Temperatures at Chatham were generally 3 °C cooler than at East Lansing. Total precipitation was more variable throughout the three years, however looking at the 30 yr averages Chatham usually receives more precipitation during the year as a result of lake effect storms.

NT continuous corn at Chatham with no amendments realized a 23% increase in SOC while the CSC and SCS with no amendments at East Lansing resulted in carbon losses of 4 and 2% respectively. Less crop residue was applied at Chatham so the efficiency of converting crop residues into SOC is higher at Chatham than East Lansing.

Summary

Rye, compost, and manure all lowered bulk density at some point during the experiment at East Lansing. Bulk densities for the 0-5 cm profile increased at Chatham for all treatments. Rye doesn't appear to provide enough residual carbon to increase carbon sequestration over NT alone at East Lansing. The addition of either compost or manure dramatically increased the amount of SOC measured. Compost treatments resulted in higher carbon levels than manure treatments at East Lansing. No differences were observed among treatments at Chatham for SOC levels in any profile.

POM-C was influenced by soil amendments at East Lansing, with POM-C increasing most with compost then manure then no amendment. No differences were observed in POM-C at Chatham.

Compost generally resulted in higher TN at East Lansing than manure or no amendment. There were no differences among treatments at Chatham. Cover crop rye decreased nitrate-N levels in 2002 and 2003 at East Lansing. In the fall of 2004 nitrate-N was actually higher under rye than under no rye. Compost and manure increased nitrate-N at both Chatham and East Lansing. Compost resulted in higher phosphorous levels at both Chatham and East Lansing.

Latitude does appear to have a significant affect on carbon sequestration. Treatments at Chatham were more efficient at sequestering carbon then treatments at East Lansing. Soil at Chatham was a fine sandy loam while soil at East Lansing was a mix of sandy loam and loam. Though the soil is classified as a sandy loam at Chatham it seems to have a much higher sand content than the soil at East Lansing. Heavy soils showed the highest level of organic matter (loamy clay), followed by medium textured soils (sandy loam), and light soils (loamy sand) contained the lowest organic carbon stock (Dersch and Bohm 2001). Fine textured soils retained more crop residue carbon, and the turnover of this carbon in these soils appeared to be slower than in soils with coarse textures (Liang et al.1998).

Conclusions

Rye cover crop does not add enough carbon to the system to be used by itself. Compost and manure can increase SOC significantly depending on type of amendment and location. However the use of these amendments needs to be monitored carefully to avoid leaching and loading of nitrates and phosphorous. Rye cover crop used in conjunction with either compost or manure will help control the leaching and loading of those nutrients.

Sequestration rates were affected by latitude as expected. There is little added benefit to using a cover crop or applying compost or manure at Chatham. NT alone accounted for 23% of the carbon sequestered over the three growing seasons.

Tables

Table 1. Dates of soil sampling, planting, herbicide application, and harvest at East Lansing and Chatham.

	East Lansing			Chatham		
	2002	2003	2004	2002	2003	2004
	Soil sampling					
Spring 0-25	19/4*	21/5	9/4	14/5	5/5	23/4
Fall 0-25	-	-	9/11	-	-	8/11
Spring deep	-	22/5	19/6	-	-	-
Fall deep	6/11	10/11	-	-	-	-
PSNT	28/6	27/6	1/7	-	-	-
	Planting					
Corn	23/5	5/22	5/13	6/12	5/20	5/17
Soybean	23/5	5/22	5/13	6/6	-	5/29
Cover crop	1/10/01	8/10/02	4/10/03	-	10/9/02	-
	Herbicide application					
Burndown	5/5	8/5	3/5	-	30/4	-
	Harvest					
Silage	12/9	17/9	14/9	3/10	7/10	11/10
Soybean	28/9	11/10	8/10	5/9	-	14/9
Cover crop	8/5	9/5	5/5	-	5/5	-

* Dates expressed as day, month, year

Table 2. Dates of application and analyses of amendments at East Lansing

	Manure					Compost				
	24/4/02*	13/12/02	8/4/03	6/12/03	6/4/04	24/4/02	4/12/02	8/4/03	6/12/03	6/4/04
	Mg/ha									
Rate	22.000	22.450	22.450	22.450	15.700	19.540	22.450	22.450	22.450	22.450
	%									
Carbon	43.1	*14.72*	13.05	14.52	16.61	24.55	*21.7*	18.9	11.91	10.75
Nitrogen	0.389	0.509	0.384	0.264	0.668	0.757	0.96	1.36	0.73	0.64
Phos.	0.084	0.067	0.085	0.077	0.103	0.373	0.38	0.52	0.17	0.17
Potasium	0.400	0.333	0.327	0.350	0.391	0.741	0.64	0.58	0.71	0.64
Moisture	72.16	71.96	75.63	71.96	68.59	59.11	36.24	69.56	64.36	68.76
Solids	27.84	28.04	24.37	28.04	31.41	40.89	63.76	30.44	35.64	31.24
C:N	110.80	*28.93*	33.98	55.00	24.87	32.43	*22.6*	13.9	16.32	16.8

* Dates expressed as day, month, year

Abbreviations: Phos, phosphorous

Table 3. Date of amendment application, rate and analyses at Chatham

	Manure			Compost		
	15/5/02*	6/5/03	2004	17/5/02	6/5/03	5/7/04
	Mg/ha					
Rate	8.220	3.870	5.670	41.770	*8.980*	8.980
	%					
Carbon	2.96	*2.25*	1.54	7.91	20.28	10.24
Nitrogen	0.256	0.224	0.239	0.516	0.543	0.429
Phos.	0.055	0.037	0.038	0.152	0.173	0.109
Potasium	0.213	0.173	0.120	0.160	0.449	0.129
Moisture	93.74	96.81	94.95	70.18	65.87	78.0
Solids	6.26	3.19	5.05	29.82	34.13	22.0
C:N	11.56	*10.04*	6.44	15.33	37.35	23.87

* Dates expressed as day, month, year

Abbreviations: Phos, Phosphorous

Table 4. ANOVA for bulk density of the 0-5 and 5-25 cm profiles of the corn – soybean – corn rotation (CSC) and soybean – corn – soybean (SCS) rotations.

		CSC				
Profile (cm)	Factor	2002	2003	Spring 2004	Fall 2004	Chg
0-5	Cover crop	NS	**	NS	NS	NS
	Amendment	NS	*	NS	**	NS
	Interaction	NS	NS	NS	NS	NS
5-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	*	NS
		SCS				
0-5	Cover crop	NS	NS	NS	NS	**
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	NS	NS
5-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	NS	NS

* = $P<0.05$

** = $P<0.01$

*** = $P<0.001$

Table 5. Main effect means for the soil bulk densities of the 0-5 and 5-25 cm profiles at East Lansing

Rot.	0-5 cm					5-25 cm				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
CSC	g/cm^3				%	g/cm^3				%
Comp	1.69	1.42	1.61	1.32	-22	1.68	1.68	1.62	1.58	-6
Man	1.61	1.44	1.49	1.35	-15	1.63	1.66	1.61	1.57	-3
None	1.65	1.57	1.58	1.50	-9	1.69	1.64	1.59	1.57	-7
LSD	NS	0.09	NS	0.09	5	NS	NS	NS	NS	NS
None	1.63	1.56	1.51	1.39	-14	1.65	1.65	1.63	1.57	-4
Rye	1.67	1.39	1.62	1.39	-16	1.68	1.67	1.58	1.58	-6
LSD	NS	0.0742	NS	NS	NS	NS	NS	NS	NS	NS
SCS										
Comp	1.75	1.45	1.15	1.33	-24	1.62	1.64	1.57	1.63	1
Man	1.74	1.49	1.30	1.33	-23	1.74	1.68	1.56	1.61	-7
None	1.75	1.45	1.28	1.42	-19	1.69	1.69	1.51	1.60	-5
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
None	1.72	1.45	1.25	1.40	-18	1.69	1.69	1.54	1.61	-4
Rye	1.77	1.48	1.24	1.32	-25	1.67	1.65	1.55	1.61	-3
LSD	NS	NS	NS	NS	4	NS	NS	NS	NS	NS

Abbreviations: Chg, change; CSC, corn-soybean-corn rotation; SCS, soybean-corn-soybean rotation; Comp, compost; Man, manure.

Table 6. Interaction means for bulk densities of the 0-5 and 5-25 cm profiles at East Lansing

Rot.	0-5 cm					5-25 cm				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
CSC	----------------g/cm^3----------------				%	----------------g/cm^3----------------				%
R	1.66	1.43	1.64	1.53	-8	1.73	1.68	1.54	1.62	-6
R+C	1.73	1.35	1.70	1.35	-22	1.63	1.68	1.59	1.58	-4
M	1.59	1.48	1.47	1.40	-11	1.56	1.66	1.61	1.60	3
C	1.65	1.49	1.52	1.30	-22	1.73	1.68	1.66	1.57	-9
R+M	1.63	1.40	1.52	1.30	-20	1.69	1.66	1.61	1.54	-9
U	1.65	1.26	1.52	1.48	-10	1.65	1.60	1.64	1.52	-8
LSD	NS	NS	NS	NS	NS	NS	NS	NS	0.08	NS
SCS										
R	1.76	1.44	1.31	1.42	-19	1.67	1.66	1.52	1.60	-4
R+C	1.77	1.47	1.11	1.28	-28	1.59	1.61	1.59	1.62	3
M	1.70	1.47	1.30	1.42	-16	1.72	1.68	1.57	1.60	-7
C	1.73	1.42	1.19	1.38	-20	1.64	1.68	1.56	1.64	0
R+M	1.77	1.52	1.30	1.24	-29	1.76	1.69	1.54	1.62	-7
U	1.74	1.46	1.24	1.41	-19	1.71	1.72	1.49	1.60	-6
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Abbreviations: Chg, change; CSC, corn-soybean-corn rotation; SCS, soybean-corn-soybean rotation; R, rye; R+C, rye plus compost; M, manure; C, compost; U, untreated.

Table 7. ANOVA for crop residue carbon inputs and total carbon (C) inputs for both CSC and SCS.

C inputs	Factor	2002	2003	2004	Total
		CSC			
Crop residue	Cover crop	NS	NS	*	NS
	Amendment	NS	NS	*	NS
	Interaction	NS	NS	NS	NS
Total C input	Cover crop	***	NS	***	***
	Amendment	***	***	***	***
	Interaction	NS	NS	NS	NS
		SCS			
Crop residue	Cover crop	NS	NS	NS	NS
	Amendment	NS	**	NS	NS
	Interaction	NS	NS	NS	NS
Total C input	Cover crop	***	***	NS	***
	Amendment	***	***	***	***
	Interaction	NS	NS	NS	NS

* = P<0.05
** = P<0.01
*** = P<0.001

Table 8. Carbon input from crop residue and total input

	Crop residue input				Total carbon input			
Trt	2002	2003	2004	Total	2002	2003	2004	Total
CSC	kg C/ha							
Comp	1050	1940	810	3790	11200	9090	3370	23660
Man	1000	1670	720	3400	14210	8030	3500	25470
None	1070	2020	740	3820	1450	2140	860	4450
LSD	NS	NS	50	NS	180	260	60	380
None	1010	2010	730	3740	8490	6370	2400	17270
Rye	1070	1750	790	3600	9410	6470	2760	18640
LSD	NS	NS	40	NS	150	NS	50	310
SCS								
Comp	1840	980	1710	4530	11910	8110	4330	24580
Man	1710	990	1880	4320	14800	7050	4680	26560
None	1620	960	1940	4510	1960	1150	2130	5210
LSD	NS	130	NS	NS	310	140	380	840
None	1680	860	1840	4390	9170	5230	3520	17960
Rye	1760	890	1850	4520	9950	5640	3910	19610
LSD	NS	NS	NS	NS	290	120	NS	720

Table 9. ANOVA for SOC in the 0-5, 5-25, and 0-25 cm profiles of the CSC and SCS rotations

		CSC				
Profile (cm)	Factor	2002	2003	Spring 2004	Fall 2004	Chg
0-5	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	***	***	***	***
	Interaction	NS	NS	NS	NS	NS
5-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	NS	NS
0-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	*	NS	***	***
	Interaction	NS	NS	NS	NS	NS
		SCS				
0-5	Cover crop	NS	**	NS	NS	NS
	Amendment	NS	***	***	***	***
	Interaction	NS	*	NS	***	**
5-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	NS	NS
0-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	**	***	NS
	Interaction	NS	NS	NS	NS	NS

* = P<0.05
** = P<0.01
*** = P<0.001

Table 10. Main effect means for SOC in the 0-5, 5-25, and 0-25 cm profiles as affected by soil amendments and rye cover crop at East Lansing in the CSC and SCS rotations.

Rot.	0-5 cm					5-25 cm					0-25 cm				
Trt	2002	2003	2004S	2004F	Chg	2002	2003	2004S	2004F	Chg	2002	2003	2004S	2004F	Chg
	kg/ha				%	kg/ha				%	kg/ha				%
CSC															
Comp	7250	12780	11710	17580	146	26220	28650	24530	29710	14	33470	41430	36240	47290	43
Man	7040	9460	9610	12570	81	25320	27890	24350	27880	10	32360	37350	33960	40460	26
None	7150	8090	7240	7290	4	25830	26290	23780	24580	96	32970	34380	31020	31870	-3
LSD	NS	2190	1480	1610	25	NS	NS	NS	NS	NS	NS	6630	NS	5840	9
None	6910	10400	9030	12420	83	25290	28060	24900	27570	10	32200	38460	33930	39990	25
Rye	7380	9810	10020	12540	71	26290	27160	23530	27200	4	33670	36980	33550	39750	19
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SCS															
Comp	7610	13660	11160	18000	141	25220	27630	24630	28690	17	32830	41290	35790	46690	46
Man	7210	9340	8100	12020	69	25670	26210	24760	27630	9	32880	35550	32860	39650	22
None	7170	6880	5310	7390	3	24910	26080	22200	24880	0	32080	32950	27380	32270	1
LSD	NS	1290*	1310	1180*	26*	NS	NS	NS	NS	NS	NS	NS	3730	3740	NS
None	7290	8850	7600	12000	65	25560	27460	23560	27440	8	32850	36310	31080	39450	21
Rye	7370	11060	8780	12940	77	24980	25820	24160	26690	9	32340	36880	32940	39620	25
LSD	NS	1050*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Interaction is also significant

Table 11. Interaction means for SOC (Mg/ha) in the 0-5, 5-25 and 0-25 cm profiles of corn-soybean and soybean-corn rotations at East Lansing from the spring of 2002 to the fall of 2004.

	CSC					SCS				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
0-5	Mg/ha				--%--	Mg/ha				--%--
R	7.18	6.30	7.38	7.42	5	7.13	6.91	5.68	7.10	0
R+C	7.45	13.43	12.80	16.75	127	7.54	16.29	12.22	20.72	183
M	6.56	9.22	9.35	11.69	80	6.99	8.68	7.77	13.06	90
C	7.05	12.13	10.62	18.42	165	7.67	11.03	10.10	15.27	100
R+M	7.53	9.71	9.87	13.46	81	7.43	10.00	8.43	10.99	48
U	7.12	9.87	7.11	7.15	2	7.21	6.84	4.93	7.68	6
LSD	NS	NS	NS	NS	NS	NS	2.57	2.56	2.18	53
5-25										
R	26.01	25.56	22.50	24.70	-4	23.98	24.95	22.11	24.91	4
R+C	24.99	27.35	22.61	28.76	15	24.52	26.36	25.38	28.32	21
M	22.78	27.19	23.22	27.62	20	24.90	26.26	24.51	28.43	16
C	27.46	29.95	26.44	30.65	14	25.93	28.91	23.88	29.06	13
R+M	27.87	28.58	25.47	28.15	-1	26.43	26.15	25.01	26.82	1
U	25.64	27.03	25.05	24.45	-5	25.84	27.20	22.30	24.84	-4
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total										
R	33.19	31.86	29.88	32.13	-2	31.10	31.86	27.79	32.01	3
R+C	32.44	40.78	35.42	45.51	41	32.06	42.64	37.60	49.05	60
M	29.34	36.41	32.57	39.30	34	31.89	34.94	32.28	41.49	32
C	34.51	42.08	37.06	49.07	44	33.60	39.95	33.98	44.33	32
R+M	35.39	38.29	35.35	41.61	17	33.87	36.15	33.44	37.81	12
U	32.76	36.90	32.16	31.61	-4	33.06	34.05	26.98	32.52	-2
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 12. ANOVA for POM-C for both CSC and SCS rotations.

