I. Cover Page

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Title: Improving farm nutrient management by optimizing organic matter inputs and root health (2002-41).

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III. Non-Technical Summary

Improving farm nutrient management by optimizing organic matter inputs and root health (2002-41).

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Corn is the crop in Iowa with the largest potential for overuse of nitrogen fertilizer. It would be environmentally positive if we could replace mineral N fertilizer with better use of rotations, organic manures, and soil-organic matter. The importance of organic matter management for farming is highlighted by the fact that organic matter probably provides most of the N that is utilized by corn, even when mineral N fertilizers are applied. Farmers that choose to use sustainable farming practices and to reduce or eliminate the use of mineral fertilizers must enhance the management of their soil organic matter if they are to be successful. Better knowledge about how crop rotation and manuring strategies affect the pool of soil organic matter and available N is important for improving organic matter management. The Organic Matter Budgeter Model was developed to help farmers identify how farm field balances of Active Organic Matter (AOM), Total Phosphorus (TP), and Total Potassium (TK) are affected by cropping history and by future plans for crop rotations, mineral fertilizers, and soil amendments. The budgeter calculates balances for both individual fields and for the farm as a whole.

In the first two years of our research on the budgeter in Iowa our goal was to perfect our budgeting and monitoring system, while learning more about how managing nutrients, organic matter, and root health might help farmers tighten N budgets for corn while maintaining yields. We used strip trial experiments, and constructed field-based budgets to validate our nutrient and organic matter budgeting model. Root health of the corn was studied in these trials because we assumed that it might affect the efficiency by which corn could extract N from soil organic sources.

The budgeter was also developed further by the third year to produce an overview of how management practices affected the balance of organic matter and nutrients on a whole farm basis. We tested this whole farm planning tool together with participating farmers with the goal of making it work in practice and to provide useful information.

The work done with funding from the Leopold Center was part of a more comprehensive set of trials that encompassed farms in two other states (Illinois, and Wisconsin) with funding from the National Fish and Wildlife, the Cavaliere Foundation, the Audubon Society, the Kellogg Foundation, USDA-SARE and EQIP, and the Illinois Dept. of Agriculture. The results from those states supplement the Iowa results. The data reported here are derived from that overall data set, because we believe them to be more powerful and interesting than results from Iowa alone.

Methods

Methods for assessing root health were developed on the basis of studies conducted on long term trials (Wisconsin Integrated Cropping Systems Trials) and methods developed while making a survey of root health in 2000 on 17 farms in Wisconsin and Illinois. Trials in 2001 and 2002 involved 12 farms in Iowa (with Leopold Center money), 14 farms in Wisconsin, and 5 farms in Illinois. In 2001 and 2002 about half of the farms were conventional, and half organic. They included farms with and without livestock. The field protocol was mostly replicated strip plots on one or two fields per farm, with and without manure or with and without mineral NPK fertilizer. The number of replications varied from one to three per treatment depending on the farm, site, and year. Budgets were run for fifteen different two-year crop sequences, and 30 combinations of fertilization and rotations. Besides projecting how the different farming systems would affect the long-term build up or decline of soil organic matter, we also constructed nitrogen budgets for corn based on field data. We measured total soil nitrogen content in the topsoil, spring nitrate and ammonium-nitrogen in the soil profile in the spring, nitrogen uptake by corn and weeds, and the nitrate-nitrogen content of the soil at harvest. The field-based budgets allowed us to estimate how much nitrogen was mineralized (released) from organic sources in the soil when corn was grown. Root production and disease were also measured when the corn flowered and these results were related to nitrogen uptake and corn yield under the different farming systems. We analyzed the total N content of the topsoil, and biologically active fractions of soil organic matter (using the Illinois test for amino sugar N, and the Paul test for non-recalcitrant, active and slow pool-C). We tested how well these soil results could predict total N mineralization using regression.

In the third year of our project we extended the budgeting system from beyond a single field to the whole farm. Ten of our Iowa farmers participated with information about the history and future plans for fields on their farms. Field surveys completed by the farmers included historical field information on crop rotation, fertilizer and amendment applications, and results of soil nutrient testing. In addition, field slope, bulk density, and percent organic matter were estimated if actual values were unavailable. Budgets were calculated to show gains and losses of active organic matter, P, and K on individual fields and on the whole farm.

Outreach activities included:

- farm visits, discussions, and individual farm reports for individual fields and for whole farms with individual participating farmers;
- reports on overall results at the Practical Farmers of Iowa Annual conference and at their Research Planning meetings in 2002/3 and 2003/4;
- reports and budgeting workshops with individual farmers at the Upper Midwest Organic Farming Conference in Lacrosse, Wisconsin;
- a report at the annual meeting of the Wisconsin Integrated Cropping Systems Trials.
- reports on results during courses on Organic soil management at the Organic University in Lacrosse, Wisconsin in February 2004 and 2005.

- An invited presentation at the American Society of Agronomy Organic Symposium in the Fall of 2003.

