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THE IMPACTS OF CONTINUOUS CORN AND A CORN-CORN-SOYBEAN-WHEAT ROTATION GROWN UNDER VARIOUS MANAGEMENT SCHEMES ON NITRATE LEACHING, SOIL PHYSICAL CHARACTERISTICS, AND NET RETURNS

presented by

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has been accepted towards fulfillment
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By

Jeffrey Smeenk

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ABSTRACT

THE IMPACTS OF CONTINUOUS CORN AND A CORN-CORN-SOYBEAN-WHEAT ROTATION GROWN UNDER VARIOUS MANAGEMENT SCHEMES ON NITRATE LEACHING, SOIL PHYSICAL CHARACTERISTICS, AND NET RETURNS

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Nitrate leaching, maintenance of soil quality, and economic viability are major issues associated with row crop agriculture and are influenced by the production strategies chosen by the farm manager. These strategies include rotation sequence, source of nutrient inputs and the use of cover crops. A long-term rotation study on Oshtemo and Kalamazoo sandy loams (coarse-loamy, mixed, mesic Typic Hapladaulfs) at the W.K, Kellogg Biological Station near Hickory Corners, MI was established in 1993 to compare various physical and economic parameters of a corn-corn-soybean-wheat rotation to those of continuous corn under various management systems. The organic (O) and integrated compost (IC) systems used compost as the external nutrient source while the integrated fertilizer (IF) and conventional (C) systems used synthetic fertilizers. All management systems except C have cover crops interseeded at various points of the rotation. Corn yields were highest in 1st year corn. In the O and IC systems, when 1st year corn followed wheat+red clover yields were the same as for fertilized corn. Without the preceding red clover cover crop, yields of 1st year corn crops in O and IC were significantly lower. Wheat yields were lower in the O and IC treatments. No significant differences were seen in soybean yields. The leaching patterns of a crop was very dependent upon the climatic conditions. Both systems receiving compost had lower nitrate leaching rates than the

systems using fertilizer. In the IC system 1st year corn leached more nitrate (50 kg N $ha^{-1}yr^{-1}$) than 2nd year corn (35 kg N $ha^{-1}yr^{-1}$) , soybean (34 kg N $ha^{-1}yr^{-1}$) continuous corn (26 kg N $ha^{-1}yr^{-1}$), or wheat (17 kg N $ha^{-1}yr^{-1}$). In the IF system the nitrate leaching rates of 1st year corn (59 kg N $ha^{-1}yr^{-1}$), 2nd year corn (67 kg N $ha^{-1}yr^{-1}$), and continuous corn (57 kg N $ha^{-1}yr^{-1}$) were greater than the leaching rates of soybean (39 kg N $ha^{-1}yr^{-1}$) or wheat (20 kg N $ha^{-1}yr^{-1}$). Bulk density was lowest following first year corn and highest following wheat but the influence of management was not significant. Water holding capacity, while statistically significant, was not agronomically significant (41-43%). Aggregate stability was highest in wheat interseeded with red clover and lowest in the soybean plots that did not receive cover crops at any point of the rotation. The management systems receiving compost tended to have higher infiltration rates than those receiving synthetic fertilizer but these differences were not significant due to the high variability. The resistance to penetration tended to be higher in wheat than in the other crops but the differences were not consistent nor significant. Net returns to land and management expertise were highest in the O treatments (\$359-398 ha^{-1}) due to the premium prices associated with organic crops. Within the normally priced crops the IF corn-corn-soybean-wheat rotation without cover crops had the highest net returns (\$155 ha^{-1}) followed by the IF rotation with cover crops (\$128 ha^{-1}) and the C rotation (\$116 ha^{-1}). The IC continuous corn had the lowest net returns both with cover crops (\$15 ha^{-1}) and without cover crops (\$10 ha^{-1}). This research demonstrated that a corn-corn-soybean-wheat rotation had higher net returns than continuous corn while building soil quality and reducing environmental impact from nitrate leaching. The use of compost enhanced the soil quality effects but would not be effective in rotations with multiple years of corn.

Dedicated to Gottlieb "Goodie" Streicher

ACKNOWLEDGMENTS

Thank you Dr. Harwood

PREFACE

Chapter 1 in this dissertation was written in the style required for publication in the Journal of Environmental Quality. Chapter 2 was written in the style required for publication in the Journal of Soil and Water Conservation. Chapter 3 was written in the style required by the Agronomy Journal.

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CHAPTER 1

Influence of Crop Rotation and Nutrient Source on Nitrate Leaching

ABSTRACT

Nitrate leaching is a significant problem in the upper Midwest. Row crop agriculture, especially corn, has been implicated in the nitrate contamination of ground water. This study looked at the influence of compost and fertilizers on the nitrate leaching rates of both a diverse rotation and continuous corn. The influence of lysimeter size on the estimation of nitrate leaching was also evaluated. Fifty six 30.5 cm and four 91 cm intact core lysimeters were installed in a long-term rotation study on Oshtemo and Kalamazoo sandy loams (coarse-loamy, mixed, mesic Typic Hapladaulfs) at the Kellogg Biological Station near Hickory Corners, MI. A corn - corn - soybean - wheat rotation was compared to continuous corn under various management systems. The organic (O) and integrated compost (IC) systems used compost as their external nutrient source while the integrated fertilizer (IF) and conventional (C) systems used synthetic fertilizers. All management systems except C had cover crops interseeded at various points of the rotation. The O and IC systems had similar nitrate leaching rates. The IF and C nitrate leaching rates were similar to each other and both were greater than the IC and O leaching rates. In the IC system 1st year corn leached more nitrate (50 kg N ha^{-1}) than 2nd year corn (35 kg N ha^{-1}) , soybean (34 kg N ha^{-1}) continuous corn (26 kg N ha^{-1}), or wheat (17 kg N ha^{-1}). In the IF system the nitrate leaching rates of 1st year corn (59 kg N ha^{-1}), 2nd year corn (67 kg N ha^{-1}), and continuous corn (57 kg N ha^{-1}) were greater than the leaching rates of soybean (39 kg N ha^{-1}) or wheat (20 kg N ha^{-1}). The lower leaching rates of IC 2nd year and continuous corn corresponded with grain yields that were also

about 15% lower. The coefficient of variation (CV)s of the nitrate leaching rates from the large (91.5 cm) lysimeters were greater than the CVs of the small (30.5 cm) lysimeters for the last 5 of the 7 leaching seasons reported. When the leaching data were aggregated over the seven years, the resulting CV of the small lysimeters was 67% and the CV of the large lysimeters was 59%. A highly productive corn system using compost did not leach more nitrate N than a fertilized system with comparable yields. Wheat and soybeans leached less nitrate N than fertilized corn. A rotation including soybeans and wheat should leach significantly less than continuous corn. The leaching patterns of a crop were very dependent on the climatic conditions. Growing crops with different seasonal leaching patterns will decrease the impact of adverse climatic conditions on the total nitrate leaching of a farm since fields with different crops will vary in their sensitivity to high rainfall events in any given season.

INTRODUCTION

In southwest Michigan, as in many regions, nitrate leaching is an important factor in designing sustainable farming systems that operate in areas with significant suburban encroachment. The combination of sandy soils, nearby surface water, and an increasing number of residential and community wells in this mixed usage area, mandates effective nitrate management. Since nitrate readily leaches, agronomic crops receiving fertilizer are often implicated in increasing nitrate levels in ground and surface water.

Non-point nitrate losses can be reduced through optimization of fertilizer usage and replacement of some continuous row crop acreage with alternative crops that have longer periods of active rooting (Mitsch et al., 1998). One mechanism of accomplishing both of these goals is through the use of crop rotations that include legumes and/or cover crops. Not only is the active rooting period, and thus time for plant nitrate uptake, longer in a rotation with cover crops than in continuous corn (*Zea mays* L.), the release of nitrogen can be manipulated to reduce the amount of added N fertilizer necessary for high yields.

Of the major crops grown in the upper Midwest, corn receives the most fertilizer N per hectare. Much of this N is susceptible to loss by leaching. Owens et al. (2000) reviewed a number of tile effluent studies and summarized that NO_3-N concentrations under conventionally grown corn typically ranged from 10 to 60 ppm and were similar under several multiple cropping systems. The lysimeter studies he reviewed showed even higher nitrate concentrations. A Minnesota study showed that leachate concentration varied from 52 to 116 ppm NO_3-N and represented 27-43% of applied N. An Ohio study with much higher fertilization rates yielded leachate concentrations that ranged from 44 - 73 ppm, NO_3-N representing 40% of the N applied in the fertilizer. A Pennsylvania study with corn (Jemison and Fox, 1994) reported loss rates equivalent to 24 to 55% of the nitrate applied at optimum economic rates of around 190 kg/ha.

A corn - soybean (*Glycine max* L.) rotation has lowered N fertilizer inputs compared to continuous corn and would be expected to have lower N leaching loss. Klocke et al. (1996), Weed and Kanwar (1996), and Randall et al. (1997) reported lower leaching rates under a corn - soybean rotation than under continuous corn. Owens et al. (1995) reported that less nitrate leached under a corn - soybean/rye cover rotation than under continuous corn with no cover crop. A reduction in the amount of fertilizer applied to the corn in the rotation can also result from nitrogen credits from the soybeans (Owens et al., 2000). In the corn - soybean - wheat (*Triticum aestivum* L.) rotation common in southwest Michigan, corn typically receives 157 kg N ha^{-1}, wheat typically receives 84 kg N ha^{-1}, and soybean is usually not fertilized with nitrogen. A rotation of corn-corn-soybean-wheat would be expected to receive 398 kg N ha^{-1} over the four years while over the same period continuous corn would receive 628 kg N ha^{-1}. The actively growing winter wheat crop should also decrease late fall and winter leaching following soybeans both by increasing transpairation and by scavenging residual soil nitrate prior to winter, the period of greatest leaching loss in Michigan.

Alternative management systems using compost and leguminous cover crops as the sole external nutrient source gave similar 1st year corn yields as were seen with synthetic fertilizer and no cover crops (Jones et al., 1998) A soil with an enhanced (both quantity and quality) pool of mineralizeable N is likely to provide adequate N for crop growth (Sanchez, 2002). Much of the N from a red clover (*Trifolium pretense* L.) cover crop goes into the soil to be released in future years (Harris et al., 1994). This increase in mineralization potential and the possibility of the cover crop to leach N over several years highlights the need for careful N management in alternative systems as well as conventionally fertilized systems.

The major objective of this study is to compare nitrate leaching under a system that used compost and cover crops to supply nutrients with a system that used synthetic fertilizer and cover crops. Concurrently, the rate of N leaching under a corn-corn-soybean-wheat rotation was compared to that of with continuous corn, and whether the size of the lysimeter influenced the stability of the data.

MATERIALS AND METHODS

Site Description, Lysimeter Construction and Operation

During the summer of 1992, sixty intact core lysimeters (Fig. 1) were installed in the sandy soils of "The Living Field Laboratory", a corn-corn-soybean-wheat rotation study (Fig. 2), at the W.K. Kellogg Biological Station near Hickory Corners in southwest Michigan. Soils are Oshtemo and Kalamazoo sandy loams (coarse-loamy, mixed, mesic Typic Hapladaulfs). The climate is temperate with an average annual precipitation of 890 mm.

A long-term mixed stand of alfalfa and grass hay was sprayed with glyphosphate prior to lysimeter establishment. The Ap horizon above the lysimeter was removed and set aside prior to lysimeter installation. A truck-mounted pile driver was used to press the 61 cm segment of 30.5 cm (ID) PVC pipe through the Bt horizon and subsequent layers until the leading edge of the core was into the sand-gravel layer that underlies the entire field. The soil around the north side of the pipe was pulled away and the intact core of soil was removed. The ends of the PVC pipe were occluded with a large clamp that also served as a lifting connection. The pipe with the soil core was inverted and plumbed. A layer of fiberglass tile drain cloth was inserted with a 3 cm layer of fine stones held in place with a 6.6 mm screen. A PVC pipe end cap with a small 90° elbow inserted in its center diverted the leachate into the storage reservoir (a 20 liter carboy) placed below and adjacent to the lysimeter. A surface access tube was also plumbed into the carboy and the entire assembly was buried in the plot. The Ap horizon was then replaced over the lysimeter. In the conventional continuous corn plots this process was also repeated with a 91.5 cm (ID) steel pipe installed about 2 m south of the small lysimeter at the same depth and with similar plumbing.

Installation of the 60 lysimeters was completed by Nov. 1992. All accumulated leachate was pumped from the reservoirs and discarded. Following this initial emptying the reservoirs were emptied and sampled approximately monthly. The leachate was removed from the reservoir by inserting a thin tube through the PVC access tube (1.9 cm ID). The thin tube was connected to a graduated cylinder to which a vacuum was applied. The volume was recorded and a sample of the leachate was stored for laboratory analysis. The concentrations of N as nitrate and ammonium were determined using a Lachat auto-analyzer (Lachat Instrument Co., Milwaukee, WI).

Prior to primary tillage the lysimeters were emptied, the access tube removed, and the buried portion of tube was capped. A metal end cap along with a steel collar facilitated the use of a metal detector to relocate the buried pipe for re-connection. Since all parts of the lysimeter were buried well below the depth of tillage, commercial scale farm equipment (6-row) was used for all field operations. Following final cultivation of corn and soybeans in late June the access tubes were re-installed and the lysimeters were sampled. The access tube terminated 10-20 cm above the soil surface to prevent surface water from entering the carboy. The access tube was unobstructed to prevent the lysimeter from becoming vapor-locked. Although rain had the opportunity to enter the access tube, the actual amount of rain that fell into the tube was negligible compared to the amount that leached into the lysimeter.

Experimental Design and Layout

The entire experiment was a split-split-plot design, with management system as the main factor (4 treatments), crop as the split-plot (5 treatments) and cover crop as the split-split plot (2 treatments). There were four replications. Each crop in a corn- corn - soybean - wheat rotation, along with continuous corn, was present under the four different management systems. Each crop plot was further divided into a cover crop side and a no-cover crop side. Table 1 outlines the major differences between the management treatments. The conventional plots, due to their full coverage herbicide program, do not receive cover crops. Figure 2 illustrates the layout of the lysimeters within the experiment.

Crop Management

Corn. Compost was applied to the Organic (O) and Integrated Compost (IC) plots in April prior to tillage at the following rates: 4,500 kg/ha on 1st year and continuous corn and 9,000 kg/ha on 2nd year corn. All plots were chisel plowed and disced at least a week prior to planting. On the day of planting all plots were field cultivated and planted (69,000 seeds/ha) in 76 cm rows. A starter fertilizer (10-20 kg N ha^{-1} either granular or liquid) was applied in the Integrated Fertilizer (IF) and Conventional (C) treatments and a pre-emerge grass herbicide (Dual II) was banded over the row in the IC and IF treatments and broadcast in the C treatments at planting. Continuous and 2nd year corn received a banded soil insecticide for corn rootworm control. Mechanical weed control in O, IC, and IF usually consisted of two rotary hoeings, a cultivation with the rolling shields down and a final aggressive cultivation prior to canopy closure (Table 1). Nitrogen, initially as ammonium nitrate and in the last two seasons as liquid 28% N, was usually sidedressed at rates recommended for a 9.4 Mg/ha yield goal by the pre-sidedress nitrate test (PSNT) in the IF and C treatments. The fertilizer was incorporated in the final cultivation. Immediately following final cultivation crimson clover (*Trifolium incarnatum*) was banded at 19 kg/ha between the corn rows in 1st year and continuous corn and annual ryegrass (*Lolium multiflorum*) was banded at 30 kg/ha in 2nd year corn. Yield data were recorded from the center 2 rows of the entire length of the 15.3 m plots after the boarder plants were removed.