Profile (cm)	Factor	CSC 2002	 Fall 2004	 Chg
0-5	Cover crop	NS	NS	NS
	Amendment	NS	***	NS
	Interaction	NS	NS	NS
5-25	Cover crop	NS	NS	NS
	Amendment	NS	NS	NS
	Interaction	NS	NS	NS
0-25	Cover crop	NS	NS	NS
	Amendment	NS	***	NS
	Interaction	NS	NS	NS
			SCS	
0-5	Cover crop	NS	NS	NS
	Amendment	NS	***	***
	Interaction	NS	***	NS
5-25	Cover crop	NS	NS	NS
	Amendment	NS	NS	NS
	Interaction	NS	NS	NS
0-25	Cover crop	NS	NS	NS
	Amendment	NS	***	NS
	Interaction	NS	NS	NS

* = P<0.05
** = P<0.01
*** = P<0.001

Table 13. Main effect means for POM-C in the 0-5, 5-25, and 0-25 cm profiles at East Lansing

Rot.	0-5			5-25			0-25		
Trt	2002	2004	Chg	2002	2004	Chg	2002	2004	Chg
CSC	----kg/ha----		--%--	----kg/ha----		--%--	----kg/ha----		--%--
Comp	580	8930	1160	3460	4270	57	3820	13200	154
Man	940	4770	594	3240	4200	177	4180	8970	200
None	950	1230	90	4420	2160	63	5360	3380	14
LSD	NS	1050	NS	NS	NS	NS	NS	1380	NS
None	670	4990	630	3050	3650	150	3440	8630	148
Rye	970	4960	600	4360	3440	47	5470	8400	97
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS
SCS									
Comp	750	9620	1334	2130	5200	234	2880	14800	592
Man	780	4690	667	1230	3410	416	1900	8100	455
None	740	1490	147	1630	3190	225	2360	4690	134
LSD	NS	940*	350	NS	NS	NS	NS	2310	NS
None	710	4710	720	1510	3840	339	2150	8550	418
Rye	800	5820	712	1810	4030	244	2610	9840	369
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Interaction is significant

Table 14. Interaction means for POM-C

	CSC			SCS		
Trt	2002	Fall 2004	Chg	2002	Fall 2004	Chg
0-5	---------kg/ha--------		--%--	--------kg/ha-------		--%--
R	1060	1290	21	820	1420	88
R+C	800	8220	1080	860	11990	1545
M	830	4170	494	840	5330	832
C	350	9630	1240	630	7250	223
R+M	1050	5380	695	710	4050	503
U	830	1160	158	660	1560	205
LSD	NS	NS	NS	NS	1890	NS
5-25						
R	5700	1940	7	1140	3460	282
R+C	3480	4760	101	2430	5080	240
M	2570	4780	321	590	3270	622
C	3430	3790	13	1830	5330	228
R+M	3910	3620	34	1870	3560	210
U	3130	2370	119	2120	2930	167
LSD	NS	NS	NS	NS	NS	NS
Total						
R	6770	3230	-13	1950	1880	164
R+C	4690	12980	134	3300	17030	715
M	3400	8940	230	1220	8600	682
C	2950	13420	173	2460	12580	469
R+M	4960	9000	170	2580	7610	229
U	3960	3530	41	2780	4490	105
LSD	NS	NS	NS	NS	NS	NS

Table 15. ANOVA for TN in the 0-5, 5-25, and 0-25 cm profiles of the CSC and SCS rotations

		CSC				
Profile (cm)	Factor	2002	2003	Spring 2004	Fall 2004	Chg
0-5	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	***	**	***	***
	Interaction	NS	NS	NS	NS	NS
5-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	NS	NS	*
	Interaction	NS	NS	NS	NS	NS
0-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	*	*	***
	Interaction	NS	NS	NS	NS	NS
		SCS				
0-5	Cover crop	NS	*	NS	NS	NS
	Amendment	NS	**	***	***	***
	Interaction	NS	*	NS	**	*
5-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	NS	NS
0-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	***	**	NS
	Interaction	NS	NS	NS	NS	NS

* = $P<0.05$
** = $P<0.01$
*** = $P<0.001$

Table 16. Main effect means for TN in the 0-5, 5-25 and 0-25 cm profiles as affected by soil amendments and rye cover crop at East Lansing in the CSC and SCS rotations.

Rot.	0-5 cm					5-25 cm					0-25 cm				
Trt	2002	2003	2004S	2004F	Chg	2002	2003	2004S	2004F	Chg	2002	2003	2004S	2004F	Chg
	kg/ha				%	kg/ha				%	kg/ha				%
CSC															
Comp	560	1130	1000	1510	171	2490	-	2460	2270	-9	3050	-	3600	3270	7
Man	560	800	780	910	68	2400	-	2350	2020	-17	2960	-	3160	3800	-6
None	560	710	650	500	-9	2460	-	2330	1880	-25	3020	-	3090	2510	-17
LSD	NS	170	120	210	27	NS		NS	NS	12	NS		NS	660	8
None	540	900	760	990	82	2410	-	2480	2050	-15	2940	-	3410	2810	-5
Rye	580	870	860	960	70	2500	-	2280	2060	-18	3070	-	3150	2910	-5
LSD	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS		NS	NS	NS
SCS															
Comp	570	1160	920	1450	161	2370	-	2140	2340	2	2940	-	3300	3260	14
Man	540	800	670	860	57	2390	-	2080	2340	-1	2930	-	2880	3010	4
None	530	630	470	530	1	2370	-	1880	2080	-12	2900	-	2540	2550	-12
LSD	NS	110*	120	100*	36*	NS		NS	NS	NS	NS		280	390	NS
None	550	780	650	900	62	2420	-	2010	2260	-5	2970	-	2810	2910	-1
Rye	540	940	730	990	84	2330	-	2070	2250	-2	2880	-	3010	2970	4
LSD	NS	90*	NS	NS	NS	NS		NS	NS	NS	NS		NS	NS	NS

* Interaction is also significant

Table 17. Interaction means for TN (Mg/ha) in the 0-5, 5-25, and 0-25 cm profiles of corn-soybean and soybean-corn rotations at East Lansing from the spring of 2002 to the fall of 2004.

	CSC					SCS				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
0-5	------------Mg/ha----------------				--%--	--------------Mg/ha----------------				--%--
R	0.57	0.6	0.67	0.51	-8	0.52	0.62	0.50	0.97	98
R+C	0.57	1.17	1.09	1.38	149	0.56	1.35	1.01	1.67	208
M	0.52	0.78	0.74	0.84	65	0.54	0.75	0.66	0.92	74
C	0.56	1.10	0.91	1.64	192	0.58	0.97	0.84	1.23	113
R+M	0.6	0.83	0.81	0.98	69	0.55	0.85	0.67	1.27	136
U	0.55	0.82	0.62	0.49	-10	0.55	0.63	0.45	0.54	-1
LSD	NS	NS	NS	NS	NS	NS	0.22	NS	0.83	182
5-25										
R	2.50	-	2.21	1.93	-23	2.27	-	1.92	2.11	-8
R+C	2.37	-	2.20	2.17	-9	2.27	-	2.16	2.36	9
M	2.18	-	2.27	1.95	-11	2.33	-	2.05	2.43	7
C	2.61	-	2.73	2.38	-8	2.46	-	2.12	2.31	-6
R+M	2.62	-	2.44	2.09	-22	2.46	-	2.12	2.26	-9
U	2.43	-	2.45	1.83	-27	2.46	-	1.85	2.04	-18
LSD	NS	-	NS	NS	NS	NS		NS	NS	NS
Total										
R	3.06	-	2.81	2.58	-15	2.79	-	2.54	2.61	-7
R+C	2.94	-	3.37	3.26	11	2.83	-	3.52	3.37	23
M	2.69	-	3.05	2.69	0	2.86	-	2.80	3.08	10
C	3.17	-	3.83	3.29	5	3.04	-	3.09	3.15	4
R+M	3.22	-	3.27	2.90	-11	3.01	-	2.97	2.93	-3
U	2.97	-	3.36	2.45	-19	3.00	-	2.53	2.49	-17
LSD	NS	-	NS	NS	NS	NS	-	NS	NS	NS

Table 18. ANOVA for nitrate-N in the 0-5, 5-25, and 0-25 cm profiles of the CSC and SCS rotations

		CSC				
Profile (cm)	Factor	2002	2003	Spring 2004	Fall 2004	Chg
0-5	Cover crop	***	***	NS	NS	NS
	Amendment	NS	***	NS	NS	NS
	Interaction	NS	**	NS	NS	NS
5-25	Cover crop	***	***	NS	NS	NS
	Amendment	NS	**	NS	NS	NS
	Interaction	NS	*	NS	NS	NS
0-25	Cover crop	***	***	NS	NS	NS
	Amendment	NS	***	NS	NS	NS
	Interaction	NS	*	NS	NS	NS
		SCS				
0-5	Cover crop	***	NS	NS	NS	***
	Amendment	NS	NS	***	NS	NS
	Interaction	NS	NS	NS	NS	NS
5-25	Cover crop	***	***	NS	NS	***
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	NS	NS
0-25	Cover crop	***	***	NS	NS	***
	Amendment	NS	*	***	NS	NS
	Interaction	NS	NS	NS	NS	NS

* = P<0.05
** = P<0.01
*** = P<0.001

Table 19. Nitrate-N in the 0-25 cm profile as affected by soil amendments and rye cover crop at East Lansing in the CSC and SCS rotations.

	0-5 cm					5-25 cm					0-25 cm				
	2002	2003	2004S	2004F	Chg	2002	2003	2004S	2004F	Chg	2002	2003	2004S	2004F	Chg
	kg/ha				%	kg/ha				%	kg/ha				%
CSC															
Comp	7	8	11	6	13	16	19	22	19	29	23	27	32	25	20
Man	6	3	10	4	-11	17	14	23	16	-4	22	17	33	20	-7
None	5	5	9	5	16	17	15	16	14	-9	22	20	25	18	-5
LSD	NS	1.0*	NS	NS	NS	NS	2*	3	NS	NS	NS	2*	NS	NS	NS
None	8	7	8	5	-32	20	21	21	16	-18	27	29	29	21	-22
Rye	4	4	11	5	44	13	10	20	17	28	17	14	31	21	27
LSD	2	1*	NS	NS	47	3	1*	NS	NS	19	4	2*	NS	NS	23
SCS															
Comp	9	7	9	8	29	19	19	24	19	10	28	26	32	27	13
Man	7	4	13	6	5	21	16	27	19	0	29	20	41	24	1
None	8	5	5	6	-2	22	16	19	17	-14	30	21	24	23	-11
LSD	NS	NS	2	NS	NS	NS	NS	4	NS	NS	NS	3	5	NS	NS
None	12	6	9	6	-35	26	22	24	17	-31	38	28	34	24	-33
Rye	4	5	8	7	57	15	12	23	19	28	19	17	31	25	34
LSD	3	NS	NS	NS	40	3	2	NS	NS	20	5	3	NS	NS	19

* Interaction is significant

Table 20. Interaction means for Nitrate-N (kg/ha) in the 0-5, 5-25, and 0-25 cm profiles of corn-soybean and soybean-corn rotations at East Lansing from the spring of 2002 to the fall of 2004.

	CSC					SCS				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
0-5	-----------------kg/ha-------------				--%--	-----------------kg/ha-----------------				--%--
R	3.0	1.9	10.9	4.3	57	4.3	2.5	4.8	5.5	38
R+C	6.2	6.6	11.1	6.3	54	4.5	7.4	8.5	9.0	98
M	7.2	3.8	7.7	3.8	-44	10.8	3.4	14.7	6.2	-25
C	7.8	9.4	9.9	5.4	-27	12.8	7.4	8.5	6.9	-39
R+M	3.8	3.1	11.7	4.3	22	4.0	5.3	11.5	5.4	35
U	7.4	8.9	6.2	5.1	-25	12.1	6.7	5.0	5.9	-41
LSD	NS	2.1	NS	NS	NS	NS	NS	NS	NS	NS
5-25										
R	12.7	9.4	14.3	14.8	17	16.8	9.4	16.9	18.1	11
R+C	12.7	11.3	20.6	19.9	62	14.2	13.7	23.2	19.5	43
M	20.0	17.9	22.0	16.9	-15	27.9	20.0	25.9	18.6	-30
C	18.7	25.9	22.8	18.0	-3	23.6	24.4	24.3	18.1	-23
R+M	13.9	10.0	24.6	14.7	6	14.6	12.2	28.8	18.7	30
U	20.5	19.9	17.8	12.7	-35	26.8	22.8	21.8	15.4	-39
LSD	NS	3.2	NS	NS	NS	NS	NS	NS	NS	NS
Total										
R	15.7	11.3	25.2	190.0	22	21.1	11.9	21.7	23.6	18
R+C	18.9	17.9	31.6	26.2	51	18.6	21.1	31.2	28.5	55
M	27.2	21.6	29.7	20.7	-23	38.7	23.4	40.6	24.7	-30
C	26.5	35.3	32.7	23.4	-11	36.5	31.8	32.8	24.9	-29
R+M	17.6	13.1	36.3	19.0	9	18.6	17.4	40.4	24.1	31
U	27.9	28.8	24.0	17.9	-33	38.8	29.5	27.1	21.3	-40
LSD	NS	4.2	NS	NS	NS	NS	NS	NS	NS	NS

Table 21. ANOVA for phosphorous in the 0-5, 5-25, and 0-25 cm profiles of the CSC and SCS rotations

		CSC				
Profile (cm)	Factor	2002	2003	Spring 2004	Fall 2004	Chg
0-5	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	***	***	***	***
	Interaction	NS	NS	NS	NS	NS
5-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	NS	NS
0-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	**	***	***	***
	Interaction	NS	NS	NS	NS	NS
		SCS				
0-5	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	***	***	***	***
	Interaction	NS	**	NS	*	*
5-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	NS	NS	NS	NS
	Interaction	NS	NS	NS	NS	NS
0-25	Cover crop	NS	NS	NS	NS	NS
	Amendment	NS	***	***	***	***
	Interaction	NS	NS	NS	NS	NS

* = P<0.05
** = P<0.01
*** = P<0.001

Table 22. Phosphorous in the 0-25 cm profile as affected by soil amendments and rye cover crop at East Lansing in the CSC and SCS rotations.

