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MANAGEMENT OF CROPPING SYSTEM AND COMPOST ADDITIONS FOR ENHANCED NITROGEN AVAILABILITY AND CARBON SEQUESTRATION

presented by

Ann-Marie Fortuna

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Crop and Soil Sciences

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MANAGEMENT OF CROPPING SYSTEM AND COMPOST ADDITIONS FOR ENHANCED NITROGEN AVAILABILITY AND CARBON SEQUESTRATION

By

Ann-Marie Fortuna

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Crop and Soil Sciences

2001

ABSTRACT

MANAGEMENT OF CROPPING SYSTEM AND COMPOST ADDITIONS FOR ENHANCED NITROGEN AVAILABILITY AND CARBON SEQUESTRATION

By

Ann-Marie Fortuna

The uniformity, low cost and ease of application associated with inorganic fertilizers have diminished the use of organic nutrient sources. Concern for food safety, the environment and the need to dispose of animal and municipal wastes have focused attention on organic sources of N such as animal derived amendments, green manures, and crop rotations. Providing nutrients to row crops from organic sources demands intensive management of the N and C cycles. Managing organic N sources to provide sufficient N at the grand phase of crop growth requires knowledge of C and N decomposition over several years particularly where manure and compost is applied. Management practices of this trial included: a comparison of compost and chemical fertilizer, use of a corn-corn-soybean-wheat rotation compared to continuous corn and the addition of a cover crop within each cropping system. Management strategies that reduced potential nitrification rates without limiting plant available N tended to increase plant biomass to N content (PNC), the above ground net primary productivity (ANPP) per unit of N in ANPP, and decrease the amount of NO_3^- available for leaching, and/or conversion to N_2O. Nitrification potentials of integrated-compost

treatments were 25% lower than integrated-fertilizer treatments during 1998 and 1999. Integrated-compost increased plant PNC (104 - 137 g g^{-1} N) above that of integrated-fertilizer (88 g g^{-1} N). Lowered soil N levels in compost managements decreased nitrification potential and the potential for NO_3^- leaching but diminished corn yield in some treatments and may have reduced grain quality.

Soil samples were taken in April prior to tillage from a 0-25 cm depth in the 2nd (1994) and 6th year (1998) of the experiment. These soils were used to conduct N (150 d) and C incubations (320 d) to determine the effect of cropping system and nutrient management on: N mineralization potential (NMP), the mineralizable organic N pool (No), the mean residence time (MRT) of No, C mineralization (C_{min}), and soil organic carbon (SOC) pool sizes and fluxes. Compost applications increased the resistant pool of C by 30% and the slow pool of C by 10%. The compost treatment contained 10% greater soil organic C than the fertilizer management. Nitrogen was limiting on all compost treatments with the exception of 1st y corn following wheat fallow and clover cover crop. The added diversity of the clover cover crop and wheat-fallow increased inorganic N in both nutrient managements. We recommend that growers adjust their N fertilizer recommendation to reflect the quantity and timing of N mineralized from organic N sources. Proper management of nutrients from compost, cover crops and rotations can maintain soil fertility, improve soil quality, and increase C sequestration.

ACKNOWLEDGMENTS

I thank Dr.s Dick Harwood and Eldor Paul for their dedication, support, and friendship without which this doctorate degree would not have been possible. I thank my committee members Dr.s: Joe Ritchie, Nathaniel Ostrom, Eldor Paul, and Dick Harwood for standing by me. It has been a pleasure to work with you on a professional and personal level. I extended my gratitude once again to all my teachers past and present, who have given me the encouragement and inspiration to push my abilities to the limit and pursue my dreams.

Special thanks to the Mottly Crew: Anne Conwell, Elaine Parker, Jose Sanchez, Jeff Smeenk, and Tom Willson for there bad jokes, interest, and support and all of the students who have worked for me. I would like to thank the C.S. Mott Chair of Sustainable Agriculture, Michigan State Agricultural Experiment Station and the USDA for their financial support without which this research would not have been possible.

The author also wishes to thank her parents, Shirley and Roger Fortuna, and grandparents, Helen and Edgar Roccati and Roger and Marguerite Fortuna for their love and support throughout the years. Special thanks to her brother; Roger Fortuna who has been a tremendous influence in her life.

Past things shed light on future ones; the world was always of a kind; what is and will be was at some other time; the same things come back, but under different names and colors; not everybody recognizes them, but only he who is wise and considers them diligently. – Francesco Guicciardini

PREFACE

Chapter 1 written in publication format for *Agriculture, Ecosystems, and Environment*

Chapter 2 written in publication format for *Soil Biology and Biochemistry*

Chapter 3 written in publication format for *Soil Science Society of America Journal*

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CHAPTER 1

SEASONAL CHANGES IN NITRIFICATION POTENTIAL UNDER SUSTAINABLE MANAGEMENT SYSTEMS.

ABSTRACT

Nitrification potential is the maximum capacity of a soil's population of nitrifying bacteria to transform NH_4^+ -N to NO_3^- -N. Management strategies that reduce potential nitrification rates without limiting plant available N may increase plant biomass to N content (PNC), the aboveground net primary productivity (ANPP) per unit of N in ANPP, and decrease the amount of NO_3^- available for leaching, and/or conversion to N_2O. The current study was designed to compare the effect of several sustainable management practices on nitrification potentials. These practices include: substitution of compost for N fertilizer, use of a rotation in place of continuous corn and the addition of cover crops. We also used a previously tilled, successional grassland as a contrast. Under fertilizer management, nitrification potential increased until late May, decreased during the summer, and increased again in late August to early fall. The seasonal pattern was similar but less pronounced where compost was applied. Average nitrification rates in the fertilizer management were 42 to 75% greater than that of the successional site. Nitrification potentials on integrated-compost treatments were 25% lower than integrated-fertilizer treatments during 1998 and 1999 in the 6^{th} and 7^{th} years of the rotation. In some instances, nitrification potentials could be correlated with in

situ NO_3^--N measurements. Average PNCs were equivalent in the continuous corn integrated-fertilizer treatment (94 g g^{-1} N) and successional grassland site (83 g g^{-1} N). Integrated-compost (137- 104 g g^{-1} N) and low-input managements (142- 98 g g^{-1} N) increased PNC. Utilization of compost decreased nitrification potentials, maintained yields, and increased PNC. Grain quality should be monitored where compost is applied due to lowered crop N content.

INTRODUCTION

Management strategies that affect the quantity, timing, and location of plant-available N modify nitrification rates in the field (Boehm and Anderson, 1997; Malhi and McGill, 1982). Potential nitrification rates calculated from laboratory incubations are sensitive to changes in field management and can provide rapid, qualitative information about in situ nitrification rates. Several incubation techniques using various NH_4^+ concentrations and optimum temperature and pH have been employed to measure the change in nitrification due to variation in cropping, fertilizer, and tillage systems (Berg and Rosswall, 1985; Chantigny et al., 1996; Kandeler and Böhm, 1996; Kandeler et al., 1999). Incubation time is typically no longer than 24hr. It is assumed that the nitrifier community structure and population size do not change significantly during the 24hr incubation period. Therefore, nitrification potentials should reflect management-induced changes and the legacy of substrate availability in situ.

Nitrogen fertilizer management has been shown to be the most significant factor affecting nitrification rates (Chantigny et al., 1996; Berg and Rosswall, 1985). Management practices that result in high soil ammonium levels increase nitrification potentials. In addition, N fertilizer increases plant biomass that may lead to greater total soil N and C over time (Gregorich et al., 1996; Franzluebber et al., 1994; Campbell et al., 1991). Soils with greater residue returns and/or total soil N may mineralize more N. Mineralized N can undergo nitrification, contributing to elevated nitrification potential.

The choice of cropping system affects the quantity, quality and C:N ratio of residues returned, as well as, the turnover and amount of N released. Boehm and Anderson (1997) reported lowered labile C, N mineralization levels in incubations, and nitrification potentials in a crop-fallow when compared to that of continuous cropping systems. The period of N release and amount of inorganic N supplied by annual and perennial systems are unequal due to differences in the timing of maximum annual net primary productivity (ANPP) and the complete senescence of annuals.

The quantity of labile C affects nitrifier activity. The presence of wheat residue has been shown to immobilize N early in the growing season, lowering both N mineralization and nitrification rates (Recous et al., 1999). Use of manure with a low C:N ratio and soluble forms of N affect nitrification potentials. Application of manure in place of N fertilizer increased nitrification potentials (Chao et al., 1996). Greater tillage intensity has been shown to decrease the quantity of labile soil C and N resulting in lowered N mineralization and nitrification potentials during subsequent laboratory incubations (Boehm and

Anderson, 1997). Nitrification potentials under reduced tillage, such as chisel-plowing, fell between that of mold-board plow and no-till.

Management strategies that reduce nitrification rates without limiting plant available N may result in greater plant biomass to N content (PNC) the amount of biomass produced per unit of available N. Grassland systems have been shown to have higher PNC than agricultural systems (Groffman et al., 1986). Lowered nitrification potentials can be used as an indicator of a management practice's ability to enhance system N use efficiency.

Agricultural systems that decrease nitrification rates and minimize the amount of inorganic N in the soil without limiting yield provide economic and environmental benefit. Crop rotations, cover crops, and compost applications affect the quantity and timing of nitrification. Elevated soil NO_3^- levels are in part the result of high nitrification rates. Excess NO_3^- is available for leaching into ground or surface waters and/or conversion to N_2O, a greenhouse gas. Plants are able to utilize either form of inorganic N, NH_4^+ or NO_3^- (Barber et al., 1992). The purpose of the current study was to: (i) evaluate changes in nitrification potentials due to variations in N source (compost vs. N fertilizer) and the use of complex crop rotations including cover crops vs. continuous corn; (ii) compare changes in nitrification potential in a successional grassland system to compost and N fertilizer based agriculture systems; and (iii) determine whether a decreases in nitrification potential can be used as an indicator of enhanced system N use efficiency in both agronomic and unmanaged ecosystems.

MATERIALS AND METHODS

Field sites were located on a Kalamazoo loam and a similar Oshtemo sandy loam (coarse-loamy, mixed, mesic, Typic Hapludalfs) at the Kellogg Biological Station Hickory Corners, MI. All agronomic treatments are part of the Living Field Laboratory (LFL). The LFL was in its 5th, 6th, and 7th y in 1997, 1998, and 1999. The LFL uses a split-split-plot, randomized complete block design. Split-split-plots are 15 x 4.5 m. Main plot treatments consist of a continuous corn (*Zea Mays* L.) and a corn-corn-soybean (*Glycine max* L.)-wheat (*Triticum aestivum* L.) rotation including all entry points each year. Cropping systems are subdivided into nonrandomized cover crop and control sub-plots. Managements reflect a range of agronomic practices from low-input to integrated-fertilizer. The low-input system utilizes compost as a nutrient source, no pesticides, and is cultivated. The integrated-compost system differs from that of the low-input only in the application of banded herbicides. Integrated-fertilizer management utilizes fertilizer as a nutrient source, banded herbicides, and cultivation. The current study was designed to compare the effect of several sustainable management practices on N cycling.

Practices include substitution of compost for N fertilizer, use of a rotation in place of continuous corn and the addition of a cover crop within each cropping system. The total amount of N applied to continuous and 1st y corn as dried compost material (4.48 Mg ha^{-1} y^{-1}) was 117 kg N ha^{-1} y^{-1}. Nitrogen requirements for 2nd year corn required doubling of the compost rate in order to maintain yields. Decomposition of compost applied during a growing season was estimated to be 9% y^{-1}. Cumulatively, compost applied plus previous compost applications provided 40- 53 kg N ha^{-1} y^{-1} inorganic N (Willson et al., 2000a). Nitrogen was applied as Urea to treatments in corn under N fertilizer management at a rate of 170 kg N ha^{-1} y^{-1}. Cover crop varied with crop. Crimson clover (*Trifolium incarnatum* L.) was sown into standing corn in late July. Red clover (*Trifolium pratense* L.) was frost seeded into wheat in late March. Soybean contained no cover crop during the soybean season.

A previously-tilled successional grassland treatment located on an adjacent Long-Term Ecological Research site (LTER) was contrasted with that of agronomic treatments. The LTER was in its 9^{th} and 10^{th} y of treatments in 1998 and 1999. The statistical design is a randomized complete block. Soil samples were taken from a sub plot of 10 m x 30 m within each of the six replicate one ha plots.

Corn, wheat, and soybean above-ground net primary productivity (ANPP) was sampled at physiological maturity from 1993 to 1999. Cover crop and no cover crop plots in continuous corn, 1^{st} y corn and soybean treatments were sampled under integrated-fertilizer, compost and low-input managements. Plant samples were dried at 40°C and ground to pass a 2 µm mesh screen. Total C and N in plant tissue was measured from 1994 – 1996 with a Carlo Erba N A 1500 Series 2N/C/S analyzer (CE Instruments Milan, Italy). Total N in plant tissue collected 1997-1999 was estimated from total N values in 1994 and 1996.

Estimates of the N contribution of cover crops were taken from previous cover crop research on the LFL (Dehne, 1995).

Plant biomass to N content (PNC) was calculated as grams of aboveground net primary productivity (ANPP) per gram of N in ANPP at crop physiological maturity and is based on the concept of plant N use efficiency (Groffman et al, 1986). Estimates of ANPP and the total N content of the successional grassland treatment were obtained from the LTER database at http://lter.kbs.msu.edu/npp/. The PNC of the successional grassland treatment was calculated in 1997, 1998, and 1999 from annual ANPP and the N content of the ANPP.

Soil samples were collected in the LFL at various times during the 1997, 1998, and 1999 growing season from a depth of 0- to 25-cm in the integrated fertilizer and compost managements (Table 1). During 1998, samples were collected: prior to tillage, after chisel plowing, prior to silking, and approximately one month after crop maturity. Samples in 1999 were collected at pre-planting, on June 4th and August 23rd at the end of grain fill in corn. Low-input treatments were sampled on June 9th 1997 and May 28th 1998 at a 0- to 25-cm depth by John Fisk. Cropping treatments sampled were continuous corn and 1st y corn with and without crimson clover cover crop. Composite samples of 12 or more 2 cm diameter cores from each plot were collected, cooled, sieved through a 4 mm screen and stored at 4°C.

Soil samples from each date were analyzed for moisture content, inorganic N, and nitrification potentials. Ten gram samples were weighed for soil moisture content and placed in a 104°C oven for 24 h. Inorganic N (NH_4^+ + NO_3^-) -N was extracted from 20 g soil samples with 1N KCl extract. Aliquots were run on an auto analyzer to determine the concentration of (NH_4^+ + NO_3^-) -N (Lachat Instruments Inc. Milwaukee, WI). A portion of the soil samples collected on April 10th 1998 were used to conduct a 150 d N incubation to measure N mineralization (Table 1). Details of the 150 d N incubation procedure can be obtained from Fortuna et al., (2001).

Nitrification potentials were determined via the shaken slurry method (Hart et al., 1994). Fifteen gram soil samples were placed in 250 ml Erlenmeyer flasks that contained 100 ml of a mixture of 1.5 m*M* of NH_4^+, and 1 m*M* of PO^{3-}_4. Samples were placed on an orbital shaker at 180 rpm to incubate for 24 h at 25°C. This method provides an excess of NH_4^+ and eliminates substrate concentration as a limiting factor. Nitrate from the centrifuged supernatant was measured on an auto analyzer (Lachat Instruments Inc. Milwaukee, WI).

Variation in nitrification potentials and inorganic N data due to N fertilizer management, cropping system, cover crop, and date were analyzed using SAS Proc Mixed (SAS Institute, 1997). A second Proc Mixed analysis was performed on April 27th 1998 and May 5th 1999 data to compare across growing seasons. Changes in N mineralization potential (N_0) and the mean residence time (MRT) of N in the soil system, resulting from sustainable management practices, were estimated from N incubation curves using the SAS NLIN procedure (SAS Inst., 1988; Willson, et. al., 2000b).

RESULTS

Nitrification Potentials

On the previously-tilled successional grassland treatment, nitrification potentials were not significantly different across dates in either year (Table 2). Nitrification potentials measured in the successional grassland site ranged from 1.30- 2.75 µg N g^{-1} soil d^{-1}. Nitrification potentials on agronomic treatments were higher and seasonal trends differed from that of the successional grassland treatment (Table 3 and 4). Although nitrification potentials were significantly different at some sample dates during the growing season (April to October) in agronomic managements, there was no significant effect of year (Figure 1). Samples taken from agronomic treatments on June 9th 1997 and May 28^{th} 1998 were not significantly different (Figure 2). Analysis of variance of a second set of samples taken April 27^{th} 1998 and June 5^{th} 1999 revealed no significant difference between the sample dates indicating a consistent pattern of nitrification potential during the growing season in 1998 and 1999.