Soybean. All plots were chisel plowed and disced at least a week prior to planting. Neither compost nor fertilizer was added to these plots in this point of the rotation. On the day of planting all plots were field cultivated and planted (370,000 seeds/ha) in 76 cm rows. Mechanical weed control in O, IC, and IF usually consisted of two rotary hoeings, a cultivation with the rolling shields down and a final aggressive cultivation prior to row closure. In the early years of the experiment, pre-emerge herbicides were used, and more recently post-emerge herbicides were used. Round-up resistant varieties were used in the last three years with two applications of glysphosphate at low rates. Yield data were recorded from the center 2 rows of the entire length of the plots after the boarder plants were removed.

Wheat. Compost was applied (4,500 Kg/ha) in the O and IC plots immediately following soybean harvest. At planting, the plots were disced or field cultivated and then planted (5,000,000 seeds/ha). In early spring 84 kg/ha nitrogen (as urea) was applied to the IF and C plots. At the same time 'Michigan Mammoth' red clover was frost seeded (18 kg/ha) into the wheat. The wheat was harvested in July using a plot combine and the straw was baled and removed. The plots were clipped in September to stimulate the clover cover crop and/or to control weeds.

Statistical Methodology

Of the 2900 lysimeter readings taken from April 1993 - April 2000, six values were missing and were approximated using SAS (SAS Institute) Least Square Means (LS-means). The measured leaching interval of March 24, 1995 - July 24, 1995 was divided into two smaller intervals (March 24 - April 12 and April 12 - July 24) using a ratio of daily leaching volumes determined for this period by the other six years of leaching volumes. Dividing this long interval into to two smaller intervals facilitated assigning the early interval leaching to the 1994-1995 leaching season and the latter interval to the 1995-1996 leaching season. The volume and concentration curves were generated using

LS-means rather than the actual means to compensate for the high variability of the actual data.

The volume and concentration data set was converted into kg per ha N as nitrate. Nitrate accumulation from the first pumping of the lysimeters following access tube opening in the spring until the last pumping prior to access tube closure in the following spring was summed to estimate annual leaching. To attribute the nitrate leaching to the crop associated with it the "leaching year" was defined as the period from access tube closure prior to spring planting until the date of access tube closure in the following spring.

When the calculated N leaching rates were ranked, there were six individual leachate values that were more than 10 standard deviations from the resulting mean with them removed. These six calculated leaching rates were removed, treated as missing values, and approximated using SAS-generated least squared means (LS- means). The resulting annual values were normalized using a natural log transformation. The means reported are the least square means of the un-transformed data (kg/ha) while the significant differences between treatments are always determined based on the transformed data set (*ln* kg/ha) using SAS's MIXED model (SAS, 1999).

RESULTS AND DISCUSSION

Leaching patterns over the season

While individual readings of lysimeter volumes varied from no leachate captured to volumes that represented 300% of rainfall, when the data were aggregated over replications and seasons the leachate volume averages were remarkably similar. Thirty six percent of the annual precipitation was represented as leachate captured at 80 cm depth (Table 2). The leaching volumes of the various management systems were fairly consistent within seasons but there were large differences between years. The slightly higher year to year variability seen with the O and C management compared to the IC and IF treatments may be due to fewer data points in the averages, or they may represent a stronger crop influence. The O and C managements have lysimeters only in continuous corn and one point in the rotation while the IC and IF management have lysimeters in the continuous corn and all four points of the rotation

Daily leaching volumes, determined by dividing the volume pumped by the number of days since last pumping, varied throughout the season. During the mid- and late-growing season the average leaching volumes decreased to about 15 ml per day (Figs. 3 and 4). Average daily leaching volumes increased through the late fall and early winter reaching a peak of about 120 ml per day in early spring. From May until September evapo-transpiration exceeds rainfall (Cavigelli et al., 1998) and, with the exception of preferential flow following major rain events, the majority of precipitation never leaches beyond the root zone. From October to April precipitation exceeds evapo-transpiration and the profile has a chance to recharge and then leach excess soil water. From December until March significantly greater volumes usually leached from the corn plots than from the soybean and wheat plots. Except for 1st year corn in the late winter leaching period, the differences between the leachate volumes for crops under IC management and the crops under IF management were not significant.

The leachate nitrate concentration data is also highly variable (Figs. 5 and 6). The lowest concentration measured was 0.8 ppm N as nitrate and concentrations of over 200 ppm were recorded from several lysimeters. Toth and Fox (1998) identified and removed a value of 180 ppm, attributing it to possible rodent activity. In our data set 200 ppm was the upper end of a continuum rather than an outlier. Most of the nitrate concentration patterns in the IC management systems were similar to those in the IF systems. A notable exception was continuous corn. In the IC plots the continuous corn leachate NO_3-N concentration was usually more dilute than those of the rotation crops, while in the IF plots the continuous corn leachate NO_3-N was more concentrated than the rotation crops. These differences were significant in the heavy leaching periods of fall and winter. Similar patterns were observed in the seasonal soil nitrate levels in these plots (Sanchez, 2000). In IC continuous corn plots average soil nitrate levels from April to December remained fairly constant at around 4-7 ppm throughout the season while the soil nitrate levels in IF continuous corn plots ranged from 4 ppm in April to a maximum of 28 ppm in August and then returned to 8 ppm in December.

The seasonal leaching loss curves are driven by the leaching volume curves since the seasonal concentrations are relatively stable (Figs. 7 and 8). During the winter and early spring, when leaching is at it highest, the average daily nitrate N leaching rates for all of the IC corn treatments ranged from 0.15 to 0.25 kg N ha^{-1} per day. Conversely, the corn grown with fertilizer ranged from 0.28 to 0.45 kg N ha^{-1} per day for the same period. These differences were significant in the Feb-March heavy leaching period. The leaching rate for IC 1st year corn significantly increased to 0.17 kg N ha^{-1} per day in Oct-Nov period while all other IC corn treatments remained in the 0.06 kg N ha^{-1} per day range. This increase probably reflects the higher August soil nitrate levels present with 1st year corn and its preceding red clover cover crop (12 ppm N as NO_3) compared to the lower levels (5 ppm) associated with IC 2nd and continuous corn treatments (Sanchez, 2000) .

Annual leaching losses over the six seasons: Integrated Compost and Integrated Fertilizer

In the first year of the experiment leaching was high, because the alfalfa/grass hay crop that preceded it (Jones et al., 1998), and the data were removed from the analysis. The hay had been baled in mid-summer of 1992 to facilitate lysimeter instalation resulting in high N mineralization. In four of the last six seasons IC 1st year corn leached more nitrate per year than IC 2nd or continuous corn (Fig. 9). Soybean leaching was very erratic under compost. In the 1995-1996 and 1996-1997 seasons the levels of nitrate leached under soybeans were the second highest and in the 1997-1998 season they were the highest. In the 1998-1999 season soybean nitrate leaching was less than all other crops and in the 1999-2000 season it was next to least. It was noted that heavy nitrate leaching under soybean occurred when excessive rains fell in late spring/early summer, before the soybeans reached the late vegetative stage. Precipitation later in the soybean growing season was not associated with heavy leaching. This lack of leaching may have been due to greater transpairation associated with larger plants or that as the soybeans reached maximum growth rates they took up most of the mineralized N. The April-April leaching year concept works well with corn crops but there were problems with the soybean and wheat leaching seasons. The leachate during the winter following soybeans was confounded with the fall-planted wheat present in that plot. The nitrate leached was arbitrarily attributed to soybean but it may actually have been associated with the newly planted wheat crop. Lower October soil temperatures probably resulted in minimal mineralization of the compost that was applied prior to wheat planting. The low October nitrate levels probably caused the fall planted wheat to act as a N scavenger further decreasing the winter leaching from the 'soybean' plots. The wheat plots under IC management were consistently in the middle or low leaching range each season.

In the fertilizer treatments some of the same patterns were observed (Fig. 10). Wheat again was consistently in the middle or low leaching range and soybean leaching was very erratic. Some seasons soybean leaching was greater than corn leaching and in other seasons it was less than corn leaching. The IF wheat was not fertilized in the fall so, like the IC wheat treatment, the wheat may act as a nitrate scavenger crop until it is fertilized in the spring. In most leaching seasons the leaching from IF soybean is very similar to the leaching of IC soybean. The major difference between the annual IC and IF nitrate leaching patterns was that under IF management, 1st year corn did not consistently leach more nitrate than 2nd year or continuous corn. In most seasons, there were only slight differences between the nitrate leaching amounts from each of the corn crops. Unlike the IC corn, no IF corn crop consistently leached nitrate more than any other corn crop. Similarities in IF corn leaching patterns were expected since all three treatments were fertilized to the same yield goal using PSNT. The elevated corn leaching rates in the 1996-1997 leaching year were probably associated with a mid and late season drought. Following side-dress N application in early July there was insignificant rainfall until

October. In late fall, intact ammonium nitrate granules could be found in the soil and were probably the source of the elevated leaching rates for the season.

Leaching Losses over the six seasons

When the yearly data were aggregated the amount of nitrate leached under IC 1st year corn following wheat/red clover is similar to the amounts leached under all the IF corn treatments and greater than the amounts leached under IC 2nd year and IC continuous corn (Fig. 11). As shown in Table 3, the estimate of N available to IC 1st year corn is very similar to the estimate of N available to IF 1st year corn and both are greater than the estimate of N available to IC continuous corn (Fortuna et al., 2002). First year corn from both IC and IF managements leach similar amounts of nitrate as IF continuous corn in spite of estimates of available N that are 33% and 28% lower respectively. These differences cannot be explained on a basis of yield alone since the 0.1 Mg/ha lower yield of IF continuous corn only accounts for 18 kg N ha^{-1}. Sanchez et al. (2001) found that mineralization in the IC 1st year corn plots in the presence of corn roots was 50% higher than in the soil in these plots without corn. This would increase the estimate of N available to IC 1st year corn to 309 kg N ha^{-1} which is similar to the estimate of 306 kg N ha^{-1} available for IF continuous corn. Unfortunately, we do not have any data on the corn root influence on the N mineralization of soils without compost or clover residue. Another possibility for this incongruity is that the timing of N availability may be more important to crop production and N leaching than the actual amounts of N in the system.

The leaching losses measured for corn were lower than some reported in the literature (Owens, 1987; Chichester, 1977; Jamison and Fox, 1994; Yadav, 1997). One possible explanation is that the levels of N inputs used in this study were lower than in the levels used in the above studies. The Oshtemo and Kalamazoo soils in southern MI have historical grain yield averages of 8.2 Mg/ha with 9.4-11 Mg/ha attainable, weather permitting. We fertilize for yield goals of 9.4 Mg/ha using PSNT. Many trials reported in the literature fertilize to significantly higher yield goals. The 56 kg N ha^{-1} annual leaching rate measured under fertilized corn was more than the 16 kg N ha^{-1} that Sogbedji et al. (2000) reported when also using PSNT to set fertilizer rates on a coarse textured soil.

Soybean leached similar amounts of nitrate regardless of management system. Based on 150 day laboratory N mineralization potentials Fortuna et al. (2002) calculated that the IC soil (25 cm depth) prior to soybean planting could have 161 kg N ha^{-1} available while the IF soil ahead of soybeans could have 124 kg N ha^{-1}. The higher mineralization potential of the IC management system may not be realized *in-situ* since there were no significant differences between yields or annual leaching over the six years.

Although it does not appear significantly different on the graph of LS-means of the un-transformed kg/ha data, after the natural log transformation necessary to normalize the data, the amount of nitrate leached by IC wheat was significantly (α=0.05) less than the amount leached by IF wheat (Fig 11). The majority of this leaching occurred in the winter following harvest. During the wheat's active growing season there was very little nitrate leached from the system. Even though the soil nitrate levels averaged 8 ppm for the fertilized wheat (Sanchez, 2000) from April to June the leaching rate for this period was only about 0.06 kg N ha^{-1} per day. The majority of precipitation into an actively growing wheat field is lost as transpiration, so in spite of higher soil N levels in the IF wheat, leaching was minimal.

Leaching Losses over all four managements

The leaching patterns of the O management lysimeters were very similar to those seen in the IC management. The O rotation plots usually leached more nitrate than their IC counterparts (significant at $\alpha=0.05$ in 1996-1997). The leaching pattern for O continuous corn was usually similar to the pattern of IC continuous corn. In the 1995-1996 season continuous corn from the O management leached significantly more than the continuous corn from IC, and in 1996-1997 IC continuous corn leached more than O continuous corn. When the six seasons were combined (Fig. 12) the annual amount of N leached under the rotation crops was greater in the O plots than in the IC plots. This difference is perplexing since management operations between these treatments are very similar. The major difference between these treatments is a 30 cm band of herbicides in the corn and soybean crops. Possibly, the greater weed pressure (mainly summer annuals) seen in the O treatment may be associated with the difference in leaching rates. Another possibility is that the differences are associated with the smaller dataset of O and C leaching values. There is a lysimeter in only one rotation plot in the O and C managements while the IC and IF results are the averages of lysimeters in each of the four plots.

The leaching patterns of the lysimeters in the C management were very similar to those of the IF management. The amounts of nitrate leached under the rotation plots were not significantly different (α=.05) between the IF and C managements. In four of the six seasons reported, there were no differences in the nitrate amounts leached under continuous corn. In the 1997-1998 leaching year IF continuous corn leached significantly more nitrate than did the C continuous corn. This situation was reversed in the following season. When the crops over the last six years are combined over management systems (Figs. 12), the management systems receiving fertilizer (IF and C) leached significantly more nitrate than the management systems receiving compost (IC and O). This observation may be a function of the relatively slow nutrient release compost that we applied. Fortuna (2003) indicated that the steady state mean residence time of the mineralizable organic pool of soil N was about 40% longer in selected plots receiving compost than in the corresponding fertilized plots.

Cover Crop influence

There are several reports in the literature of using annual ryegrass after corn as a nitrate catch crop (Isse et al., 1999, Vyn et al., 1999). In both the 1993-1994 season and the 1997-1998 leaching season the rotation sequence had fertilized 2nd year corn with annual ryegrass (IF) and fertilized 2nd year corn without a cover crop (C) above the lysimeters. Over these two seasons, the difference in leaching between the corn with annual ryegrass (55 kg N ha^{-1}) and the corn with no cover crop (67 kg N ha^{-1}) was not significant. It is possible that with more observations this difference would become significant. We also saw no difference in leaching amounts associated with the crimson clover cover crop under continuous corn versus continuous corn with no cover crop (both 61 kg N ha^{-1}) under similar (IF and C) fertilizer inputs.