	0-5 cm					5-25 cm					0-25 cm				
	2002	2003	2004S	2004F	Chg	2002	2003	2004S	2004F	Chg	2002	2003	2004S	2004F	Chg
	kg/ha				%	kg/ha				%	kg/ha				%
CSC															
Comp	32	97	131	145	361	87	76	83	123	53	119	172	214	268	137
Man	34	40	59	51	58	76	84	65	81	10	110	124	124	132	25
None	34	25	27	27	-19	87	69	60	67	-19	121	94	87	94	-20
LSD	NS	12	13	14	44	NS	NS	NS	NS	NS	NS	29	23	25	31
None	32	55	69	72	130	82	73	70	87	11	114	129	139	159	42
Rye	34	53	75	77	137	85	79	70	94	18	119	132	144	170	52
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SCS															
Comp	40	95	123	139	265	90	89	105	107	25	129	184	228	246	98
Man	37	42	53	54	56	93	82	90	98	13	129	124	143	152	25
None	39	25	29	27	-31	95	83	80	77	-19	134	110	108	104	-23
LSD	NS	10*	10	8*	41*	NS	NS	NS	NS	NS	NS	26	32	16	31
None	41	50	63	72	78	95	86	91	96	7	136	136	155	168	28
Rye	36	59	73	75	116	90	84	92	92	6	126	142	164	166	39
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Interaction is significant

Table 23. Interaction means for Bray-P (kg/ha) in the 0-5, 5-25, and 0-25 cm profiles of corn-soybean and soybean-corn rotations at East Lansing from the spring of 2002 to the fall of 2004.

	CSC					SCS				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
0-5	----------------kg/ha----------------				--%--	----------------kg/ha----------------				--%--
R	31.4	21.5	24.1	26.2	-12	37.3	24.0	32.6	26.5	31
R+C	40.8	94.0	139.9	150.0	388	34.5	92.2	131.1	247.6	335
M	28.1	38.4	56.3	49.0	81	37.4	42.3	51.2	58.4	69
C	32.0	95.4	121.5	139.9	334	43.7	77.3	114.3	129.4	196
R+M	39.8	39.0	60.9	53.9	36	34.7	36.7	55.0	50.1	43
U	35.2	28.2	29.1	27.3	-26	39.9	28.1	24.9	27.6	-31
LSD	NS	NS	NS	NS	NS	NS	10.8	NS	14.4	82
5-25										
R	91.0	71.3	58.3	69.0	-19	91.2	74.1	81.4	78.3	-16
R+C	77.2	68.2	80.2	124.4	65	77.8	91.3	107.7	109.4	43
M	67.1	74.1	61.2	74.0	12	87.7	78.5	93.5	109.1	35
C	94.7	78.0	85.7	121.2	42	96.5	82.9	102.8	105.2	7
R+M	80.9	88.5	68.9	87.8	9	93.3	78.7	85.4	86.9	-9
U	80.6	62.0	61.8	65.0	-20	94.4	83.2	76.6	74.9	-22
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total										
R	122.4	92.8	82.3	95.2	-17	128.5	98.0	113.9	104.8	-20
R+C	108.0	162.1	220.1	274.4	158	112.3	183.6	238.7	257.0	-131
M	95.2	112.5	117.5	122.9	33	125.1	120.7	144.7	167.5	45
C	126.6	173.5	207.2	261.1	116	140.2	160.2	217.1	234.6	65
R+M	120.6	127.5	129.8	141.7	17	128.0	115.5	140.4	137.0	5
U	115.8	90.2	90.8	92.4	-22	134.3	111.6	103.0	102.5	-25
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 24. Bulk Density of the 0-5 and 5-25 cm profiles at Chatham

	0-5 cm					5-25 cm				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
	g/cm^3				%	g/cm^3				%
CC-U	1.41	1.35	1.61	1.52	10	1.26	1.27	1.33	1.29	3
CC-C	1.24	1.28	1.64	1.35	10	1.36	1.27	1.52	1.28	-10
CC-M	1.28	1.23	1.74	1.52	23	1.33	1.28	1.45	1.28	-4
SC-U	1.14	1.24	1.59	1.52	33	1.28	1.30	1.40	1.15	-10
SC-C	1.22	1.10	1.68	1.25	10	1.23	1.24	1.40	1.27	4
SC-M	1.37	1.12	1.55	1.37	3	1.20	1.36	1.38	1.25	5
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	11

Table 25. Carbon added to the soil from cover crops, amendments, and crop residues at Chatham.

	Cover	Manure/compost				Crop residue				Total			
Trt	2003	2002	2003	2004	Total	2002	2003	2004	Total	2002	2003	2004	Total
	Mg/ha												
CC-U	-	-	-	-		0.58	0.36	0.69	1.56	0.58	0.36	0.69	1.55
CC-C	-	3.30	1.82	0.92	6.04	0.66	0.34	0.46	1.46	3.96	2.16	1.38	7.50
CC-M	-	3.89	2.96	1.87	8.73	0.56	0.43	0.74	1.84	4.45	3.39	2.61	10.55
SC-U	0.13	-	-	-		1.49	0.59	0.95	3.04	1.49	0.73	0.95	3.17
SC-C	0.13	3.30	1.82	0.92	6.04	1.42	0.66	1.31	3.39	4.72	2.61	2.23	9.56
SC-M	0.13	3.89	2.96	1.87	8.73	1.28	0.64	1.16	3.09	5.17	3.73	3.03	11.94
LSD	NS	-	-	-		0.17	0.14	0.23	0.33	0.17	0.14	0.23	0.33

Table 26. SOC and nitrogen (Mg/ha) in the 0-5, 5-25, and 0-25 cm profiles at Chatham from the spring of 2002 to the fall of 2004.

	Carbon					Nitrogen				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
0-5	--------------Mg/ha--------------				--%--	--------------Mg/ha--------------				--%--
CC-U	18.78	19.88	20.50	18.07	-4	1.58	1.79	1.83	1.55	-3
CC-C	16.71	17.13	25.51	26.66	64	1.39	1.77	2.28	2.25	65
CC-M	16.59	20.76	21.87	25.83	60	1.39	1.87	2.01	2.68	103
SC-U	15.25	19.69	20.07	24.52	65	1.28	1.75	1.78	2.15	69
SC-C	15.76	19.44	20.43	27.18	79	1.31	1.69	1.83	2.29	85
SC-M	18.97	20.76	18.65	22.15	21	1.58	1.86	1.79	2.00	32
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5-25										
CC-U	46.27	58.27	51.06	61.43	34	4.28	5.35	3.45	5.11	20
CC-C	51.13	57.11	52.89	65.78	30	4.66	4.97	3.63	5.56	20
CC-M	46.26	55.56	54.53	53.87	18	4.29	5.22	3.61	4.56	8
SC-U	50.62	55.80	56.09	55.56	10	4.72	6.43	3.96	5.73	21
SC-C	43.92	60.21	53.18	65.15	49	4.00	4.34	3.54	5.09	27
SC-M	41.87	58.28	48.69	62.11	51	3.83	4.41	3.26	5.33	41
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total										
CC-U	65.06	78.16	71.55	79.50	23	5.86	7.19	5.28	6.66	14
CC-C	67.84	74.24	78.39	92.44	37	6.05	6.79	5.91	7.82	30
CC-M	62.86	76.32	76.40	79.70	29	5.69	7.05	5.61	7.24	30
SC-U	65.87	75.49	76.16	80.07	22	6.00	8.18	5.74	7.88	31
SC-C	59.68	79.65	73.60	92.33	55	5.31	6.03	5.37	7.38	39
SC-M	60.84	79.75	67.34	84.25	40	5.42	6.39	5.05	7.34	37
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 27. POM-C fraction of the 0-5 and 5-25 cm soil profiles at Chatham in the spring of 2002 and fall of 2004.

	0-5 cm			5-25 cm			0-25 cm		
Trt	2002	2004	Chg	2002	2004	Chg	2002	2004	Chg
	------kg/ha-------		--%--	------kg/ha-------		--%--	------kg/ha-------		--%--
CC-U	4010	6090	-11	4690	16920	755	11300	20530	51
CC-C	3640	11430	219	4840	21350	955	8590	32780	400
CC-M	3430	8720	146	7560	13070	198	10820	21790	189
SC-U	3200	8830	179	5310	11220	687	8520	20050	182
SC-C	3130	12620	487	3390	18180	680	6140	30800	382
SC-M	4990	7480	53	1570	14230	830	6540	21710	255
LSD	1180	NS	NS	NS	NS	NS	NS	NS	NS

Table 28. Nitrate-N and Bray-P (kg/ha) in the 0-5, 5-25, and 0-25 cm profiles at Chatham from the spring of 2002 to the fall of 2004.

	Nitrate-N					Bray-P				
Trt	2002	2003	2004	2004F	Chg	2002	2003	2004	2004F	Chg
0-5	-----------------kg/ha----------------				--%--	----------------kg/ha-----------------				--%--
CC-U	6.6	8.5	6.9	6.3	13	27.1	70.1	1087.0	686.0	155
CC-C	6.0	5.4	9.7	11.0	107	27.4	67.5	962.0	2108.0	759
CC-M	7.7	4.6	6.1	8.3	34	31.3	80.3	1449.0	874.0	191
SC-U	5.5	3.5	6.6	8.4	67	28.6	52.0	1041.0	782.0	175
SC-C	5.5	3.5	8.1	14.0	235	32.4	71.4	998.0	2157.0	593
SC-M	6.2	3.9	5.2	9.7	77	33.8	77.6	1012.0	1256.0	294
LSD	NS	NS	NS	3.3	NS	NS	NS	NS	575.0	371
5-25										
CC-U	159	147	149	175	13	1396	1497	1701	1310	-5
CC-C	171	147	153	386	138	1221	1337	1563	1771	46
CC-M	189	158	130	226	22	1304	1373	1414	1167	-11
SC-U	176	137	141	180	2	1442	977	1287	1350	-6
SC-C	168	119	120	327	114	1364	1220	1170	2360	76
SC-M	149	140	158	236	61	1453	1432	1506	1821	27
LSD	NS	NS	33.0	8800.0	NS	151	NS	NS	604	48
Total										
CC-U	226	232	218	238	10	1667	2199	2788	2005	20
CC-C	231	201	251	496	130	1495	2012	2524	3878	165
CC-M	266	204	191	309	22	1617	2176	2863	2041	26
SC-U	231	173	206	264	16	1728	1497	2327	2132	24
SC-C	222	154	201	467	138	1088	1934	2167	4518	171
SC-M	211	179	210	333	63	1791	2208	2517	3077	72
LSD	NS	NS	NS	0.0570	NS	178	NS	NS	976	74

Table 29. Average daily temperatures at East Lansing and Chatham, MI.

	East Lansing				Chatham*			
Month	2002	2003	2004	30 yr Avg	2002	2003	2004	30 yr Avg
	°C							
January	-0.8	-8.0	-8.4	-5.7	-5.9	-11.2	-4.4	-9.0
February	-1.1	-6.9	-4.8	-4.6	-5.7	-13.3	-6.6	-8.0
March	-0.5	0.6	3.7	0.8	-7.9	-6.4	-2.1	-3.5
April	9.0	7.8	9.5	8.1	2.3	1.8	3.0	4.1
May	11.2	12.6	14.8	14.2	7.4	9.9	9.2	10.6
June	20.5	17.3	18.0	19.4	16.7	16.5	14.3	15.4
July	22.8	20.9	20.3	21.5	20.9	18.3	16.3	18.6
August	21.1	21.3	18.4	20.6	18.3	19.1	15.5	17.9
September	18.6	16.0	17.9	16.7	15.5	15.9	16.3	13.5
October	8.3	9.2	10.1	10.6	3.3	7.3	7.8	8.3
November	2.5	5.1	4.4	3.7	-3.4	0.5	2.1	0.8
December	-2.8	-0.8	-2.5	-2.8	-5.4	-3.6	-4.8	-5.8

* Temperatures for 2002 and January-June 2003 at Chatham are from the NWS at Marquette, 30 miles NW of Chatham.

Table 30. Total monthly precipitation at East Lansing and Chatham, MI.

	East Lansing				Chatham*			
Month	2002	2003	2004	30 yr Avg	2002	2003	2004	30 yr Avg
	mm							
January	10.4	6.1	6.9	35.6	27.9	17.8	35.3	50.0
February	38.9	10.4	12.3	30.7	135.9	49.0	61.7	42.4
March	41.2	38.3	69.3	53.1	144.8	85.1	80.3	49.5
April	55.6	78.5	14.0	71.4	129.5	88.6	53.1	62.5
May	120.9	103.6	205.0	69.3	79.5	156.7	111.8	80.0
June	53.9	37.3	89.2	89.9	96.8	41.1	48.0	91.7
July	95.0	35.8	101.6	76.7	86.1	70.1	79.8	90.4
August	35.6	46.2	87.1	79.2	78.0	27.9	117.1	90.4
September	13.2	65.5	26.7	63.5	145.0	139.4	39.4	105.7
October	31.5	46.7	49.0	55.9	129.5	82.8	130.1	82.3
November	34.5	118.4	80.8	56.4	53.3	60.5	50.6	78.7
December	25.9	37.3	38.6	46.5	14.2	32.5	95.8	60.2

* Temperatures for 2002 and January-June 2003 at Chatham are from the NWS at Marquette, 30 miles NW of Chatham.

Literature Cited

Anderson, S.H., C.J. Gantzer, and J.R. Brown. 1990. Soil physical properties after 100 years of continuous cultivation. J. Soil Water Conserv. 45:117-121.

Balesdent, J, and M. Balabane. 1996. Major contribution of roots to soil carbon storage inferred from maize cultivated soils. Soil Biol. Biochem. 28:1261-1263.

Barber, S.A. 1979. Corn residue management and soil organic matter. Agron. J. 71:625-627.

Beare, M.H., M.L. Cabrera, P.F. Hendrix, and D.C. Coleman. 1994. Water Stable aggregates and organic matter fractions in conventional and no-tillage soils. SSSAJ 58:777-786.

Blevins, R.L., M.S. Smith, and G.W. Thomas.1984. Changes in soil properties under no-tillage. P 190-230. In R.E. Phillips and S.H. Phillips (ed.) No-tillage Agriculture: Principles and Practices, Van Nostrand Reinhold, New York.

Bloom, P.R., W.M. Schuh, G.L. Malzer, W.W. Nelson, and S.D. Evans. 1982. Effect of N fertilizer and corn residue management on organic matter in Minnesota Mollisols. Agron. J. 74:161-163.

Bolinder, M.A., D.A. Angers, M. Giroux and M.R. Laverdiére. 1999. Estimating C inputs retained as soil organic matter from corn (*Zea Mays*). Plant and Soil 215:85-91.

Bremer, E., H.H. Janzen and A.M. Johnson. 1994. Sensitivity of total, light fraction and mineralizable organic matter to management practices in a Lethbridge soil. Can. J. Soil Sci. 74:131-138.

Buyanovsky, G.A., C.L. Kucera, and G.H. Wagner. 1987. Comparative analyses of carbon dynamics in native and cultivated ecosystems. Ecology 68:2023-2031.

Buyanovsky, G.A., and G.H. Wagner. 1986. Post-harvest residue input to cropland. Plant Soil 93:57-65.

Cambardella, C.A., and E.T. Elliot. 1992. Particulate Soil organic matter changes across a grassland cultivation sequence. SSSAJ 56:777-783.

Campbell, C.A., B.G. McConkey, R.P. Zentner, F.B. Dyck, F. Selles, and D. Curtin. 1995. Carbon sequestration in a Brown Chernozem as affected by tillage and rotation. Can. J. Soil Sci. 75:449-458.

Campbell, C.A., G.P. Lafond, R.P. Zentner, and V.O. Biederbeck. 1991. Influence of fertilizer and straw baling on soil organic matter in a thin Black Chernozem in western Canada. Soil Biol. Biochem. 23:443-446 .

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpely, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. Applic. 8:559-568.

Crasswell, E.T., and S.A. Waring. 1972. Effect of grinding on the decomposition of soil organic matter. II. Oxygen uptake and N mineralization in virgin and cultivated crackling clay soils. Soil Biol. Biochem. 4:435-442.