The N fertilizer treatment tended to have higher nitrification potentials throughout the growing season (Table 3 and Figure 1). The average nitrification potential across N fertilizer treatments (8.20 µg N g^{-1} soil d^{-1}) was 37% higher than that of the compost treatment (5.14 µg N g^{-1} soil d^{-1}) and 76% higher than the successional grassland system (1.95 µg N g^{-1} soil d^{-1}) on August 27^{th} 1999 (Figure 1). Nitrification potentials averaged across compost treatments were lower in July of 1998 (2.65 µg N g^{-1} soil d^{-1}) than at any other sampling date. Nitrification potentials reached a minimum under N fertilizer management on April 27th (4.22 µg N g^{-1} soil d^{-1}) and July 14th (4.90 µg N g^{-1} soil d^{-1}) 1998 (Figure 1). Application of compost did not have an immediate affect on nitrification potentials. Nitrification potential increased after tillage under N fertilizer management on April 27th 1998 (Figure 1). Nitrification potentials on the low-input treatment were measured once during the 1997 and 1998 growing season (Table 1). Nitrification potentials were not significantly different between nutrient managements on June 9th 1997 and May 28th 1998 (Figure 2).

Cropping system (rotation vs. continuous corn) had no significant effect on nitrification potential. Treatments with cover crops had higher nitrification potentials than no cover control treatments 2 out of 3 y. Nitrification potentials were significantly higher on cover crop plots during 1997 (7.44 and 6.32 µg N g^{-1} soil d^{-1}) and 1999 (5.78 and 5.15 µg N g^{-1} soil d^{-1}) (data not shown).

Fertilizer and Residue N Inputs

The N content of the successional grassland above-ground biomass ranged from 37- 56 kg N ha^{-1} during the period 1997 – 1999 (Table 2). The use of compost in place of N fertilizer reduced the N content of corn and wheat residues by at least 30% (Table 5). The greatest difference between N residue returned and nutrient management was in the continuous corn treatment. The amount of N returned from corn residues under fertilizer management was 106 kg N ha^{-1} y^{-1} in 1998. Residues in compost management were nearly half that of the fertilizer system, 54 kg N ha^{-1} y^{-1}. Residues from the wheat rotation contained 69 and 28 kg N ha^{-1} y^{-1} in 1998. However, the majority of the N was removed when wheat straw and grain were harvested from the field plots. Red clover above-ground biomass was harvested from the plots for fodder in the fall of 1997 and 1998. Despite decreased N content in residues on compost treatments, yields in compost plots were not lower than in plots under integrated-fertilizer management. Yields in the 1st y of the corn rotation were not significantly different between nutrient managements in 1997 – 1999 (Table 6). First year corn tended to out yielded corn in all nutrient managements.

Inorganic N (NH_4^+ + NO_3^-) -N

On the previously-tilled successional grassland treatment, in situ soil mineral N [(NH_4^+ + NO_3^-)- N] was highest in spring and reached a minimum in the fall (Table 2). On agronomic treatments, soil inorganic N peaked in June (Table 4). Inorganic N levels in compost treatments never exceeded inorganic N levels measured in the integrated fertilizer management.

In situ soil inorganic N levels were correlated with nitrification potentials. Correlation coefficients were highest for regression of April 27th and October 1998 nitrification potentials against field (NH_4^+ + NO_3^-) –N for the same dates across management and cropping system. Between 60 and 80% of variability in nitrification potential measurements was due to NH_4^+ concentrations in the field in the 1st y corn rotation (Table 7). Correlation coefficients for continuous corn integrated-fertilizer management and integrated-compost in October were 0.77

and 0.96, respectively. More than 50% of the variability in nitrification potential measurements was due to NH_4^+ concentrations.

The correlation coefficients for nitrification potentials vs.1N KCl extractable (NH_4^+ + NO_3^-) –N from laboratory incubations at 70d were lower than those of in situ extractable (NH_4^+ + NO_3^-) –N (Table 7). There were no identifiable trends in the regression coefficients based on date, fertilizer management, and/or cropping system. Correlation coefficients ranged from 0.06 to 0.84.

Plant Biomass to N Content

The PNC of the successional grassland treatment in late July early August 1997 – 1999 was 82- 85 g g^{-1} N (Table 2). Values for PNC in the LFL were higher in the low-input (140- 98 g g^{-1} N) and compost treatments (136- 104 g g^{-1} N) than in the LTER successional grassland system. The average PNC of the integrated-fertilizer treatment (93 g g^{-1} N) was equivalent to the successional grassland treatment (83 g g^{-1} N). High PNC measurements did not consistently lead to decreased yield (Table 6). Several of the high yielding systems had high PNC. In 1998, yield in 1st year corn treatments were equal across integrated-fertilizer, integrated-compost, and low-input managements. However, PNCs in the integrated-compost and low-input 1st year corn treatments were significantly higher than in the N fertilizer treatment (Table 6).

DISCUSSION

During seasons with average rainfall and temperature, use of compost in place of N fertilizer reduced nitrification potentials by 25%. Nitrification potentials averaged across cropping system in late August were 50% greater on N fertilizer treatments as compared to those of integrated-compost. On agronomic treatments nitrification potentials peaked after crop senescence when the potential for NO_3 leaching was greatest. Regression coefficients for nitrification potential vs. 1N KCl extractable N in situ on October 29th 1998 were high. Forty-five to 92% of the variability in nitrification potential measurements across nutrient managements and cropping systems with the exception of the integrated-compost 1st y corn was a function of inorganic soil N [(NH_4^+ + NO_3^-) – N].

Groffman et al. (1986) reported increased N mineralization and nitrification in November after harvest. They attributed increased N mineralization and nitrification in part to the decomposition of N rich crop and weed residues. The N content of crop residues returned was on average 38% higher under integrated-fertilizer management than on the integrated-compost management. Field measurements of (NH_4^+ + NO_3^-) –N taken on October 29th 1998 were approximately 50% higher in the integrated-fertilizer 1st y corn and continuos corn treatments than in the same cropping system under integrated-compost management. Significantly lower inorganic N and a 50% reduction in nitrification potential on integrated compost treatments in October may reduce NO_3 leaching. In 1998, NO_3 leaching on the integrated-fertilizer continuous corn treatment (60 kg N ha^{-1}) was more than double that of continuous corn in integrated-compost (17 kg N ha^{-1}). Similarly in 1999 leaching in the integrated-fertilizer continuous corn treatment was 60 kg N ha^{-1} and 30 kg N ha^{-1} in the continuous corn integrated-compost plots (Smeenk, 2001). Previous research on the LFL showed that inorganic N levels during the previous growing season were correlated with leaching loss (Willson et al., 2000a).

Treatments with larger pools of mineralizable N (N_0) had lower in situ (NH_4^+ + NO_3^-) –N. The average soil (NH_4^+ + NO_3^-) –N content of the integrated fertilizer management was 34% higher than that of integrated compost. The mineralizable organic N pool (N_0) measured during a 150 d N incubation was equal to 26 kg N ha^{-1} soil N and had a MRT of 206 d in the compost system. Nitrogen fertilizer management decreased N_o to 16 kg N ha^{-1} soil N and the MRT of N in the system to 149 d (Fortuna et al., 2001). Previous research on the LTER in a corn-soybean-wheat rotation revealed that a moldboard plow system increased soil NO_3^- but decreased N mineralization potential relative to the same cropping sequence under organic management with legume cover (Robertson et al., 2000).

The successional grassland treatment was dominated by herbaceous perennials (Huberty et al., 1998). Maximum turnover of C and N from senesced portions of perennials occurred in spring coinciding with maximum in situ (NH_4^+ + NO_3^-) –N concentrations (Table 2). Nitrification rates in annual cropping systems tend to peak in spring when soil temperatures are above 5°C and tillage has occurred (Recous et al., 1999). May soil samples taken from a perennial grassland had greater nitrification production and (NH_4^+ + NO_3^-) –N concentrations during a 30 d incubation than samples taken in August of the same year (Robertson and Vitousek, 1981).

The successional grassland treatment had significantly lower nitrification potentials and inorganic N levels relative to that of agronomic systems (Table 2, 3, & 4). Yet, PNC values on the successional grassland site (82 – 85 g g^{-1} N) were close to those of agronomic treatments, integrated-fertilizer (102 - 86), integrated-compost (137 - 104), and low-input (142 - 98) managements. The N content of the successional grassland above ground biomass was two to three times higher than that of corn biomass. Measurements of N_2O loss on the historically tilled, successional grassland treatment (1 g ha^{-1} d^{-1}) were approximately one-third that of the cropping systems. Unmanaged systems are often N deficient. Consistently low levels of N tend to increase system NUE (Robertson, 1987).

Compost applications: increased PNC above that of the N fertilizer management; reduced seasonal nitrification potentials; and coupled with cover crops and rotations allowed for maintenance of equivalent yields while in some instances reducing the potential for NO_3^- leaching. Estimates of gaseous loss due to denitrification and volatilization in temperate row-crops are in the range of 20 – 40 kg N ha^{-1} y^{-1} (Robertson, 1997). Denitrification rates were equal (3.5 – 3.2 g ha^{-1} d^{-1}) across agronomic systems on the LTER (Robertson et al., 2000). Loss of N as N_2O does not necessarily increase when N is added to a farming system if soil N dynamics are not accelerated (Robertson et al., 2000). System N use efficiency appeared to increase with compost management.

However, compost applications tended to immobilize N if other sources of N such as clover residues were not present. Compost and low-input managements returned less biomass of lower N content to field plots and increased PNC above that of the integrated-fertilizer management. Lowered soil inorganic N in the compost treatment significantly decreased the grain N content of the compost management (15.2 g N kg^{-1}) in 1996 (unpublished data 1996). The average grain N content of the fertilizer management was 17.8 g N kg^{-1}. Increasing agroecosystem diversity by adding a clover cover crop and or addition of a wheat-fallow rotation increased soil inorganic N resulting in significantly higher corn grain N contents. The N content of corn grain grown after a clover cover crop was 16.6 g N kg^{-1} and without 15.8. Corn grain in the 1^{st} y corn rotation contained 16.9 g N kg^{-1} and 15.5 in the continuous corn treatment. Plowed clover provided a soluble source of organic N in June when crops were entering their grand phase of vegetative growth and could utilize additional NO_3. Thus, temporary increases in nitrification potential in June due to increased inorganic N from a clover cover crop and/or wheat-fallow on integrated-compost treatments did not contribute to potential NO_3 leaching. Grain quality should be monitored where compost is applied.

Nitrification potentials can be used as an indicator of the tightness of the N cycling in an agronomic system when N sources are not applied as NO_3.

Lowered nitrification potential and increased systems NUE is not necessarily equated with maintenance of crop yield and quality. The PNC of a system tends to increase as N becomes less available. However, maximum PNC must be correlated with sufficient crop N uptake for maintenance of fodder or grain protein. Sustainable management practices that reduce the amount of seasonal soil inorganic N beyond that required for optimal yield can increase PNC, reduce nitrification potentials, and minimize the potential for NO_3^- leaching, and N_2O emissions.

The shaken slurry method does not provide information in regard to population size and species diversity of autotrophic ammonia-oxidizing bacteria (AAO). The form and quantity of N applied can effect the biomass and structure of the nitrifier community. Competitive PCR (cPCR) measurements conducted in fertilized agronomic treatments on the LTER revealed that the use of N fertilizer led to a larger population of ammonia oxidizers (Phillips et. al, 2000). A never-tilled successional grassland ecosystem at KBS had a greater diversity of AAO bacteria than either fertilized agronomic treatments or a previously tilled successional grassland (Bruns et al., 1999; Phillips et al., 2000). A change in a system's dominant nitrifier species may result in variation of observed nitrification rate due to differing capacities of AAOs to denitrify (Bruns et al., 1998). Further research is required to determine the effect of compost applications on AAO population size and species diversity.

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Table 1. Plot sampling dates for nitrification potentials and KCl extracts.

	10-Apr-98	27-Apr-98	14-Jul-98	29-Oct-98	5-May-99	1-Jun-99	27-Aug-99
Integrated-Fertilizer							
Cropping System							
Continuous Corn	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
& Crimson Clover							
Continuous Corn	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
1st Year Corn	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
& Crimson Clover							
1st Year Corn	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
Soybean Cover Split	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
Soybean	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
Integrated-Compost							
Cropping System							
Continuous Corn	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
& Crimson Clover							
Continuous Corn	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
1st Year Corn	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
& Crimson Clover							
1st Year Corn	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
Soybean Cover Split	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #
Soybean	†, #, §	†, #	†, #	†, #	†, #	†, #	†, #

†=soil samples taken from the field (0-25-cm) for nitrification potentials via the shaken slurry method.

#=soil samples taken from the field (0 -25-cm) for analysis of (NH_4+NO_3)- N in 1 N KCl extract.

§=soil samples taken from the field (0-25-cm) for measurement of N mineralization during a 150 d laboratory incubation.

Table 2. Nitrogen measurements from the previously tilled successional grassland at the Long-Term Ecological Research Site.

Date	†Nitrification Potentials	Inorganic N $(NH_4^+ + NO_3^-)$ -N	Date	N Content in Biomass	Plant Biomass to N Content
	$\mu g\ N\ g^{-1}$ soil d^{-1}	$\mu g\ N\ g^{-1}$		$kg\ N\ ha^{-1}$	‡$g\ g^{-1}$ N
10-Apr-98	2.61	5.45 a			
27-Apr-98	2.75	4.36 ab			
14-Jul-98	1.30	2.72 bc	30-Jul-97	37	85
29-Oct-98	1.90	1.91 c	10-Aug-98	56	82
			11-Aug-99	46	83
5-May-99	1.47	14.71 a			
1-Jun-99	1.32	9.54 b			
27-Aug-99	1.95	4.63 c			

†Nitrification potentials were not significantly different across dates for a given year.
‡Grams of biomass produced per unit N uptake.

Table 3. Inorganic N ($NH_4^+ + NO_3^-$) -N field samples and nitrification potentials 1998 Living Field Lab.

Cropping System	Date	Nitrification Potentials		Field ($NH_4^+ + NO_3^-$)- N	
		Management System		Management System	
		Fertilizer	Compost	Fertilizer	Compost
		μg N g^{-1} soil d^{-1}		μg N g^{-1}	
Continuous Corn					
	10-Apr	†*5.35 a	3.52 a	‡9.5 ±2.18	7.6 ±2.18
	27-Apr	3.94 b	3.59 a	7.1 ±2.18	7.6 ±2.18
	14-Jul	4.73 ab	2.31 b	21 ±2.45	6.8 ±2.18
	29-Oct	4.99 ab	3.69 a	12 ±2.18	5.4 ±2.18
1st Year Corn					
	10-Apr	*6.36 b	3.53 b	9.0 ±2.18	8.4 ±2.18
	27-Apr	4.65 c	4.21 ab	3.3 ±2.45	14 ±2.18
	14-Jul	*6.39 b	2.91 b	34 ±2.18	9.0 ±2.18
	29-Oct	*8.95 a	5.33 a	19 ±2.18	10 ±2.45
Soybean					
	10-Apr	4.76 a	3.64 a	9.3 ±2.18	6.0 ±2.18
	27-Apr	4.08 ab	3.55 a	7.1 ±2.18	6.3 ±2.18
	14-Jul	3.59 b	2.73 a	6.5 ±2.18	6.4 ±2.18
	29-Oct	4.17 ab	4.46 a	7.4 ±2.18	11 ±2.18

†Values followed by different lower case letters are significantly different within a nutrient management and cropping treatment (P=0.05).
Values followed by a * are significantly different (P=0.05) across management.
‡($NH_4^+ + NO_3^-$) -N ± standard deviation.

Table 4. Inorganic N ($NH_4^+ + NO_3^-$) -N field samples and nitrification potentials 1999 Living Field Lab.