Comparisons of Coefficients of Variations (CVs)

As indicated by the stars in Fig. 13, the CVs (Std Dev / mean) of the continuous corn plots of all management systems changed each year. Initially, there was a trend towards decreasing CVs, but since the 5th season the average of the CVs remained between 25-65%. The trend lines in Fig. 13 indicate that aggregating the annual leaching data decreases and stabilizes the CVs at 60-90%. This influence may have been more mathematical than biological. In the 1993-1994 season there were only four values (reps) for each CV while by the 1999-2000 season the cumulative CVs were composed of 28 values (7 seasons * 4 reps each). The increase in observations going into the CV estimate decreased the standard deviation while the mean remained fairly constant

The small (30 cm) lysimeters and large (91 cm) lysimeters in the continuous corn plots under C management were within 2 m of each other in the same corn row. The stars in Fig. 14 indicate that the CVs for individual seasons were actually lower for the small lysimeters than for the large lysimeters for these continuous corn comparisons, using equal observation numbers. In the 1st season (93-94) the CV for the small lysimeter was 105% but for seasons 3-7 the CVs have averaged around 30%. The annual CVs for the large lysimeters averaged around 60%. As the data were aggregated over seasons the small lysimeter CV trend line decreased while the large lysimeter CV trend line remained stable at around 60%.

The choice of lysimeter size and design involves a series of tradeoffs. Designs that have a lip above the soil level eliminate surface flow into and out of the fetch area. This lip also eliminates the proper use of farm scale equipment over the lysimeter. Large undisturbed monolith lysimeters necessitate such extensive soil disturbance around them that plot data outside the lysimeter may be meaningless. Reconstructed profile lysimeters may have different water patterns than would be seen in the undisturbed profile. The buried quartz lysimeters have minimal soil disturbance but do not measure water flow rates. The 30.5 cm buried intact core lysimeters were as stable in their estimates of nitrate leaching as the 91 cm lysimeters despite having a much smaller fetch area.

CONCLUSIONS

It is important to measure leachate during the winter since that is when the majority of leaching occurs in the Michigan agroecosystem. Studies that only measure nitrate leaching after rain events during the growing season would miss the majority of leaching events in the Michigan system.

The use of 30.5 cm PVC pipe allowed 56 lysimeters to be installed in one summer to facilitate a good estimate of the same season's effect on different crops and management systems. Increasing the size of lysimeter to 91.5 cm did not decrease the CVs of the data despite the higher cost and increased complexity involved in the installation of the four large lysimeters.

Agronomic systems with enhanced active N pools such as the compost with cover crop management seen by 1st year corn can have similar yields as fertilized systems and have nitrate leaching that is the same or less than those fertilized systems. The 60% higher mineralization potentials seen in 1st year corn the compost treatments with a preceding red clover cover crop probably resulted in higher percentages of N coming from the soil than in the treatments that were fertilized. In spite of the higher mineralization potentials, the compost treatments did not leach more N than did the lower N mineralization potential treatments that were fertilized.

Manure disposal challenges are a limiting factor in the expansion of area livestock operations. Composting the manure and applying it to a neighbor's row crop land may benefit both operations. Sanchez (2000) showed that the addition of clover to a conditioned soil increased *in-situ* mineralization more than the addition of compost. Thus, red clover is also an important component of a productive system. Other portions of our current cover crop scheme need to be adjusted to capture excess fall nitrate. The annual ryegrass currently used is not aggressive enough to scavenge the residual soil N in the small window of opportunity between corn maturity and winter freeze

To spread out labor demands and minimize risk most farms have each crop in the rotation every year. The expected annual leaching load from the farm would be less in a corn-soybean-wheat rotation than from a continuous corn operation. The late season drought in 1996 that was associated with excessive N leaching under corn did not affect wheat yields or leaching. Crop diversification may be a way for a farm to decrease the risks associated with the crop x season interactions. Since wheat leaches less nitrate than corn, any fields that are planted to wheat should decrease the total farm's average leaching loads. Unfortunately, throughout the duration of the trial, nitrate concentrations in all of our lysimeters were well above the 10 ppm maximum in the Federal Drinking Water Standard.

A highly productive system using compost and red clover preceding 1st year corn, no supplementary N for soybeans, and spring applied fertilizer for wheat could be expected to maximize yields while keeping the same nitrate leaching rates. This would be expected to decrease the amount of fertilizer inputs and provide the soil quality benefits associated with an enhanced active pool of soil N.

Excess nitrate, regardless of source (red clover vs. fertilizer), is subject to leaching. A rotation with organic inputs can leach as much nitrate as a rotation that uses synthetics fertilizers. If soil N levels are adequate for high corn productivity there is the risk that N will be leached. An important corollary is that production systems that have increased soil mineralization potentials need to have an actively growing crop present to capture the N as it is mineralized or that N will likely leach.

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Table 1: Characteristics of Management Schemes

Management	Rotary Hoe Operations	Cultivation Operations	Herbicide Program	Nutrient Source
Organic	3	3	None	Compost
Integrated Compost	2	2	30 cm band	Compost
Integrated Fertilizer	2	2	30 cm band	Fertilizer
Conventional	0	1	Full spray	Fertilizer

Table 2: Leachate volumes compared to precipitation over seven years

		Organic			Integrated Compost			Integrated Fertilizer			Conventional		
Year	Precip[1] (mm)	vol. (l)	vol.[2] / lys. area	% precip	vol. (l)	vol. / lys. area	% precip	vol. (l)	vol. / lys. area	% precip	vol. (l)	vol. / lys. area	% precip
1	780	11	153	20	14	191	25	12	162	21	12	163	21
2	920	15	199	22	16	224	24	17	227	25	11	156	17
3	741	20	268	36	16	218	29	22	300	40	9	118	16
4	799	31	423	53	32	445	56	35	480	60	37	506	63
5	817	27	370	45	26	354	43	31	422	52	32	439	54
6	628	11	153	24	16	223	36	17	234	37	18	251	40
7	543	14	194	36	16	225	41	12	169	31	15	210	39
Cum	5228	140	1760	34	146	1880	36	154	1993	38	146	1842	35

[1] From KBS LTER site - (http//lter.kbs.msu.edu/Weather/index.html)

[2] Leachate volume divided by lysimeter area (730 cm^2). Results are expressed as mm.

Table 3: Nitrate available for crop growth

	Applied N (kg/ha)			Potential Min. N in Soil [1] (kg N/ha)	Sum N Inputs (kg N/ha)	Crop Yield (Mg/ha)
	Compost	Starter	Sidedress			
Integrated Compost						
1st Corn	4			203	207	7.8
Soybean	0			161	161	2.4
Cont. Corn	4			143	147	6.2
Integrated Fertilizer						
1st Corn		16	77	127	220	7.9
Soybean		0	0	124	124	2.2
Cont. Corn		16	160	130	306	6.9

[1] Data from Fortuna, 2000

Fig. 1 Lysimeter diagram

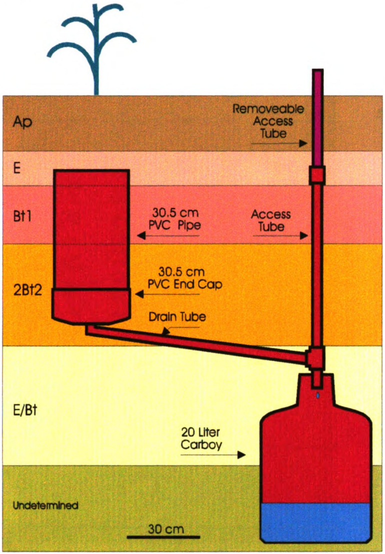


Fig. 2 Plot Layout with Lysimeters

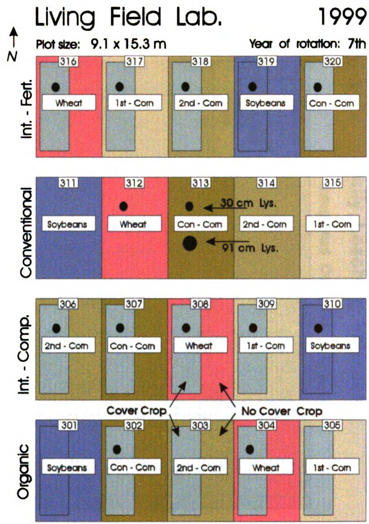


Fig. 3

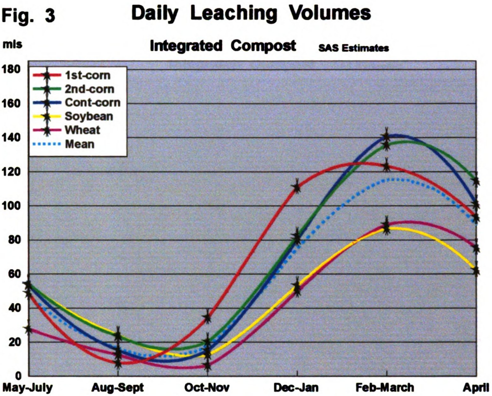

Daily Leaching Volumes
mls
Integrated Compost
SAS Estimates
180
160
140
120
100
80
60
40
20
0
1st-corn
2nd-corn
Cont-corn
Soybean
Wheat
Mean
May-July
Aug-Sept
Oct-Nov
Dec-Jan
Feb-March
April

Fig. 4

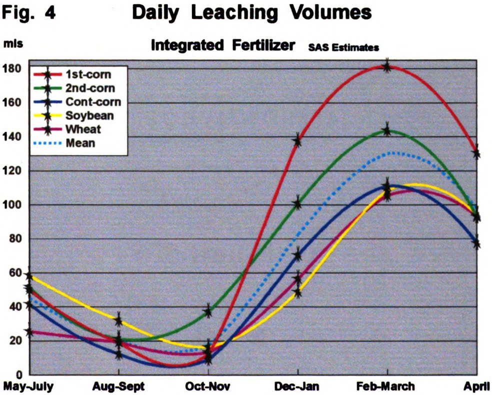

Daily Leaching Volumes
mls
Integrated Fertilizer
SAS Estimates
180
160
140
120
100
80
60
40
20
0
1st-corn
2nd-corn
Cont-corn
Soybean
Wheat
Mean
May-July
Aug-Sept
Oct-Nov
Dec-Jan
Feb-March
April

Fig. 5 Nitrate Concentrations in Leachate over the Season

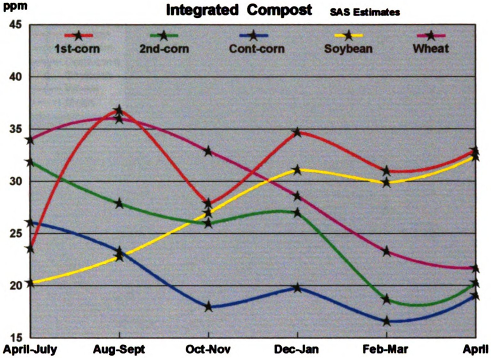


Fig. 6 Nitrate Concentrations in Leachate over the Season

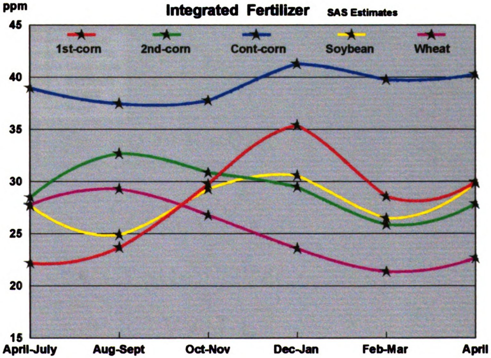


Fig. 7 Daily Nitrate Leaching Rates over the Season

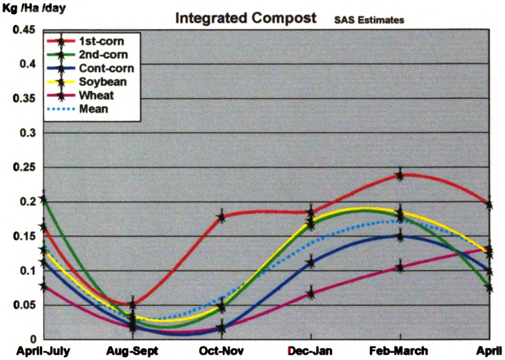


Fig. 8 Daily Nitrate Leaching Rates over the Season

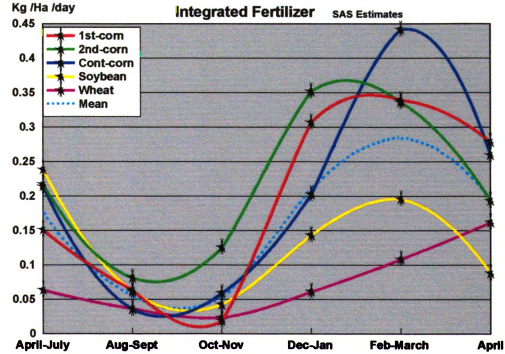


Fig. 9 Annual Nitrate Leaching (by Crop) over Seasons 2-7

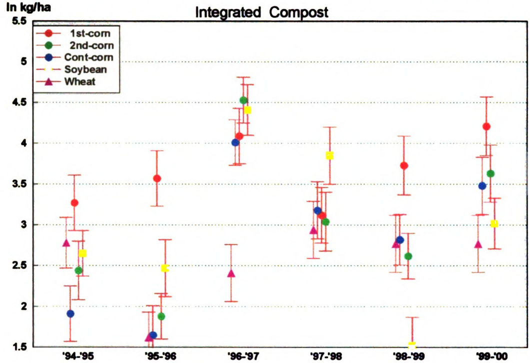


Fig. 10 Annual Nitrate Leaching (by Crop) over Seasons 2-7

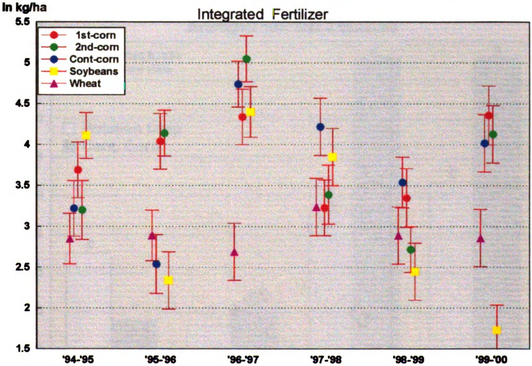


Fig. 11 Influence of Management on Annual Leaching

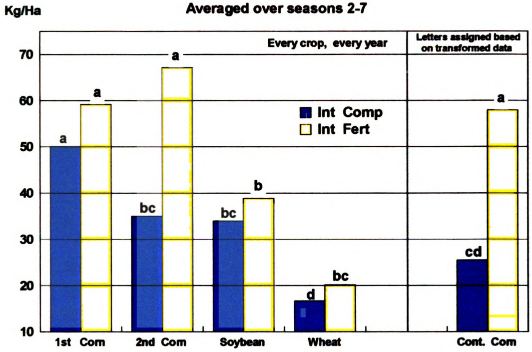


Fig. 12 Annual nitrate leaching under rotational crop compared to continuous corn by management