Dersch, G. and K. Bohm. 2001. Effects of agronomic practices on the soil carbon storage potential in arable farming in Austria. Nut. Cycling in Agroecosystems. 60:49-55.

Derpsch, R. J.R. Benites, Second World Congress on Conservation Agriculture, 11 to 15 August 2003, Ignassu Falls, Parana, Brazil.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396:262-265.

Eghball, B. 2002. Soil properties as influenced by phosphorous- and nitrogen-based manure and compost applications. Agron. J. 94:128-135.

El-Hout, N.M., and A.M. Blackmer. 1990. Nitrogen status of corn after alfalfa in 29 Iowa fields. J. Soil Water Conserv. 45:115-117.

Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus, Chapter 6. *In* J.R. Brown (ed.) Recommended Chemical Soil Test Procedures for the North Central Region *in* North Central Regional Research Publication No. 221 (Revised). Missouri Agricultural Experiment Station.

Franzluebbers, A.J. and M.A. Arshad. 1996. Soil organic matter pools during early adoption of conservation tillage in northwestern Canada. Soil Sci. Soc. Am. J. 60:1422-1427.

Franzluebbers, A.J. and J.L Steiner. 2002. Climatic Influences on Soil Organic Carbon Storage with No Tillage, Chapter 7. *In* J.M. Kimble, R. Lal, and R.F. Follett (ed.) Agricultural Practices and Policies for Carbon Sequestration in Soil. CRC Press, Boca Raton, FL.

Fraser, D.G., J.W. Doran, W.w. Sahs, and G.W. Lesoing. 1988. Soil microbial populations and activities under conventional and organic management. J. Environ. Qual. 17:585-590.

Grant, R.F., N.G. Juma, J.A. Robertson, R.C. Izaurralde, and W.B. Mcgill. 2001. Long-term changes in soil carbon under different fertilizer, manure, and rotation: Testing the Mathematical model ecosys with data from the Breton plots. SSSAJ 65:205-214.

Gelderman, R.H. and D. Beegle. 1998. Nitrate-Nitrogen, Chapter 5. *In* J.R. Brown (ed.) Recommended Chemical Soil Test Procedures for the North Central Region *in* North Central Regional Research Publication No. 221 (Revised). Missouri Agricultural Experiment Station.

Hassink, J. 1992. Density fractions of soil macroorganic matter and microbial biomass as predictors of C and N mineralization. Soil Biol. Biochem. 27:1099-1108.

Havlin, J.L, D.E. Kissel, L.D. Maddux, M.M. Claasen, and J.H. Long. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J 54:448-452.

Huggins, D.R., C.E. Clapp, R.R. Allmaras, J.A. Lamb, and M.F. Layese. 1998. Carbon dynamics in corn-soybean sequences as estimated from natural carbon-13 abundance. SSSAJ 62:195-203.

Iazurralde, R.C., W.B. McGill, J.A. Robertson, N.G. Juma, and J.J. Thurston. 2001. Carbon balance of the Breton Classical Plots over Half a Century. SSSAJ 65:431-441.

Janzen, H.H., C.A. Campbell, E.G. Gregorich, and B.H. Ellert. 1998. Soil carbon dynamics in Canadian agroecosystems. P 57-80. In R. Lal et al (ed.) Soil processes and the carbon cycle. CRC press, Boca Raton, FL.

Janzen, H.H., C.A. Campbell, R.C. Izaurralde, B.H. Ellert, N. Juma, W.B. Mcgill, and R.P. Zentner. 1998. Management effects on soil C storage on the Canadian prairies. Soil Till. Res. 47:181-195.

Janzen, H.H., C.A. Campbell, S.A. Brandt, G.P. Lafond, and L. Townley-Smith. 1992. Light-fraction organic matter in soils from long-term crop roations. SSSAJ 56:1799-1806.

Jastrow, J.D., T.W. Boutton, and R.M. Miller. 1996. Carbon dynamics of aggregate-associated organic matter estimated by carbon-13 natural abundance. SSSAJ 60:801-807.

Kern, J.S., and M.G. Johnson, 1993. Conservation tillage impacts on national soil and atmospheric carbon levels. SSSAJ 57:200-210.

Kuo, S. U.M. Sainj, and E.J. Hellum. 1997. Winter cover crop effects on soil organic carbon and carbohydrate in soil. SSSAJ 61:145-152.

Koutika, L.S., S. Hauser, and J. Henrot, 2001. Soil organic matter assessment in natural regrowth, *Pueraria phaseoloides and Mucuna pruriens* fallow. Soil Biology and Biochemistry 33: 1095-1101.

Lal, R. 1999. Prog. Environ. Sci. 1:307.

Lal, R. M. Griffin, J. Apt, L. Lave, and M.G. Morgan. 2004. Managing Soil carbon. Science. 304:393.

Lal, R., J. Kimble, E. Levine, and C. Whitman. 1995. World soils and greenhouse effect: An overview. p. 1-8. in R. Lal et al.(ed.) Soils and global change. Lewis Publ., Boca Raton, FL.

Lal, R., J.M. Kimble, R.F. Follett, and C.V. Cole. 1998. The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Sleeping Bear Press, Chelsea, MI.

Lamb, J.A., G.A. Peterson, and C.R. Fenster. 1985. Wheat fallow tillage systems effect on a newly cultivated grassland soils' N budget. SSSAJ 49:352-356.

Liang, B.C., E.G. Gregorich, A.F. MacKenzie, M. Schnitzer, R.P. Voroney, C.M. Monreal, and R.P. Beyaert. 1998. Retention and turnover of corn residue carbon in some eastern Canadian soils. Soil Sci. Soc. Am. J. 62:1361-1366.

Logan, T.J., R. Lal, and W.A. Dick. 1991. Tillage systems and soil properties in North America. Soil Tillage Res. 20:241-270.

Marland, G. and T.A. Boden. Trends: A compendium of Data on global change (carbon dioxide information Analysis center, Oak Ridge National Laboratory, TN, 1997.

McCarty, G.W., N.N. Lyssenko, J.L. Starr. 1998. Short-term changes in soil carbon and nitrogen pools during tillage management transition. Soil Sci Soc Am J 62:1564-1571.

McCarty and J.J. Meisinger, 1997. Effects of N fertilizer treatments on biologically active N pools in soils under plow and no tillage. Biol. Fertil. Soils 24:406-412.

McCarty, Meisinger, and F.M.M. Jenniskens. 1995 Relationships between total-N, biomass-N and active-N in soil under different tillage and N fertilizer treatments. Soil Biol biochem 27:1245-1250.

McVay, K.A., D.E. Radcliffe, and W.L. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. SSSAJ 53:1856-1862.

Mendes, I.C., A.K. Bandick, R.P. Dick, and P.J. Bottomley. 1999. Microbial biomass and activities in soil aggregates affected by winter cover crops. SSSAJ. 63:873-881.

Ortega R.A., G.A. Peterson, and D.G. Westfall. 2002. Residue accumulation and changes in soil organic matter as affected by cropping intensity in no-till dryland agroecosystems. Agron. J. 94:944-954.

Paustian, K., H.P. Collins, and E.A. Paul. 1997. Management controls in soil carbon. p. 15-49. *In* E.A. Paul et al. (ed.) Soil organic matter in temperate ecosystems: Long term experiments in North America. CRC Press, Boca Raton, FL.

Paustian, K., W.J. Parton, and J. Persson. 1992. Modeling soil organic matter in organic-amended and N-fertilized long-term plots. SSSAL 56:476-488.

Post, W.M., T.H. Peng, W.R. Emanuel, A.W. King, V.H. Dale, and D.L. DeAngelis. 1990. The global carbon cycle. Am Sci. 78:310-326.

Post, W.M., W.R. Emanuel, and A.W. King. 1992. Soil organic matter dynamics and the global carbon cycle. In: N.H. Batjes and E.M. Bridges (eds.), World inventory of soil emission potentials. International soil reference information center, Wageningen, The Netherlands.

Rasmussen, P.E. R.R. Allmaras, C.R. Rhode, and N.C. Roager. 1980. Crop residue influences on soil carbon ad nitrogen in a wheat-fallow system. Soil Sci Soc Am J. 44:596-600.

Rasmussen, P.E. and W.J. Parton. 1994. Long-term effects of residue management in wheat-fallow: I. Inputs, yield, and soil organic matter. SSSAJ 58:523-530.

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

Robinson, C.A., R.M. Cruse, and M. Ghaffarzadeh. 1996. Cropping system and nitrogen effects on mollisol organic carbon. SSSAJ 60:264-269.

Rochette, P., E.G. Gregorich. 1998. Dynamics of soil microbial biomass C, soluble organic C and CO2 evolution after threee years of manure application. Can J Soil Sci 78:283-290.

Schlegel, A.J. 1992. Effect of composted manure on soil chemical properties and nitrogen use by grain sorghum. J. Prod. Agric. 5:153-157.

Schlesinger, W.H. 1984. Soil organic matter: A source of atmospheric CO2. pp. 111-127. In: G.M. Wooddwell (ed.) The role of Terrestrial Vegetation in the Gloal Carbon Cycle. John Wiley & Sons, New York, NY.

Schlesinger, W.H. 1999. Carbon and agriculture: Carbon Sequestration in soils. Science 284:2095.

Schulten, H.R. and P. Leinwever. 1991. Influence of long-term fertilization with farmyard manure on soil organic matter:characteristics of particle-size fractions. Biol. Fertil. Soils 12:81-88.

Solberg, E.D., M. Nyborg, R.C. Izaurralde, S.S. Malhi, H.H. Janzen and M. Molina-Ayala. 1998. Carbon Storage in soils under continuous cereal grain cropping:N fertilizer and straw. P. 235-254. In R. Lal et al. (ed.) Management of carbon sequestration in soil. Adv. Soil Sci. CRC Press, Boca Raton Fl.

Sommerfeldt, T.G., C. Chang, and T. Entz. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. SSSAJ 52:1668-1672.

Tiessen, H. and J.W.B. Stewart. 1983. Particle-size fractions and their use in studies of soil organic matter. II. Cultivation effects on organic matter composition in size fractions. SSSAJ 47:509-514.

Torbert, H.A., S.A. Prior, and D.W. Reeves. 1999. Land Management effects on nitrogen and carbon cycling in an ultisol. Commun Soil Scie Plant Anal 30:1345-1359.

Unger, P.W. 1991. Organic matter, nutrient, and pH distribution in no-and conventional-tillage semiarid soils. Agron. J. 83:186-189.

Varvel, G.E. 1994. Rotation and nitrogen fertilization effects on changes in soil carbon and nitrogen. Agron. J 86:319-325.

West, T.O. and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Sci. Soc. Am. J. 66:1930-1946.

Wood, C.W., D.G. Westfall, and G.A. Peterson. 1991. Soil carbon and nitrogen changes on initiation of no-till cropping systems. SSSAJ 55:470-476.

Wright, A.L., and F.M. Hons. 2004. Soil aggregation and carbon and nitrogen storage under soybean cropping sequences. SSSAJ 68:507-513.

CHAPTER 2

COVER CROP AND SOIL AMENDMENT EFFECTS ON GREENHOUSE GAS FLUXES IN SILAGE CORN – SOYBEAN CROPPING SYSTEMS AT TWO DIFFERENT LATITUDES

INTRODUCTION

Mitigating the accumulation of greenhouse gases (GHG) in the atmosphere is essential to the protection of the Earth's climate. Accumulation of GHG in the atmosphere may lead to global warming causing climate change around the world. Temperate regions may move farther north and south of the equator causing significant changes in the ability of certain areas to produce agricultural crops.

Agriculture has played a major role in the increase of GHG carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). N_2O and CH_4 have approximately 300 and 20 times the global warming potential of CO_2 on a mole to mole basis (CAST 2004; Izaurralde et al. 2004). However, CO_2 has been the main focus for greenhouse gas mitigation due to the increase in atmospheric concentration from 280 ppm to 370 ppm since the mid-1800s. and therefore has the greatest effect on global warming.

CO_2 and N_2O flux increases after tillage events and CH_4 is a main byproduct of livestock production, specifically cattle. Agriculture affects atmospheric CO_2 concentrations through consumption of fossil fuels, clearing of forested lands for food production (Wallace et al. 1990) and alteration of SOC levels by agricultural management practices. Population increases and industrial expansion have also resulted in increased atmospheric CO_2 concentration (Warneck 1988; Holland1978). N_2O emissions are largely attributed to nitrification and denitrification of N added to the soil to maintain crop productivity (Rochette et al. 2004). Agricultural activities such as rice cultivation and livestock are major contributors to CH_4 emissions however, soils generally act as a sink.

Short sighted farming practices have resulted in loss of an estimated $4\pm1 \times 10^9$ Mg of carbon from soils of the United States, and $78\pm12 \times 10^9$ Mg from the world's soils, a large fraction of which ended up in the atmosphere (Lal 1999). Soils play a major role in the global carbon budget not only because of the large amount of carbon stored in soil, with estimates ranging from 1395 to 1636×10^8 Mg (Post et al. 1992; Schlesinger 1984) but also because the annual flux of CO_2 to the atmosphere from soil is 10 times the amount of CO_2 contributed by fossil fuel usage (Post et al. 1990). Soils can serve as both a source and sink for atmospheric CO_2, therefore soil and crop management can affect the global balance of CO_2 (CAST 2004).

Approximately one-third of the atmospheric CO_2 that has accumulated since pre-industrial times is derived from land use practices that involve soil disturbance and removal of vegetation. Storage of soil organic carbon (SOC) is a balance between carbon additions from non-harvested portions of crops and organic amendments, and carbon losses, primarily through organic matter decomposition and release of respired CO_2 to the atmosphere (Huggins et al. 1998). Additions and losses of carbon are regulated by agricultural practices such as crop rotation (Janzen et al. 1992), residue and tillage management (Havlin et al 1990), and fertilization (Bloom 1982; Paustian et al. 1992).

Agriculture plays a major role in the global fluxes of GHG and has been promoted as a partial means for slowing further increases in radiative forcing through the potential for soil carbon sequestration in cropping systems under reduced tillage (Paustian 1995; Lal et al. 1999) and organic management regimes (Drinkwater et al. 1998). Conservation of SOC should be a goal in production agriculture to decrease agricultural GHG emissions. It is possible to conserve SOC through appropriate choices of tillage, fertility, residue management, and cropping systems. Such management of SOC should decrease agricultural CO_2 emissions through reduced SOC decomposition, increased sequestration of atmospheric GHG, and reduced fossil fuel consumptions (Robinson et al. 1996).

The objectives of this study were to investigate the effect of rye cover crop, composted manure, and fresh manure on GHG emissions in no-till cropping systems consisting of corn and soybean rotations and determine the best management practices utilizing a whole accounting process for GHG.

MATERIAL AND METHODS

Field experiments were conducted near East Lansing (N 42.43, W 84.28) and Chatham (N 46.29, W 86.76), MI over a three year period beginning in the fall of 2001. Soil at East Lansing was a mixture of Aubbeenaubbee-Capac sandy loams (Fine-loamy, mixed, mesic Aeric Ochraqualfs) and Colwood-Brookston loams (Fine-loamy, mixed mesic Typic Argiaquolls and Typic Haplaquolls). Chatham soil was a Trenary fine sandy loam (Coarse-loamy, mixed frigid Alfic Fragiorthods). Experimental design was a randomized complete block with four replications at each location. Treatments were arranged as a 2x3 factorial at East Lansing. Factors consisted of rye vs. no rye, and compost amendment vs manure amendment vs no amendment.