		Nitrification Potentials		Field ($NH_4^+ + NO_3^-$)- N	
		Management System		Management System	
Cropping System	Date	Fertilizer	Compost	Fertilizer	Compost
		μg N g^{-1} soil d^{-1}		μg N g^{-1}	
Continuous Corn					
	5-May	5.55	3.84	‡21.8 ± 3	29 ±3
	1-Jun	5.4	3.75	46.3 ± 3	44 ±3
	27-Aug	8.3	4.10	19.6 ± 3	2.72 ±3.54
1st Year Corn					
	5-May	5.09	4.31	23.7 ± 3	35 ±3.27
	1-Jun	4.97	4.66	58.6 ± 3	63 ±3.27
	27-Aug	8.33	6.22	20.7 ± 3	7.6 ±3.27
Soybean					
	5-May	6.16	3.82	21.0 ± 3	21 ±3.27
	1-Jun	6.42	4.38	37.1 ± 3	35 ±3.27
	27-Aug	7.94	5.12	3.27 ± 3	3.27 ±3.27

Analysis of variance summary for nitrification potentials.

	F Value	
date	58	†*
cover	15	*
management	42	*
crop*date	3	**
management*date	11	*
management*crop	5	**
management*cover*date	3	**
management*crop*cover	4	**

†*, ** Significant at P • 0.05 and 0.01 probability levels, respectively.
‡(NH_4+NO_3)- N ± standard deviation.

Table 5. Nitrogen content of above-ground crop biomass 1997 - 1998 and N content of cover crop above-ground biomass in 1993 and 1994.

Year 1997				Year 1998			
Fertilizer Management	Fertilizer	Compost	Low-Input	Fertilizer Management	Fertilizer	Compost	Low-Input
Crop†	Residue N inputs above ground biomass kg N ha^{-1}			Crop	Residue N inputs above ground biomass kg N ha^{-1}		
Monoculture Continuous Corn	106e*	54b	47	Monoculture Continuous Corn	69cd*	46a	44
Rotation‡ 2nd Year Corn	76d	49a		Rotation 2nd Year Corn	65c	43a	

Nitrogen Inputs from Cover Crop Residues 1993 and 1994§

Year 1993			Year 1994		
Cover Crop	Management: Fertilizer	Management: Compost	Cover Crop	Management: Fertilizer	Management: Compost
Red Clover in Wheat	31	80	Red Clover in Wheat	31	29
Annual Ryegrass in 2nd Year Corn	22	14	Annual Ryegrass in 2nd Year Corn	10	6

†Residue inputs are based on the above-ground net primary productivity of the previous crop.

‡Estimates of N residues returned from wheat residues are not included. Wheat straw and grain were removed from research plots.

* Values are significantly different (P=0.01) across a management by cropping system.

§Estimates of residue N returned are from previous above-ground biomass measurements on the Living Field Lab (Dehne, 1995).

Table 6. Yields 1997-1999 and plant biomass to N content (PNC) 1997 and 1998 Living Field Lab.

Year	1997	1998	1999	1997	1998
	†Yield			Plant Biomass to N Content	
	Mg ha^{-1}			‡g g^{-1} N	
Management					
Integrated-Fertilizer					
Cropping System					
1st Year Corn & Clover	6.6±0.21	6.7±0.21	5.6±0.21	102 c	95 c
1st Year Corn	6.8±0.21	7.4±0.21	5.9±0.21	95 c	86 c
Continuous Corn & Clover	5.3±0.21	6.3±0.21	5.5±0.21	92 c	86 c
Continuous Corn	5.1±0.21	5±0.21	5.7±0.21	88 c	98 c
Soybean Cover Split	2.1	2.6	2.3		
Soybean	2.0	2.4	2.4		
Management					
Integrated-Compost					
Cropping System					
1st Year Corn & Clover	6.5±0.21	6.6±0.21	6.8±0.21	114 b	104 b
1st Year Corn	6.3±0.21	7±0.21	6.2±0.21	114 b	109 b
Continuous Corn & Clover	4.8±0.21	5.5±0.21	5.8±0.21	128 b	117 b
Continuous Corn	4.6±0.21	4.4±0.21	5.1±0.21	136 a	137 a
Soybean Cover Split	2.4	2.6	2.2		
Soybean	2.2	2.6	2.2		
Management					
Low-Input					
Cropping System					
1st Year Corn & Clover	6.3±0.21	7.7±0.21	6.1±0.21	124 b	98 c
1st Year Corn	6.2±0.21	7±0.21	5.8±0.21	116 b	104 b
Continuous Corn & Clover	4±0.21	5.4±0.21	5.7±0.21	142 a	127 b
Continuous Corn	4.3±0.21	5.3±0.21	5.4±0.21	140 a	129 b
Soybean Cover Split	2.6	2.0	2.3		
Soybean	2.4	2.0	2.2		

†There was a significant interaction between nutrient, crop, and cover crop management and year the standard deviation for corn yields was ±0.214.

‡Grams of biomass produced per unit N uptake. Values followed by different lower case letters are significantly different (*P*=0.01).

Table 7. Correlation coefficients for nitrification potential vs. KCl extractable (NH_4^+ +NO_3^-)- N in situ and KCl extractable (NH_4^+ + NO_3^-)- N from N incubations at 70 d 1998 Living Field Lab.

Cropping System	Date	Nitrification Potentials via the Shaken Slurry Method vs. In situ (NH_4^+ +NO_3^-) -N — Management System: Fertilizer, correlation† coefficient	n‡	Compost, correlation coefficient	n	Nitrification Potentials via the Shaken Slurry Method vs. N Incubation (NH_4^+ +NO_3^-) -N — Management System: Fertilizer, correlation coefficient	n	Compost, correlation coefficient	n
Continuous Corn									
	10-Apr	0.8	8	0.16	8	0.23	8	0.41	7
	27-Apr	0.39	8	0.81	8	0.27	8	0.35	7
	14-Jul	0.78	5	0.65	8	0.25	5	0.41	7
	29-Oct	0.77	8	0.96	8	0.49	8	0.28	7
1st Year Corn									
	10-Apr	0.69	8	0.58	8	0.82	8	0.56	8
	27-Apr	0.9	7	0.78	8	0.56	8	0.55	8
	14-Jul	0.79	5	0.23	8	0.82	4	0.24	8
	29-Oct	0.83	7	0.08	6	0.36	7	0.15	6
Soybean cover treatment	10-Apr	0.11	8	0.31	8	0.42	8	0.06	8
	27-Apr	0.8	8	0.16	8	0.18	8	0.1	8
	14-Jul	0.56	8	0.22	8	0.84	8	0.11	8
	29-Oct	0.67	8	0.7	8	0.13	8	0.74	8

†Correlation coefficients were calculated using the Pearson correlation.

‡Sample size

Figure 1. The effect of management and time of season on nitrification potentials: Comparison of a succesional grassland, integrated-compost, and integrated-fertilizer treatments.

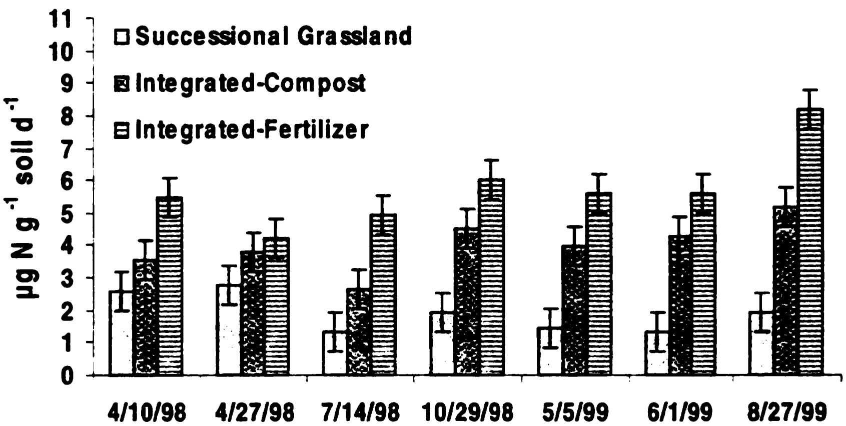
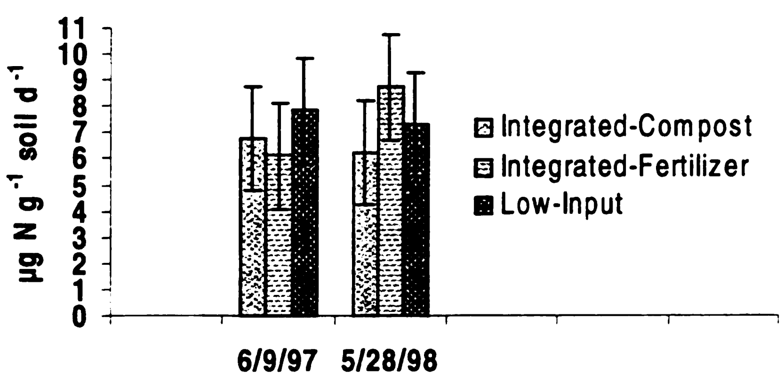


Figure 2. The effect of management and time of season on nitrification potentials: A comparison of low-input, integrated-compost and integrated-fertilizer treatments.



CHAPTER 2

OPTIMIZING NUTRIENT AVAILABILITY AND POTENTIAL CARBON SEQUESTRATION IN AN AGROECOSYSTEM

ABSTRACT

The uniformity, low cost and ease of application associated with inorganic fertilizers have diminished the use of organic nutrient sources. Concern for food safety, the environment and the need to dispose of animal and municipal wastes have focused attention on organic sources of N such as animal derived amendments, green manures, and crop rotations. Providing nutrients to row crops from organic sources demands intensive management of the N and C cycles. Managing organic N sources to provide sufficient N at the grand phase of crop growth requires knowledge of C and N decomposition over several years particularly where manure and compost is applied. Management practices of this trial included: a comparison of compost and chemical fertilizer, use of a corn-corn-soybean-wheat rotation compared to continuous corn and the addition of a cover crop within each cropping system. Soil samples were taken in April prior to tillage from a 0-25 cm depth in the 2nd (1994) and 6th year (1998) of the experiment. Nitrogen (150 d) and C incubations (320 d) were conducted to determine the effect of cropping system and nutrient management on: N mineralization potential (NMP), the mineralizable organic N pool (No), the mean

residence time (MRT) of No, C mineralization (C_{min}), and soil organic carbon (SOC) pool sizes and fluxes. Compost applications increased the resistant pool of C by 30% and the slow pool of C by 10%. The compost treatment contained 14% greater soil organic C than the fertilizer management. Nitrogen was limiting on all compost treatments with the exception of 1st y corn following wheat fallow and clover cover crop. The added diversity of the clover cover crop and wheat-fallow increased inorganic N in both nutrient managements. We recommend that growers adjust their N fertilizer recommendation to reflect the quantity and timing of N mineralized from organic N sources. Proper management of nutrients from compost, cover crops and rotations can maintain soil fertility, improve soil quality, and increase C sequestration.

INTRODUCTION

The potential of agricultural land to mitigate greenhouse gases and sequester C may be an added benefit of maintaining soil fertility levels through the use of sustainable management practices. Residue management can increase C sequestration levels by 11-67 MMTC y^{-1} (Lal et al., 1999). Additional C inputs from organic manures have the potential to sequester 3-9 MMTC y^{-1}. A recent study of global warming potential (GWP) on a coarse-textured soil found that land farmed using best-management practices had nearly zero net impact on the GWP increase of N_2O emissions from all sites (Robertson, 2000).

Maintenance of soil quality, fertility, and SOC require management of N fertilizer and organic inputs. Increases in N fertilizer up to the yield sufficiency level have been shown to increase residue returned to the soil which may lead to greater SOC and total soil N (TSN). The C sequestration efficiency (based on above and below ground productivity) of a barley system increased 11% above that of the zero N fertilizer control at the highest N fertilizer rate (Halvorson et al., 1999). After 30 y of N fertilizer additions to corn, 22 to 30% of the SOC in the plow layer was corn-derived and had turned over. Turnover of corn-derived C was 15 – 20% on unfertilized plots (Gregorich, 1996). Additions of N fertilizer above that required for maximum yield have caused increased soil organic matter (SOM) decomposition and NO_3 leaching (Green et al., 1995). After 50 y of wheat, 11% of the N fertilizer applied (144 kg N ha^{-1} y^{-1}) was incorporated into SOM and 1% was subsequently released each y (Rasmussen et al., 1998).

Nitrogen mineralization potential has been shown to increase at greater N levels and higher residue rates. Nitrogen mineralization rate increased linearly with increased N rate (El-Haris et al., 1983). A direct relationship was found between residue returned and the mineralizable organic N pool (No) in several 20 y cropping systems. A 1 mg kg^{-1} change in No required 0.33 Mg ha^{-1} of crop residue (Christenson and Butt, 1997).

The cropping system employed affects C and N cycling by determining: the total quantity of organic material returned to the soil, the C:N ratio of the material, and the biochemical composition of the organic material entering the soil system. Ten years of continuous corn and corn-soybean rotation resulted in higher SOC contents under continuous corn management (Omay et al., 1997). Estimates of above ground residues returned from soybean were 7 Mg ha^{-1} y^{-1} and (13.5) and

(14.5) for corn. A 10 y study found, aboveground and root C returned was greater in corn (25– 30 Mg ha^{-1}) than soybean (20– 23) (Huggins et al., 1998).

The best parameters for estimating N_{min} and C_{min} at the end of a 150 d incubation have been found to be the initial C:N ratio and N content of the residue (Quemada and Cabrera, 1995). Greater than 70% of the variability in N_{min} regression analysis could be explained using the C:N or the square-root transformation of the N concentration in crop residue. Adding the lignin-N ratio explained 80% of the variability (Vigil and Kissel, 1991). This relationship holds true where N availability is limiting. The C:N ratio at which N mineralization and immobilization were equal was 40. The biochemical quality of a residue controls decomposition when N is not limiting (Trinsoutrot et al., 2000). Nonlimiting N conditions often occur within the first few weeks after residue application.

Survey information on SOM content as a function of long-term land use history revealed that SOM content was higher in organic systems as compared to land in conventional, arable use (Pulleman et al., 2000). Organic systems received greater manure input than the conventional systems. The MRT of N and C pools has been shown to increase with application of sludge, compost or manure. Sewage sludge contains little soluble C. Continuous application of sewage sludge for 8 y decreased soil nitrification potential and retained N in microbial cells (a labile N fraction) for more than 4 y (Boyle and Paul, 1989). Thus, greater SOC and TSN can lead to immobilization of inorganic N if not properly managed. Manure applications continued to augment SOC after 100 y on the Rothamsted study (Jenkinson et al., 1977).

Sustainable management practices that include the use of cover crops, crop rotations, and application of compost influence the quantity, quality, and timing of N and C inputs to the system. Concurrent work in the Living Field Lab (LFL) has shown that the addition of clover residues and the added diversity associated with the wheat-fallow in the rotation increased the supply of inorganic N in the soil (Sanchez et al., 2001). Management of organic N sources to provide sufficient N at the grand phase of crop growth requires knowledge of C and N decomposition over several years particularly when compost is utilized as a nutrient source. Additional C added as compost can increase C sequestration but must be managed to prevent N immobilization. The current study was designed to assess the multi-seasonal effect of N fertilizer management and crop diversity on: (I) the supply of inorganic N to row crops, (ii) the mean residence time (MRT) of N and C in soil organic matter (SOM) pools and (iii) C sequestration.

MATERIALS AND METHODS

The Living Field Lab (LFL) located at the Kellogg Biological Station in Hickory Corners, MI was designed to test the effects of several sustainable management practices on crop yield and soil biogeochemical processes. The trial is located on a Kalamazoo loam and a similar Oshtemo sandy loam (coarse-loamy, mixed, mesic, Typic Hapludalfs). Practices include: comparison of compost and chemical fertilizer, use of a corn-corn-soybean-wheat rotation compared to continuous corn and the addition of a cover crop within each cropping system. Managements reflect a range of agronomic practices from that of low-input to use of inorganic fertilizer and pesticides. The current study includes the integrated-compost and integrated fertilizer managements. A more detailed discussion of management practices on the LFL can be found in Jones et al. (1998). The integrated compost system utilizes compost as a N fertilizer source and banded herbicide with cultivation. Integrated-fertilizer management utilizes fertilizer as a nutrient source, banded herbicides, and cultivation. Both use rootworm insecticide on corn as needed.

The statistical design of the LFL is a split-split-plot, randomized complete block. Split-split-plots are 15 x 4.5 m. Main plot treatments consist of a continuous corn (*Zea Mays* L.) and a corn-corn-soybean-wheat rotation including all entry points each year. This study includes information from 1994 and 1998, the 2nd and 6th year of the crop rotation. Individual crop split plots are subdivided into nonrandomized cover crop and control sub-plots. Crimson clover (*Trifolium incarnatum* L.) is sown into standing corn in late July after final cultivation. Red clover (*Trifolium pratense* L.) is frost seeded into wheat (*Triticum aestivum* L.) in late March. Soybean (*Glycine max* L.) contains no cover crop during the soybean season.