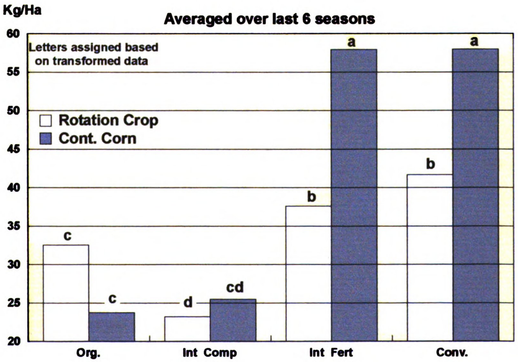


Fig. 13

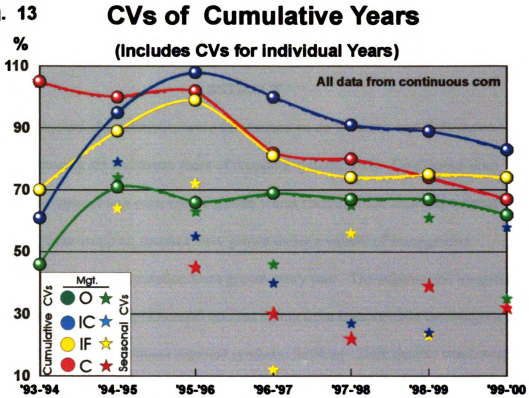
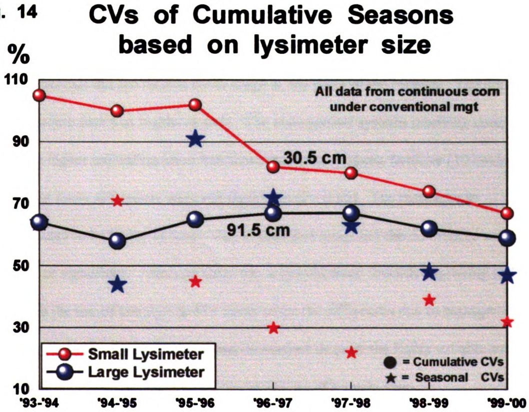

CVs of Cumulative Years
(Includes CVs for individual Years)
%
110
90
70
50
30
10
All data from continuous corn
Mgt.
Cumulative CVs
Seasonal CVs
O
IC
IF
C
'93-'94
'94-'95
'95-'96
'96-'97
'97-'98
'98-'99
'99-'00

Fig. 14


CVs of Cumulative Seasons based on lysimeter size
%
110
90
70
50
30
10
All data from continuous corn under conventional mgt
30.5 cm
91.5 cm
Small Lysimeter
Large Lysimeter
= Cumulative CVs
= Seasonal CVs
'93-'94
'94-'95
'95-'96
'96-'97
'97-'98
'98-'99
'99-'00

CHAPTER 2

The Influence of Cropping System on Selected Soil Physical Characteristics

ABSTRACT

Selected soil physical characteristics were determined on an Oshtemo and Kalamazoo sandy loam following six and seven years of cropping systems trials. Continuous corn systems were compared to a corn-corn-soybean-wheat rotation each with and without cover crops. These cropping systems were grown under a variety of management schemes, and all crops in the rotation were grown every year. The organic and integrated compost systems received supplemental nutrient inputs from compost and the integrated fertilizer and conventional systems received synthetic fertilizer. Bulk density was lowest following first year corn and highest following wheat. The influence of management schemes on bulk density were not significantly different. Water holding capacity differences, while statistically significant, were probably not agronomically significant (41-43%). Aggregate stability was highest in wheat interseeded with red clover and lowest in the soybean plots that did not receive cover crops at any point of the rotation. The double ring infiltration rate data was highly variable. The management systems receiving compost tended to have higher infiltration rates than those receiving synthetic fertilizer (10 cm/hr vs. 8 cm/hr) but these differences were not significant (P= 0.05). The resistance to penetration tended to be higher in wheat than in the other crops but the differences were not consistent or significant. Although there was a general trend towards improving soil quality through the use of compost and/or cover crops the differences due to management were not always significant. Differences may be masked through the highly variable soil and the difficulty of changing the physical characteristics of a sandy loam.

INTRODUCTION

Soil quality as defined by Doran and Parkin (1994) is the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health. The status of the physical characteristics of a soil is an important aspect of the total quality of the soil. The physical characteristics of the soil influence the flora and fauna in the soil which in turn further influence the physical characteristics of the soil. Management choices of cropping system, use of cover crops and the addition of organic amendments influence the soil's physical characteristics. Some of the basic physical characteristics include bulk density, aggregate stability, water holding capacity, infiltration capability, and the resistance to penetration. Measurements of these physical characteristics can give an indication of a soil's suitability to grow crops and can identify some management problems.

Numerous studies have looked at the differences in soil physical qualities seen in 'alternative' production systems compared to 'conventional' systems. Islam and Weil (2000) saw no difference in the cropping system's influence on soil bulk density in organic vs. conventional systems which included a no-till corn-soybean-wheat rotation and conventionally tilled continuous corn. The bulk density from a continuous grass system was significantly less than any of the annual cropping systems evaluated. Weil et al. (1993) also found no differences in cropping systems except all annual systems were greater than continuous grass on a sandy loam.

Studies that applied sewage sludge at agronomic rates generally see little affect on bulk density (Kaheel et al., 1983). Where organic matter is applied at disposal rates (10 -300 t/ha) as compost (Porter et al., 1999) or as sludge the decreases in bulk density seen may be simple mechanical dilutions (Kaheel et al., 1983, Metzger and Yaron, 1987, Lindsay, 1998). MacRae's (1985) review of cover crop's influence on soil properties found that five of the seven studies reported decreases in bulk density associated with the incorporation of green manures. Power et al. (1998) also reported a decrease in bulk density associated with cover crops. Although tillage regimes strongly influence bulk density, the bulk densities of a silt loam managed organically for over 70 years were not significantly different from those of nearby conventionally managed fields (Reganold, 1988).

Biological processes are the major influences in the process of soil aggregate stabilization in most agricultural soils. Earthworm activity and physical enmeshment by roots and fungal hyphae contribute to aggregate stability by physically holding the particles in close proximity (Brady and Weil, 1999). The production of organic binding agents by microorganisms then acts to aggregate the particles together (Lynch and Bragg, 1985). Species differences are seen in the efficacy of roots assisting the formation of stable aggregates with sod, pasture, or hay crops being more effective than annual field crops (Bullock, 1992). Hay crops increase aggregate stability more than short rotations of grain crops. This is due to the species involved, greater time periods in the field, absence of tillage for a longer period of time (Harris et al., 1966) and simultaneously occurring conditions for enhanced aggregate formation and stabilization (Allison, 1968). Including sod grasses or legumes as winter crops or in short term rotations with summer grains can also increase aggregate stabilization (Smith et al., 1987). Rasse (1997) reported that the addition of alfalfa shoots increased aggregate stability on a Kalamazoo sandy loam more than the addition of alfalfa roots but both increased aggregate stability relative to soil with no alfalfa addition. Islam and Weil (2000) also reported that conservation practices such as reduced tillage, crop rotation and the use of cover crops can increase aggregate stability relative to a conventionally managed cash grain (corn and soybean) system.

The literature presents a mixed picture of the influence of cropping systems on water holding capacity (WHC). The addition of organic matter as cover crops (MacRae and Mehuys, 1985), peat humus (McCoy, 1998), sewage sludge (Lindsay and Logan, 1998, and Metzger and Yaron, 1987), or manure (Martens and Frankenberger, 1992) has been shown to increase the water holding capacity of sandy soils. Alternatively, Weil et al. (1993) found that differing cropping systems and tillage management did not significantly influence WHC on a sandy loam.

Increases in infiltration rate have been associated with winter cover crops (Smith et al., 1987, and Unger and Vigil, 1995) and interseeded corn (Smeltkop et al., 1997). Increases in infiltration rates are also associated with the addition of relatively high rates of organic matter as manure or sludge (Smith et al., 1937, Albrecht and Sosne, 1944, Kaheel et al., 1981, Martens and Frankenberger, 1992).

Soil resistance to penetration does not seem to be strongly influenced by rotation (Pikul and Aase, 1996, and Hammel, 1989). Chen and Heenan (1996) observed a crop difference with higher resistance to penetration under a barley grain than under canola, field peas, or Lupin but these differences were only significant at the 5-10 cm depths.

The objective of this study is to determine the influence of various farming systems, managed using accepted 'best management practices', on selected soil physical characteristics. The characteristics should give insight to the farming system's long-term influence on soil quality.

MATERIAL AND METHODS

Site Description

A long-term corn-corn-soybean-wheat rotation study was established in "The Living Field Laboratory" at the W.K. Kellogg Biological Station (Hickory Corners, MI). The site is a glacial till composed of Oshtemo and Kalamazoo sandy loams (coarse-loamy, mixed, mesic Typic Hapladaulfs). The climate is temperate with an average annual precipitation of 890 mm.

Experimental Design and Layout

The experiment was a split-split-plot design, with management as the main factor (4 treatments), crop as the split-plot (5 treatments) and cover crop as the split-split plot (2 treatments). There were four replications. Each crop in a corn- corn - soybean - wheat rotation along with continuous corn was present under the four different management systems. Each crop plot was further divided into a cover crop side and a no-cover crop side. Table 1 outlines the major differences between the management treatments. The conventional plots, due to their full coverage herbicide program, did not receive cover crops. Data were collected over a three year period. Further information of this site is available at the W.K. Kellogg Biological Station Long-Term Ecological Research data website http://lter.kbs.msu.edu/

Crop Production

Corn. Compost was applied to the Organic (O) and Integrated Compost (IC) plots in April prior to tillage at the following rates: 4,500 kg/ha on 1st year and continuous corn and 9,000 kg/ha on 2nd year corn. All plots were chisel plowed and disced at least a week prior to planting. On the day of planting all plots were field cultivated and planted (69,000 seeds/ha) in 76 cm rows. A starter fertilizer (10-20 kg N ha^{-1} either granular or liquid) was applied in the Integrated Fertilizer (IF) and Conventional (C) treatments and a pre-emerge grass herbicide (Dual II) was banded over the row in the IC and IF treatments and broadcast in the C treatments at planting. Continuous and 2nd year corn received a banded soil insecticide for corn rootworm control. Mechanical weed control in O, IC, and IF usually consisted of two rotary hoeings, a cultivation with the rolling shields down and a final aggressive cultivation prior to canopy closure. Nitrogen, initially as ammonium nitrate and in the last two seasons as liquid 28% N, was sidedressed at rates recommended for a 9.4 Mg/ha yield goal by the pre-sidedress nitrate test in the IF and C treatments.

The fertilizer was incorporated in the final cultivation. Immediately following final cultivation crimson clover (*Trifolium incarnatum*) was banded at 19 kg/ha between the corn rows in 1st year and continuous corn and annual ryegrass (*Lolium multiflorum*) was banded at 30 kg/ha in 2nd year corn. Yield data were recorded from the center two rows of the entire length of the 15.3 m plots following removal of the boarder plants.

Soybean. All plots were chisel plowed and disced at least a week prior to planting. Neither compost nor fertilizer was added to these plots in this point of the rotation. On the day of planting all plots were field cultivated and planted (370,000 seeds/ha) in 76 cm rows. Mechanical weed control was similar to that of corn. In the early years of the experiment, pre-emerge herbicides were used and more recently post-emerge herbicides were used. Round-up resistant varieties were used in the last three years with two applications of glysphosphate at low rates. Yield data were recorded from the center two rows of the entire length of the 15.3 m plots following removal of the boarder plants.

Wheat. Compost was applied (4,500 Kg/ha) in the O and IC plots immediately following soybean harvest. At planting, the plots were disced or field cultivated and then planted (5,000,000 seeds/ha). In early spring 84 kg/ha nitrogen (as urea) was applied to the IF and C plots. At the same time 'Michigan Mammoth' red clover was frost seeded (18 kg/ha) into the wheat. The wheat was harvested in July using a plot combine and the straw was baled and removed. The plots were clipped in September to stimulate the clover cover crop and/or to control weeds.

Bulk Density Protocol

Corn and wheat samples were taken in November of 1997, 1998, and 1999 and soybean samples were taken in early October prior to tillage in preparation for wheat planting. The samples from the corn and soybean plots were taken in the crop row. A flat shovel was used to remove the top 1-2 cm of soil and crop residue from each of five measurement sites in each plot. A double-cylinder, hammer-driven core sampler was used to remove an uncompressed core of soil (7.6 cm height and 7.6 cm diameter). The soil was dried, weighed, and sieved to remove stones. Samples where stones comprised more than 10% of the weight were removed from the analysis.

Infiltration Protocol

Samples were taken in October and November of 1998 and 1999. Segments of aluminum irrigation pipe (20 and 30 cm diameter, 3.2 mm wall thickness) were driven at least 7 cm into the soil to form a double ring infiltration unit. Four layers of burlap were placed in the bottom of the center ring to decrease surface soil disturbance when the water was added. The soil in the infiltration rings was pre-saturated with at least 10-15 cm of water two hours prior to the beginning of the test period. At the initiation of the measurement period approximately 5-8 cm of water was poured into both rings. At 20 minute intervals the height of the water column in the center ring was measured and the water loss was replaced to maintain a relatively constant head pressure. Measurements were made for at least two hours from each of three infiltration units in each plot.

Aggregate Stability Protocol

A modification of Gruver and Weil (1998) was used. Air dried soil from the bulk density cores was dry sieved for 10 seconds to collect aggregates greater than 4 mm diameter. Since aggregates of this soil type are sensitive to rapid wetting they were brought up to saturation over a period of 4-6 hours in a mist chamber. The saturated aggregates on a 0.5 mm mesh sieve were submerged in 2 cm of water and shaken (100 rpm) on a rotary shaker for 120 seconds. The 'Unstable' soil that slaked off the aggregates and passed through the sieve during shaking was dried. The 'Stable' soil remaining on the sieve was extruded through the sieve with slight finger pressure and dried. The 'Debris' that would not pass through the sieve was also dried. Samples where the sum of 'Stable', 'Unstable', and 'Debris' was less than 98% of the initial sample weight were discarded. The percent of stable aggregates was determined using the formula,

$$\text{\% of Stable Aggregates} = 100 * \text{wt. Stable} / (\text{wt. Stable} + \text{wt. Unstable}).$$

Water Holding Capacity Protocol

Drainage units were made by melting many holes in the bottoms of '5 oz' (approx. 130 ml) disposable plastic drinking cups and covering the bottom with non-absorbent filter paper. The drainage units were wetted and allowed to drip away excess moisture prior to use. The wet drainage units were filled with 130-150 g of air-dried soil from the 1998 and 1999 bulk density samples. The soil was wetted from the bottom by placing the units on a tray with 1 cm of water. When the soil "glistened", the drainage units with soil were placed in a sealed 100% humidity chamber for a week. The sealed chamber allowed gravimetric drainage but prevented the soil from drying out. Water Holding Capacity was determined using the formula,

$$\% \text{ WHC} = 100 * (\text{Soil Final Wet wt.} - \text{Soil Dry wt.}) / \text{Soil Dry wt.}$$

Resistance to Penetration Protocol

Soil resistance to penetration was determined in Fall 1997, Fall 1998 and Spring 1999 using a recording penetrometer (Pike Agri-Lab Supply Inc. Strong, Maine). Following profile moisture recharge, ten resistance/depth profiles were made for each plot. Corn and soybean plots were sampled within the rows and wheat stubble plots were sampled randomly. The stones in this glacial till influenced the resistance curves so the following criteria were established to eliminate questionable data.

1. Initial readings must begin below 60 psi. If not, the curve will be deleted from the data set.
2. Slope of the curve must be less than 20 psi per cm. If not, the data following the rapid rise in slope will be removed from the data set.
3. Slope of the curve must be positive. A sudden negative slope in this glacial till usually means that a stone obstruction has been pushed aside.