Prior to experiment establishment at East Lansing the site was under a corn-soybean rotation with conventional tillage. Corn was planted in 2001, harvested as silage and no-till production practices were implemented when the winter rye cover crop was planted. The site was split into two rotations, corn-soybean-corn (CSC) and soybean-corn-soybean (SCS). Treatments at East Lansing were; winter rye cover crop (R) alone or in combination with either composted manure (R+C), or fresh manure (R+M), composted manure (C) alone, fresh manure (M) alone, and an untreated check (U) applied to both rotations.

The Chatham site was an alfalfa field prior to experiment establishment. The experiment at Chatham consisted of two rotations, continuous silage corn (CC) and a forage soybean–silage corn rotation (SC). A winter rye cover crop was planted after removal of forage soybean in 2002. Treatments consisted of composted manure (C), liquid dairy manure (M), and an untreated check (U) applied to both rotations.

Plot size varied between locations; plots at East Lansing were 6.1 x 12.2 m with 76 cm wide rows of corn or 38 cm wide rows of soybean and plots at Chatham were 18.3 x 18.3 m wide with 76 cm wide rows of corn or soybean in 19 cm wide rows. Planting dates, and harvest dates can be found in Table 31.

Winter rye was terminated approximately two weeks prior to planting with glyphosate (840 g ae/ha) at East Lansing and glufosinate (140 g ai/ha) at Chatham. Solid beef manure and composted manure were applied in the spring and fall of each year through the spring of 2004 at East Lansing (Table 32). Liquid dairy slurry and solid composted manure were applied in the spring of each year at Chatham (Table 33).

Greenhouse gas flux from the soil was determined using semi-permanent sampling chambers placed in each plot. Chambers were polyvinyl chloride (PVC) rings 25 cm in diameter and 10 cm in height with a beveled edge on the bottom to ease placement. Chambers were inserted about 5 cm into the soil. A PVC cap with a 90° plastic elbow in the center and a 10 cm piece of plastic tubing was placed over the sampling chamber before sampling. A 10 cm wide strip of latex glued to the outside of the cap was folded down around the sampling chamber during sampling. A butyl-rubber O-ring was used to seal the latex strip tight against the chamber and to help hold the cap in place. A three-way stopcock permanently attached to the tubing allowed for mixing of the headspace atmosphere in the chamber.

A disposable 20 mL polypropylene syringe attached to the stopcock was used to draw air from the headspace atmosphere. The syringe was filled then the air was injected back to mix the atmosphere; this was repeated a total of three times before collecting any samples. After mixing this atmosphere 20 ml of air was withdrawn and injected into a 10 ml exetainer which had a 25 gauge needle placed in the rubber septum to allow for excess air to be forced out. This flushed any air trapped in the vial when capped out. This was repeated three times before removing the needle from the septum and filling the exetainer until pressurized.

Gas samples were collected at random times throughout the growing seasons in 2002, 2003, and 2004 (Table 31). Samples were to be collected at scheduled times but due to technical problems with the analytical equipment samples were collected when possible and not all samples collected were analyzed. Samples were collected after the cap was placed on the sampling chamber and at approximately 48 minute intervals up until 144 minutes after placing the cap. Gas samples were analyzed using a HP5890 Series II gas chromatogrpah (Hewlett PackardPalo Alto, CA 94304). CH_4 was analyzed with a flame ionization detector (300 degrees C), while N_2O was analyzed with a 63Ni electron capture detector (350 degrees C). CO_2 was analyzed using an infrared gas analyzer. Gases for both CH_4 and N_2O were separated on a Poropak Q column (1.8 m, 80/100 mesh) at 80 degrees C. Carrier gas for CH_4 was nitrogen, while carrier gas for N_2O was argon/methane (90/10).

Soil temperature at the 10 cm depth was measured each time a gas sample was collected and soil moisture to a depth of 15 cm was measured when the first and last samples are collected. Soil moisture was measured using a TRIME® TDR (MESA Systems, Medfield, MA 02052) moisture meter which measured moisture on a volume/volume basis. Three measurements were taken within 0.6 m of the canister and averaged. Height of the sampling chamber plus the cap was measured on four sides to determine the volume of the headspace.

GHG flux was calculated using the following equation:

$F=(C/T)*((V*M)/(A*V_{\mathrm{mol}}))$ where (C/T) is rate of change of chamber concentration of gas X, V is the chamber volume, M is the molecular weight of gas X, A is the soil area covered by the chamber, V_{mol} is the volume of a mole of gas X. This equation provides μmol of gas X/min/cm^2 which was converted to g gas X/day/ha.

Annual flux rate was calculated by averaging the measured daily flux rates and multiplying by 180 d for East Lansing and 132 d for Chatham. Growing season was determined to be the time between the 30 y average last spring freeze (-2°C) and first fall freeze. In this step N_2O-N and CH_4-C were converted to CO_2 equivalents using 20 yr time horizon factors of 275 for N_2O and 62 for CH_4 (CAST 2004).

Global warming calculation for soil carbon accumulation was determined using the following equation:

X g CO^2/m^2/yr=$(((x_1$ kg C/m$^2 - x_2$ kg C/m$^2)/x_3)$*(4400 g CO^2/12 kg C))

where x_1 = soil C in treatment X in the fall of 2004

x_2 = soil C in the Untreated in the fall of 2004

x_3 = period of accumulation in years

GWP for inputs were obtained from values published by West and Marland (2002) and IPCC (1997). Values take into account fuel for production and transportation of seed, chemical, and fertilizer. Flux from manure production was calculated using 47 kg methane head-1 y-1 and original manure before composting was calculated at a rate of 118 kg head-1 y-1. The difference between the manure and compost-manure is that the manure came from beef while the compost-manure came from dairy cows. CO_2 and total carbon loss during the composting procedure was calculated and included in the flux rate. GWP values for inputs included in this study can be found in Table 34.

Net GWP for treatments were calculated with the following eqution:

Net GWP = Soil C GWP + Soil GHG flux + Input GHG flux – (Residue carbon - mineralized carbon)

The residue carbon – mineralized carbon is to adjust for residue carbon added to the system but that is not part of the SOC or released as GHG. In some treatments large portions of the applied carbon still remain on the soil surface and therefore should not be counted against the GWP of the treatment. By subtracting the mineralized carbon from the residue carbon it was possible to determine the amount of carbon left on the surface.

RESULTS AND DISCUSSION

Ancillary measurements

Average daily temperatures at East Lansing and Chatham during the growing seasons were ± 3 °C of the 30 yr average (Table 35). Total monthly precipitation compared to the 30 yr averages at East Lansing and Chatham during the growing seasons were more variable (Table 36).

Soil temperature was significantly affected by cover crop and soil amendment treatment in 2003 and 2004 at East Lansing though all treatments were within 2 °C of each other at every sampling (Tables 37 and 38). When cover crop was significant the rye treatments had higher soil temperature than the non-rye treatments. Compost and manure generally had lower soil temperatures than the no amendment treatment. There were differences between compost and manure also however, there was no distinguishable pattern. The lower soil temperatures of the amended treatments were probably due to the insulating affect of the material. The application of the organic material produced a buffer zone between the soil surface and the sun protecting the soil from direct sunlight therefore decreasing the ability of the sunlight to heat the soil. It is possible that lower soil temperatures in the amended treatments may have slowed mineralization of organic matter but it is hard to estimate since the temperatures were only different by a couple of degrees at most.

Soil moisture was also significantly affected by cover crop and amendment treatments at East Lansing (Table 37). Manure, compost and rye usually had higher soil moisture content than treatments without either soil amendment or rye cover crop (Table 39). A similar argument to the one made above about the protection the amendments provide the soil from the sun can be made here. Keeping the soil cool will result in less evaporation of water from the soil surface. The organic matter in the amendments is also much better at retaining water than the soil so when it rains more is absorbed in those treatments than the treatments without amendments. The same could be said for the rye cover crop. The root biomass of the terminated rye cover crop may provide additional soil moisture by absorbing water during precipitation events and holding it in the soil profile longer.

Soil temperature and moisture at Chatham were also different among treatments (Table 40). Similar to the results at East Lansing, treatments containing compost and manure had lower soil temperatures and higher soil moistures.

Daily GHG Flux

Daily flux rates of N_2O, CO_2, and CH_4 were significantly affected by the application of soil amendments, cover crop, or the interaction of the soil amendment and cover crop at certain sampling dates at East Lansing in 2003 and 2004 (Table 41).

Soil amendment significantly affected CO_2-C flux on five of seven sampling dates in 2003 for both rotations and on five of six and four of six sampling dates for the CSC and SCS rotations, respectively in 2004 (Table 41). Manure emitted more CO_2-C than either compost or no amendment in both rotations when soil amendment was significant (Table 12). Emissions from compost were lower or similar to the no amendment treatment in the CSC rotation both years except for June 7, 2004 and in the SCS rotation in 2003. In 2004 in the SCS rotation compost had higher emission rates of CO_2-C than no amendment except on August 11.

These data suggest that the use of compost in place of manure would be beneficial due to the large differences in CO_2-C emissions. The reason for this large difference is due to the prior decomposition of the manure during the composting procedure. During composting the majority of easily degraded organic matter is decomposed leaving more recalcitrant organic matter. Therefore it could be expected that fresh manure applied to the field would have a much higher CO_2-C flux than compost. Hao et al. (2004) found that composting straw bedded manure resulted in a loss of 52.8% total carbon during the process and actually released more CO_2-C to the atmosphere than the initial total carbon content of the manure. This will be discussed in more detail in the *TOTAL ANNUAL GHG FLUX* section.

Cover crop significantly affected CO_2-C flux on two and five of the thirteen sample dates in the CSC and SCS rotations, respectively (Table 41). The rye cover crop treatment increased CO_2-C flux compared to non-rye treatments (Table 42). Soil temperatures tended to be warmer under the rye cover crop however on the sampling dates with significant differences between the two levels of the cover crop soil temperature was not significantly different. Results from the 19 April 2003 sampling were the most surprising since the rye cover crop was alive in the sampling chamber during the sampling. It was expected that the rye would utilize the CO_2 in the chamber for photosynthesis and cause a reduction not an increase in CO_2 concentration. Higher CO_2-C flux was not surprising from 18 May 2003 through the remainder of the season due to the availability of the rye cover crop biomass for decomposition after being terminated.

Significant interaction between soil amendments and cover crop occurred on 3 May and 18 May 2003 in both rotations and on 27 July 2004 in the CSC rotation (Table 11). Rye plus manure (RM) resulted in the highest CO_2-C flux in both rotations on 3 May and 18 May 2003 followed by the rye alone treatment (Table 43). Compost (C) and Untreated (U) had the lowest level of CO_2-C flux on as expected due to the smaller concentration of easily decomposable carbon in those treatments. Similar to results from 2003, RM had the highest CO_2-C flux on 27 July 2004 in the CSC rotation.

Multiple soil N sources can result in N_2O production and emission including mineral fertilizers, manure, crop residues, and biological fixation by legumes (Bremner 1997). N_2O is naturally produced in soils as an intermediate during microbial nitrification (Bremner and Blackmer 1981) and denitrification (Dejwiche 1981).

N_2O-N was affected by soil amendment on three of seven sampling dates in 2003 and one sampling date in 2004 in the CSC rotation, and on four of seven samplings dates in 2003 and four of six sampling dates in 2004 for the SCS rotation (Table 41). Nitrification and denitrification of N that is added to the soil to sustain crop productivity are responsible for the majority of N_2O emissions (Rochette et al. 2004).

When soil amendment was significant, manure had higher N_2O-N emissions than no amendment except for on 18 May and 9 October 2003 in the SCS rotation (Table 44). Manure and compost had similar N_2O-N emissions on most sampling dates. Manure emitted 12.7 g N_2O-N ha^{-1} day^{-1} more than compost on April 19, 2003 in the CSC rotation while in the SCS rotation the difference was only 2.7 g N_2O-N ha^{-1} day^{-1}. This large difference is probably best explained by the previous crop. 2003 was the second year of the three year rotation so the previous crop in the CSC rotation was corn and in the SCS rotation was soybean. Mineralization of soybean root biomass probably contributed to the higher N_2O-N emissions from SCS rotation in early April. According to Rochette et al. (2004) N_2O emissions after soybean harvest and early in the following growing season indicated that soybean crop residues can induce significant N_2O

production in soils. Manure and compost were applied on 8 April 2003 (Table 31) which may have also contributed to the high levels of N_2O-N released.

Cover crop treatment affected N_2O-N emission on 3 May 2003 in the SCS rotation with rye significantly reducing N_2O-N emissions (Tables 41 and 44). Rye cover crop tended to have lower N_2O-N emissions in April and May, higher emissions in June, and similar emissions in July through October to non-rye treatments. Lower emissions in April and May were probably due to the use of available soil nitrogen by the rye while growing. The spike in June was likely due to e mineralization of the rye biomass after being terminated resulting in a release of N_2O-N. Rye cover crop actually resulted in mitigation of N_2O-N on 24 April 2004 in the SCS rotation.

Interaction between cover crop and soil amendment occurred on 3 May 2003 and 24 April 2004 in the CSC rotation (Table 41). Manure had the highest flux of 39.0 g N_2O-N ha^{-1} day^{-1} on 3 May 2003 followed by compost (13.7 g) both of these were significantly different than the other treatments (Table 45). The addition of rye cover crop to the manure and compost treatments reduced N_2O-N emissions by 95 and 97% respectively, on 3 May 2003. When the rye cover crop was growing it generally reduced N_2O-N emissions though not always significantly. This was probably due to utilization of the available soil nitrogen before it could be denitrified. Sanchez et al. (2004) reported that winter wheat may have reduced NO_3-N leaching losses during the winter and and spring by drying the soil and immobilizing mineralized N from soybean residues.

N_2O emissions were usually highest in the treatments that were the coldest and wettest corresponding to work by McKenney et al. (1993) who found that denitrification losses were higher with no-till compared to conventional till due to higher soil moisture.

CH_4-C emissions were influenced by soil amendments on 14 June 2003 in the SCS rotation and on 27 July 2004 in both rotations (Table 41). Agricultural soils generally act as a sink for CH_4-C except under anaerobic conditions (CAST 2004). Therefore it is interesting that manure resulted in emissions of 0.7 g CH_4-C ha^{-1} day^{-1} on 14 June 2003 in the SCS rotation and 1.3 and 0.2 g on 27 July 2004 in the CSC and SCS rotations, respectively (Table 16). Compost emitted 0.7 g CH_4-C ha^{-1} day^{-1} on July 27, 2004 in the SCS rotation. These emissions appear to be resulting from the soil amendment because when no amendment was applied atmospheric CH_4-C concentration was mitigated. Soil moisture was 27 to 29% volume:volume (Table 49) so anaerobic conditions were not present to account for the CH_4-C emissions.

CO_2-C flux at Chatham was only different among treatments on 10 June and 14 September 2004 (Table 47). There was no obvious pattern to the differences among treatments on these two sampling dates; SC-M had the highest flux of CO_2-C on 10 June while SC-C had the highest flux on 14 September. Both were greater than the untreated and compost treatments.

N_2O-N emissions differed among treatments on 3 July 2003, 15 July and 14 September 2004 (Table 47). Similar to CO_2-C no distinct pattern to the differences were evident. SC-M was highest on 3 July 2003, CC-M on 15 July 2004, and CC-C on 14 September 2004. The higher flux from SC-M in 2003 could be caused by the mineralization of the forage soybean roots from the 2002 crop as discussed earlier.

CH_4-C emissions were significantly different on 10 June and 15 July 2004 (Table 47). Mitigation of CH_4-C was greatest with SC-U on 10 June and SC-C on 15 July. All treatments mitigated CH_4-C on 10 June while CC-U and CC-M emitted CH_4-C on 15 July.