The total amount of N applied to continuous and 1st year corn, as dried compost material (4480 kg ha^{-1} y^{-1}) was 116.5 kg N ha^{-1} y^{-1}. Nitrogen was applied to treatments in corn under N fertilizer management at a rate of 170 kg N ha^{-1} y^{-1}. Nitrogen requirements for 2nd year corn required doubling of the compost rate in order to maintain yields. No compost is used in the following soybean crop, maintaining the average of 4480 kg ha^{-1} y^{-1} for the rotation, as well as, continuous corn. Decomposition of compost was estimated to be 9% y^{-1} and provided 40- 53 kg N ha^{-1} y^{-1} inorganic N (Willson et al., 2001a). Dolomitic limestone was applied to the LFL at a rate of 4.48-Mg ha^{-1} on March 30th 1998 prior to soil sampling.

Soil samples were collected as composite samples of 12 or more 2-cm diameter cores from each plot, cooled, sieved through a 4 mm screen and stored at 4°C prior to N analysis. Samples were collected from 0- 25 cm in April of 1994 and 1998 prior to aboveground residue incorporation, compost application and planting. Samples were further subdivided into 0- 10 cm and 10- 25-cm increments in 1994. The separate depths were combined into one 0- 25-cm increment on a weight by volume basis. Treatments included in the present study from the 1994 sample date are integrated-fertilizer and integrated-compost treatments at two points in the rotation, 1st year corn and soybean on cover/ no cover splits. The plots that had been in corn in 1993, and were designated as continuous corn plots were included. Samples in 1998 included the above-mentioned treatments and integrated-fertilizer and compost plots cropped to continuous corn cover and no cover.

Soil samples were analyzed for moisture content, initial inorganic N (NH_4 + NO_3) concentration, and total C and N. Inorganic N (NH_4^+ + NO_3^-) -N was extracted from 20 g soil samples with 1N KCl. Aliquots were run on an auto analyzer to determine the concentration of (NH_4^+ + NO_3^-) -N (Lachat Instruments Inc. Milwaukee, WI). Total soil N and the C and N content of residues was measured on a Carlo Erba N A 1500 Series 2 N/C/S analyzer (CE Instruments

Milan, Italy). Total soil C was measured by dry combustion on a Leco Carbon Analyzer (Leco Corp., St. Joseph, MI) or using a Carlo Erba N A 1500 Series 2 N/C/S analyzer (CE Instruments Milan, Italy).

Laboratory Incubations

A portion of the soil samples collected on April 10th 1998 were used to conduct two 150 d N incubations in the laboratory. One incubation contained unamended soil; the second a series of residue applications (Table 1). Several 350 d C incubations were run using the April 1994 and 1998 samples. Soils were air dried prior to incubating. Treatments in C incubations included unamended soil controls, dolomitic limestone applied to incubations at a rate of 4.8 Mg ha^{-1}, and residue amendments (Table 1). The limestone treatment was applied to incubated soil collected in 1994 that contained no liming material. The lime treatment was added to determine the effect of the lime applied to all plots prior to soil sampling in 1998. Residues, approximately 4 cm in length, were applied at a rate of 7.5 Mg ha^{-1} clover, 12 Mg ha^{-1} wheat, and 26 Mg ha^{-1} corn to C and N incubations. These residues were applied to determine the mineralization pattern of the previous seasons crop residues. Corn and clover residue included root residues. The shoot/root ratios used were 1.42 for corn and 1.15 for clover (Buyanovsky and Wagner, 1997; Kunelius et al., 1992). Residues were dried at 60°C. The quantity of hemicellulose, cellulose, and lignin in clover materials, corn root, and compost were measured (Van Soest, 1963). Estimates of the lignin, hemicelllulose, and cellulose content in corn stover and wheat straw were taken from the literature (Buyanovsky and Wagner, 1997).

Twenty-five gram samples were weighed into specimen vials. Nitrogen incubations were run at 25°C and 50% of water holding capacity (Paul et al., 2000). Sub-samples were removed at day 0, 10, 21, 30, 50, 70,98, 122, and 150. Inorganic N (NH_4^+ + NO_3^-)-N was extracted from each interval with 1N KCl extract. Aliquots were run on an auto analyzer to determine the concentration of (NH_4^+ + NO_3^-)-N (Lachat Instruments Inc. Milwaukee, WI).

Nitrogen incubation data from 1994 was obtained from Willson et al. (2000b). Cumulative N mineralization curves from 1998 and the1994 data sets were fit using the SAS NLIN procedure (SAS Inst., 1988; Willson, et. al., 2000b). The impact of sustainable management practices on the steady state mean residence time (MRT) of the mineralizable organic N pool (N_0) was estimated from N incubation curves fitted in SAS NLIN (SAS Inst., 1988). Two first order exponential models were used for curve fitting of cumulative N data (Willson, et. al., 2001b). The parameter N_i is the initial inorganic N content and N_t is the quantity of extractable inorganic N at time t. MRT, MRT_1, and MRT_2 are the steady state mean residence times of the mineralizable organic N pools. Use of the single pool 1st order exponential model, Eq. [1] provided a smaller residual sum of squares value than the two-pool 1st order exponential model, Eq. [2].

Eq. [1] $$Nt = Ni + No(1\text{-}e^{-t/MRT})$$

Eq. [2] $$Nt = Ni + N_1(1\text{-}e^{-t/MRT_1}) + N_2(1\text{-}e^{-t/MRT_2})$$

A sum of square reduction test was used to determine whether fertilizer, cropping system, and or cover crop management were significant at $\alpha = 0.05$.

Carbon incubations were conducted in the laboratory for 350 d at 50% water holding capacity (WHC) estimated via the funnel method (Paul et al., 2000). Twenty-five g soil samples were incubated in 500 ml jars in a darkened control temperature room at 25°C. Soils were preincubated for 2 wk upon rewetting of air dried soil. The CO_2 content in the headspace of each jar was measured using an infrared gas analyzer (Beckman Instruments, Fullerton, CA). Jars were degassed with CO_2-free air when CO_2 levels in the headspace of the majority of samples reached 5- 6%.

A two-pool first-order constrained model; Eq. [3] was used to estimate the size and turnover rates of individual pools. The model includes an interval correction adapted from Ellert and Bettany, (1988).

Eq. [3] $$C_{(t)} = C_a(e^{(-ka*t1)}-e^{(-ka*t1-ka*t2)}) + (Ct_1 - Cr_1 - Ca_1)(e^{(-ks*t1)}-e^{(-ks*t1-ks*t2)})$$

C_a, k_a=active pool; k_s=slow pool; C_r=resistant pool; t_1=start of sample interval; t_2=end of sample interval. The slow pool is defined as $C_s = (Ct_1 - Cr_1 - Ca_1)$ where Ct_1 is defined as initial total soil organic C. The resistant fraction was equated to the total C content of the residue of acid hydrolysis (Paul et al., 2000). Curve fitting of the CO_2 evolved per unit time; $C_{(t)}$ was performed using the NLIN procedure of SAS (SAS Inst., 1988). The MRT of each C pool was adjusted to average field temperature by assuming a Q_{10} of 2 (Kätterer et al., 1998; Paul et al., 1999).

RESULTS

Nitrogen Mineralization Potential (NMP)

NMP (cumulative N mineralized from 150 d N incubation) was significantly greater on integrated compost treatments (P=0.05) in 1998 (Tables 2 and 3). Cropping system NMP was highest after wheat straw (P=0.01) in 1994 and 1998. There was a significant nutrient management*sampling interval interaction at the (P=0.05) probability level in 1998. Compost contained greater mineralizable N than the integrated fertilizer management (P=0.001) at all time intervals (10, 30, 70, and 150) during incubation of field soils sampled in April 1998 (Tables 3).

Application of corn and wheat residues resulted in immobilization of N in both nutrient managements (Table 4). Addition of clover to integrated-fertilizer continuous corn treatments doubled the amount of N mineralized. This was the only treatment in which residue additions increased N mineralization. Clover residues contained 281 kg N ha^{-1} (Table 5). Corn residues that had remained in the field for ~6 months provided 146 kg N ha^{-1} and 10400 kg C ha^{-1} (C:N 72) and contained 136 g kg^{-1} lignin. Corn caused the greatest amount of N immobilization. The quantity of N immobilized was greater in compost treatments after application of corn residue than in N fertilizer treatments. Application of wheat straw resulted in release of inorganic N after 30 d. Wheat residues that had previously weathered in the field for ~ 8 months provided a similar quantity of

N to that of corn residues 146 kg N ha^{-1} but contained half the C (4800 kg C ha^{-1}). The lignin content of wheat straw was 141 g kg^{-1} lignin and the C:N ratio 33.

Four years of compost application increased the total N pool: No, the MRT and NMP of LFL soil. The MRT of N in the integrated-compost system was 206 d in April 1998 (Table 6). The MRT of N in the integrated-fertilizer system was 149 d. The No of the compost treatment was 37% greater (258 g N kg^{-1} soil N) than that of the N fertilizer management (163). The goodness of fit of N incubation data was not affected by the cropping system or cover crop employed in 1994. The reduced and full model were not significantly different (P=0.10) based on the sums of squares of the residuals test.

Carbon Mineralization

The quantity of cumulative CO_2-C evolved from unamended soil samples was affected by crop management in 1994 (P=0.01). A greater portion of CO_2-C was evolved in the soybean treatments previously cropped to 2nd y corn (Table 7 and 8). The quantity of CO_2-C evolved from unamended soil samples in 1998 differed significantly due to a time interval*nutrient management*cropping system*cover crop interaction. Fertilizer managements tended to have greater cumulative CO_2-C evolved after 50 d (Table 7 and 8). Eight to twelve percent of total soil C was lost as CO_2 in 1994 and (6-9%) in 1998. Approximately 10% greater CO_2-C was mineralized from fertilizer treatments than that of compost treatments in 1998.

Nine to eleven percent of the C added as dolomitic limestone (4.48 Mg ha^{-1}) to 1994 soil samples was evolved as CO_2-C by day 284 (Table 7 and 8). There were no nutrient or crop management effects where limestone was applied. Application of lime retarded the mineralization of C from 30-70 d on all treatments except that of the integrated-compost soybean plots following 2nd year corn. Compost applications were doubled in 2nd year corn.

Crop residue additions in the laboratory increased C mineralization on all treatments. Eleven percent of the wheat straw C added to soil previously cropped to wheat was lost as CO_2 on N fertilizer plots (Table 8). Wheat straw applied to plots previously cropped to wheat under compost management evolved 34% more CO_2-C than the unamended soil (Table 7). Corn residue added in the laboratory to soil previously in the 2nd year corn integrated-compost management increased cumulative C mineralized by 25%. The same treatment under fertilizer management increased cumulative C by 16%. Wheat straw was assumed to contain 141 g kg^{-1} of lignin and corn residue (136) (Table 5). Carbon inputs from wheat straw were approximately half that of corn. Clover residues contributed the least amount of C 3000 kg $ha^{-1}$and had the greatest impact on C mineralization.

Carbon Dynamics and Pool Sizes

Analyses of the residual sums of squares indicated that no sustainable management practice had a significant effect on curve fitting of the rate of CO_2 evolved per unit time in April of 1994. Total soil C was divided into active, slow, and resistant C fractions. Active pool C following alfalfa constituted 5% of total soil C (500 mg C kg^{-1}) and had an estimated MRT of 108 d in the field. Slow pool

C was equal to 43% of total soil C and had a field MRT of 12 y (Table 9). Fifty-two percent of total soil C was in the resistant fraction.

Nutrient management was the only sustainable agriculture practice to affect curve fitting of the rate of CO_2 evolved per unit time in 1998 (Table 9). The greatest gain of C across N fertilizer managements occurred in the slow pool. Slow pool C increased by more than 30% after 4 y of compost application. Values for the resistant fraction did not vary from those of 1994 under N fertilizer management. Application of compost augmented the slow (40%) and resistant C (30%) fractions. Active C was the only C fraction that decreased over time. Active pool C dropped to 1% of SOC in 1998 (160 mg C kg^{-1}) under compost management and 4% (440) in the N fertilizer system. The MRT of active pool C increased with N fertilizer use to an estimated 268 d in the field. Compost contributed little C to the active pool. The small portion of C present in the active pool had a rapid turnover rate, a 14 d estimated field MRT.

Active pool C in the fertilizer management was more than double that of the compost management in 1998. In some instances, crop, cover crop and nutrient management had a significant affect on the size and MRT of active pool C but did not change the overall curve fit of CO_2 evolved per unit time. Active pool C was slightly higher in the fertilizer management in 1994. Treatments that were previously cropped to corn had significantly larger active pools of C than the 1st y corn treatment previously cropped to wheat (Table 10). Crop management did not cause variation in the MRT of active pool C.

DISCUSSION

Nitrogen Mineralization

Nitrogen fertilizer management and cropping system had an affect on NMP in 1994 and 1998. Measurements of NMP on the fertilizer management were higher in 1994 than 1998. Residual N from previous alfalfa production may have affected measurements of NMP in 1994. In a study of 47 agronomic residues, alfalfa shoots maintained the highest net N mineralization level (+50 g N kg^{-1} C) and corn residue the lowest (-28) (Trinsoutrot et al., 2000).

Compost treatments had higher NMP and lowered field inorganic N in 1998. Field inorganic N was limited in all compost treatments with the exception of 1st y corn following wheat fallow and clover cover crop in 1998 (Fortuna et al., 2001a). The added diversity of the clover cover crop and wheat-fallow increased field inorganic N and in some instances improved corn yields in both nutrient managements. Plots previously cropped to wheat in both seasons had greater N_{min} values than plots previously cropped to 2nd y corn and continuous corn. Wheat-fallow has consistently increased soil inorganic N on the LFL (Willson, 2001b). Winter wheat was in fallow for 2 months prior to harvesting of corn on treatments cropped to corn. A study using 15N-labelled winter wheat in the field found that 23% of total residue N was lost over the 1st winter. Fifty-five percent of the wheat N was found in SOM by the end of the 2nd y (Haynes, 1997). Corn residues were left standing on the LFL and had little time to decompose before temperatures dropped below 5°C. It is likely that the presence of the corn residues induced N immobilization the subsequent spring. Previous research at the LFL indicated that N immobilization was greatest in April prior to tillage (Willson et al, 2001b).

Decomposition of residues during long term C and N incubations provided information concerning the mineralization pattern of the previous season's residues. Addition of wheat residue or corn stover and roots to laboratory incubations initially resulted in net immobilization of N due to the low N content of residues. Wheat residues caused immobilization of N in the 0-30 d interval but provided 59 kg N ha^{-1} to compost treatments and (26) to fertilizer treatments at 150 d. A 16 wk incubation of wheat straw 4 Mg ha^{-1} added to soil produced similar results. Mineral N ranged from 63 to 105 kg N ha^{-1} (Christensen and Olesen, 1998).

Application of corn residues that had over wintered in the field tended to immobilize N for the entire 150 d N incubation. This time period would be equivalent to approximately 300 d in the field, a period longer than the growing season. Corn root residues have been shown to immobilize N for as much as 24 wk (Risasi et al., 1999). Immobilization of N in the LFL was greatest following 2^{nd} y corn and in continuous corn fertilized with compost. Decreased N_{min} has resulted in reduced corn yields (Fortuna et al., 2001a). This indicates that the integrated-compost continuous corn treatment without clover and 2^{nd} y corn rotation without clover require additional N inputs to maintain corn yields.

Application of clover to N fertilizer managements increased N_{min}. Clover applied to compost resulted in some N immobilization. This may be due to additional C contained in compost that consists of oak leaf- alfalfa based feed silage. Compost C may have distorted the available C:N ratio of the system. Utilization of compost as a nutrient source increased NMP, No and the MRT of N in the soil. Sludge applications have been shown to increase N retention for several years after termination of applications (Boyle and Paul, 1989).

The effect of residues and residual organic amendment applications on the quantity of available N must be quantified and used to adjust N recommendation when applying organic or inorganic N fertilizer sources. Corn residues increased the N requirement of the proceeding corn crop in the LFL. Corn grown after winter wheat and clover cover crops had lowered N requirements. Mineralization of organic N from clover was immediate. Release of mineral N from wheat residues was within the first 30 d of the N incubation.