Least Square Means were generated from the processed data using the SAS Mixed model (SAS, 1999).

RESULTS AND DISCUSSION

Bulk Density

Mean bulk densities ranged from 1.18- 1.54 g/cc (Figs. 1-3). Although there were differences in crops, management, and year, none of the plots approached the 1.80 - 1.85 g/cc levels of root inhibition in a sandy loam proposed by Bowden (1981), or Grossman and Berdanier (1982). In the 1999 data where only wheat, 1st year corn and continuous corn were sampled, the main effects of crop and management were significant (P=0.05). In the 1997-1998 data set where all plots were sampled there was a significant (P=0.05) crop x management interaction. The presence of cover crops was usually not significant. In the 1999 data the cover crop sub-plots usually had slightly lower (but not significant) bulk densities than the no-cover sub-plots. But in the 1997-1998 data there were a number of instances where the cover sub-plots had higher mean bulk densities than their no-cover counterparts. In the IF continuous corn plots the cover cropped sub-plots had lower bulk densities than the no-cover sub-plots and significantly (0.05) lower bulk densities than the conventionally cropped continuous corn. Possibly, the use of a cover crop in continuous corn could ameliorate some of the bulk density problems associated with continuous corn. The lack of a strong cover crop influence on bulk density as reported by MacRae and Mehuys (1985) and Power et al. (1998) may be due to the moderate crimson clover residues returned in two of the four years of the rotation.

Over the three years sampled, there was a consistent pattern in bulk densities associated with management. The organic plots had the lowest bulk densities and the conventional plots had the highest bulk densities. This pattern also matches the pattern of increasing soil carbon reported by Sanchez et al. (2003) in these plots (Table 2). These findings agree with those of Logsdon et al. (1993), who found that the bulk density of an organically managed field (with ridge tilling) was less than that of a nearby conventionally managed field. Initially it was surprising that the organic plots, in spite of the highest amount of traffic from field operations, had the lowest bulk densities and the conventional plots with the least traffic had the highest bulk densities. Our plot dimensions and equipment size necessitated a form of controlled traffic where our wheel tracks were always in the same location and the bulk density samples were not taken from the wheel tracks. Logsdon et al. (1999) reported low bulk densities with both chisel plowing and no-till systems when looking at a controlled traffic situation in a corn - soybean rotation on silt loams. It is unlikely that these differences in bulk density are artifacts of sampling or cultivation since the last cultivation in both corn and soybeans is aggressive. The amount of settling of the top 10 cm from June to October is a function of rainfall, gravity, and soil characteristics. Since rainfall and gravity are relatively uniform on the entire experiment the differences in bulk density between the various corn treatments and the soybean treatment is probably due to differences in the soil characteristics.

We expected the bulk density in the IC plots to be lower than the bulk density in the IF plots due to the addition of the lower bulk density compost. However, at the low annual rate of 4,400 kg/ha in six years only 26,400 kg/ha was applied. Even if none of the compost mineralized this amount is only 1.3% of the mass of a 16 cm furrow-slice (ave bd= 1.30 g/cc). Kaheel et al. (1981) reported that when sewage sludge was applied at agronomic rates generally little change on bulk density was seen.

The wheat plots had the highest bulk densities and the following 1st year corn crop had significantly lower bulk densities (Figs. 1 and 2). When wheat was sampled in the fall it had been 13 months since the previous tillage while the corn and soybean plots had been aggressively tilled only five months prior. Gravity and rainfall over the 13 months may play a role in increasing the bulk density. Weinhold and Halverson (1998) found that bulk densities in a wheat-fallow system, with tillage occurring every other year, were higher than in annually cropped wheat under both conventional and no-till systems. The bulk densities of the continuous corn plots were similar to their 1st and 2nd year rotational counterparts also possibly due to the aggressive final cultivation which throws about 5 cm of soil into the row. The differences between the continuous corn 1997-1998 data and 1999 data indicate the importance of the temporal effect on bulk density.

Water Holding Capacity

The procedure for determining water holding capacity was very repeatable. When the test was performed on five aliquots of the same soil the results were within 1-2% of each other. In both years the treatments that used compost and/or cover crops tended to have higher water holding capacities than the treatments that used neither (Figs. 4 and 5). It is unknown why IC with cover had relatively low WHC in 1999 when it received both compost and cover crops and exhibited a higher WHC in the previous season.

In 1998, the WHC was highest following 1st year corn and decreased through the rotation points reaching its lowest level with wheat (Fig. 6). It is likely that the increase in WHC is not so much associated with corn as it is with the breakdown of the previous wheat roots that were present in the 1st year corn soil. Likewise, WHC under wheat may be at its lowest since the previous wheat roots had several seasons to break down and the current wheat roots had not yet begun to break down. In 1999, there were no differences associated with the crops (Fig. 7) possibly indicating a stronger environmental influence than crop influence on WHC. Although various treatment differences were statistically significant (P=0.05), the difference between a soil WHC of 39% and a soil WHC of 43% may be negligible to plant water uptake. Field observations occasionally noted differences in moisture stress but they were usually more of a spatial nature than associated with specific treatments.

Aggregate Stability

The 1998 data indicated that the management systems receiving compost and/or cover crops tended to have a higher percentage of stable aggregates (Fig. 8). A notable exception was IC with cover which, while having both compost and cover, was not significantly different from the conventional treatment which received neither. In 1999 the aggregate stability of each treatment (Fig. 9) was lower than it was in 1998 and differences due to management were not significant. With both grass and legume cover crops and a relatively stable compost it is surprising that aggregate stability was not uniformly higher in organic and compost managements than in the conventional and fertilizer-no cover treatments. This lack of difference may be due to our uniform method of primary tillage. It has been well documented that moldboard plowing reduces aggregate stability compared to less disruptive forms of primary tillage. The use of the chisel plow in our conventional treatment may be part of the reason that significant differences are not seen consistently. Martin (1942) found that properly composted material did not increase the percentage of stable aggregates formed and concluded that the composting process utilized the easily decomposable material, leaving the less decomposable material that is not as effective in aggregate stabilization. This observation was supported by Diaz et al. (1994) who found that the addition of un-composted urban refuse rapidly increased aggregate stability while the addition of a stable peat was not effective in increasing aggregate stability. Numerous studies reported increases in aggregate stability associated with the application of sewage sludge (Metzger and Yaron, 1987, Lindsay and Logan, 1998) and animal waste (Martens and Frankenberger, 1992). These materials have readily available food sources for bacterial and fungal production of the polysaccharides and other microbial by-products associated with aggregate stabilization.

The readily available by-products formed by the decomposition of cover crops is thought to enhance the production of stable aggregates (Allison, 1968) but Benoit et al. (1962) noted that several years of incorporating of ryegrass were necessary to significantly increase aggregate stability on a sandy loam. Conversely, Smeltkop et al. (1997) saw no change in water stable aggregates associated with the use of sava snail medic cover crop in corn. Although the treatments have experienced 6-7 seasons of cover cropping the amount of biomass incorporated each year are not equal. The red clover cover crop produced more biomass than annual ryegrass and, in most years, both produced more biomass than crimson clover. It is possible that the cumulative biomass produced over the rotation by the cover crops in this study is less than the biomass produced by the cover crops in the published studies.

There were significant differences in percentage of stable aggregates associated with crop in both years (Figs. 10 and 11). Wheat had a higher percentage of stable aggregates than all other crops. Our findings agree with those of Jordahl and Karlen (1993) and Bruce et al. (1990) who found that the preceding crops had significant effects on aggregate stability and that preceding sod crops had a positive influence on aggregate stability. Martens (2000) showed that the previous crop species has much to do with the aggregate stability seen under the current crop. Our data does not support Martens' finding that soybean decreases aggregate stability more than corn. The aggregate stability measured in the 1998 soybean plots was not significantly less than that of corn. These plots in 1999, when measured under the standing wheat crop, had an aggregate stability ratio that was higher than that of 1st year corn (previously wheat in 1998).

Our data did not support Raimbault and Vyn's (1991) observation that winter wheat with red clover had a greater influence on the aggregate stability seen in the next crop than winter wheat alone. The percent of stable aggregation seen in 1st year corn following frost-seeded red clover in wheat was not significantly different from that seen in the 1st year corn following wheat without clover (data not shown). Raimbault and Vyn also noted that the percentage of stable aggregates was more in 1st year corn following wheat with red clover than was seen in continuous corn. In our trial there were no significant differences seen between these treatments in either year.

Across all treatments the percentage of water stable aggregates was greater in 1998 than in 1999 indicating a strong temporal effect. Islam and Weil (2000) proposed that aggregate stability measurements may be useful components in soil quality indices but our data indicates the danger of taking a set of measurements on a single date. The value of 61% stable aggregates seen in conventional management in 1998, while the lowest treatment in 1998, was greater than almost all of the treatments values in 1999. Measurements taken by Raimbault and Vyn (1991) throughout the growing season indicated that while the absolute stability of aggregates fluctuated widely through the year the relative ranking of the treatment's aggregate stabilities was quite similar throughout the year.

Infiltration

The infiltration measurements showed large spatial variations agreeing with Smith et al. (1937). Infiltration measurements in the same plot, separated by only 20 cm, sometimes indicated infiltration rates that differed by 100%. The actual mean infiltration rates ranged from 7-15 cm/hr depending on treatment. When the data was normalized using a natural log transformation there were significant differences in infiltration rates associated with crops and with management systems. Within management systems, the differences associated with cover crops were neither significant nor consistent (Fig. 12). This lack of agreement with some of the published literature (Smith et al., 1987, Unger and Vigil, 1995, and Smeltkop et al., 1997) may be due to our infiltration sampling dates. Late fall or very early spring may not be the optimum time to see consistent treatment differences due to cover crops. Our results indicate a trend towards greater infiltration rates in the management systems that use compost and/or cover crops than in the management systems that do not use either. This supports the literature reports of high rates of organic amendments being associated with increases in infiltration (Smith et al., 1937, Albrecht and Sosne, 1944, Kaheel et al., 1988, Martens and Frankenberger, 1992). Wheat, soybean, and 2nd year corn had higher infiltration rates than 1st year corn or continuous corn (Fig 13). It is unknown why 2nd year corn had infiltration rates that were so much higher than the other treatments but these higher rates were seen across all management systems.

Penetrometer

Wheat treatments usually required more force to penetrate than the corn or soybean treatments (Fig. 14). These differences were significant in the zone just below chisel plowing (15-18 cm) for two of the three seasons. The differences in resistance to penetration associated with the various management systems were not significant. The lack of management influences agrees with Pikul and Aase (1995) and Hammel (1989) who saw tillage differences but saw no influence of crop rotation or previous cropping history on resistance to penetration. Chen and Heenan (1996) observed higher resistance to penetration under a barley grain than under canola, field peas, or Lupin but these differences were only significant at the 5-10 cm depths.

As illustrated by the force-depth curves for continuous corn (Fig. 15), measurements of resistance to penetration showed a strong temporal response. The force-depth curve resulting from the Spring 1999 sampling was more similar to the Fall 1997 results than it was to the Fall 1998 results taken only five months prior. These relationships were also noted in the rotation crops (data not shown). This relationship is difficult to explain since the Spring 1999 and Fall 1998 determinations came from the same plots while the Fall 1997 determinations came from the same treatment but, due to rotations, different plots. All determinations were made at soil moisture levels near field capacity which should allow season to season and within-season comparisons (Bradford, 1986).

CONCLUSIONS

The addition of an annual average of 4,500 kg/ha of compost was usually associated with better soil physical characteristics. The influence of cover crops on the soil physical characteristics examined was inconsistent in the treatments that received compost but in the treatments that received fertilizer the presence of cover crops was associated with improved soil physical characteristics. Unfortunately, with the high variability associated with these glacial till soils, these differences were usually not significant (P=0.05 level).

Winter wheat may play an important role in the rotation by maintaining good soil physical characteristics. In the fall following wheat harvest, the soil's bulk density, resistance to penetration, and aggregate stability are all at the highest levels in the rotation and the water holding capacity was at the lowest level in the rotation. In the following fall (after 1st year corn) when the wheat roots have had a chance to break down, bulk density was at the lowest point in the rotation, water holding capacity was at the highest level in the rotation, and aggregate stability was beginning a three-year decline through the rotation. These soil enhancing characteristics may increase the long-term financial value of having wh

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wheat in the rotation above the monetary value received for the grain and straw. Wheat may be the point in the corn-corn-soybean-wheat rotation to improve soil physical characteristics thus encouraging greater yields of the more financially rewarding crops.

Soil physical characteristics fluctuate throughout the rotation and, as shown by the continuous corn plots, change from year to year. This highlights the potential problems of evaluating a site against a series of static performance criteria with only a single sampling date.

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Table 1: Characteristics of management schemes

Management	Rotary Hoe Operations	Cultivation Operations	Herbicide Program	Nutrient Source
Organic (O)	3	3	None	Compost
Integrated Compost (IC)	2	2	30 cm band	Compost
Integrated Fertilizer (IF)	2	2	30 cm band	Fertilizer
Conventional (C)	0	1	Full spray	Fertilizer

Table 2: 1999 Total carbon levels in the 0-25 cm profile by management scheme[1]

Management	mg C kg^{-1}
Organic	11,310
Integrated Compost	10,210
Integrated Fertilizer	8,330
Conventional	6,740

[1] Data from Sanchez et al. (2003?)