TOTAL ANNUAL SOIL GHG FLUX

Total annual soil GHG flux is the sum of all three greenhouse gases in CO_2 equivalents emitted or mitigated over the period of a growing season. The growing season at East Lansing was calculated to be 180 days while at Chatham it was determined to be 132 days. Growing season length was determined by counting the days between the last spring freeze and the first fall freeze

East Lansing

Soil amendment had a significant effect on annual soil GHG flux (Table 48). Manure had the highest emission rate of 2678 g CO_2 m^{-2} y^{-1} and was significantly greater than no amendment (1335 g) and compost (1099 g) in the CSC rotation (Table 48). Compost and no amendment treatments were not significantly different from each other. The same trend was present in the SCS rotation however; compost was significantly less than no amendment.

Soil amendments significantly differed in the amounts of each gas they contributed toward the annual soil GHG flux in both rotations (Table 50). The proportion of the total annual CO_2 equivelent flux in the CSC rotation from CO_2 was 93.19% with compost which was significantly less than that from manure and no amendment. Compost released significantly more N_2O than either manure or no amendment. This contradicts the findings of Castellanos and Pratt (1981) who reported that during the composting process manure-N was stabilized through microbial assimilation and humification resulting in a considerably slower rate of mineralization. Also, GHG were measured as soon as possible however, it is possible that the measured N_2O flux is represented here smaller than the actual flux due to the inability to measure the large fluxes for N_2O associated with soil thawing (Goodroad et al. 1984 and Christensen and Tiedje 1990). Trends in treatment differences for each gas were the same between rotations.

Rye cover crop significantly increased GHG flux compared to no cover crop in both rotations (Table 48). Rye cover crop resulted in more CO_2 being released and less N2O than no cover crop. As discussed earlier the higher rate of CO_2 evolution is due to the decomposition of the rye biomass. Utilization of soil nitrogen by the rye cover crop during the fall and spring when N_2O emissions are highest (Rochette et al. 2004) is the reason for no cover crop to have higher N_2O emissions.

Chatham

Total annual soil GHG flux was lowest with CC-C which was significantly less than CC-M, SC-C, and SC-M (Table 49). SC-M had the highest GHG flux at 1876 g CO_2 m^{-2} yr^{-1}. SC rotation treatments had significantly higher GHG emissions than either the CC-U or CC-C treatments. It is possible that the inclusion of soybean in the rotation could increase the emission of N_2O compared to continuous corn. Also as seen at East Lansing the inclusion of rye cover crop increased CO_2 emission compared to no cover crop.

Soil GHG flux derived from the three gases was significantly different among treatments for CO_2 and N_2O (Table 51). SC-U released the most CO_2 which was significantly greater than CC-C, CC-M, and SC-C. An interesting result was that the

Untreated treatments in both rotations emitted the most CO_2. Considering the only additional carbon in these treatments was crop residue it was an unexpected result. However, when soil temperatures are considered the Untreated treatments generally had warmer temperatures than either the compost or manure treatments within the same rotation. These higher temperatures would have been conducive to increased decomposition of SOC.

Proportion of the total annual GHG flux from N_2O was highest with CC-M. SC-U and SC-M were significantly less than CC-M which could have been expected. At East Lansing rye cover crop decreased N_2O emissions and the SC rotation at Chatham includes a rye cover crop. Also the manure at Chatham was liquid slurry so the nitrogen in the manure would have been more easily taken up by the cover crop shortly after application.

Surprisingly, the total annual flux rates were pretty similar between locations. It was believed that Chatham would have a smaller flux of GHG than East Lansing. When averaged across treatments and rotations the total annual GHG flux at East Lansing was 1632 g CO_2 m^{-2} y^{-1}compared to 1533 g CO_2 m^{-2} y^{-1}. However, when converted to a daily basis because of the difference in growing season lengths, the daily flux at Chatham (11.61 g CO_2 m^{-2} d^{-1}) exceeds that of East Lansing (9.07 g CO_2 m^{-2} d^{-1}). Due to the shorter growing season Chatham has a lower annual flux rate but that does not mean that it is more suited for carbon sequestration than East Lansing.

SOIL C GWP

Soil carbon content changes were presented and discussed in the previous chapter. The means are presented here again as a function of the Untreated allowing for the comparison of the soil amendments and cover crop effects to the effect of normal no-till practices (Table 48). Calculation of soil C GWP is simply made by subtracting the baseline soil C content from the ending soil C content, dividing by the period of accumulation, and converting the amount of carbon into its equivalent mass as CO_2. Two different baselines were available to use with this experiment; 1) the initial spring 2002 carbon levels, or 2) the fall 2004 carbon level of the untreated. We chose to use the fall 2004 carbon level of the untreated as the baseline as this would allow us to compare the effect of the treatments to straight no-till instead of comparing all the treatments to conventionally tilled carbon levels from 2002.

Soil amendments had a significant effect on Soil C GWP (Table 48). All treatments resulted in a potential to mitigate global warming in the CSC rotation (Table 48). Compost had the most significant affect with a mitigation potential of 2212 g CO_2-C m^{-2} y^{-1} which was greater than manure (1248 g) and no amendment (37 g). Similar to the CSC rotation, compost had the greatest effect on potential for mitigation in the SCS rotation followed by manure; however, no amendment resulted in carbon loss not gain. Cover crop had no effect on soil C GWP in either rotation (Table 48). Soil C GWP seems to be greater in the CSC rotation than the SCS rotation, possibly due to more recalcitrant carbon in the corn residues compared to the soybean residue.

All treatments appear to have the potential to mitigate global warming though there were no differences among treatments. Treatments containing compost had the highest potential of global warming mitigation. This result is not surprising since the compost treatment returns the most carbon to the system of any of the treatments.

Residual carbon from organic inputs

Carbon applied as compost, manure, crop residue, or rye cover crop biomass can either be mineralized into SOC, decomposed into CO_2, or remains on the soil surface in the form it was applied in. To accurately account for GHG mitigation, all of the carbon applied in the treatments needs to be accounted for. This was accomplished by subtracting the known amount of carbon incorporated into SOC (Fall 2004 SOC – Spring 2002 SOC) from the amount of carbon applied. With the mineralized portion of the applied carbon accounted for the decomposed portion needs to be removed, that is done by subtracting the annual soil GHG flux rate leaving the amount of carbon remaining as residue in the applied form which is used as a credit against global warming.

Residual carbon minus the mineralized portion of the applied carbon is presented in Table 48. Soil amendment and cover crop both had significant effects on residual carbon levels. Manure resulted in the highest level of residual carbon remaining after removing the mineralized portion. All treatments had carbon remaining on the soil surface before subtracting the annual soil GHG flux.

Results at Chatham differed from East Lansing in that more carbon was sequestered in the soil than was applied with the treatments therefore no residual carbon credit was given (Table 49). It is believed that the large amount of carbon sequestered in the soil at Chatham is due to the experimental site being an alfalfa period for a significant amount of time prior to the experiment. Alfalfa produces large amounts of root biomass which when mineralized would greatly affect the SOC content.

Input GHG flux

Average total annual input GHG flux for both rotations is in Table 48. The difference between rotations at East Lansing is due to two years of corn in the CSC rotation, and the additional nitrogen fertilizer required for the corn crop. The high flux rate from compost is due to CO_2 loss during the composting procedure. CO_2 loss from composting was calculated by comparing total carbon levels before and after composting. Average loss of carbon during composting was 947.5 kg CO_2 eq. Mg^{-1} compost dry matter which is more than double the loss of CO_2 during composting reported by Hao et al. (2001 and 2004). This is still an underestimation of CO_2 loss from composting since these calculations did not include the fuel used when the compost was periodically mixed.

Net GWP

Soil amendment and cover crop had significant impacts on net GWP (Table 48). Compost and manure resulted in similar mitigation potentials ranging between 708 and 1159 g CO_2 m^{-2} y^{-1} in the CSC and SCS rotations when residual carbon on the surface was accounted for. Compost and manure went from mitigating global warming to increasing the GWP when residual carbon is removed from the equation. Without credit for residual carbon, manure emits significantly more CO_2 equivalents than compost. The addition of a rye cover crop significantly increased GWP of those treatments, mostly due to increased GHG flux from the soil.

No significant differences were observed among treatments at Chatham for net GWP (Table 49). Compost did provide mitigation potential. Unlike East Lansing the compost was not actively mixed so the additional input GHG flux from that process is not missing here. However, there is still some GHG not accounted for from the composting process which would increase the GWP of the compost treatments.

CONCLUSIONS

Compost treatments appear to have the most significant effect on soil carbon GWP while emitting less than half of the soil GHG flux than manure. Net GWP of compost was similar to that of manure though due to the high flux of GHG from the composting process. GHG emissions from soil though smaller during November through March compared to April through October still occur and should be included to be as accurate as possible when making decisions about best management practices. These questions need to be answered and included in the whole accounting process before recommending the use of compost or any other methods as a mitigation strategy of GHG.

Table 31. Dates of soil sampling, planting, herbicide application, and harvest at East Lansing and Chatham.

	East Lansing			Chatham		
	2002	2003	2004	2002	2003	2004
	Soil sampling					
Spring 0-25	19/4[d]	21/5	9/4	14/5	5/5	23/4
Fall 0-25	-	-	9/11	-	-	8/11
Spring deep	-	22/5	19/6	-	-	-
	Planting					
Corn	23/5	22/5	13/5	12/6	20/5	17/5
Soybean	23/5	22/5	13/5	6/6	-	29/5
Cover crop	1/10/01	8/10/02	4/10/03	-	10/9/02	-
	Herbicide application					
Burndown	5/5	8/5	3/5	-	30/4	-
	Gas sampling					
	18/6[a]	19/4	24/4	3/7[a]	15/5	28/4
	19/7[a]	3/5	7/6[c]	13/8[a]	29/5	9/6[c]
	18/8[a]	18/5	14/6[a]	3/9[b]	13/6	24/6[a]
	11/9[b]	1/6	26/6	3/10[b]	7/7	15/7
		14/6	12/7		28/8	27/7
		16/7[†]	27/7			11/8
		25/8	11/8			14/9
		9/10	25/8			
	Harvest					
Silage	12/9	17/9	14/9	3/10	7/10	11/10
Soy	28/9	11/10	8/10	5/9	-	14/9
Cover crop	8/5	9/5	5/5	-	5/5	-

[a] Samples were collected but not analyzed

[b] Samples were collected, analyzed, but not included in analysis

[c] Large gap between samplings is due to mechanical problems with gas chromatograph

[d] Dates expressed as day, month, year

Table 32. Date of manure and compost application, manure rates and analyses at East Lansing

	Manure					Compost				
	24/4/02[a]	13/12/02	8/4/03	6/12/03	6/4/04	24/4/02	4/12/02	8/4/03	6/12/03	6/4/04
	Mg/ha									
Rate	22.000	22.450	22.450	22.450	15.700	19.540	22.450	22.450	22.450	22.450
	%									
Carbon	43.1	14.72	13.05	14.52	16.61	24.55	21.7	18.9	11.91	10.75
Nitrogen	0.389	0.509	0.384	0.264	0.668	0.757	0.96	1.36	0.73	0.64
Phos.	0.084	0.067	0.085	0.077	0.103	0.373	0.38	0.52	0.17	0.17
Potasium	0.400	0.333	0.327	0.350	0.391	0.741	0.64	0.58	0.71	0.64
Moisture	72.16	71.96	75.63	71.96	68.59	59.11	36.24	69.56	64.36	68.76
Solids	27.84	28.04	24.37	28.04	31.41	40.89	63.76	30.44	35.64	31.24
C:N	110.80	28.93	33.98	55.00	24.87	32.43	22.6	13.9	16.32	16.8

[a] Dates expressed as day, month, year

Abbreviations: Phos, phosphorous

Table 33. Date of amendment application, rate and analyses at Chatham

	Manure			Compost		
	15/5/02[a]	6/5/03	2004	17/5/02	6/5/03	7/5/04
	Mg/ha					
Rate	8.220	3.870	5.670	41.770	8.980	8.980
	%					
Carbon	2.96	2.25	1.54	7.91	20.28	10.24
Nitrogen	0.256	0.224	0.239	0.516	0.543	0.429
Phos.	0.055	0.037	0.038	0.152	0.173	0.109
Potasium	0.213	0.173	0.120	0.160	0.449	0.129
Moisture	93.74	96.81	94.95	70.18	65.87	78.0
Solids	6.26	3.19	5.05	29.82	34.13	22.0
C:N	11.56	10.04	6.44	15.33	37.35	23.87

[a] Dates expressed as day, month, year

Abbreviations: Phos, phosphorous

Table 34. GHG flux from all inputs during crop production (adapted from West and Marland 2002)

Crop	Planting[a]	Seed	Spraying(x2)	Fertilizer	Harvest
	g CO_2 m^{-2}				
Corn	0.679	2.15	1.96	1.24	1.65
Soybean	0.679	2.03	1.96		1.65
Rye	0.679	1.93			

Amendment	Application	2002	2003	2004
	g CO_2 m^{-2}			
EL Manure	0.52	10.4[b]	9.9	4.1
EL Compost	0.52	2113.0[b]	1405.2	663.3
CH Manure	0.52	2.1	0.9	1.0
CH Compost	0.52	10.4	2.6	1.7

[a] Includes fuel used for production and transportation of all products

[b] Calculated using average values obtained from MWPS-18 (1985), and IPCC (1997)

Table 35. Average daily temperatures at East Lansing and Chatham, MI.

	East Lansing				Chatham[a]			
Month	2002	2003	2004	30 yr Avg	2002	2003	2004	30 yr Avg
	°C							
January	-0.8	-8.0	-8.4	-5.7	-5.9	-11.2	-4.4	-9.0
February	-1.1	-6.9	-4.8	-4.6	-5.7	-13.3	-6.6	-8.0
March	-0.5	0.6	3.7	0.8	-7.9	-6.4	-2.1	-3.5
April	9.0	7.8	9.5	8.1	2.3	1.8	3.0	4.1
May	11.2	12.6	14.8	14.2	7.4	9.9	9.2	10.6
June	20.5	17.3	18.0	19.4	16.7	16.5	14.3	15.4
July	22.8	20.9	20.3	21.5	20.9	18.3	16.3	18.6
August	21.1	21.3	18.4	20.6	18.3	19.1	15.5	17.9
September	18.6	16.0	17.9	16.7	15.5	15.9	16.3	13.5
October	8.3	9.2	10.1	10.6	3.3	7.3	7.8	8.3
November	2.5	5.1	4.4	3.7	-3.4	0.5	2.1	0.8
December	-2.8	-0.8	-2.5	-2.8	-5.4	-3.6	-4.8	-5.8

[a] Temperatures for 2002 and January-June 2003 at Chatham are from the NWS at Marquette, 30 miles NW of Chatham.

Table 36. Total monthly precipitation at East Lansing and Chatham, MI.

	East Lansing				Chatham[a]			
Month	2002	2003	2004	30 yr Avg	2002	2003	2004	30 yr Avg
	mm							
January	10.4	6.1	6.9	35.6	27.9	17.8	35.3	50.0
February	38.9	10.4	12.3	30.7	135.9	49.0	61.7	42.4
March	41.2	38.3	69.3	53.1	144.8	85.1	80.3	49.5
April	55.6	78.5	14.0	71.4	129.5	88.6	53.1	62.5
May	120.9	103.6	205.0	69.3	79.5	156.7	111.8	80.0
June	53.9	37.3	89.2	89.9	96.8	41.1	48.0	91.7
July	95.0	35.8	101.6	76.7	86.1	70.1	79.8	90.4
August	35.6	46.2	87.1	79.2	78.0	27.9	117.1	90.4
September	13.2	65.5	26.7	63.5	145.0	139.4	39.4	105.7
October	31.5	46.7	49.0	55.9	129.5	82.8	130.1	82.3
November	34.5	118.4	80.8	56.4	53.3	60.5	50.6	78.7
December	25.9	37.3	38.6	46.5	14.2	32.5	95.8	60.2

[a] Total monthly precipitation for 2002 and January-June 2003 at Chatham are from the NWS at Marquette, 30 miles NW of Chatham.