Growers should take into account the timing and quantity of N released from organic N sources when deciding to sample for soil nitrates at preplant (PPNT) vs. presidedress (PSNT). An evaluation of soil NO_3^- testing and corn N response across the North Central Region indicated that PPNT sampling following small grain and soybean was most effective in determining the critical soil NO_3^- level (CSNL) (Bundy et al., 1999). The CSNL is the soil NO_3^- concentration above which no crop yield response to additional N is expected. Mineralization of organic N from corn residues, manure, and SOM in fine textured soils occurred later in the growing season. Therefore, PSNT sampling was recommended.

Information concerning mineralization of organic N from a variety of sources including: row crop, cover crop residues and compost on the LFL should be used in conjunction with other information in our data base to adjust N recommendations and the timing of soil nitrate testing in Michigan for optimum yield response and decreased nitrate leaching.

Carbon Mineralization

Second year corn planted to soybean had greater cumulative CO_2-C evolved than wheat planted to 1st y corn in 1994. Crop residue inputs from 2nd y corn (5 Mg C ha^{-1}) were higher than those of wheat (0.7-1.3) (Fortuna et al., 2001b). Greater residue returns could have increased the amount of C mineralized following 2nd y corn.

The compost management evolved 10% less CO_2-C than the fertilizer management in 1998 and total soil organic C was 14% higher in the compost management. The C:N ratio of the compost was low (13). However, much of the C and N in compost has been incorporated into highly stable humic materials that are not moderately decomposible (Inbar et al., 1989).

The percent of residue C evolved was higher in compost treatments than that of the fertilizer management. The percent of residue C evolved was estimated by subtracting the quantity of CO_2-C evolved per gram of C in the unamended treatment from the amount of CO_2-C evolved per gram of C from the residue amended treatment. Application of residues to compost treatments may have enhanced decomposition of compost C above that of the unamended soil treatment. The N incubation study indicated that N was limited in the compost management which could reduce C mineralization. Clover additions to compost treatments increased the cumulative CO_2-C evolved by more than 20% that of the N fertilizer management (Table 7 and 8). The increase in C_{min} was likely due to greater inorganic N associated with clover additions. This effect was particularly pronounced in the soybean treatment following 2nd y corn where inorganic N was particularly limiting (Table 4).

Addition of slaked dolomitic limestone acted as a sink for CO_2 in the initial 30-70 d of the C incubation. However, cumulative CO_2 evolved at 317 d was 9-11% higher than the unamended soil treatment. Previous studies have shown that the first year lime was applied to slightly acidic soil (pH 5.7 to 5.8) C mineralization increased 37-67% (Curtin et al., 1998). They found that change in pH can increases the solubility of organic matter. The long-term affect of Ca additions will be to stabilize SOM leading to decreased C_{min}.

Carbon Dynamics and Pool Size

The amount of active C decreased between 1994 and 1998 irrespective of the residue applied (Table 9). Initially, high active pool C was likely due to termination of alfalfa production. An adjacent alfalfa plot mineralized twice as much C in April 1993 and 1994 than mold-board plow and no-till treatments in a corn-soybean-wheat rotation (Paul et al.,1999). Active pool C was lower in treatments cropped to wheat and higher in treatments previously cropped to corn. The corn residue contribution was more than double that added by wheat residue C.

The potential to sequester C increased across all LFL treatments over time. The integrated compost treatment contained 14% more SOC than the N fertilizer treatment in 1998. Estimates of C pool sizes suggest that the increase in SOC associated with compost applications is slow and some resistant pool C. Rate curves for CO_2-C evolved per unit time level off after 150 d (Figure 1). The resistant pool of C does not have a significant seasonal affect on C and N cycling but may improve physical soil properties such as soil tilth (Smeenk, 2001). The MRT of slow pool C decreased from 6 y in 1994 to 13 y in the fertilizer management and 9 y in the compost management. Slow pool C increased by a minimum of 30% in both fertilizer managements (Table 9).

Chisel plowing, intensive cropping, and application of compost increased the quantity of C sequestered. Cumulative CO_2-C evolved was reduced by 10% when compost was applied reducing the potential of radiative forcing by CO_2-C. The majority of agricultural systems have a neutral affect on global warming potential (GWP) no-till management is one of the few agronomic systems that can sequester C (Robertson, 2000). Application of highly degraded materials such as compost may have a similar potential to sequester C and mitigate greenhouse gas emissions.

Sustainable management practices required intensive management in order to synchronize N mineralization from organic sources with that of the grand phase of vegetative growth for a given crop. The effect of residues and residual organic amendment applications on the quantity of available N must be quantified and used to adjust N recommendation when applying organic or inorganic N fertilizers. We recommend that growers adjust their N fertilizer recommendation to reflect the quantity and timing of N mineralized from organic N sources. Proper management of nutrients from compost, cover crops and rotations can maintain soil fertility, improve soil quality, and increase C sequestration.

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Table 1. Treatment description of soil C and N incubations April 1994 and 1998 from the Living Field Lab.

Year	1998	1994				
	Unamended	Unamended	Limestone	Residue		
Amendments	Soil	Soil		clover	corn	wheat
Management						
Integrated-Fertilizer						
Cropping System						
Continuous Corn & Clover	x					
Continuous Corn	x					
1st Year Corn & Clover	x	x		x		
1st Year Corn	x	x	x			x
Soybean Cover Split	x	x		x		
Soybean	x	x	x		x	
Management						
Integrated-Compost						
Cropping System						
Continuous Corn & Clover	x					
Continuous Corn	x					
1st Year Corn & Clover	x	x		x		
1st Year Corn	x	x	x			x
Soybean Cover Split	x	x		x		
Soybean	x	x	x		x	

Table 2. Cumulative (NH_4^+ + NO_3^-)- N mineralized from a 150 d incubation integrated-fertilizer management Living Field Lab April 1994 and 1998.

Year	Cropping System	Day	Cumulative (NH_4^+ + NO_3^-)- N Mineralized† (kg N ha^{-1})					
			2nd Yr Corn Planted to Soybean		Wheat Planted to 1st Year Corn			
			cover	no cover	cover	no cover		
1994		10	0.54	4.73	34.2	13.0		
		30	21.7	15.5	36.5	19.1		
		70	41.0	26.2	97.0	56.6		
		150	138	121	171	152		
			2nd Yr Corn Planted to Soybean		Wheat Planted to 1st Year Corn		Continuous Corn	
			cover	no cover	cover	no cover	cover	no cover
1998		10	20.8	21.3	27.0	20.6	24.8	18.6
		30	48.5	46.0	55.5	42.8	46.5	42.8
		70	81.2	80.5	86.4	78.1	82.5	68.1
		150	124	121	127	113	130	102

†Compost management had significanlty greater cumulative N mineralized also referred to as nitrogen mineralization potential (NMP) than fertilizer management (P=0.05) in 1998.

Treatments previously cropped to wheat had the greatest NMP (P=0.01) in 1994 and (P=0.05) in 1998.

Fertilizer management*sampling interval was significant in 1994 (P=0.03) and 1998 (P=0.01). Compost management contained greater cumulative N at day 10, 30, 70, & 150.

Table 3. Cumulative (NH_4^+ + NO_3^-)- N mineralized from a 150 d incubation integrated-compost management Living Field Lab April 1994 and 1998.

Year	Cropping System	Day	2nd Yr Corn Planted to Soybean: cover	2nd Yr Corn Planted to Soybean: no cover	Wheat Planted to 1st Year Corn: cover	Wheat Planted to 1st Year Corn: no cover	Continuous Corn: cover	Continuous Corn: no cover
			Cumulative (NH_4^+ + NO_3^-)- N Mineralized† (kg N ha^{-1})					
1994		10	11.3	29.2	31.4	25.3		
		30	34.1	46.5	54.1	35.0		
		70	57.0	78.0	88.5	82.2		
		150	133	116	158	143		
1998		10	24.8	22.6	45.0	59.7	27.9	28.8
		30	52.4	57.1	66.3	60.2	65.2	33.6
		70	108	86.3	123	142	103	101.0
		150	161	137	203	180	143	146

†Compost management had significantly greater cumulative N mineralized also referred to as nitrogen mineralization potential (NMP) than fertilizer management (P=0.05) in 1998.
Treatments previously cropped to wheat had the greatest NMP (P=0.01) in 1994 and (P=0.05) in 1998.
Fertilizer management*sampling interval was significant in 1994 (P=0.03) and 1998 (P=0.01). Compost management contained greater cumulative N at day 10, 30, 70, & 150.

Table 4. Nitrogen ($NH_4^+ + NO_3^-$)- N mineralized (NMP) from residue amended soil relative to unamended soil during a 150 d incubation Living Field Lab April 1998.

Management	Nitrogen ($NH_4^+ + NO_3^-$)- N Mineralized† (kg N ha^{-1})						
Integrated-Fertilizer							
Cropping System	2nd Yr Corn Planted to Soybean		Wheat Planted to 1st Year Corn		Continuous Corn		
	corn residue	no residue	wheat straw	no residue	corn residue	clover residue	no residue
Day							
10	-28.2	21.3	-9.94	20.6	-20.2	123	18.6
30	-24.5	24.7	-3.9	22.2	-29.4	31.2	24.2
70	5.25	34.4	45.6	35.3	18.0	87.1	25.3
150	-51.1	40.2	26.0	34.9	56.3	19.4	34.5
Management							
Integrated-Compost							
Cropping System	2nd Yr Corn Planted to Soybean		Wheat Planted to 1st Year Corn		Continuous Corn		
	corn residue	no residue	wheat straw	no residue	corn residue	clover residue	no residue
Day							
10	-37.0	22.6	-49.1	59.7	-39.4	33.2	28.8
30	-30.6	34.5	27.7	0.56	12.8	33.1	4.76
70	6.80	29.2	0.53	81.4	-38.7	12.4	67.3
150	-49.0	50.6	59.4	38.4	-11.1	-19.3	45.2

†$NH_4^+ + NO_3^-$- N values presented for residue amended soils are equal to $NH_4^+ + NO_3^-$- N for a given interval minus $NH_4^+ + NO_3^-$- N from unamended soil for the same interval.

Table 5. Biochemical constituents and C and N sources in incubation systems.

Amendment additions†						Total Soil C§	
	Residue and Compost Application Rates		Biochemical Constituents			g kg^{-1}#	
			lignin	hemicellulose	cellulose		
	kg ha^{-1}						
	C	N		g kg^{-1}‡		1994	9.5*a
Composted Manure	1523	116	90	53	692	1998	12.5
Red clover + root	3000	281	106	94	100		
Corn + root	10400	146	136				
Wheat	4800	146	141	184	361	nutrient management	
Lime	582						
						fertilizer	11.5b
						compost	13.4c

†Residues were oven dried at 60°C.
‡Previously published in (Sanchez et al., 2000).
§Total C values 0- 25-cm depth. Sample depth 0- 25-cm in 1998.
Sample depths were combined 0- 10-cm and 10- 25-cm in 1994.
*Significantly higher total organic C (*P*=0.01) in 1998 than 1994
Values with the same lower case letter are not significantly different (*P*=0.01).

Table 6. Living Field Lab regression parameters describing the mean residence time (MRT), decay rate (k), and size of the pool of readily available N (N_0) as influenced by nutrient management in April 1998 prior to planting.

Single Pool 1st Order‡ $N_t = N_i + N_o(1-e^{-t/MRT})$	Regression parameters residue unamended soil†			
	Ni	No	k	MRT
Nutrient management§	(g N kg^{-1} soil N)		d^{-1}	d
Integrated fertilizer	22	163	0.0067	149
Integrated compost	30	258	0.0048	206

†Nt is inorganic N at time t.

‡Ni is the inorganic N at time zero. No is an estimate of the mineralizable organic N fraction.
MRT is the steady-state mean residence time of the mineralizable organic N fraction.

§The curve fit of N mineralized during a 150 d incubation of unamended soil sampled in April 1998 from the integrated-compost management was significantly different from that of integrated-fertilizer (P=0.01) based on the sums of squares of the residuals test.

Table 7. Cumulative CO_2-C evolved integrated compost management Living Field Lab 1994 and 1998.

		Cumulative C Mineralized†						
	Year	1994		1994		1994	1998	
		Unamended Soil		Residue		Lime	Unamended Soil	
Cropping System		cover	no cover	cover	no cover	no cover	cover	no cover
Previously Wheat	Day†	(μg CO_2-C g^{-1} soil)		The % of Amendment Derived C Evolved			(μg CO_2-C g^{-1} soil)‡	
Carbon source		(%) total soil C decomposed		clover	wheat	lime	(%) total soil C decomposed	
				(%)	(%)	(%)		
	19	771 (1.2)	592 (1.3)				151 (1.0)	125 (1.0)
	34	1124 (1.8)	837 (1.8)	8.8	9.1	2.0	199 (1.1)	167 (1.1)
	52	1304 (3.3)	963 (3.3)	12.6	15.3	3.4	249 (1.7)	212 (1.7)
	80	1368	1007				476 a	398 a
	132	1424	1034				570 a	486 a
	160	1435 (5.5)	1046 (5.4)	19.7	23.4	5.4	615 a (4.1)	528 a (4.2)
	185	1531 (7.1)	1099 (6.3)	21.5	25.2	6.7	742ab (4.8)	629ab (5.0)
	226	1594	1133				826 a	709 a
	284	1636 (10)	1155 (8.5)	31.4	33.7	9.4	1128a (7.7)	908a (7.3)
Previously 2nd Yr Corn				clover	corn	lime		
	19	1057 (1.4)	1066 (1.5)				145 (1.0)	53 (0.59)
	34	1464 (2.4)	1378 (2.5)	29	18	2	206 (1.1)	76 (0.70)
	52	1674 (4.2)	1579 (4.2)	33	20	4	261 (1.7)	174 (1.5)
	80	1752	1673				508 a	323 a
	132	1818	1771				612 a	384 a
	160	1845 (7.0)	1086 (7.6)				659a (4.0)	412 a (3.4)
	185	1926 (8.1)	1911 (8.9)	39	22	1	802ab (4.8)	503 a (4.0)
	226	1975	1968	40	23	9.3	858 a	521 a
	284	2015 (11)	2019 (12)	48	25	11	1216a (7.3)	798 a (6.3)

†Cumulative C Mineralized on day 34 and 160 of the 1994 unamended soil treatments are predicted values simulated using SAS NLIN.

‡Values followed by the same letter are significantly different (P=0.01). Crop had a significant effect in 1994 unamended soil treatment (P=0.01).

Table 8. Cumulative CO_2-C evolved integrated fertilizer management Living Field Lab 1994 and 1998.

		Cumulative C Mineralized†						
	Year	1994		1994		1994	1998	
		Unamended Soil		Residue		Lime	Unamended Soil	
Cropping System		cover	no cover	cover	no cover	no cover	cover	no cover
Previously Wheat	Day†	($\mu g\ CO_2$-C g^{-1} soil)		The % of Amendment Derived C Evolved			($\mu g\ CO_2$-C g^{-1} soil)‡	
Carbon source		(%) total soil C decomposed		clover	wheat	lime	(%) total soil C decomposed	
				(%)	(%)	(%)		
	19	954 (6.9)	1186 (1.4)	9.4	3.5	1.5	369 (1.5)	173 (0.91)
	34	1237 (7.8)	1485 (1.7)	9.8	3.9	2.3	488 (1.8)	245 (1.2)
	52	1422 (10)	1628 (3.3)				635	347
	80	1492	1697				1162 b	620 a
	132	1562	1784				1412 b	753 a
	160	1580 (11)	1814 (5.5)	18	8.4	6.3	1543b (5.9)	822 a (4.3)
	185	1668 (12)	1896 (6.4)	22	8.6	7.4	1799b (6.8)	986 b (5.1)
	226	1719	1942				1993 b	1092 a
	284	1762 (12)	1977 (8.8)	28	11	10	2340 b (8.8)	1297b (6.7)
Previously 2nd Yr Corn				clover	corn	lime		
	19	1100 (1.7)	1477 (2.2)	5.0	5.3	2.8	156 (1.1)	339 (1.4)
	34	1412	1775	5.4	5.8	4.0	200 (1.3)	477 (1.6)
	52	1532	1919				263	608
	80	1598	1978				462 a	1343 b
	132	1695	2086				559 a	1697 b
	160	1714 (7.2)	2106 (7.2)	12	12	6.5	608 a (4.2)	1870b (5.2)
	185	1776 (8.2)	2187 (8.4)	13	13	7.6	704ab (4.9)	2353b (6.4)
	226	1810	2233				752 a	2557 b
	284	1840 (9.4)	2268 (11)	18	16	9.8	893 a (6.3)	3366b (8.8)

†Cumulative C Mineralized on day 34 and 160 of the 1994 unamended soil treatments are predicted values simulated using SAS NLIN.