Fig. 1 1997 and 1998 soil bulk density by crop and management

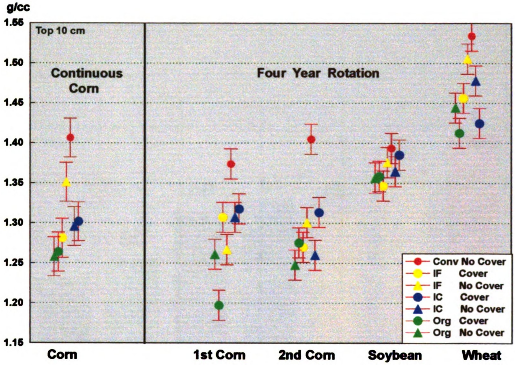


Fig. 2 1999 soil bulk density by crop

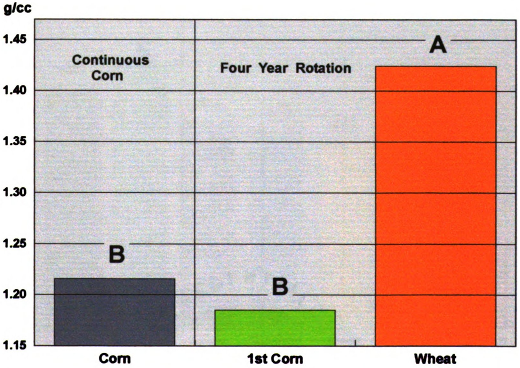


Fig. 3 1999 soil bulk density by management

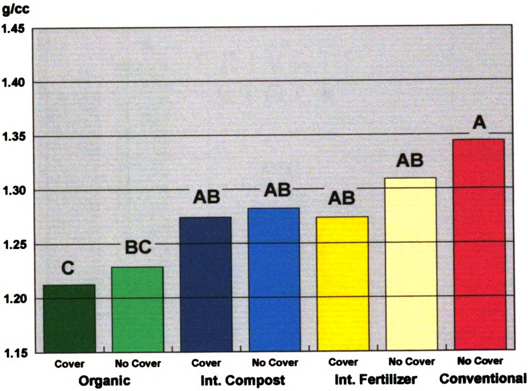


Fig. 4 1998 soil water holding capacity by management

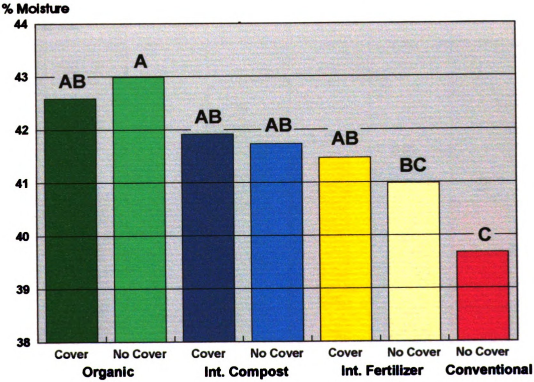


Fig. 5   1999 soil water holding capacity by management

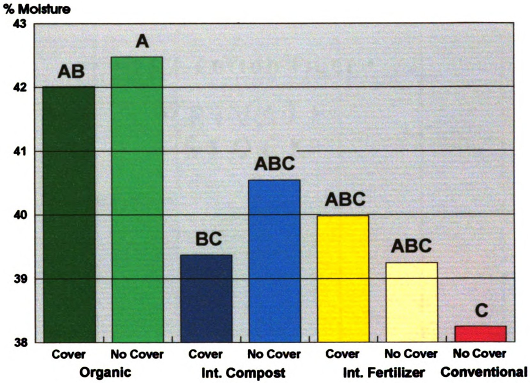


Fig. 6   1998 soil water holding capacity by crop

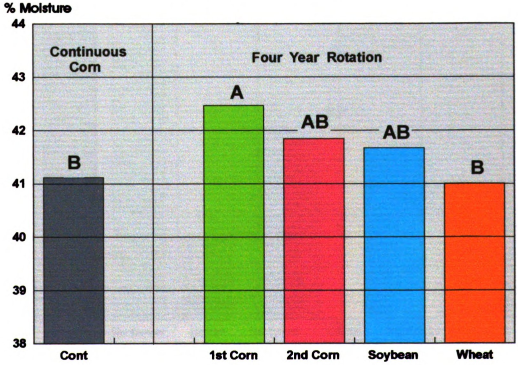


Fig. 7 1999 soil water holding capacity by crop

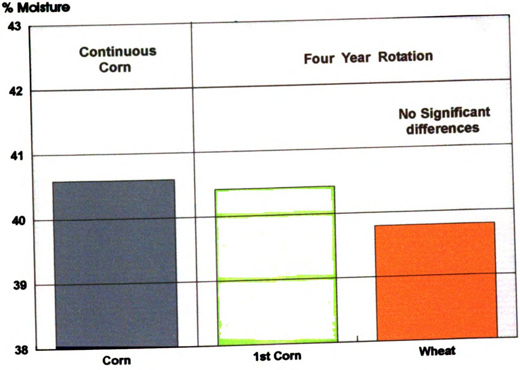


Fig. 8 1998 soil aggregate stability by management

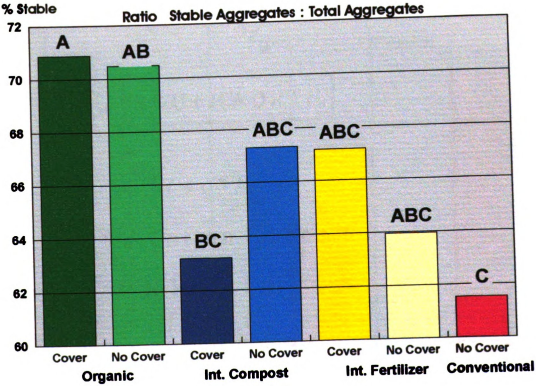


Fig. 9 1999 soil aggregate stability by management

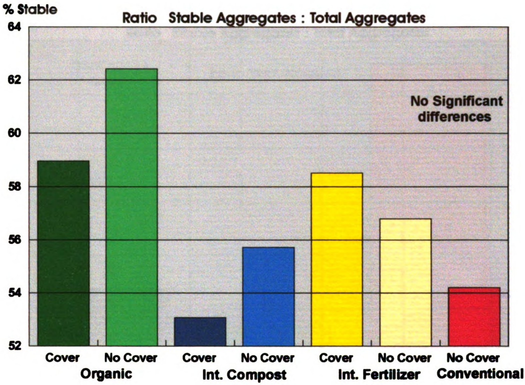


Fig. 10 1998 soil aggregate stability by crop

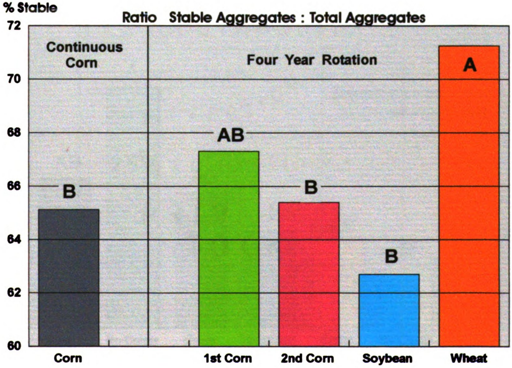


Fig. 11 1999 soil aggregate stability by crop

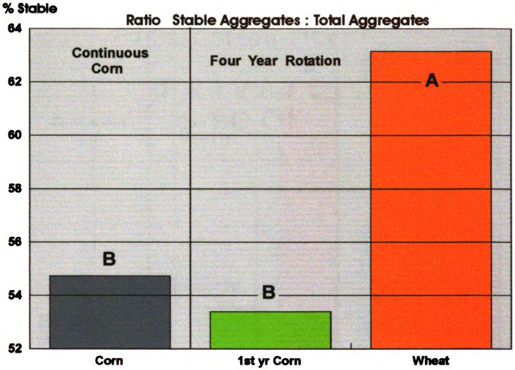


Fig. 12 1999 water infiltration rate by management

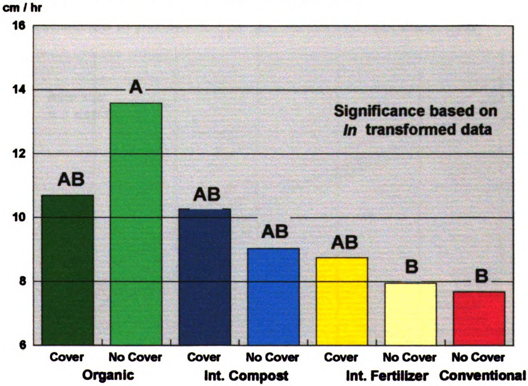


Fig. 13 1999 water infiltration rate by crop

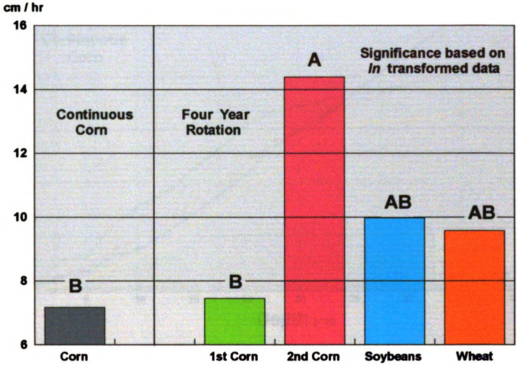


Fig. 14 Resistance to penetration by soil associated with each crop

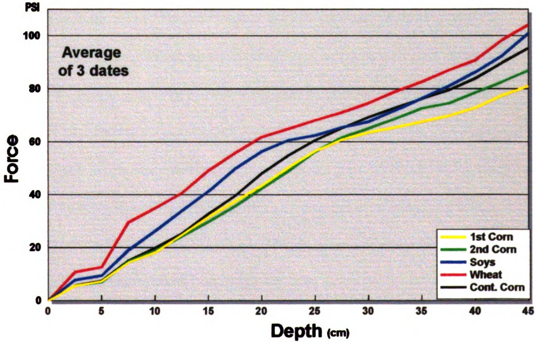
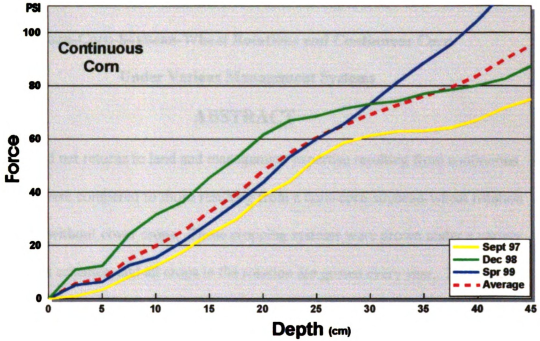


Fig. 15 Resistance to penetration by soil at each sampling date



CHAPTER 3

Yields and Economic Returns from Eight Years of Corn-Corn-Soybean-Wheat Rotations and Continuous Corn Under Various Management Systems

ABSTRACT

Crop yields and net returns to land and management expertise resulting from continuous corn systems were compared to those resulting from a corn-corn-soybean-wheat rotation each with and without cover crops. These cropping systems were grown under a variety of management schemes, and all crops in the rotation are grown every year. The organic (O) and integrated compost (IC) systems received supplemental nutrient inputs from compost and the integrated fertilizer (IF) and conventional (C) systems received commercial fertilizer. Yields of 1st year corn following wheat+red clover were higher than continuous corn and 2nd year corn. These differences were significant in the treatments that received compost but not in the treatments receiving fertilizer. First year corn following wheat with no cover crop, while better than 2nd year and continuous corn in each management treatment, did not equal the yields seen when 1st year corn followed wheat+red clover. Wheat yields were lower in the treatments that received compost than in the treatments with fertilizer. No difference was seen in soybean yields. Net returns to land and management expertise were highest in the O treatments (\$359-398 ha^{-1}) due to the premium prices associated with organic crops. Among the conventionally priced crops, the IF corn-corn-soybean-wheat rotation without cover crops had the highest net returns (\$155 ha^{-1}) followed by the IF rotation with cover crops (\$128 ha^{-1}) and the C rotation without cover crops (\$116 ha^{-1}). The IC continuous corn had the lowest net

returns both with cover crops ($15 ha^{-1}) and without cover crops ($10 ha^{-1}). Treatment ranking was quite robust and changed only slightly with simulated increases in crop prices and selected input costs.

Introduction

Cropping systems depend on the mix and sequence of crops or rotations that farmers select (Francis and Clegg, 1990). Successful cropping systems utilize 'biological structuring' (Harwood, 1985) where efficient transfer of energy and growth factors along with altered population structure of pests, pathogens and their control agents within the ecology of the production system reduces the need for additional inputs such as fertilizer and pesticides.

It has been frequently reported that corn in rotation yields more than does continuous corn under various tillage systems (Peterson and Varvel, 1989, Lund et al., 1993, Raimbault and Vyn, 1991, Singer and Cox, 1998a). Edwards et al., (1988) reported similar findings in soybeans. The factors responsible for the yield increases seen with crop rotation are not completely understood. Sometimes a nitrogen (N) contribution or a breaking of a pest cycle is mainly responsible, but often no amount of pesticide or fertilizer can completely compensate for crop rotation (Bullock, 1992). The increased yields of 1st year corn may be associated with a general improvement of plant nutrition (Copeland and Crookston, 1992) or increased water use efficiency (Copeland et al., 1993).

There are management benefits in addition to the biological benefits of crop rotation. While a more diverse complement of machinery is necessary (Colvin et al.,1990) for a corn-soybean-wheat rotation than would be necessary for continuous corn, peak labor demands, crop yield risk, and marketing risk can be reduced through the crop diversity. The scale of equipment can be smaller on a corn-soybean-wheat rotation operation than is necessary on an comparably sized continuous corn operation to complete field operations in a timely fashion. Crop yield risk and marketing risk are reduced by having a variety of crops that are influenced differently by growing conditions and are marketed independently. It is more likely that at least one of the several crops in the rotation will be profitable than that the only crop grown will have both a productive season and a favorable selling price.

Cover crops provide many services to agronomic systems including weed suppression (Teasdale 1996), erosion control (Stocking, 1994), and increasing biodiversity. Cover crops have been reported to increase aggregate stability and water holding capacity in sandy soils (McRae and Mehuys, 1985, Smeenk et al., 2003?), maintain or increase the organic matter levels in the soil (Smith et al., 1987), increase the rate of water infiltration into the soil (Unger and Vigil, 1998) and reduce the amount of fall nitrate leaching (Isse et al., 1999, Vyn et al., 1999).

The importance of legumes in crop rotations has long been recognized (Oakly, 1925). Varvel and Peterson (1990) and Stute and Posner (1995) demonstrated that crop rotations with legumes could reduce the N fertilizer needs compared to continuous corn. Corn following a leguminous cover crop can exhibit even higher yields than corn that has received proper amounts of N fertilizer (Jones et al., 1998). There are also potential drawbacks to the inclusion of cover crops in the cropping system. These include possible loss of soil moisture prior to planting if not properly controlled, the additional costs of cover establishment, and the additional expertise necessary to manage an additional crop.

Proponents of organic farming systems advocate that the fields are "healthier" while yields can be similar to those of conventional farms (Stockstad, 2002). Mader et al. (2001) found higher biological activity associated with soils managed organically than in conventionally managed soils while organic crop yields were only 20% lower than conventional yields, and Clark et al. (1998) reported increases in organic matter associated with organic productions compared to conventional systems. Delate et al. (2002) listed several studies across various cropping systems that showed no statistical differences between organic yields and conventional yields.

Although farmers are very interested in high yields, they generate their income through net profits. The highest net profits are not always associated with the highest yields. Christenson et al. (1995) found that sugar beets yields were highest in four year rotations but net returns were highest when beets were in a two year rotation. Chase and Duffy (1991) reported higher net profits with a corn-soybean rotation (\$366 ha^{-1}) than in continuous corn (\$324 ha^{-1}) under chisel tillage. Liu and Duffy (1996) found that farmer results across Iowa generally indicted that rotated corn had higher net returns per hectare than continuous corn across a variety of tillage systems. In New York, Katsvairo and Cox

(2000) saw that under chisel plowed systems net returns and yields under high chemical input continuous corn (ha^{-1}) were less than those seen of corn in a soybean-wheat/red clover-corn rotation (\$156 ha^{-1}) but the net returns to the soybean and wheat/red clover portions of the rotation were only \$7 ha^{-1} and -\$85 ha^{-1} respectively. Not all of the benefits of rotation are reflected in net returns. Reductions in pesticide use, nitrate leaching and improvement of soil quality benefit society but are not indicated in farm net returns (Duffy, 1991). Roberts and Swinton (1996) reported a lack environmental evaluations in the 58 economic analysis they reviewed of crop production systems. They suggested incorporating biophysical simulations with the economic optimization methods to model both financial and environmental system stability.

This study evaluates the yields and net returns to land and management expertise of a corn-corn-soybean-wheat rotation and a continuous corn cropping system produced under a variety of management systems that range from organic to conventional.