Table 37. ANOVA for soil temperature and moisture at East Lansing

Rot.	2003							2004					
Trt	19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
CSC							Temperature						
Amd	NS	NS	**	NS	NS	NS	NS	***	***	NS	***	***	***
Cover	NS	***	***	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Inter	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SCS													
Amd	NS	NS	NS	NS	NS	NS	NS	***	***	***	NS	**	**
Cover	NS	***	***	NS	NS	***	**	*		*	NS		
Inter	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
							Moisture						
CSC													
Amd	**	NS	NS	**	**	**	***	***	***	***	NS	***	**
Cover	NS	NS	NS	**	**	***	**	***	***	***	NS	NS	NS
Inter	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SCS													
Amd	***	NS	NS	**	**	***	**	***	***	NS	NS	**	NS
Cover	NS	NS	NS	***	NS	**	*	***	**	NS	NS	NS	NS
Inter	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS

[a] Dates expressed as day, month

CSC, corn-soybean-corn; C, compost; M, manure; U, untreated; RC, rye plus compost; RM, rye plus manure; R, rye; SCS, soybean-corn-soybean

Table 38. Main effect means for soil temperature at East Lansing

Rot.	2003							2004					
Trt	19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
CSC	°C												
Comp	8.00	10.3	15.9	11.9	18.8	20.4	13.0	11.4	20.5	18.8	25.9	21.8	20.9
Man	8.00	10.5	16.3	11.8	18.8	20.9	13.0	11.0	19.9	18.4	25.9	22.3	21.3
None	8.4	10.5	16.6	11.5	19.4	21.3	13.3	12.9	22.3	18.8	27.4	23.3	22.4
LSD	NS	NS	0.3	NS	NS	NS	NS	0.5	0.7	NS	0.3	0.4	0.4
None	8.1	10.0	15.9	11.6	19.1	20.9	13.0	11.8	20.9	18.6	26.3	22.3	21.6
Rye	8.2	10.8	16.6	11.8	18.8	20.8	13.2	11.8	20.8	18.7	26.5	22.5	21.4
LSD	NS	0.1	0.3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SCS													
Comp	9.5	8.6	13.4	17.5	16.1	21.4	11.5	13.4	21.8	20.6	22.9	19.3	18.4
Man	9.8	8.6	13.5	17.4	16.0	21.5	11.5	13.3	21.9	20.4	23.0	19.8	19.0
None	10.9	8.4	13.5	18.1	16.0	21.9	11.9	18.4	25.8	22.3	23.0	20.1	18.9
LSD	NS	NS	NS	NS	NS	NS	NS	0.3	0.6	0.4	NS	0.5	0.4
None	10.0	7.8	13.1	17.4	16.0	21.2	11.3	14.8	22.9	20.8	22.9	19.7	18.8
Rye	10.1	9.3	13.8	17.9	16.1	22.0	11.9	15.3	23.3	21.3	23.0	19.8	18.7
LSD	NS	0.3	0.2	NS	NS	0.4	0.2	0.3	NS	0.3	NS	NS	NS

[a] Dates expressed as day, month

CSC, corn-soybean-corn; C, compost; M, manure; U, untreated; RC, rye plus compost; RM, rye plus manure; R, rye; SCS, soybean-corn-soybean

Table 39. Main effect means for soil moisture at East Lansing

Rot.	2003							2004						
Trt	19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
CSC	% moisture volume													
Comp	30.0	31.1	27.4	31.3	27.6	29.4	28.9	24.7	25.8	29.7	31.5	29.2	29.9
Man	30.5	30.5	28.8	29.6	27.8	28.9	28.5	24.8	25.6	29.6	30.8	28.9	29.7
None	27.4	30.6	27.0	28.8	25.0	27.0	26.3	22.8	24.3	28.4	30.4	28.1	29.0
LSD	0.2	NS	NS	0.4	0.4	0.4	0.2	0.5	0.7	0.6	NS	0.4	0.4
None	29.2	30.8	26.9	29.0	25.8	27.4	27.0	23.7	24.8	28.9	30.8	28.6	29.4
Rye	29.4	30.8	28.5	30.8	27.8	29.4	28.8	24.5	25.7	29.5	31.0	28.8	29.7
LSD	NS	NS	NS	0.4	0.3	0.3	0.2	0.5	0.6	0.5	NS	NS	NS
SCS													
Comp	29.4	32.0	30.1	29.0	28.9	29.1	28.8	24.6	24.4	26.4	31.2	27.4	28.4
Man	29.4	31.6	30.1	30.0	29.5	29.8	29.8	24.6	24.4	26.5	31.1	27.3	28.3
None	26.8	30.8	30.9	27.8	27.0	27.5	27.4	23.4	22.6	26.0	30.4	26.5	27.8
LSD	1.0	NS	NS	0.9	1.1	0.8	0.8	0.3	0.6	0.4	NS	0.5	NS
None	28.8	31.5	30.2	27.8	28.1	28.1	28.1	23.7	23.5	26.1	31.1	27.0	28.2
Rye	28.3	31.4	30.6	30.1	28.8	295	29.2	24.7	24.1	26.6	30.8	27.2	28.2
LSD	NS	NS	NS	0.8		0.7	0.6	0.3	0.5	0.3	NS	NS	NS

[a] Dates expressed as day, month

CSC, corn-soybean-corn; C, compost; M, manure; U, untreated; RC, rye plus compost; RM, rye plus manure; R, rye;
SCS, soybean-corn-soybean

Table 41. ANOVA for soil GHG flux at East Lansing

		2003							2004					
CSC		19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
Gas	Factor													
N_2O	Amd	***	**	NS	NS	**	**	NS	NS	NS	NS	NS	NS	*
	Cover	NS	***	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Inter	NS	**	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
CO_2	Amd	***	***	***	***	***	***	*	NS	***	**	***	***	*
	Cover	***	***	***	**	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Inter	NS	**	**	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
CH_4	Amd	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
	Cover	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Inter	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SCS														
N_2O	Amd	NS	*	*	*	*	NS	**	NS	*	*	*	***	NS
	Cover	NS	***	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Inter	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CO_2	Amd	**	***	***	***	***	**	*	NS	**	NS	***	**	*
	Cover	**	***	***	*	*	**	NS	NS	NS	NS	*	NS	NS
	Inter	NS	**	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CH_4	Amd	NS	NS	NS	NS	***	NS	NS	NS	NS	NS	NS	*	NS
	Cover	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Inter	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] Dates expressed as day, month

*=$P<0.05$, **=$P<0.01$, ***=$P<0.001$

CSC, corn-soybean-corn; SCS, soybean-corn-soybean

Table 42. Main effect means for CO_2-C flux at East Lansing

Rot.	2003							2004					
Trt	19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
CSC	----------------------------						-kg CO_2-C ha^{-1} day^{-1}-						----------------------------
Comp	7.0	19.2	42.3	7.0	16.9	32.2	15.3	0.3	12.5	16.2	38.0	18.3	8.8
Man	37.0	64.3	118.8	38.4	51.3	65.2	25.4	0.4	25.2	32.1	58.5	32.2	15.3
None	14.4	28.0	62.1	8.6	19.6	39.6	25.6	0.5	9.2	12.4	37.8	20.8	12.0
LSD	5.5	11.2*	20.0*	8.4	4.1	7.6	5.5	NS	2.3	7.0	6.0	4.5*	NS
None	13.4	11.7	22.5	12.5	28.2	43.3	23.2	0.6	14.5	17.5	42.9	23.2	12.7
Rye	25.6	62.6	126.3	23.6	30.4	48.0	21.0	0.2	16.7	23.0	46.7	24.4	11.4
LSD	5.2	9.8*	17.7*	7.5	NS	NS	NS	NS	NS	NS	NS	NS*	NS
SCS													
Comp	12.7	4.6	13.6	11.5	15.6	47.2	19.7	-1.6	18.4	16.0	28.6	13.4	8.2
Man	35.1	26.3	85.6	53.6	43.9	72.0	33.3	3.1	26.6	22.1	38.6	17.1	10.5
None	22.5	15.6	48.9	31.7	29.2	56.6	34.4	0.4	13.2	14.8	21.7	10.6	7.9
LSD	8.8	4.2*	14.5*	10.0	5.4	8.2	7.2	NS	4.6	NS	3.9	2.2	1.3
None	13.9	6.1	20.0	24.7	25.6	50.6	30.8	-0.1	18.0	16.0	27.0	12.8	8.2
Rye	32.9	24.9	78.8	39.9	33.6	66.6	27.4	1.3	20.8	19.3	32.3	14.5	9.5
LSD	7.2	3.5*	11.8*	7.9	4.4	6.7	NS	NS	NS	NS	3.2	NS	NS

[a] Dates expressed as day, month

*Interaction of main effects was significant

CSC, corn-soybean-corn; C, compost; M, manure; U, untreated; RC, rye plus compost; RM, rye plus manure; R, rye; SCS, soybean-corn-soybean

Table 43. Interaction means for CO_2-C flux at East Lansing

Rot.	2003							2004					
Trt	19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
CSC	kg CO_2-C ha^{-1} day^{-1}												
C	3.88	3.42	13.38	3.10	14.40	27.29	16.18	0.69	11.64	14.03	36.41	19.08	8.77
M	28.91	25.76	41.52	30.45	54.42	64.98	28.52	0.76	22.49	28.65	53.98	27.60	15.13
U	7.32	5.96	12.56	3.91	15.72	37.76	24.93	0.40	9.56	9.97	38.22	22.80	14.12
RC	10.14	34.91	71.18	11.00	19.49	37.09	14.46	-0.11	13.31	18.46	39.57	17.59	8.84
RM	45.08	102.75	196.17	46.36	48.10	65.51	22.35	0.12	27.94	35.60	63.07	36.82	15.47
R	21.44	50.07	111.55	13.34	23.52	41.41	26.32	0.66	8.87	14.91	37.42	18.84	9.89
LSD	NS	19.1	32.4	NS	NS	NS	NS	NS	NS	NS	NS	6.9	NS
SCS													
C	8.48	2.67	6.90	7.94	12.30	37.88	20.86	-0.97	17.11	19.78	26.63	13.31	8.09
M	21.63	11.97	37.48	46.91	41.38	63.31	33.96	1.15	24.12	16.57	36.63	16.57	10.57
U	11.61	3.76	15.56	19.12	23.00	50.56	37.56	-0.29	12.83	11.50	17.64	8.66	6.05
RC	17.00	6.59	20.27	15.02	18.89	56.47	18.60	-2.16	19.67	12.30	30.50	13.50	8.23
RM	48.50	40.72	133.76	60.19	46.47	80.67	32.56	5.00	29.02	27.67	40.61	17.57	10.40
R	33.30	27.42	82.28	44.37	35.45	62.72	31.14	1.13	13.55	18.00	25.86	12.53	9.72
LSD	NS	8.5	28.9	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] Dates expressed as day, month

CSC, corn-soybean-corn; C, compost; M, manure; U, untreated; RC, rye plus compost; RM, rye plus manure; R, rye; SCS, soybean-corn-soybean

Table 44. Main effect means for N_2O-N flux at East Lansing

Rot.	2003							2004					
Trt	19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
CSC	-- g N_2O-N ha^{-1} day^{-1} --												
Comp	2.8	7.1	15.8	17.4	6.7	3.2	1.1	0.5	7.7	22.8	-	17.0	1.8
Man	15.5	20.5	7.3	12.2	9.6	3.3	1.3	0.6	7.3	33.1	-	26.0	4.2
None	2.2	2.2	2.5	2.4	1.6	1.2	1.2	0.2	3.7	8.5	-	27.6	1.7
LSD	4.3	5.7*	NS	NS	3.1	1.0	NS	NS*	NS	NS	-	NS	1.5
None	5.9	18.9	10.0	8.8	6.9	2.5	1.3	0.5	6.9	30.2	-	22.5	2.8
Rye	7.8	0.9	7.0	12.5	5.1	2.6	1.0	0.4	5.6	12.8	-	22.6	2.4
LSD	NS	4.7*	NS	NS	NS	NS	NS	NS*	NS	NS	-	NS	NS
SCS													
Comp	12.7	8.2	10.1	10.2	6.4	8.0	1.5	-2.6	5.0	7.4	2.6	1.8	0.8
Man	15.4	5.7	5.6	12.4	5.3	20.9	2.2	-3.5	10.8	22.1	5.1	2.0	0.8
None	4.7	2.7	2.6	5.5	2.5	14.8	2.7	1.9	4.1	8.0	2.8	0.1	0.4
LSD	6.2	2.5	4.0	3.5	2.4	NS	0.7	NS	3.8	8.1	1.8	1.2	NS
None	8.0	9.4	7.2	7.7	4.3	15.7	2.3	1.6	7.6	9.0	3.7	1.2	0.6
Rye	13.8	1.7	4.9	11.1	5.1	13.5	1.9	-4.4	5.6	15.9	3.4	1.3	0.7
LSD	NS	2.1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] Dates expressed as day, month

CSC, corn-soybean-corn; C, compost; M, manure; U, untreated; RC, rye plus compost; RM, rye plus manure; R, rye;
SCS, soybean-corn-soybean

Table 45. Interaction means for N_2O-N flux at East Lansing

Rot.	2003							2004					
Trt	19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
CSC	g N_2O-N ha^{-1} day^{-1}												
C	2.89	13.70	18.73	13.25	6.92	3.51	1.10	0.70	9.15	30.85	-	16.66	2.04
M	13.47	38.99	8.09	11.56	12.59	3.13	1.56	1.12	5.76	46.56	-	20.91	3.96
U	1.46	4.07	3.31	1.59	1.25	0.92	1.31	-0.44	5.68	13.14	-	29.83	2.31
RC	2.66	0.41	12.80	21.46	6.54	2.91	1.07	0.33	6.20	14.70	-	17.42	1.51
RM	17.62	2.03	6.53	12.87	6.66	3.41	0.99	0.08	8.92	19.70	-	31.01	4.51
R	3.01	0.28	1.70	3.18	1.98	1.53	1.08	0.76	1.76	3.91	-	25.35	1.06
LSD	NS	11.4	NS	NS	NS	NS	NS	1.1	NS	NS		NS	NS
SCS													
C	7.81	12.83	10.82	9.57	5.04	4.20	1.43	1.55	5.70	7.04	2.99	2.10	0.81
M	12.84	10.23	7.05	8.67	5.62	29.20	2.52	1.44	11.37	9.33	5.45	1.94	0.78
U	3.48	5.08	3.73	4.78	2.29	13.57	3.05	1.78	5.67	10.71	2.70	-0.31	0.29
RC	17.64	3.63	9.19	10.80	7.81	11.77	1.55	-6.73	4.29	7.69	2.29	1.52	0.88
RM	17.95	1.25	4.19	16.21	4.96	12.59	1.85	-8.36	10.17	34.85	4.85	1.97	0.78
R	5.91	0.25	1.42	6.23	2.62	16.04	2.39	1.94	2.49	5.27	2.95	0.47	0.58
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] Dates expressed as day, month

CSC, corn-soybean-corn; C, compost; M, manure; U, untreated; RC, rye plus compost; RM, rye plus manure; R, rye;
SCS, soybean-corn-soybean