‡Values followed by the same letter are significantly different (P=0.01). Crop had a significant effect in 1994 unamended soil treatment (P=0.01).

Table 9. Living Field Lab estimates of active, slow, and resistant C pool size and mean residence times (MRT) of active and slow pool C.

	Active C			Slow C			Resistant C
Treatment	% Total C	Lab MRT‡	Field MRT	% Total C	Lab MRT	Field MRT	% Total C
	(%)	days	days	(%)	years	years	(%)
1994†							
	5	54	108	43	6	12	52
1998							
Nutrient management§							
Integrated fertilizer	4	134	268	52	13	26	44
Integrated compost	1	7	14	50	9	18	49

Carbon content	Active C Pool	Slow C Pool	Resistant C Pool
		(g C kg^{-1})	
1994			
	0.5	4	4.9
1998			
Nutrient management			
Integrated fertilizer	0.43 a	6 a	5.1
Integrated compost	0.16 b	6.7 b	7.0

† Curve fitting of the CO_2 evolved per unit time; $C_{(t)}$ was performed with a two-pool 1st order constrained model using the SAS NLIN procedure (SAS Inst., 1988).

The curve fit of 1994 CO_2-C evolved per unit time was significantly different from that of 1998 (P=0.01) based on the sums of squares of the residuals test.

‡ Laboratory mean residence times (MRT) were converted to field MRT using a Q_{10} of 2

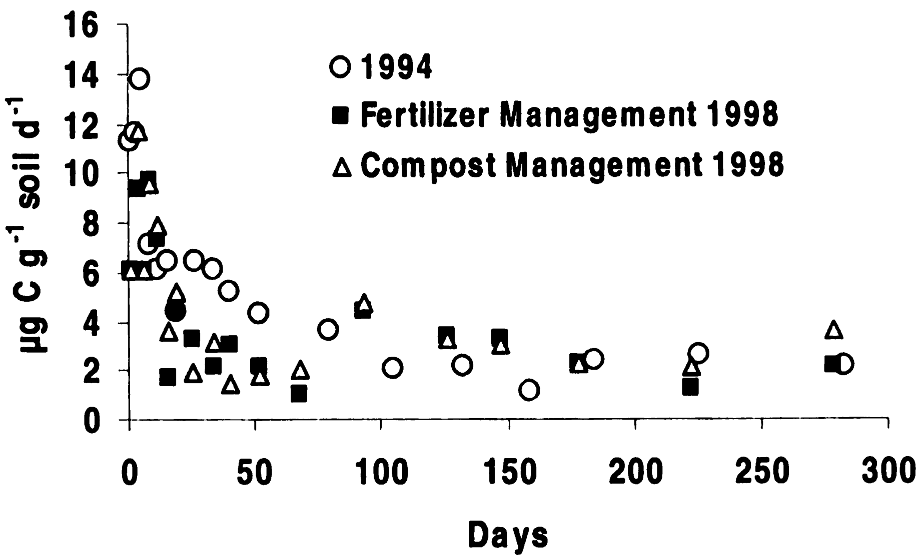
§The curve fit of CO_2-C evolved from the integrated-compost management was significantly different from that of integrated-fertilizer in 1998 (P=0.01) based on the sums of squares of the residuals test.

Table 10. Living Field Lab regression parameters describing the mean residence time, decay rate, and size of active pool C April 1998 prior to planting.

Treatment Effects‡	Regression parameters†					
	1994			1998		
	C_a	Lab MRT	Field§ MRT	C_a	Lab MRT	Field MRT
	mg kg^{-1}	d	d	mg kg^{-1}	d	d
Nutrient Management						
Fertilizer	156 (0.01)a	9 B	18	434 (0.13)a	134 A	18
Compost	120 (0.01)b	14 A	28	159 (0.05)b	7 B	28
Cover Crop Management						
cover crop	147 (0.01)a	9 B	18	158 (0.05)b	9	18
No cover crop	132 (0.01)b	13 A	26	192 (0.05)a	9	18
Cropping Treatment						
Corn residue in continuous corn				179 (0.06)a	10	20
Wheat residue in 1st year corn	121 (0.01)b	11	22	172 (0.05)b	8	16
Corn residue in soybean	158 (0.01)a	10	20	180 (0.06)a	9	18

†Curve fitting of the CO_2 evolved per unit time was performed with a two-pool 1st order constrained model using the SAS NLIN procedure (SAS Inst., 1988). Ca is active pool C. MRT is the mean residence time of active pool C.
‡Values with the same lower or upper case letter are not significantly different (P=0.05) within a year and treatment effect.
§Laboratory mean residence times (MRT) were converted to field MRT using a Q_{10} of 2.

Figure 1. Change in CO_2-C evolved April 1994 vs. 1998 due to nutrient management during a 317 d incubation of unamended soil 0- 25-cm Living Field Lab.



CHAPTER 3

USE OF ^{13}C NATURAL ABUNDANCE TO DETERMINE THE EFFECTS OF COMPOST AND CROP ROTATIONS ON CARBON TURNOVER IN THE PARTICULATE ORGANIC MATTER FRACTION

ABSTRACT

Management practices that affect the quantity of C inputs returned to the soil from cropping systems and compost applications contribute to seasonal fluctuation in nutrient dynamics and may increase C sequestration. The effects of crop rotations and compost applications on soil-C decomposition, and the turnover rate of C_4-derived C were assessed via changes in the C content and ^{13}C values of particulate organic matter (POM) and total soil-C (TOC). The majority of organic inputs enter the POM fraction. Defined as the sand sized soil separates remaining on a 53 µm sieve after removal of residues (>2 mm), dispersion in 5% sodium polyphosphate and 12 hr of shaking. Eighty-five percent of compost material was initially associated with the POM fraction. Measurements of POM-C were 45% higher after 5 y of compost applications. The POM fraction was an indicator of increased TOC in the integrated-compost management. Compost applications increased TOC by an additional 14% relative to the N fertilizer management. The turnover time of C_4-derived C in the POM fraction was 12 y and 22 in SOM. The presence of compost C did not appear to affect the turnover time of corn-derived C, indicating that effects were

additive. Compost application, high cropping intensity, and chisel plow management have the potential to increase C sequestration.

INTRODUCTION

Use of crop residues and animal wastes where available are considered excellent management practices in most agroecosystems (Kapkiyai et al., 1999). Public interest in food safety and global climate change have created new markets for organic and earth-sustainable products (The Hartman Group, 1997; and The Hartman Group, 1996). Maintenance of soil C levels is beneficial to soil quality, and can increase the potential for C sequestration, and improve soil fertility levels (Lal et al, 1999).

Agricultural practices that increase the quantity of plant residues returned and decrease soil disturbance by tillage augment C sequestration. Sufficient N fertilizer levels are required to maintain C inputs provided by crop residues, as well as for the stabilization of soil organic matter (Paul and Clark, 1996). Combining management practices that augment TOC such as manuring, and reducing harvest removal and tillage has an additive effect (Grant et al., 2001). Application of N fertilizer to continuous corn for 27 y increased TOC by 7 Mg C ha^{-1} above that of the unfertilized control (0- 26-cm) (Gregorich et al., 1996). Use of manure as fertilizer provides an additional source of soil C. Reduced fallow frequency can lead to greater TOC levels (Campbell et al., 1991). Greater cropping intensity coupled with a reduction in tillage sequesters additional C

(Sanchez et al., 2001). Loss of TOC due to chisel plowing (CP) is greater than that of NT but less than that of moldboard plow (CT) (Hussain et al., 1999).

Rapid changes (<10 y) in TOC have been measured when cropping intensity and/ or tillage is changed. However, a difference in TOC was not detected 6 y after the conversion of agricultural land to perennial grassland (Robles and Burke et al., 1998). Changes in TOC do not provide information concerning the mineralization of N from crop residues and/or organic amendment. Models designed to quantify the size and turnover rate of C pools based on data from long-term C incubations are effective but time consuming and do not provide information about soil N (Paul et al., 1999; Collins et al., 2000). Dispersion and physical separation of particulate organic matter C (POM) is rapid and has proven to be a sensitive indicator of seasonal changes in soil C and N associated with management (Cambardella and Elliot, 1993). In addition, shifts in POM-C have been shown to reflect changes in TOC before significant changes in TOC can be measured (Wander et al., 1998; Six et al., 1999).

POM-C (50-2000 μm) is associated with sand size fractions and contains the most recent additions of plant material. Results of radiocarbon dating indicate that the oldest C materials are silt-associated (Anderson and Paul, 1984). Several studies have combined particle size fractionation with natural ^{13}C tracer techniques to determine the location and turnover rate of plant residues (Balesdent and Mariotti, 1987; Bonde et al., 1992). They indicated that long-term cropping of forest soil to continuous corn decreased C associated with the sand (50-200 μm) and silt (2-50 μm) fractions and increased the quantity of organic C associated with the clay (0-2 μm) fraction (Balesdent and Mariotti, 1987). Residues initially entered the POM fraction, underwent decomposition and then became mineral associated (Bonde et al., 1992).

Manure and paper sludge applied to previously unamended soils, also entered the system as particulate material associated with the sand-size fraction, and become the core of enhanced macro-aggregate structure (Aoyama et al., 1999; and Chantigny et al., 1999). These results correlate with the conceptual framework of aggregate structure proposed by Tisdall and Oades (1982). Elliott, (1986) and others have equated the concept of aggregate structure to increases in soil C associated with greater quantities of macroaggregates under grasslands and no-till management (Cambardella and Elliott, 1994; and Six et al., 1998). POM acted as a nucleus for macroaggregate formation (Six et al., 1999).

Previous research in the Living Field Lab (LFL) at the Kellogg Biological Station in MI revealed that POM-C was a sensitive indicator of seasonal changes in soil C and N associated with management (Willson et al., 2001). Accumulated inorganic N at day 150 of a laboratory incubation was correlated with original POM-C (>53 μm) ($r = 0.64$). Forty-one percent of the total N content of compost was contained in the POM fraction and compost additions increased POM-C by 25% in the year of application (Willson et al., 2001). The steady-state turnover rate estimate of POM during the study was 20 – 40 y. Most organic inputs enter the POM fraction. Knowledge of long-term changes in POM-C can facilitate management of nutrients from organic amendments. We hypothesized that changes in the quantity of C inputs returned to the soil from cropping systems and compost applications would contribute to seasonal fluctuations in nutrient dynamics and result in long-term changes in POM-C that would be reflected in future TOC levels. The objective of our study was to monitor the impact of crop rotations and compost applications on C sequestration, SOM decomposition, and the turnover rate of C_4-derived C via changes in the C content and ^{13}C values of POM.

MATERIALS AND METHODS

Field sites are located in Hickory Corners, MI on a Kalamazoo loam and a similar Oshtemo sandy loam (coarse-loamy, mixed, mesic, Typic Hapludalfs). The Living Field Lab (LFL) was designed to compare the effects of several sustainable-management practices on crop yield and soil biogeochemical processes. Management practices to be assessed were compost and chemical fertilizer, substitution of a corn-corn-soybean (*Glycine max* L.)-wheat (*Triticum aestivum* L.) rotation in place of continuous corn (*Zea Mays* L.), and the use of a cover crop within each cropping system. The statistical design of the LFL is a split-split-plot, randomized complete block. Split-split-plots are 15 x 4.5 m. Main plot treatments consist of a continuous corn and a corn-corn-soybean-wheat rotation including all entry points each year. The current study did not include the full range of fertilizer regimes and cropping systems. A thorough description of all management systems on the LFL was provided by Fortuna et al. (2001a).

The current study includes data from the LFL in 1994, 1998, and 1999 the 2nd, 6th, and 7th year of the crop rotation. Archived data from 1992, prior to implementation of LFL treatments, were also analyzed. The integrated-compost and integrated-fertilizer managements were sampled all years. The integrated-compost management utilizes compost as a nutrient source. Inorganic fertilizers supply crop nutrients in the integrated-fertilizer management. Banded herbicides and cultivation are used in both managements. Compost rates were adjusted such that treatments maintained an average rate of 4480 kg ha^{-1} y^{-1} of compost. Compost was not applied to the soybean crop. The compost application was doubled in 2nd y corn due to the treatment's supplemental N requirement. This made the total compost input over the rotation equal to that of continuous corn. Cropping systems with cover crops were excluded from this study. The 1st y corn and soybean treatments were sampled in 1994. The 1998 and 1999 samples included the continuous corn treatment, and 1st y corn and soybean entry points in the rotation. A previously-tilled successional grassland treatment located on the adjacent Long-term Ecological Research (LTER) site was contrasted with that of the agronomic treatments. The LTER was in its 10th and 11th y in 1998 and 1999. Soil samples were taken from a sub plot of 10 m x 30 m within each of the 4 replicate, one ha plots.

Total Soil C

Samples were taken in November 1992 with a 5 cm diameter hydraulic probe to 1 m and split into 25 cm increments. Three cores per plot were mixed to obtain one composite sample. Soil samples were collected as composite samples of 12 or more 2 cm diameter cores from each plot in April 1994 and 1998 prior to tillage. Soil samples in 1994, were taken at 0- to 10- and 10- to 25-cm depths. The two sets of samples were combined to obtain one 0- to 25-cm increment. The quantity of soil taken from each depth was on a weight by volume basis. Total soil C samples from the 0- to 25-cm increments in 1992, 1994, and 1998 were measured by dry combustion on a Leco Carbon Analyzer (Leco Corp., St Joseph, MI) or using a Carlo Erba N A 1500 Series 2 N/C/S analyzer (CE Instruments Milan, Italy). Total soil C values for the successional grassland treatment at 0- to 25-cm were obtained from the KBS-LTER data base (http://lter.kbs.msu.edu/soil/cn/). The soil sampling protocol can be obtained at (http://lter.kbs.msu.edu/protocols/Prot_bas.htm#Soil_Sampling).

In-Situ Soil Litter Incubation

Soil samples to be used in an in-situ soil/residue incubation were collected in April of 1998 and 1999 prior to tillage and compost application. Bulk soil samples weighing 1.5 kg were collected as composite samples of 2 cm diameter cores from each plot. Surface crop residue had been carefully eliminated in the sampling. Soil was cooled, sieved through a 4 mm screen and stored at 4°C. Nylon pouches 9 cm x 11 cm sewn together with fishing line were constructed for the purpose of conducting in-situ incubations. Openings in the nylon mesh were 50 µm. One hundred g of soil were placed in each nylon pouch along with a single residue material. The receptacles were sealed with a glue gun and fitted with plastic tags. There were 5 time intervals per y for pouch recovery from the field at 1, 2, 4, 8, and 16 wk and a total of 40 samples per time interval.

Treatments containing in-situ incubations were placed on integrated fertilizer and integrated compost managements. The cropping systems included: the continuous corn no cover treatment with red clover residue (7.5 Mg ha^{-1}) and corn residues (26 Mg ha^{-1}) added to separate pouches, 1st y corn no cover with wheat residue additions (12 Mg ha^{-1}), and the soybean no cover treatment with corn residue (26 Mg ha^{-1}). These residue additions applied to soil in pouches were in lieu of the normal surface residue incorporation through tillage.

Five intact soil cores 13.5 cm x 13.5 cm were removed with a cup cutter at approximately 1 m intervals in the NW corner of each subplot. A nylon pouch was placed in each hole and the soil core placed above it. Each time a pouch was excavated, a soil sample was taken adjacent to the incubation site for determination of soil moisture. Pouches were cooled and stored at 4°C until they were opened and left to air dry.

Particulate Organic Matter (POM)

Residues were defined as material greater than 2 mm. Air dried soil was sieved through a 2mm mesh. After removal of residue, particulate organic matter (POM) was extracted from a 50 or 25 g subsample. POM (53-2000 µm) was defined as the sand sized soil separates remaining on a 53 µm sieve after removal of residues (>2 mm), dispersion in 5% sodium polyphosphate and 12 hr of shaking. The sand sized soil separates were dried at 60°C and ground with a mortar and pestle. Total N, on select POM samples, and POM C, in all samples from June 26th and November 25th 1998 and June 26th and December 3rd 1999 sample dates, were measured. Seasonal differences in POM were minimal which allowed us to eliminate all but these two time intervals. POM-C was separated from archived soil samples taken in November 1992 (0- to 25-cm) and April 1994 samples (0- to 10 and 10- to 25-cm). The 1994 samples were previously combined in one 0- to 25-cm increment for total soil organic C analysis. The quantity of total C and/or N in POM was determined by dry combustion on a Leco Carbon Analyzer (Leco Corp., St Joseph, MI) or using a Carlo Erba N A 1500 Series 2 N/C/S analyzer (CE Instruments Milan, Italy).