MATERIALS AND METHODS

Site Description and Experimental Design

A long-term corn-corn-soybean-wheat rotation study was established in "The Living Field Laboratory" at the W.K. Kellogg Biological Station (Hickory Corners, MI). The soil is a sandy loam and the county's corn yield average is 8.1Mg/ha (130 bu/A). The experiment was analyzed as a split-plot design with management as the main factor (7 treatments: Organic (O), Integrated Compost (IC) and, Integrated Fertilizer (IF), each with and without cover crops and Conventional (C) with no cover crops). and crop as the split-plot

(5 treatments: 1st year corn, 2nd year corn, soybeans, wheat, and continuous corn). There were four replications. Each crop in a corn-corn-soybean-wheat rotation along with continuous corn was present every year. The conventional management system, due to a full coverage herbicide program, did not have a cover crop component. All plots were managed using the best management practices appropriate to each treatment. Although the three year corn-soybean-wheat rotation is more typical in the region, a second year of corn was added to the rotation with the objectives of increasing carbon inputs, nitrogen demands, and profitability of the entire rotation.

Crop Production

Corn. Compost was applied to the O and IC plots in April prior to tillage at the following rates: 4,500 kg ha^{-1} on 1st year and continuous corn and 9,000 kg ha^{-1} on 2nd year corn. All plots were chisel plowed and disced at least a week prior to planting. On the day of planting all plots were field cultivated and planted (69,000 seeds ha^{-1}) in 76 cm rows. A starter fertilizer (10-20 kg N ha^{-1} either granular or liquid) was applied in the IF and C treatments and usually a pre-emerge grass herbicide (Dual II) was banded over the row in the IC and IF treatments and broadcast in the C treatments at planting. Continuous and 2nd year corn received a banded soil insecticide for corn rootworm control when indicated by prior sampling. Mechanical weed control in O, IC, and IF usually consisted of two rotary hoeings, a cultivation with the rolling shields down and a final aggressive cultivation prior to canopy closure. Nitrogen, initially as ammonium nitrate and in the last two seasons as liquid 28% N, was usually sidedressed at rates recommended for a 9.4 Mg ha^{-1} (150 bu/A) yield goal by the pre-sidedress nitrate test (Magdoff, 1991) in the IF and C treatments. The fertilizer was incorporated in the final cultivation. Immediately following final cultivation hairy vetch (*Vicia villosa*), red clover (*Trifolium pratense*), crimson clover (*Trifolium incarnatum*) and/or annual ryegrass (*Lolium multiflorum*) was applied. Yield data were recorded from the center 2 rows of the entire length of the 15.3 m plots following removal of the boarder plants.

Soybean. All plots were chisel plowed and disced at least a week prior to planting. Neither compost nor fertilizer was added to these plots in this point of the rotation. On the day of planting all plots were field cultivated and planted (370,000 seeds/ha) in 76 cm rows. Insect damage in 1999 necessitated replanting all treatments. Mechanical weed control was similar to that of corn. In the early years of the experiment, pre-emerge herbicides were used and, more recently, post-emerge herbicides were used. Round-up resistant varieties were used in the last three years with two applications of glysphosphate at low rates. Yield data were recorded from the center 2 rows of the entire length of the 15.3 m plots following removal of the boarder plants.

Wheat. Compost was applied (4,500 Kg/ha) in the O and IC plots immediately following soybean harvest. At planting, the plots were chisel plowed, disced or field cultivated, and then planted (5,000,000 seeds/ha). In early spring 84 kg/ha nitrogen (as urea) was applied to the IF and C plots. At the same time

'Michigan Mammoth' red clover was frost seeded (18 kg/ha) into the wheat plots that received cover crops. The wheat was harvested in July using a plot combine and the straw was baled and removed. The plots were clipped in September to stimulate the clover cover crop and/or to control weeds.

Production costs

Published Michigan custom work rates (Dartt and Schwab, 2001) were used whenever possible to avoid advantages that individual farmers may gain by aggressive purchasing tactics and to factor in the value of labor and depreciation of capital equipment. For operations with no published custom rates, the authors estimated rates based on the cost of equipment and the similarity to tasks with published rates. Fertilizer costs were based on a local supplier's (The Andersons) 2002 prices and those published by USDA (2001). Pesticide prices came from a variety of sources including various land grant university websites, USDA (2001), and local retail prices. Where pesticide prices were unavailable, the product was converted to another formulation on an active ingredient basis and the equivalent price was substituted.

Gross Revenue

The national average annual corn, wheat and soybean prices from 1991 to 2000 reported by the USDA National Agriculture Statistics Service were converted to 2001 dollar equivalents by multiplying the reported annual prices by the respective Producer Price Indexes for Major Commodity Groups for that year (2002), and then dividing the results by the 2001 Producer Price Index. Gross revenue was determined by multiplying the grain yield of each treatment by the average of the adjusted commodity prices. The average prices used for the organic commodities determined by consulting a Michigan broker of organic corn, wheat, and soybeans. Although the actual amount of straw removed from the wheat plots was not measured, an estimate of 1.4 Mg ha^{-1} (2/3 ton/A) was used. The \$66 Mg^{-1}(\$60/ton) value of the straw is based on the local market.

Price and Cost Sensitivity

Prices received by the farmer and the costs incurred in producing the crops are constantly changing thus making differences in net returns between treatments a relative measurement for the conditions modeled. Within the arena of changing prices and changing costs there are differing impacts of a increase in cost of a specific input on the relative profitabilities of the various management systems. For example, an increase in the cost of pesticides has less of an impact on the net returns of the IC and IF systems which band the herbicides and consequently use only 1/3 of the amounts used by the C managements. Likewise an increase in the price of corn would have a much greater impact on the profitability of the continuous corn management systems than on the rotation systems. When comparing the profitability of different production systems it is important to determine the sensitivity of net returns to various input costs and various selling prices. A robust ranking of the management systems would not be expected to have a major re-ranking of cropping system net returns with a slight modification of a single input cost, or a slight increase a single crop selling price.

An increase of one standard deviation of the adjusted annual commodity prices (1990 - 2000) was used in the model to determine the influence of corn, soybean or, wheat price fluctuations on the gross incomes and net returns of the various treatments. The organic treatments were adjusted by increasing the average organic price the same proportion that the corresponding commodity price had been increased using the following formula

$$\text{Modified Organic Price} = \text{Average Organic Price} + \text{Average Organic Price} * \frac{\text{Std Dev of commodity price}}{\text{Ave. commodity price}}$$

Each simulation was run with only one crop price modified at a time with the other prices reset to the average prices determined previously.

Input cost sensitivities were simulated as drastic cost increases in the input cost being modified. The modified pesticide simulation was a doubling of all of the base pesticide prices and the modified nitrogen simulation was a doubling of the prices of urea, ammonium nitrate, and liquid 28% N. The modified tillage simulation was a doubling in the costs of both rotary hoeing and row cultivating. The modified compost simulations were run at costs of \$0 and \$50 Mg^{-1} (\$45 per ton) rather than the \$16.5 Mg^{-1} (\$15 per ton) used in the standard conditions of the model. The \$0 purchase price of compost represents a situation where a large dairy operation with an inadequate land base would haul the compost to the 'buyers' farm just to dispose of the material. The \$50 Mg^{-1} simulation price would be comparable to a situation where a dairy has a strong established market for the compost such as the local landscape industry.

RESULTS AND DISCUSSION

Yields

The range of average annual yields within treatments was often greater than the range between treatments in any one year (data not shown). These differences were usually associated with summer rainfall patterns. The corn yields in the '93-'95 growing seasons were much higher than the yields of the '96-'99 seasons which were associated with sparse summer rains at critical corn growth stages. The July- August dry conditions seen in the '96 season also lowered the soybean yields in all treatments. Wheat had completed grain filling prior to the '96 dry conditions and yield was not affected.

In the plots that received compost (O and IC) the average yields of 1st year corn were significantly greater than those of 2nd year or continuous corn (Table 1). Within the treatments receiving compost, the yields of 1st year corn following wheat+red clover were significantly greater than the yields following wheat without a cover crop. These results agree with those observed by Singer and Cox (1998a) and Peterson and Varvel (1989). There were few differences in yield associated with cover crop in the 2nd year or continuous corn plots. The N contribution from the preceding red clover crop was necessary to produce high yielding corn when compost was the only nutrient input. Although treatments of both 2nd year and continuous corn were planted following crimson clover cover crops, soil nitrate levels were well below those following wheat+red clover (Sanchez Thesis, 2000).

In the treatments receiving fertilizer (IF and C), 1st year corn also yielded more than 2nd year and continuous corn but there was no difference associated with cover crop. The yields of the fertilized 2nd year and continuous corn treatments were higher than the yields of 2nd and continuous corn treatments that received compost. All IF and C corn plots were side-dressed by treatment at rates determined by the pre-sidedress nitrate test which compensated for differing initial levels of soil N associated with previous crops and/or cover crops (Vitosh, 1995).

The lower yields of soybeans from the O treatment were probably due to within-row weed competition. The cultivator was adequate in controlling the weeds that emerged after rotary hoeing between the rows, but in many seasons the soil was not dry enough to properly "flow" into the soybean row and cover the weed seedlings without burying the soybean seedlings. Post-emerge herbicides successfully controlled within-row weeds in the IC, IF, and C treatments. Our results differed from Cox et al. (1999) who saw fewer weeds in soybean than in corn following mechanical cultivation in chisel plowed systems.

The yields of wheat from treatments receiving compost were significantly less than those of the treatments receiving fertilizer. It is likely that the N associated with the compost is not adequately mineralized in April and early May to fully meet the wheat's N needs in these critical growth periods. In early April, cool soil temperatures limit mineralization and in May and June mineralization in the wheat plots is limited by the low soil moisture conditions caused by the heavy crop moisture demand. Previous research on this site estimated that 40-50 kg N ha^{-1} yr^{-1} resulting from the current and former compost applications was available for the entire growing season (Fortuna et al., 2002). Sanchez et al. (2002), also on this site, indicated that the soil in the rotation plots was less effective in mineralizing the N from added compost than from added clover. Thus, the compost treatments received less total N than the fertilized treatments and the N was not as available during periods of peak demand.

Within a production year, the same variety of wheat was used under all management treatments to keep the trial as statistically balanced as possible. It is possible that the wheat yields in the O and IC treatments may have benefitted from use of an alternative variety that is better adapted to the low soil nitrogen levels seen in these treatments.

Production expenses

The production expenses associated with soybeans and wheat were less than the expenses associated with corn (Table 2). Most machinery expenses in soybean production were similar under all management systems with the C treatment receiving slightly less secondary tillage. The slight decrease in machinery expense seen with C was more than offset by the increase in input costs (mainly as broadcast herbicide). The production expenses associated with wheat were also similar across management systems with the differences being associated with the input costs of cover crop seed, compost and urea. The machinery expenses associated with corn were very similar under O, IC, and IF managements. The reduced machinery expenses of corn grown in the C treatment were due to fewer secondary tillage operations (Table 3). The increased input costs associated with 2nd and continuous corn mainly reflected increased fertilizer and pesticide costs associated with corn following corn.

Gross Income by crop and management

The higher prices received for the organic products (Table 4) more than compensated for crop yields that are occasionally lower than their IC, IF, or C counterparts. The highest average gross incomes for each crop were seen under the O managements (Table 1). Within the conventionally priced treatments, the highest gross incomes were associated with corn and the lowest gross incomes were associated with wheat. Although the average price of conventional corn is about half of the price of soybeans and about 3/4 of the price of wheat, the corn yield at this location is usually two to three times the yield of soybeans and wheat.

Though the gross revenues with organic 2nd year and continuous corn appear attractive, they are misleading because most organic certification protocols require crops to be grown in rotation so continuously grown corn could not be marketable as organic (USDA, 2001, OGM, 2000). Fortunately, given the current pricing structure, average annual gross income from an organic corn-soybean-wheat rotation (\$806 ha^{-1}) would be expected to be only slightly less than the average annual gross income from a corn-corn-soybean-wheat rotation (\$822 ha^{-1}) since the very high grossing 1st year corn crop would occure every three years rather than every four years.

In the 1990s the commodity prices for corn, wheat, and soybeans generally increased from 1990 to 1995 and then decreased from 1995 to 2000. The 2000 commodity prices of corn and wheat were very similar to the 1990 prices and the 2000 price of soybeans was less than the 1990 price (Michigan Agricultural Statistics. The prices of organic commodity crops is linked to the price structure of conventional commodity crops with an additional premium paid for the organic crops above the conventional crop price. The premium paid for organic corn and organic soybeans increased from 1995 to 1999 but decreased in 2000 and 2001. The premium paid for organic wheat fluctuated widely from 1995 to 2000 with 2000 having the highest premium (Dimitri and Greene, 2002). Unfortunately for organic crop producers, these premiums are paid on the basis of conventional crop prices, so although the organic premiums were increasing the actual prices paid for the organic crops has been decreasing in the last few years. The number of head of certified organic livestock and poultry has been increasing from 1997 to 2001 (Greene and Kremen, 2002) so it is likely that there will continue to be a demand for organic feed grains.

Net Returns to Land and Management Expertise by crop and management system

Since the value of land and the value of management expertise are constant between treatments and are not included in the cost of production, Gross Income - Cost of Production is properly called Net Return to Land and Management Expertise. For purposes of this discussion, the term Net Return will be used instead.

Net returns were higher for all crops produced under the various O managements (Table 1). The higher gross incomes for each organic crop were not associated with corresponding higher production expenses. If the organic premiums are removed the ranking changes completely. Without the organic premiums the net returns of the rotation are less than the net returns of the IC managements and the net returns of the continuous corn are slightly higher than those of the IC managements (data not shown). Within the conventionally priced commodity grains 1st year corn and soybeans usually had greater net returns than did continuous corn, 2nd year corn and wheat. Katsvairo and Cox (2000) using higher commodity prices reported negative net returns associated with the wheat-red clover crop in rotation, low net returns associated with soybeans and relatively high net returns associated with corn in a corn-soybean-wheat/red clover rotation under chisel plow management.

Within the treatments receiving compost (O and IC) the use of cover crops was associated with higher net returns in 1st year corn. Unfortunately, the cost of the red clover cover crop that boosted the 1st year corn was associated with the previous wheat crop with which it was planted. The cover crop cost that was calculated in the costs of production with 1st year corn was the crimson clover planted to aid the following 2nd year corn crop. Although these nuances influence the relative profitability of individual crops within the rotation, total profitability is determined across the entire rotation which is only influenced by total costs of all crops and total revenue from all crops.

Hesterman et al. (1992) reported N production of 94-188 lb/A from red clover when frost-seeded into wheat. The N application rates recommended by the pre-sidedress nitrate test in this trial were usually 40 kg N ha^{-1} less for 1st year corn following wheat+red clover than for 1st year corn following wheat alone. Under the price structure used, the \$21 ha^{-1} N fertilizer savings associated with the previous red clover cover crop does not quite compensate for the cost of the cover crop seed and its application (\$31 ha^{-1}). In a non-fertilized system the increase in corn yield associated with the clover more than pays for the cost of the cover crop.

There are several ways of evaluating a long-term rotation experiment. One method would be to average the net income from each crop in the rotation each year and compare the resulting rotation mean with the mean of the continuous corn plots. This method is analogous to comparing the average whole-farm net return per hectare of a continuous corn operation with the average whole-farm net return per hectare of a neighboring operation that is equally partitioned into 1st year corn, 2nd year corn, soybean, and wheat. With this method the variability associated with each season is equally applied to the treatments in the appropriate year. The rotation means and the continuous corn means for each treatment can be averaged over the eight seasons to determine a grand mean for the rotation and a grand mean for continuous corn for each management.