Table 46. Main effect means for CH_4-C flux at East Lansing

Rot.	2003							2004					
Trt	19-4[a]	3-5	18-5	1-6	14-6	25-8	9-10	24-4	7-6	26-6	12-7	27-7	11-8
CSC	g CH_4-C ha^{-1} day^{-1}												
Comp	-0.5	-0.6	-0.4	0.2	1.2	-0.5	-2.2	0.1	4.1	-3.7	-	-0.9	-0.7
Man	3.4	-0.7	-0.2	0.6	2.0	-1.0	-1.5	0.1	5.5	-1.6	-	1.3	-1.0
None	0.4	-0.7	-0.3	-0.1	1.1	-0.3	-3.1	-0.1	0.2	-2.0	-	-0.9	-1.7
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	1.6	NS
None	1.2	-0.8	-0.4	-0.1	1.3	-0.8	-2.3	0.1	1.5	-3.1	-	-0.7	-1.4
Rye	1.1	-0.5	-0.2	0.4	1.5	-0.4	-2.2	0.1	5.0	-1.7	-	0.4	-0.9
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	NS
SCS													
Comp	2.3	-0.3	-0.2	-0.5	-0.4	0.5	-.6	-0.7	-4.1	-4.6	-	0.7	0.2
Man	0.7	-0.2	-0.1	0.2	0.7	1.2	-1.8	0.2	-6.7	-0.4	-	0.2	0.1
None	-1.2	-0.2	-0.4	-0.3	-0.2	0.3	-2.0	-0.2	-4.8	-2.3	-	-1.4	0.3
LSD	NS	NS	NS	NS	0.5	NS	NS	NS	NS	NS	-	1.6	NS
None	0.1	-0.1	-0.3	-0.1	-0.2	0.5	-1.7	-0.1	-5.6	-0.8	-	-0.2	-0.1
Rye	1.1	-0.4	-0.1	-0.4	0.2	0.8	-1.9	-0.4	-4.8	-4.0	-	-0.2	0.5
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	NS

[a] Dates expressed as day, month

CSC, corn-soybean-corn; C, compost; M, manure; U, untreated; RC, rye plus compost; RM, rye plus manure; R, rye; SCS, soybean-corn-soybean

Table 47. Treatment means for N_2O-N, CO_2-C, and CH_4-C at Chatham in 2003 and 2004

Rot.	2003					2004					
Trt	15-5[a]	29-5	13-6	3-7	28-8	28-4	10-6	15-7	27-7	11-8	14-9
	g N_2O-N ha^{-1} day^{-1}										
CC-U	4.17	8.97	4.46	5.72	2.17	0.75	2.90	0.77	4.12	2.42	1.43
CC-C	5.79	2.03	7.78	8.50	2.40	11.78	1.79	4.27	5.47	3.47	3.13
CC-M	11.62	11.94	9.71	13.01	1.68	3.22	4.86	4.51	4.89	2.57	2.51
SC-R	4.87	2.74	6.89	11.15	2.71	0.33	7.43	0.29	1.20	0.60	0.29
SC-C	4.29	19.82	10.39	13.51	1.95	5.28	6.49	1.22	2.61	3.13	1.40
SC-M	9.80	11.18	7.35	19.81	1.93	2.21	4.35	0.92	1.32	1.10	1.18
LSD	NS	NS	NS	7.1	NS	NS	NS	2.6	NS	NS	1.3
	kg CO_2-C ha^{-1} day^{-1}										
CC-U	10.75	16.56	16.49	14.24	8.72	10.21	2.32	2.55	9.55	17.58	16.07
CC-C	8.57	5.15	18.34	13.91	10.10	11.70	2.47	6.67	10.96	17.20	18.06
CC-M	15.97	19.41	20.00	16.37	11.14	15.07	3.57	8.83	11.52	23.10	20.44
SC-R	23.76	8.65	23.91	17.13	10.48	7.44	3.62	4.61	13.46	27.50	16.14
SC-C	21.31	20.06	34.60	18.07	10.96	15.21	2.51	5.02	15.51	18.97	23.87
SC-M	25.50	25.77	29.04	17.42	9.51	9.88	5.38	5.42	15.34	30.08	20.71
LSD	NS	NS	NS	NS	NS	NS	2.6	NS	NS	NS	4.2
	g CH_4-C ha^{-1} day^{-1}										
CC-U	-1.51	-0.63	-1.88	-1.25	-3.65	0.35	-0.12	1.13	-4.29	-2.26	-2.52
CC-C	-1.24	-0.41	-2.27	-1.64	-3.15	2.44	-0.06	-1.07	-3.35	-2.97	-2.76
CC-M	-1.49	-1.09	-2.05	-1.85	-3.59	1.06	-0.05	0.94	-5.10	-4.61	-3.71
SC-R	-1.88	-1.22	-2.70	-1.75	-3.60	-0.65	-0.22	-1.50	-5.51	-1.73	-6.07
SC-C	-4.28	-0.94	-2.45	-1.08	-3.54	5.73	-0.19	-3.22	-3.46	-2.59	-2.71
SC-M	-1.59	-1.24	-1.79	-1.03	-3.44	2.99	-0.19	-2.49	-5.42	-4.16	-6.98
LSD	NS	NS	NS	NS	NS	NS	0.1	2.9	NS	NS	NS

[a] Dates expressed as day, month, year

CC, continuous corn; U, untreated; C, compost; M, manure; SC, soybean-corn

Table 48. ANOVA and main effect means for Soil C GWP, soil GHG flux, input GHG flux, and net GWP at East Lansing

	CSC						SCS					
Trt	Soil C GWP[a]	Res. C	Soil GHG flux[c]	Input GHG flux[d]	Net GWP[e]	Net GWP NR[f]	Soil C GWP	Res. C	Soil GHG flux	Input GHG flux	Net GWP	Net GWP NR
ANOVA												
Amd	***	***	***	-	***	**	***	***	***	-	***	*
Cover	NS	*	***	-	*	**	NS	NS	***	-	*	*
Inter	NS	NS	NS	-	NS	NS	NS	NS	NS	-	NS	*
MEANS	g CO_2 m^{-2} y^{-1}											
Compost	-2212[b]	-1203	1099	1405	-912	292	-1999	-1358	988	1404	-964	394
Manure	-1248	-2157	2678	19	-708	1449	-1006	-2406	2234	19	-1159	1247
None	-37	-272	1335	11	1037	1309	36	-482	1459	10	1022	1505
LSD	823	295	293	-	782	768	528	449	220	-	556	618
None	-1183	-1042	1261	477	-488	555	-977	-1286	1217	476	-570	716
Rye	-1148	-1379	2147	479	99	1478	-1002	-1545	1904	479	-164	1381
LSD	NS	251	265.6	-	749	711	NS	NS	180	-	524	534

[a] Soil GWP is the potential for soil sequestration of carbon with that specific treatment compared to Untreated

[b] Negative values indicate mitigation of GHG

[c] Total annual flux of GHG from the soil surface in CO_2 equivalents

[d] Average annual flux of GHG from inputs

[e] Net warming or mitigation potential (Soil C GWP + Soil GHG flux + Input GHG flux + Residual carbon – Sequestered carbon)

[f] Net GWP NR, GWP for treatment without considering residue carbon on soil surface

Table 49. Interaction means at East Lansing and treatment means at Chatham for Soil C GWP, Res.C, Soil GHG flux, Input GHG flux, Net GWP, and Net GWP NR.

	CSC						SCS					
Trt[a]	Soil C GWP[b]	Res. C	Soil GHG flux[d]	Input GHG flux[e]	Net GWP[f]	Net GWP NR[g]	Soil C GWP	Res. C	Soil GHG flux	Input GHG flux	Net GWP	Net GWP NR
	g CO_2 m^{-2} y^{-1}											
C	-2462[c]	-1004	821	1404	-1242	-237	-1666	-1534	877	1403	-920	614
M	-1086	-1842	2030	18	-880	962	-1265	-1971	1727	17	-1492	479
U	0	-280	930	9	659	939	0	-353	1047	9	703	1056
RC	-1961	-1403	1376	1406	-582	821	-2331	-1183	1099	1410	-1009	174
RM	-1410	-2472	3326	20	-536	1936	-747	-2841	2741	20	-827	2015
R	-73	-263	1740	12	1415	1678	71	-611	1871	12	1342	1953
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	1082
Chatham												
CC-U	0	0	1206	10	-	1216						
CC-C	-1825	0	1183	15	-	-627						
CC-M	-28	0	1615	12	-	1599						
SC-R	-81	0	1499	11	-	1429						
SC-C	-1809	0	1821	16	-	28						
SC-M	-670	0	1876	12	-	1218						
$LSD_{(0.05)}$	-2529	-	410	-	-	NS						

[a] U, untreated; C, compost; M, manure; R, rye

[b] Soil GWP is the potential for soil sequestration of carbon with that specific treatment compared to Untreated

[c] Negative values indicate mitigation of GHG

[d] Total annual flux of GHG from the soil surface in CO_2 equivalents

[e] Average annual flux of GHG from inputs

[f] Net warming or mitigation potential (Soil C GWP + Soil GHG flux + Input GHG flux + Residual carbon – Sequestered carbon)

[g] Net GWP NR, GWP for treatment without considering residue carbon on soil surface

Table 50. ANOVA and main effect means for specific contribution of CO_2-C, N_2O-N and CH_4-C to total annual GHG flux.

	CSC			SCS		
Factor	CO_2-C	N_2O-N	CH_4-C	CO_2-C	N_2O-N	CH_4-C
Amendment	**	**	NS	*	*	NS
Cover	***	***	*	*	*	NS
Interaction	NS	NS	NS	NS	NS	NS
Factor	% CO_2 equivalents					
Compost	93.19	6.88	-0.07	95.92	4.20	-0.12
Manure	96.12	3.84	0.04	97.16	2.87	-0.03
None	96.57	3.54	-0.11	97.75	2.39	-0.14
LSD	1.41	1.40	NS	1.19	1.17	NS
None	93.47	6.63	-0.10	96.28	3.83	-0.11
Rye	97.12	2.87	0.01	97.61	2.48	-0.09
LSD	1.15	1.14	0.09	1.06	1.03	NS

Table 51. Means for specific contribution of CO_2, N_2O and CH_4 to annual GHG flux at Chatham.

Trt	CO_2	N_2O	CH_4
	%		
CC-U	96.96	3.30	-0.26
CC-C	96.30	3.95	-0.25
CC-M	96.07	4.16	-0.23
SC-U	97.61	2.70	-0.31
SC-C	96.37	3.83	-0.20
SC-M	97.07	3.17	-0.24
LSD	0.99	0.97	NS

Literature Cited

Bloom, P.R., W.M. Schuh, G.L. Malzer, W.W. Nelson, and S.D. Evans. 1982. Effect of N fertilizer and corn residue management on organic matter in Minnesota Mollisols. Agron. J. 74:161-163.

Bremner, J.M. 1997. Sources of nitrous oxide in soils. Nutr. Cycling Agroecosyst. 49:7-16.

Bremner. J. M. and A.M. Blackmer. 1981. Terrestrial nitrification as a source of atmospheric nitrous oxide. *In* Denitrification, nitrification, and atmospheric oxide, C. C. Delwiche, ed. Pp 151-170. John Wiley, New York, New York.

Castellanos, J.Z. and P.F. Pratt. 1981. Mineralization of manure nitrogen-correlation with laboratory indexes. Soil Sci. Soc. Am. J. 45:354-357.

Christensen, S. and J.M. Tiedje. 1990. Brief and vigorous N_2O production by soil at spring thaw. J. Soil Sci. 41:1-4.

Council for Agricultural Science and Technology (CAST). 2004. Climate change and Greenhouse Gas Mitigation: Challenges and Opportunities for Agriculture. Ames, IA.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396:262-265.

Goodroad, L.L, D.R. Keeney, and L.A. Peterson. 1984. Nitrous oxide emissions from agricultural soils in Wisconsin. J. Environ. Qual. 13:557-561.

Hao, X., C. Chang, F. Larney, and G.R. Travis. 2001. Greenhouse gas emissions during cattle feedlot manure composting. J. Environ. Qual. 30:376-386.

Hao, X., C. Chang, and F. J. Larney. 2004. Carbon, nitrogen balances and greenhouse gas emission during cattle feedlot manure composting. J. Environ. Qual. 33:37-44

Havlin, J.L, D.E. Kissel, L.D. Maddux, M.M. Claasen, and J.H. Long. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J 54:448-452.

Holland, H.D. 1978. The chemistry of the atmosphere and oceans. John Wiley & Sons, New York, NY.

Huggins, D.R., C.E. Clapp, R.R. Allmaras, J.A. Lamb, and M.F. Layese. 1998. Carbon dynamics in corn-soybean sequences as estimated from natural carbon-13 abundance. SSSAJ 62:195-203.

Intergovernmental Panel on Climate Change (IPCC). 1997. Revised 1996 IPCC guidelines for national greenhouse gas inventories: Reference Manual. Organization fro Economic Corporation and Development (OECD) and the International Energy Agency (IEA) Paris.

Izaurralde, R.C., R.L. Lemke, T.W. Goddard, B. McConkey, and Z.Zhang. 2004. Nitrous oxide emissions from agricultural toposequences in Alberta and Saskatchewan. Soil Sci. Soc. Am. J. 68:1285-1294.

Janzen, H.H., C.A. Campbell, S.A. Brandt, G.P. Lafond, and L. Townley-Smith. 1992. Light-fraction organic matter in soils from long-term crop roations. SSSAJ 56:1799-1806.

Lal, R., J.M. Kimble, R.F. Follett, C.V. Cole. The potential of US cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Ann Arbor Press. Chelsea, MI. 1999.

McKenney, D.J., S.W. Wang, C.F. Drury, W.I. Findlay. 1993. Denitrification and mineralization in soil amended with legume, grass and corn residues. Soil Sci. Soc. Am. J. 57:1013-1020.

Midwest Plan Service. 1985. Livestock waste facilities handbook.

Paustian, K., W.J. Parton, and J. Persson. 1992. Modeling soil organic matter in organic-amended and N-fertilized long-term plots. SSSAL 56:476-488.

Post, W.M., T.H. Peng, W.R. Emanuel, A.W. King, V.H. Dale, and D.L. DeAngelis. 1990. The global carbon cycle. Am Sci. 78:310-326.

Post, W.M., W.R. Emanuel, and A.W. King. 1992. Soil organic matter dynamics and the global carbon cycle. In: N.H. Batjes and E.M. Bridges (eds.), World inventory of soil emission potentials. International soil reference information center, Wageningen, The Netherlands.

Robinson, C.A., R.M. Cruse, and M. Ghaffarzadeh. 1996. Cropping system and nitrogen effects on mollisol organic carbon. SSSAJ 60:264-269.

Rochette, P., D.A. Angers, G. Belanger, M.H. Chantigny, D. Prevost, and G. Levesque. 2004. Emissions of N2O from alfalfa and soybean crops in eastern Canada. Soil Sci. Soc. Am. J. 68:493-506.

Sanchez, J.E., R.R. Harwood, T.C. Willson, K. Kizilkaya, J. Smeenk, E. Parker, E.A. Paul, B.D. Knezek, and G.P. Robertson. 2004. Managing soil carbon and nitrogen for productivity and environmental quality. Agron. J. 96:769-775

Schlesinger, W.H. 1984. Soil organic matter: A source of atmospheric CO2. pp. 111-127. *In*: G.M. Wooddwell (ed.) The role of Terrestrial Vegetation in the Gloal Carbon Cycle. John Wiley & Sons, New York, NY.

Wallace, A., G.A. Wallace, and J.W. Cha. 1990. Soil organic matter and the global carbon cycle. J. Plant Nutr. 13:459-466, US Congress 1991.

Warneck, P. 1988. Chemistry of the natural atmosphere. Academic press, London, England.

West, T.O. and G. Marland. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agric. Eco. Env. 91:217-232.