Analysis of ^{13}C Natural Abundance

Whole soil, POM, and organic amendments were analyzed for $\delta^{13}C$ on a Europa Model 2020 continuous flow mass spectrometer (Europa Scientific, Crewe, UK). Standards were sugar beet sucrose (-25.68‰ V-PDB) calibrated against NBS-22 (-29.74‰ V-PDB) and sugar cane sucrose (-10.45‰ V-PDB) calibrated against (IAEA-C-6, -10.43‰ V-PDB) (Collins et al., 2000). The fraction (f) of corn (C_4) derived C in the soil was estimated using the equation:

[1] $f = (\delta_t - \delta_0)/ (\delta_c - \delta_0)$

where $\delta_t = \delta^{13}C$ at time t, δ_0 = initial $\delta^{13}C$ of the C_3 derived soil organic matter (SOM) at time $t = 0$, and $\delta_c = \delta^{13}C$ of corn residue (Six, 1998).

Turnover Rates

The turnover rates of C_4-derived POM-C and TOC were calculated based on the amount of corn C (C_4-derived C) in the continuous corn integrated-fertilizer management in 1994 vs.1998 using a single pool first-order model:

[2] $k = -\ln(A_t/A_0)/ \, t$

where A_0 = C_3 derived C at time 0 (1992), A_t is the C_3 derived C at time t [$A_t = (1 - f)$POM-C or TOC] or C_4 derived C at time t [$A_t = f$(POM-C or TOC)], t = y since conversion from alfalfa management to LFL treatments, and k = the decomposition rate of POM-C or TOC (y^{-1}). The mean residence time (MRT) of the POM-C or TOC = $1/k$.

Crop Residue C

Average crop residue C returned was based on the above ground biomass of corn, wheat and soybean crops minus grain yield in 1997 and 1998. A description of the sampling procedure can be found in Fortuna et al. (2001a). A value of 40% average above ground C content of residues based on previous analysis, was used (Fortuna et al., 2001a). Below ground biomass of crops were estimated using: root-C for corn = crop residue C x 0.53, root-C for soybean = crop residue C x 0.47 (Paul et al., 1999) and the root-C for wheat residue was based on measured above ground biomass, a shoot/ root ratio of 1.13 and a root C content of 30% (Buyanovsky and Wagner, 1997). Estimates of TOC loss per year were based on turnover rates and C pool sizes calculated from C mineralization curves obtained from 350 d C incubations and fitted using SAS NLIN (Fortuna, et al., 2001b). The protective capacity, defined as the maximum amount of C associated with clay and silt, was calculated for the LFL using: g C kg^{-1} soil = 4.09 + 0.37(% particles <20 μm) (Hassink et al., 1996).

Statistical Analyses

Variations in total organic C in: soil (TOC), POM C, $\delta^{13}C$ values of POM, and POM as a % of TOC were analyzed using SAS Proc Mixed (SAS, Institute, 1997). The effect of N fertilizer management, cropping system, residue type, date and year, as well as, the interactions between individual effects was determined for each of the previously mentioned data sets.

RESULTS

Carbon Inputs

Total-C in 1992, to a depth of 0- to 25-cm, in the previously-tilled successional grassland treatment was equal to that of the LFL site previously under alfalfa management for 9 y (Table 1). Five years of compost applications increased TOC by 14% relative to the N fertilizer management. Estimates of C inputs averaged across the rotation from 1993 through 1997 on the compost treatment were 24.1 Mg C ha^{-1} and 24.6 Mg C ha^{-1} on the N fertilizer treatment (Table 2). Continuous corn treatments receiving N fertilizer produced approximately 31.8

Mg ha^{-1} corn residue C in 5 y. Continuous corn biomass production was 31.3 Mg C ha^{-1} in the compost treatment.

Use of rotation in place of continuous corn did not affect TOC values in either nutrient management. Carbon inputs from were averaged across the rotation and continuous corn managements. Average above and below ground residue inputs on the N fertilizer management were 28.2 Mg C ha^{-1}. The estimated SOM-C loss per year was 4% in this nutrient management and was based on previously calculated C pool sizes and MRTs of soils sampled in April 1998 (Fortuna et al., 2001b). A total of 7.48 Mg C ha^{-1} of compost C was applied and 27.7 Mg residue C ha^{-1} returned to the LFL between November 1992 and 1998 (Table 3). The estimated SOM-C loss per year in the compost management was 2% in 1998.

Particulate Organic Matter

POM-C constituted 15-20% of TOC in the 0- to 25-cm depth under N fertilizer management (Table 4). Between 23 and 26% of TOC was contained in the POM fraction where compost was applied (Table 5). Sampling date ($P = 0.004$) and N management ($P = 0.04$) had a significant affect on the % of POM contained in TOC during 1999 (Table 6). There were no significant interactions in 1998. After compost was dispersed with Na hexametaphosphate and sieved through a 53 μm mesh, 84% of the compost material was contained in the POM fraction.

The C:N ratio of POM increased over time. After 9 y of alfalfa in April 1992, the C:N ratio of POM was 13.6. The C:N ratio of POM in 1994 was 15.6. Crop inputs from predominantly nonleguminous crops significantly increased the C:N ratio of POM to 17.4 by June 1998 -1999. The C:N ratio of POM was not influenced by compost applications or the rotation vs. continuous corn treatment. The successional grassland management had the widest C:N ratio 19.9 in June 1998-1999. The POM separated from compost had a C:N ratio of 13.

The quantity of POM C was greatest ($P = 0.01$) in treatments where compost was substituted for N fertilizer in 1998 and 1999 (Table 5) and (Figure 1). The quantity of POM C increased by 14% after implementation of compost management in 1993 (Figure 1). Carbon inputs from residues and compost were 20% higher than C inputs from residues in the fertilizer management (Table 2 and 3). After 5 y of compost applications, POM-C increased an average of 44.5%. The quantity of POM-C ranged from 6358-7662 kg ha^{-1} under N fertilizer management and 10012-12191 in the integrated-compost treatment during 1998-1999 (Table 4 and 5). POM values were not significantly different between years on N fertilizer treatments (Figure 1).

There was a N management by cropping system effect in 1999 (Figure 2). Cropping systems contained equal quantities of POM on N fertilizer treatments. Plots in integrated compost cropped to soybean in the year sampled contained significantly lower levels of POM-C than the continuous corn treatment under compost management. The 1st y corn compost treatment was not significantly different from that of the soybean rotation or continuous corn treatments under compost management.

13C Natural Abundance

The $\delta^{13}C$ value of whole soil after 9 y of alfalfa prior to the establishment of the LFL in 1992 was –23.1‰ at a 0- to 25-cm depth (Table 7). Whole soil after 8 y of successional grassland management had a $\delta^{13}C$ value of -22.3‰. All C inputs to the LFL were dominated by C_3-C sources ranging from -25.0 to -28.0‰ with the exception of corn (-13.0‰). Whole soil $\delta^{13}C$ values in 1994 were within half a ‰ of 1992 measurements. The $\delta^{13}C$ value of the 1st y corn integrated-compost rotation (-23.2) was equal to the whole soil measurement (-23.1) taken in 1992 (Table 7 and 8).

The percent C_4-C, corn derived C in SOC was calculated using the $\delta^{13}C$ values of soil and corn residues. The 1st y corn compost treatment contained no measurable C_4-C derived C (Table 8). Five years of rotations and compost applications reduced $\delta^{13}C$ values in whole soil by greater than 1‰ on all other treatments in the integrated-fertilizer system and integrated-compost management (Table 8 and 9). The continuous corn integrated fertilizer treatment contained 26% C_4-C. The fertilizer rotation treatments contained 10-12% corn-derived C. Seventy-three percent of the crop residue C returned to the rotation was C_3-C. Compost treatments cropped to continuous corn and the rotation in soybean contained 10% corn derived C. However, crop residue inputs in the continuous corn system were 80% C_4-C and 40% of C_4-C origin in the soybean rotation. The turnover rate of C_4-C in SOM was 22 y for 1994-1998.

The use of compost and crop residue inputs had a significant effect on $\delta^{13}C$ measurements in POM during 1998 and 1999. The average $\delta^{13}C$ value of the N fertilizer management was –20.8‰ and –22.2 for the compost management. The 1st y corn compost treatment contained the lowest $\delta^{13}C$ value –23.5 and followed two C_3 pathway crops (Table 5). The integrated-fertilizer continuous corn management contained the highest $\delta^{13}C$ value –19.4 (Table 4).

Measurements of $\delta^{13}C$ in the POM fraction were used to calculate the quantity of C_3- and C_4 (corn) derived POM-C in 1998-1999. The initial $\delta^{13}C$ value of the POM fraction in 1992 at the 0- 25-cm depth was –25.2‰. The initial quantity of C_4-derived C in the POM fraction was 1.9% in April 1992. Individual replicate values ranged from 0 to 4% C_4-C. By the end of the 7th y of the rotation, N fertilizer treatments contained 20 to 38% greater corn derived-C than compost treatments. The integrated-fertilizer continuous corn treatment contained the greatest quantity of corn-derived C nearly 50% (Table 4). The integrated compost treatment in 1st y corn contained the least amount of corn-derived C due to lower corn yields and dilution by C_3-C from compost (Table 5). The use of compost increased the average amount of C_3-C in POM to 8443 kg C ha^{-1} in 5 y. Approximately 25% of the residue C inputs were C_3-C. Carbon inputs from compost were equal to 25% of the total C residue inputs for the 7 y period and were C_3-derived. The average turnover rate of corn derived-C in the POM fraction 1994-1999 was 11 y.

DISCUSSION

Total Organic C in Soil

The previously-tilled successional grassland management and agronomic treatments on the LFL contained equal levels of TOC in 1992 (Table 1). Cropping histories differed on the LFL and LTER prior to implementation of the grassland management in 1989. The successional grassland had been in intensive corn rotation, so had ostensibly recovered some TOC by 1992. Changes in C inputs due to rotation and continuous corn management on the LFL were too small to affect TOC values during the course of our experiment.

Differences in TOC measurements on the LFL and successional grassland treatment may in part be an artifact of sampling technique and the inherent heterogeneity of soils and residue distribution. The location of sampling stations on the LTER varied each year. Total C on an adjacent LTER wheat plot was auto-correlated at a distance of less than 2 m^2 (Stoyan et al., 2000). Stored samples from 1992, 1994, and 1998 on the LFL were analyzed for total C concurrently to reduce analytical error.

The compost management contained 14% more TOC in 1998 than the N fertilizer management. Average C inputs on the compost treatment were approximately 25% higher than inputs to the fertilizer management and were compost, not crop residue derived. Compost C accounted for 25% of total C inputs to the integrated-compost treatments during the 5 y period. Loss of TOC to decomposition was 2% in compost treatments and 4% of TOC in the fertilizer treatment in 1998. These amounts coincide with similar estimates of SOM-C loss per year across several systems ranging from 2 to 5% of TOC (Kapkiyai et al., 1999; and Huggins et al., 1998)

The MRT of C inputs increased during the 4 y period between 1994 and 1998. Decreased loss of plant residues from the LFL may in part be due to termination of alfalfa production and chisel-plowing. An adjacent alfalfa plot mineralized twice as much C in April 1993 and 1994 than mold-board plow and no-till treatments in a corn-soybean-wheat rotation (Paul et al.,1999). Organic C levels in whole soil on chisel plow treatments are intermediate between that of no-till and moldboard plow managements at 0- to 15-cm depth (Hussain et al., 1999). A 6 y no-till treatment adjacent to the LFL contained approximately 16% greater TOC (0- to 20-cm) than the moldboard plow treatment (Collins et al., 2000). The turnover rate of corn derived-C in soil on the LFL was 22 y in 1998.

The protective capacity, defined as the maximum amount of C associated with clay and silt, was determined to be 71.4 g C kg^{-1} of soil on the LFL. Soil texture is assumed have a minimal effect on the decomposition rate of residues above the protective capacity. Current TOC levels in all managements are below the calculated protective capacity.

13C Natural Abundance and C Turnover in Soil and POM

The % of TOC in the POM fraction ranged from 15 to 28% (Table 4 and 5). These values are similar to data from agroforestry (22%), no-till (24.7%), stubble mulch (19.5), and bare fallow managements (18.4) (Lehmann, et al., 1998). Past C:N measurements of POM on the LFL in 1994 were (15 to 16) (Willson et al., 2001). The C:N ratio of the POM increased over time showing the effect of inputs with a wider C:N ratio. Plant residues of all treatments have much higher C:N ratios than alfalfa. The C:N of corn, wheat and soybean are 40.9, 41.1, and 18.4. (Buyanovsky and Wagner, 1997). The POM in compost had a lower C:N ratio (13) but contributed less C to POM than crop residues.

The previously-tilled successional grassland contained significantly greater POM-C than the integrated-fertilizer management in one out of two years (Figure 1). Measurements of POM C (0- to 20-cm) in a never-cultivated grassland at KBS were 40% higher than POM-C in no-till and moldboard plow treatments (Six et al., 1999). The LFL integrated-fertilizer management and previously-tilled successional grassland (LTER) may have had similar quantities of POM C due to high levels of crop residues returned and reduced tillage on LFL agronomic treatments. The tillage history of the LFL included 5 y of chisel plow management and 9 y without tillage while plots were in alfalfa prior to the research trial establishment.

The continuous corn integrated-compost treatment had higher level of POM-C than the soybean rotation following 2nd y corn (Figure 2). An equal quantity of compost was applied to the rotation and continuous corn system during a 4 y period. However, compost is not applied before the soybean crop and twice the quantity of compost is applied to 2nd y corn as in 1st y corn and winter wheat. Wheat requires fall rather than spring application of compost. Increased POM-C on the continuous corn treatment may be due to the timing of compost application and the year lag associated with compost application and mineralization of POM (Willson et al., 2001)

The quantity of POM-C was not significantly affected by crop residue inputs or the use of N fertilizer from 1992 to 1994. All plant materials were assumed to pass through the POM fraction. Five years of compost application increased POM-C an average of 44.5% above that of 1992 measurements (Figure 1). Eighty-four percent of the compost C applied was in the POM fraction. Manure applications have been shown to increase POM C by 25% over a 10 y period (0-10-cm) (Aoyama et al., 1999). Aerobic composting of manure for a 140 d was shown to increase the lignin content and double the quantity of humic substances in composted materials (Inbar et al., 1989). The presence of humic materials decreases the turnover rate of C.

The quantity of C in the TOC and POM fraction do not provide information about the rate of decomposition and incorporation of particulate materials into SOM. Natural abundance differences in the C_4- C_3 plant switch and compost were used to calculate the turnover rate of C_4, corn-derived C in POM and TOC. Crops other than corn were C_3. The $\delta^{13}C$ value of compost additions (-26.4) reflected the mixing of leaf materials, mainly of oak origin, and dairy manure. The $\delta^{13}C$ value of oak leaves (*Quercus rubra*) –27.5‰ was measured in a previous study (Collins et al., 2000). Fifty percent of the dry weight of the animal feed ration was corn material. All other C sources in the feed were of C_3 origin. Both animal nutrition and the composting process have been shown to increase the proportion of lignin in remaining materials as the other materials are removed

(Inbar et al., 1989). Lignin is depleted 2-6‰ in ^{13}C relative to whole-plant material (Benner et al., 1987). Corn C turnover in POM was 10 y and 22 y in soil. A similar tracer study determined the turnover rate of C_4 derived C in the sand sized fraction to be 4 y (Bonde et al., 1992).

The tracer study provided no information on the turnover rate of compost material. Data from a previous study on the LFL revealed that 5 y of compost applications increased the estimated sizes of slow pool C (10%) and resistant pool C by 27% (Fortuna et al., 2001b). The field MRT of slow pool C in the compost management was 18 y and 26 in the fertilizer management. The interaction between the amount of substrate and its turnover rate is well recognized in applying first order equations to SOC dynamics (Collins et al., 2000). The C content of the residue of acid hydrolysis has been equated with the size of the resistant C pool. The mean residence time of the resistant pool was previously estimated to be greater than 1000 y (Paul et al. 1999).