The alternative method of looking at the rotation trial would be to follow individual plots through the eight years of the experiment and average the annual net income generated by each individual plot. Since this trial had every point of the rotation present every year, for each management treatment, there are four different eight-year mean net incomes corresponding with the four entry points in the rotation every year. These four eight-year mean net incomes can be averaged to arrive at a grand mean for rotation within each management which can then be compared with the eight-year means for continuous corn. Unfortunately, each eight-year mean also contains eight variance components associated with seasons and when the four entry points are averaged the resulting grand means have very different variances from the treatment means of continuous corn. Both the method that focuses on seasons and the method that follows plots through the rotation give the same results for mean net income for each management system. For the sake of simplicity the season-based method was used for the following analysis.

When the rotation means and the continuous corn means were ranked, all net returns associated with the organic management were much greater than any net returns associated with the other management systems (Table 5). Again, this is mainly a function of the premium prices awarded organic crops during this period. Within the normally priced crops the rotation treatments of IF had the highest net returns. The net return of the IF rotation without cover crops was higher than the net return of the IF rotation with cover crops due to similar yields between the two treatments and the cost of the cover crops associated with the IF rotation with cover. Both the IF rotations had higher net returns than the IF continuous corn returns. The C rotation treatment also had a slightly higher net return than C continuous corn treatment. These results agree with those of Singer and Cox (1998b) who found that when the sale of straw is included in the net returns, a fertilized corn-soybean-wheat+red clover rotation had higher net returns than did continuous corn. The net returns of IC rotations with and without covers was less than those of both IF rotations. One explanation is that the yields of 2nd year corn produced in the systems receiving compost and the resulting negative net returns brings down the average net yield of the rotation. The low yields associated with continuous corn treatments of the IC management treatments resulted in the lowest net returns of all treatments.

Sensitivity to fluctuations in crop prices and selected input costs

The ranking of net returns of rotations and continuous corn by the various management systems was very robust. Even when the prices of commodity corn, soybeans, or wheat were increased one standard deviation above their average price, none of the net returns of conventional crops approached the net returns generated by organic crops without an increase in organic crop prices. A 15.6% increase in the value of organic corn (comparable to the increase in conventional corn) caused a re-ordering of the ranking. The previous \$20.00 ha^{-1} advantage of the O rotation with cover crops over the O continuous corn with cover seen under standard model conditions (all normal crop prices and all normal production expenses) became a \$29.00 ha^{-1} deficiency when the price of organic corn was increased.

Within the conventionally priced crops there was slight treatment re-ranking associated with a higher price of corn. Increasing the price of corn one standard deviation was not enough to raise the ranking of continuous corn produced under IC management. In general, raising the value of corn only slightly increased the ranking of three of the five normally priced continuous corn treatments when compared to the treatment ranking seen with standard prices and expenses. Increasing the price of soybeans or wheat also resulted in only minor re-ranking of the treatments.

When the cost of pesticide was doubled the O treatments were not affected and the IC and IF treatments that receive banded herbicide were only slightly affected. The C continuous corn treatment, which received broadcast herbicide every year and banded soil insecticide most years, was highly affected by the increase in pesticide cost. This treatment dropped from a relatively high ranking (#6) under standard price and expense conditions to the lowest net return (#14) under the high pesticide price scenario. The ranking of the IC treatments was quite sensitive to the price of compost. When there was no cost associated with the purchase of compost (only the application cost) the rank of the IC rotations improved over all IF treatments. In an alternate scenario where the cost of compost was tripled, all of the IC treatments had lower net returns than any of the other conventionally priced treatments.

CONCLUSIONS

At the prices prevailing in Michigan during 2001, the organic rotation was a very profitable system. Although organic soybean and wheat yields were slightly reduced, net returns were far greater than those of conventional crops. Although the market for organically-produced grains appears to be strong as demand for organic products increases, if the premiums paid for organic commodity crops decrease future net returns may not be as attractive as the non-organic production alternatives.

From a net return standpoint, the yield benefits over the entire rotation associated with cover crops do not compensate for the cost of the cover crops. The strong yield increase seen in the corn that does not receive fertilizer associated with the proceeding red clover cover crop does not carry through the entire rotation, while the cost of a cover crop was present in three of the four years of the rotation. However, there are benefits from cover crops that were not captured in this economic analysis. Long term benefits in yield may only show up if the experiment is run for many years. The current analysis does not give credit for the ecosystem services rendered by the cover crops nor does it account for the additional forages provided by the cover crops that may be available for grazing or haying. A late fall haying of the red clover cover crop may also occasionally be possible when weather conditions permit.

The compost rates used in this trial were inadequate to supply the N needs of corn without a significant preceding leguminous cover crop such as the wheat-red clover combination. The dairy compost used was unable to supply the early season N needs of the winter wheat crop. Possibly, a substitution of dairy manure for the compost would be able to meet these N needs. Another approach would be to evaluate more wheat varieties for their ability to produce high yields under lower soil N conditions.

The ranking of treatments was fairly robust with only minor re-rankings occurring when crop prices were increased one standard deviation from their mean value or selected input expenses were doubled. The continuous corn produced under conventional management was sensitive to the price of pesticides relative to the other treatments. The rotations that were produced in the treatments receiving compost were sensitive to the price of compost relative to the other treatments.

This intermediate-term economic analysis does not factor in the differences in value of ecosystem services provided by the various management systems. The long-term biological benefits of crop rotation, use of compost, and cover cropping may not be apparent in the short-term price structures that are typically examined for economic analysis. Some of the long-term biological benefits associated with rotation, compost and cover crops seen in this trial include an increase in soil organic matter (0-25 cm), and increases in both the total soil N pool and the mineralizable soil N pool. Changes in the nematode community structure that favor non-plant parasitic nematodes have also been seen in the treatments with compost and cover crops.

On a coarse textured soil where winter leaching complicates N management, a three year corn-soybean-wheat+red clover rotation might be preferable to the corn-corn-soybean-wheat +red clover rotation actually used. The frost-seeded red clover retains enough N through the winter to usually meet the N needs of the following corn crop under these rain-fed conditions. The residual N following soybeans is adequate to meet the fall demands of the winter wheat crop, but supplemental N in the spring is necessary for high wheat yields.

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Table 1: Eight year averages of yield, gross income, and net returns per hectare by crop and managements

		Continuous Corn			1st year Corn			2nd year Corn			Soybean			Wheat		
		Yield	Gross	Net	Yield	Gross	Net	Yield	Gross	Net	Yield	Gross	Net	Yield	Gross	Net
		(Mg)	($)	($)	(Mg)	($)	($)	(Mg)	($)	($)	(Mg)	($)	($)	(Mg)	($)	($)
O	No Cover	5.5 b	816	398 A	6.8 d	999	581 A	5.6 c	824	308 A	1.9 b	623	343 AB	2.9 ab	625	259 A
O	Cover	5.6 b	821	370 A	7.8 ab	1145	697 A	5.9 c	870	326 A	2.0 ab	655	375 A	2.8 ab	618	222 A
IC	No Cover	5.4 b	471	10 B	7.2 cd	623	177 BC	6.3 bc	544	-15 CD	2.5 a	511	198 ABC	2.6 b	371	2 CD
IC	Cover	5.9 b	509	15 B	8.0 ab	690	212 BC	6.3 bc	543	-34 D	2.5 a	504	191 BC	2.5 b	408	-40 D
IF	No Cover	6.8 a	593	87 B	8.1 a	706	220 B	7.8 a	674	165 B	2.3 ab	467	147 C	3.3 a	445	89 B
IF	Cover	6.9 a	602	68 B	7.9 ab	689	187 BC	7.5 a	647	123 B	2.3 ab	464	144 C	3.3 a	440	59 BC
C	No Cover	7.0 a	610	95 B	7.5 bc	647	151 C	7.0 ab	605	87 BC	2.4 ab	489	154 C	3.2 a	430	72 BC

Letters of significance are only appropiate within each crop

Table 2: Eight year averages of production expenses per hectare by crop and management

		Continuous Corn			1st year Corn			2nd year Corn			Soybean			Wheat		
		Mach.	Inputs	Sum	Mach.	Inputs	Sum	Mach.	Inputs	Sum	Mach.	Inputs	Sum	Mach.	Inputs	Sum
		(Mg)	($)	($)	(Mg)	($)	($)	(Mg)	($)	($)	(Mg)	($)	($)	(Mg)	($)	($)
O	No Cover	261	156	417	261	156	417	285	230	516	232	47	280	212	154	366
O	Cover	266	185	451	266	183	449	290	253	543	232	47	280	219	176	396
IC	No Cover	261	200	460	261	186	447	285	274	559	229	84	313	214	155	368
IC	Cover	265	228	494	265	213	479	290	288	578	229	84	313	221	177	398
IF	No Cover	256	250	506	256	230	486	259	250	509	230	89	320	210	145	356
IF	Cover	261	273	534	261	241	502	264	260	524	230	89	320	215	167	382
C	No Cover	215	300	515	215	281	496	218	300	518	207	128	335	210	148	358

Mach. = machinery

Table 3

Cont.
Com

1st
Com

2nd
Com

Soys

Whe

Table

Table 3: Generalized Table of operations by crop and management

			Bulk Fert	App. Comp	Disk	Field Cultiv.	Rot. Hoe	Cultiv.	Add. N	Post Herb.	App. Cover	Bale Straw	Clip Straw
Cont. Corn	Cover	O		1	1	1	3	2			1		
	None	O		1	1	1	3	2					
	Cover	IC		1	1	1	3	2		1	1		
	None	IC		1	1	1	3	2		1			
	Cover	IF	1		1	1	3	2	1	1	1		
	None	IF	1		1	1	3	2	1	1			
	None	C	1		1	1	0	1	1	1			
1st Corn	Cover	O		1	1	1	3	2			1		
	None	O		1	1	1	3	2					
	Cover	IC		1	1	1	3	2		1	1		
	None	IC		1	1	1	3	2		1			
	Cover	IF	1		1	1	3	2	1	1	1		
	None	IF	1		1	1	3	2	1	1			
	None	C	1		1	1	0	1	1	1			
2nd Corn	Cover	O		2	1	1	3	2			1		
	None	O		2	1	1	3	2					
	Cover	IC		2	1	1	3	2		1	1		
	None	IC		2	1	1	3	2		1			
	Cover	IF	1		1	1	3	2	1	1	1		
	None	IF	1		1	1	3	2	1	1			
	None	C	1		1	1	0	1	1	1			
Soys	Cover	O			1	1	1	3					
	None	O			1	1	1	3					
	Cover	IC			1	1	1	2		1			
	None	IC			1	1	1	2		1			
	Cover	IF			1	1	1	2		1			
	None	IF			1	1	1	2		1			
	None	C			1	1	0	1		1			
Wheat	Cover	O		1		1					1	1	1
	None	O		1		1						1	1
	Cover	IC		1		1					1	1	1
	None	IC		1		1						1	1
	Cover	IF	1			1			1		1	1	1
	None	IF	1			1			1			1	1
	None	C	1			1			1			1	1

All Treatments were chisel plowed, planted, and combined

Table 4: Average crop prices

	Conventional	Organic
Corn	$2.20	$3.75
Soybean	$5.50	$8.00
Wheat	$2.85	$5.00

Table 5: Average annual net returns to land and management under various crop price scenarios compared to Standard Prices

Treatment			Standard Prices*		Increasing only the price of Corn		Increasing only the price of Soybeans		Increasing only the price of Wheat	
			($)**	Rank	($)	Rank	($)	Rank	($)	Rank
O	No Cover	CC	398	(1)	527	(1)	398	(2)	398	(2)
O	Cover	Rot	390	(2)	470	(3)	405	(1)	416	(1)
O	Cover	CC	370	(3)	499	(2)	370	(4)	370	(4)
O	No Cover	Rot	359	(4)	431	(4)	373	(3)	385	(3)
IF	No Cover	Rot	155	(5)	209	(5)	167	(5)	172	(5)
IF	Cover	Rot	128	(6)	180	(7)	140	(6)	145	(6)
C	No Cover	Rot	116	(7)	165	(9)	128	(7)	132	(7)
C	No Cover	CC	95	(8)	189	(6)	95	(9)	95	(9)
IC	No Cover	Rot	90	(9)	136	(11)	103	(8)	104	(8)
IF	No Cover	CC	87	(10)	179	(8)	87	(11)	87	(11)
IC	Cover	Rot	82	(11)	130	(12)	94	(10)	94	(10)
IF	Cover	CC	68	(12)	161	(10)	68	(12)	68	(12)
IC	Cover	CC	15	(13)	94	(13)	15	(13)	15	(13)
IC	No Cover	CC	10	(14)	83	(14)	10	(14)	10	(14)

Mean conventional corn price was increased one standard deviation
Mean conventional soybean price was increased one standard deviation
Mean conventional wheat price was increased one standard deviation

Mean Organic corn price was increased 15.6%
Mean Organic soybean price was increased 9.9%
Mean Organic wheat price was increased 14.6%

* Assumes average crop prices and published input costs
** Net return to land and management per hectare

CC = Continuous corn
Rot = Average of corn-corn-soybean-wheat rotation

Table 6: Average annual net returns to land and management under various input cost scenarios compared to Standard Costs

Treatment			Standard Costs*		Double only Cost of Nitrogen Fertilizer		Double only Cost of Pesticide		Double only Cost of Secondary Tillage		Assume Free Compost		Double only Cost of Compost	
			($)**	Rank	($)	Rank	($)	Rank	($)	Rank	($)	Rank	($)	Rank
O	No Cover	CC	398	(1)	398	(1)	398	(1)	329	(2)	473	(1)	250	(1)
O	Cover	Rot	390	(2)	390	(2)	390	(2)	342	(1)	464	(2)	242	(2)
O	Cover	CC	370	(3)	370	(3)	370	(3)	301	(4)	444	(3)	222	(3)
O	No Cover	Rot	359	(4)	359	(4)	359	(4)	310	(3)	433	(4)	211	(4)
IF	No Cover	Rot	155	(5)	111	(5)	86	(5)	115	(5)	155	(7)	155	(5)
IF	Cover	Rot	128	(6)	89	(7)	64	(7)	88	(7)	128	(8)	128	(6)
C	No Cover	Rot	116	(7)	70	(9)	13	(9)	102	(6)	116	(9)	116	(7)
C	No Cover	CC	95	(8)	18	(10)	-70	(14)	76	(8)	95	(10)	95	(8)
IC	No Cover	Rot	90	(9)	90	(6)	65	(6)	50	(9)	165	(5)	-58	(11)
IF	No Cover	CC	87	(10)	15	(12)	-29	(11)	27	(11)	87	(12)	87	(9)
IC	Cover	Rot	82	(11)	82	(8)	57	(8)	42	(10)	156	(6)	-66	(12)
IF	Cover	CC	68	(12)	2	(14)	-42	(13)	9	(12)	68	(14)	68	(10)
IC	Cover	CC	15	(13)	15	(11)	-29	(10)	-45	(13)	89	(11)	-133	(13)
IC	No Cover	CC	10	(14)	10	(13)	-33	(12)	-49	(14)	85	(13)	-138	(14)

* Assumes average crop prices and published input costs
** Net return to land and management per hectare

CC = Continuous corn
Rot = Average of corn-corn-soybean-wheat rotation