Data collected from the current project indicated that compost management and cropping systems employed have increased C sequestration. The POM fraction was an indicator of increased TOC in the integrated-compost management. Measurements of POM C were 44.5% higher after 5 y of compost applications. Eighty-five percent of compost material was initially associated with the POM fraction. The turnover rate of C_4-C in POM and soil indicated that C from crop residues persisted in the POM fraction half as long (11 y) as in TOC (22 y). Compost applications added C to slow and resistant fractions. Slow pool C can be managed to influence seasonal availability of inorganic N to row crops.

Compost application, high cropping intensity, and chisel plow management (CP) increased C sequestration.

Increased POM-C particularly humified compost materials that persist in the soil system can function as a nucleus for soil aggregate formation. Enhanced stability of macroaggregates may improve soil tilth, decrease soil erosion, and prevent the depletion of soil C and N. Further research is needed to determine the effect of compost applications on soil aggregate structure. Estimates of turnover rates and the quantity of C_4-derived C associated with the silt and clay fractions would enable us to determine the location of C_4-C and improve our understanding of the role soil texture plays in C cycling.

Future research on the LFL will estimate the length of time required for TOC levels to reach equilibrium for a given cropping system, tillage, and fertilizer management. Differences in C inputs from the rotation and the continuous corn management (30%) should result in measurable changes in TOC. Equilibrium TOC levels will be compared to the value calculated for the protective capacity of the soil.

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Table 1. Description of field sites Kellogg Biological Station, MI.

Climate		Soil	
Surface soil temperature	Average yearly precipitation	**Soil series**	**Bulk density**
		Kalamazoo	
(°C)	(mm)	(Fine-loamy mixed mesic)	(Mg m^{-3})
>10 April	920	Oshtemo	1.3
<5 December to March		(Coarse-loamy mixed mesic)	

Total Soil C†			
1994		**1998**	
nutrient management	Mg C ha^{-1}‡	**nutrient management**	Mg C ha^{-1}
fertilizer	35.2 e	fertilizer	42.6 d
compost	35.5 e	compost	49.6 b
successional grassland	48.1 c	successional grassland	61.0 a
1992		**1992**	
alfalfa	35.2 e	successional grassland	35.2 e

†Total C values 0-25 cm depth. Sampling depth 0-25 cm in 1998 and 1992. Sampling depths were combined 0-10 cm and 10-25 in 1994.

‡Values with the same lower case letter are not significantly different (P=0.01).

Table 2. Estimates of above and below-ground C inputs from crop residues to the Living Field Lab 1993-1998.

Carbon Inputs	Carbon content of crop biomass†	
	Mg C ha^{-1}	
Crop	Fertilizer	Compost
Continuous Corn	5.3	5.21
Total C Inputs 4 y	**21.2**	**20.8**
Total C Inputs 1993-1998	**31.8**	**31.3**
Rotation		
1st yr corn	5.4	5.73
2nd yr corn	5.04	4.81
soybean	2.5	2.35
wheat‡	1.31	0.72
Total C Inputs Rotation	**14.2**	**13.6**
Total C Inputs 1993-1998	**24.6**	**24.1**

†Crop biomass values are the average above ground biomass measured in 1997 and 1998 plus estimated below ground biomass. Below ground estimates were calculated with the following formulas: root-C for corn = crop residue C x 0.53, root-C for soybean = crop residue C x 0.47 (Paul et al., 1999) and the root-C for wheat residue was based on measured above ground biomass, a shoot/ root ratio of 1.13 and a root C content of 30% (Buyanovsky and Wagner, 1997
‡Wheat straw was harvested. Wheat biomass is equivalent to estimated below ground biomass.

Table 3. Carbon inputs from compost applications to the Living Field Lab 1993-1998.

Year	Average Amount of Compost Applied per Year†
	Mg C ha^{-1}
1993	1.50
1994	3.10
1995	0.21
1996	0.90
1997	0.90
1998	0.90
Total C Inputs 1993-1998	**7.48**

†Compost was applied to wheat in fall. Soybean did not receive compost. The 2nd y corn treatment 1.8 Mg ha^{-1} compost.

Table 4. Characteristics of the particulate organic matter fraction (POM) integrated-fertilizer management Living Field Lab averaged across 1998 and 1999.

Management	Organic C in POM	POM as a Percent of TOC	C_4-derived POM C	Percent corn C C_4-derived C	^{13}C of the POM
	(kg C ha^{-1})†	(%)	(kg C ha^{-1})	(%)‡	(‰)
1st yr corn					
wheat residue	6358	15	1503	24	-22.5
soybean					
corn residue	7422	20	2244	30	-21.6
continuous corn					
clover residue	7662	20	3682	48	-19.8
corn residue	7490	19	3508	45	-19.4

†Samples placed in pouches were from the 0- 25-cm depth. A bulk density of 1.3 Mg m^{-3} was assumed. Fertilizer management * crop was significant at the (P = 0.02) probability level in 1999. Fertilizer management significant at the (P = 0.01) probability level in 1998.

‡Estimate of the fraction of corn derived C was calculated using $f = \delta_t - \delta_0 / \delta_c - \delta_0$. Where $\delta_t = \delta^{13}C$ at time t, $\delta^{13}C$ of corn crop, and $\delta_0 = \delta^{13}C$ of original grassland derived soil organic matter.

Table 5. Characteristics of the particulate organic matter fraction (POM) integrated-compost management Living Field Lab averaged across 1998 and 1999.

Management	Organic C in POM (kg C ha^{-1})†	POM as a Percent of TOC (%)	C_4-derived POM C (kg C ha^{-1})	Percent corn C C_4-derived C (%)‡	^{13}C of the POM (‰)
1st yr corn					
wheat residue	11022	25	1704	16	-23.5
soybean					
corn residue	10012	23	2444	24	-22.3
continuous corn					
clover residue	12191	26	4032	33	-21.9
corn residue	12149	26	3420	28	-21.3

†Samples placed in pouches were from the 0- 25-cm depth. A bulk density of 1.3 Mg m^{-3} was assumed. Fertilizer management * crop was significant at the (P = 0.02) probability level in 1999. Fertilizer management significant at the (P = 0.01) probability level in 1998.

‡Estimate of the fraction of corn derived C was calculated using $f = \delta_t - \delta_0 / \delta_c - \delta_0$. Where $\delta_t = \delta^{13}C$ at time t, $\delta^{13}C$ of corn crop, and $\delta_0 = \delta^{13}C$ of original grassland derived soil organic matter.

Table 6. The effect of N fertilizer management, cropping system, date of sampling, and year on particulate organic matter (POM) and concentration of ^{13}C POM. Table of *P* values in PROC MIXED.

	Year 1998			Year 1999			
Dependent† variable	**Date**	**N management**	**Cropping System**	**Date**	**N management**	**Cropping System**	**Management *Crop**
	***P* value‡**			***P* value**			
POM	NA	0.01	NA	0.004	0.02	0.002	0.02
POM as a % of TOC	NS	NS	NS	0.004	0.04	NS	NS
^{13}C	NA	0.02	0.0003	NS	0.02	<0.0001	NS

†*P* values are from pouches on agronomic treatments only data from the successional grassland treatment was not included.

‡NA=not applicable, NS=not significant.

Table 7. The concentration of ^{13}C in whole soil and organic amendments.

Management†	^{13}C (‰)	Organic Amendments‡	^{13}C (‰)
	1994		
Integrated-fertilizer			
1st yr corn	-23.4		
Soybean	-23.3	**Compost**	-26.4 ±0.5
		Compost POM§	-25 ±0.5
Integrated-compost			
1st yr corn	-23.2	**Clover**	-28 ±0.5
Soybean	-23.2		
		Corn	-13 ±0.5
1998		**Wheat**	-26.8 ±0.5
Successional grassland (previously-tilled)	-22.3		
1992			
Baseline Measurement Living Field Lab (LFL)	-23.1		

†Soil samples (0- 25-cm) were collected December 14th 1997 in continuous corn and plots to be cropped to 1st yr corn and soybean rotations in 1998.

‡Organic amendments were oven dried at 60°C.

§The compost was dispersed with hexametaphosphate and the ^{13}C signal of the particulate organic matter (POM) compost (>50 μm) was measured by mass spectroscopy.

Table 8. Characteristics of total organic C (TOC) integrated-compost management Living Field Lab 1998.

Management	Total Organic C in Soil	C_4-derived C	Percent corn C C_4-derived C	^{13}C of the soil
	(kg C ha^{-1})†	(kg C ha^{-1})	(%)‡	(‰)
1st yr corn				
wheat residue	44356	0	0	-23.2
soybean				
corn residue	42588	4259	10	-22.1
continuous corn				
clover residue	47150	4715	10	-22.1

†Samples are at a 0- 25-cm depth. A bulk density of 1.3 Mg m^{-3} was assumed.

‡Estimate of the fraction of corn derived C was calculated using $f = \delta_t - \delta_0 / \delta_c - \delta_0$. Where $\delta_t = \delta^{13}C$ at time t, $\delta^{13}C$ of corn crop, and $\delta_0 = \delta^{13}C$ of original grassland derived soil organic matter.

Table 9. Characteristics of total organic C (TOC) integrated-fertilizer management Living Field Lab 1998.

Management	Total Organic C in Soil (kg C ha^{-1})†	C_4-derived C (kg C ha^{-1})	Percent corn C C_4-derived C (%)‡	^{13}C of the soil (‰)
1st yr corn				
wheat residue	42100	5052	12	-22.2
soybean				
corn residue	37867	3787	10	-22.3
continuous corn				
	38510	10013	26	-20.6

†Samples are at a 0- 25-cm depth. A bulk density of 1.3 Mg m^{-3} was assumed.

‡Estimate of the fraction of corn derived C was calculated using $f = \delta_t - \delta_0 / \delta_c - \delta_0$. Where $\delta_t = \delta^{13}C$ at time *t*, $\delta^{13}C$ of corn crop, and $\delta_0 = \delta^{13}C$ of original grassland derived soil organic matter.

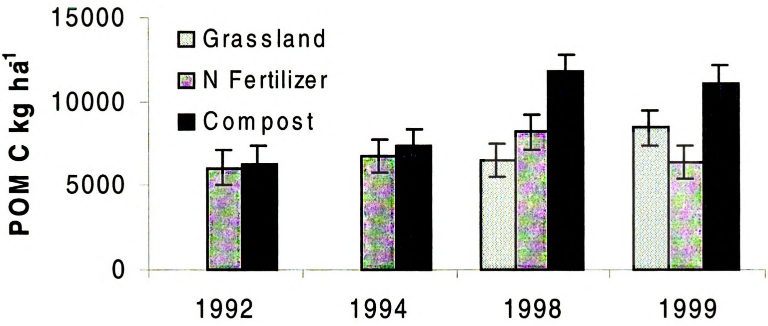

Figure 1. Particulate organic matter (POM) C in the top 25 cm under varying management in 1992, 1994, 1998 and 1999 taken from the Living Field Lab and Long-term ecological research sites. Samples in 1998 and 1999 were taken from in-situ soil litter pouches. Error bars represent the standard error of the mean. Units are based on a bulk density of 1.3 Mg m^{-1}.

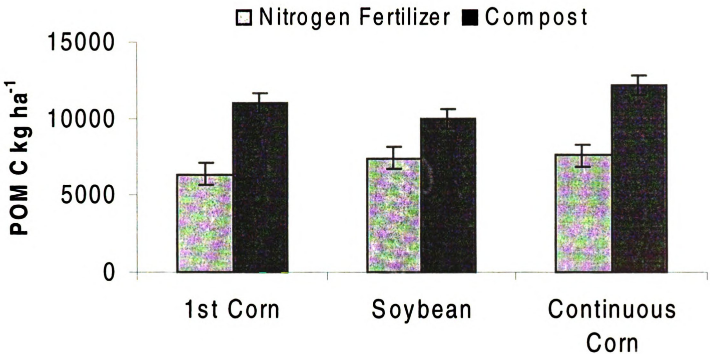

Figure 2. The effect of cropping system and N fertilizer management on particulate organic matter (POM) C in the top 25 cm. Samples were taken from the Living Field Lab in 1998 and 1999. Samples in 1998 and 1999 were taken from in-situ soil litter pouches. Error bars represent the standard error of the mean. Units are based on a bulk density of 1.3 Mg m^{-1}.

SUMMARY

The uniformity, low cost and ease of application associated with inorganic fertilizers have diminished the use of organic nutrient sources. Concern for food safety, the environment and the need to dispose of animal and municipal wastes have focused attention on organic sources of N such as animal derived amendments (manure and compost), cover crops, and crop rotations. Providing nutrients to row crops from organic sources demands intensive management of the N and C cycles. Managing organic N sources to provide sufficient N at the grand phase of crop growth requires knowledge of C and N decomposition over several years particularly where manure and compost is applied. Compost applications and increased crop diversity associated with legume cover crops and rotations can augment soil nutrient concentrations, increase equilibrium levels of C, and affect the mean residence time (MRT) of C and N in soil organic matter (SOM) pools.

The Living Field Lab (LFL) was designed to test the effects of several sustainable management practices on crop yield and soil biogeochemical processes. Nitrogen was limiting on all compost treatments with the exception of 1st y corn following wheat fallow and clover cover crop. The added diversity of the clover cover crop and wheat-fallow increased inorganic N and in some instances improved corn yields in both nutrient managements. Lowered soil N levels

decreased nitrification potential and the potential for NO_3^- leaching but diminished corn yield in some treatments and may have reduced grain quality.

Decomposition of residues during long term C and N incubations provided information concerning the mineralization pattern of the previous season's residues. Application of corn residues that had over wintered in the field tended to immobilize N for the entire 150 d N incubation. This time period would be equivalent to approximately 300 d in the field or more than one full growing season. Residues from winter wheat harvested in July had had several more months to decompose than corn residue. Addition of corn residues to compost treatments increased N immobilization. Application of dried clover increased inorganic N in the fertilizer management and reduced N immobilization in the compost management.

The effect of residues and residual organic amendment applications on the quantity of available N must be quantified and used to adjust N recommendation when applying organic or inorganic N fertilizer sources. Corn residues increased the N requirement of the proceeding corn crop in the LFL. Corn grown after winter wheat and clover cover crops had lowered N requirements. Mineralization of organic N from clover was immediate. Release of mineral N from wheat residues was within the first 30 d of the N incubation.

Growers should take into account the timing and quantity of N released from organic N sources when deciding to sample for soil nitrates at preplant (PPNT) or presidedress (PSNT). An evaluation of soil NO_3^- testing and corn N response across the North Central Region indicated that PPNT sampling following small grain and soybean was most effective in determining the critical soil NO_3^- level (CSNL) (Bundy et al., 1999) The CSNL is the soil NO_3^- concentration above which no crop yield response to additional N is expected. Mineralization of organic N from corn residues, manure, and SOM in fine textured soils occurred later in the growing season. Therefore, PSNT sampling was recommended. Information concerning mineralization of organic N from a variety of sources including: row crop, cover crop residues and compost on the LFL should be used in conjunction with other information in our data base to adjust N recommendations and the timing of soil nitrate testing in Michigan for optimum yield response and decreased nitrate leaching.

Replacement of/ or supplementing inorganic fertilizers with organic amendments such as compost can provide benefits beyond maintenance of soil fertility. Compost managements contained 14% greater total soil organic C (TOC) than fertilizer managements. The majority of C in the compost material (85%) was found in the particulate organic matter fraction (POM). Five years of compost applications increased POM-C by 44.5% indicating a low turnover rate of compost derived POM-C. The turnover time of corn-derived C (C_4-C) was not affected by the presence of compost. The corn C turnover rate in POM was 11 y and 22 y in whole soil. Increases in POM-C may improve aggregate stability. Particulate organic matter has been shown to serve as a nucleus for soil aggregate formation. Enhanced stability of macroaggregates may improve soil tilth, decrease soil erosion, and prevent the depletion of soil C and N.

Sustainable management practices required intensive management in order to synchronize N mineralization from organic sources with that of the grand phase of vegetative growth for a given crop. We recommend that growers adjust their N fertilizer recommendation to reflect the quantity and timing of N mineralized from organic N sources. Inorganic N supplied by residues must be managed in systems where organic and inorganic nutrient sources are applied. Proper management of nutrients from compost, cover crops and rotations can provide the equivalent yield and crop quality of systems utilizing inorganic fertilizer, as well as, decrease the potential for NO_3^- leaching, improve soil quality, and sequester C.

REFERENCE

Bundy, L.G, D.T. Walters, and A.E. Olness. 1999. Evaluation of soil nitrate testing for predicting corn nitrogen response in the North Central Region. North Central Regional Research Publication No. 342, Wisconsin Agricultural Experiment Station, College of Agriculture and Life Science, University of Wisconsin-Madison.

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