Results

Budgeting results with individual fields in the different farm systems in the first two years suggested that conventional grain cropping systems were often depleting their soil organic matter resources. These systems were predicted to eventually equilibrate at organic matter contents of 2.2 where only mineral fertilizers were used and at 3.3% where animal manure was applied. The results were about the same for grain crop rotations that used small grains under-seeded with clover as a green manure. However, soils that employed rotations with grain crops and a high percentage of perennial forages were estimated to be accumulating organic matter. Their equilibrium level was estimated to range from 3.9 to 5.4%, depending on how much perennial forages were used in the rotation and whether and how much animal manure was applied. The predictions made by the budgeter on how different farming systems would affect the equilibrium of soil organic matter contents were also reflected in the contents we found on the actual soils on the different farms. The cash grain systems generally had lower organic matter contents.

The budgeter results were found to be useful for predicting excess nitrate in the soil profile in the fall over a wide range of farming systems. However, the budgeter routinely underestimated the quantity of nitrogen that was extracted from soil organic matter sources in the soil where cereals were grown and no fertilizer was applied. It uses a fixed rate of decomposition (mineralization) to account for how much nitrogen will be released to corn from soil organic matter under different crops. In reality, corn seemed to take what it needed. We do not know the mechanism by which corn extracts N from soil organic sources. We can only speculate that it involves the medium of root exudates and enhanced microbial activity in the rhizosphere, but we do not know the extent to which it involves enhanced respiration of soil C. Growing corn resulted in similar quantities of nitrogen mineralized from soil organic matter, irrespective of the organic matter-nitrogen content of the soil. The richer the soil was in total organic nitrogen, the lower the percent of total nitrogen that was released. There was some effect of the state or year on this relationship, and soils with higher clay content had somewhat lower N mineralization rates. Data from the Illinois amino sugar nitrogen test did not predict nitrogen mineralization and uptake. Furthermore, the Paul test for estimating biologically active organic matter by acid digestion did not appear to relate any better to nitrogen mineralization and uptake than did the total nitrogen content of the topsoil. At this time, the best test for predicting nitrogen mineralization and uptake from soil organic matter sources appears to be done by corn itself, but that test may depend on the vagaries of the weather.

Wisconsin trials with fertilizers suggested that fertilizers had greater effects on N uptake and grain yields on those sites where the unfertilized controls produced relatively low yields. On average, corn plants took up less nitrogen from fertilizers and more nitrogen from native soil organic matter sources than we had expected. Twenty trials comparing unfertilized controls with fertilizers (applied at normal rates for the farm) indicated that fertilization with mineral nitrogen fertilizer increased nitrogen uptake in corn on average only by 11%. Furthermore, 47 trials comparing unfertilized controls with normal farm fertilization practices indicated that fertilization with manure or manure compost increased nitrogen uptake in corn on average only by 10%. Despite this, field budgets involving calculation of nitrogen mineralization rates from manure suggested that there was an apparent release (mineralization) of 43%, 36%, and 14% of the organic nitrogen from solid livestock manure, composted livestock manure, and liquid manure. This release was relatively independent of the rotation or system. There was a wide variation in mineralization of manure-nitrogen from farm to farm.

Three years of field trials indicated that corn had almost twice as high disease scores where it was grown under conventional systems (26%) relative to grown in organic systems (15%) (see Table 2). The highest disease incidence was found where corn followed corn (30%) and the least disease was found where corn followed organic soybeans (15%). In trials conducted in 2001 and 2002, corn grown after corn or soybeans in conventional systems produced more roots (5232 lbs/acre) than corn grown in the organic systems after soybeans or forages (4,442 lbs/acre), possibly to compensate for poorer soil quality and greater root disease problems. On average, corn grown conventionally after corn and soybeans on 27 sites had root/bushel ratios of 65:1, while corn grown organically after forages or soybeans on 53 sites had root/bushel ratios of 38:1. By shifting its resources away from grain production and towards root production, this corn apparently also mineralized more nitrogen from soil organic matter, took up more nitrogen, and needed more nitrogen for every bushel of grain produced than did the other systems. Corn grown after small grains with under-seeded green manure legumes such as red clover had low root and grain production and also showed poor nitrogen efficiency. This green manure system seemed to be associated with a lowered ability for corn to compete with weeds and with a lowering of yield potential. The most efficient systems for transforming soil organic nitrogen into grain were where corn followed after alfalfa, alfalfa + grass, or after soybeans in an organic rotation that included perennial forages and routine applications of animal manure.

Results from the whole farm nutrient and organic matter budgets suggested that moderate decreases in P and K were occurring on most of the farms. Almost every farm had management units with contrasting losses or gains in these nutrients, suggesting that even within individual farms, there were wide differences in losses. Losses and gains of soil organic matter were generally proportional to the original organic matter content of the soil. It was more difficult to maintain soil organic matter where native levels were high than where native levels were low. Only half of the farms that we worked with had measured values of organic matter for all their field soils. The whole-farm equilibrium levels for soil organic matter for these farms was calculated. Equilibrium levels varied from 3.4 to 4% for three organic farmers that included perennial forages in their rotations and used animal manures, to 2.9% for a farm that was using underseeding green manure clover crops into small grains, to 1.5% for a cash grain farmer employing a conventional, corn and soybean rotation. Fields were predicted to lose organic matter above those levels and to gain it below them, depending on the native level of soil organic matter.

Discussion and Implications of Research

Some results of this study challenge both common thinking and the budgeter's assumptions of how soil fertility and management work. Despite indubitable evidence that mineral and organic fertilizers can cause large increases under some conditions our results suggested that on average the vast majority of nitrogen taken up by corn probably comes from soil organic matter even where fertilizers are applied. Corn seemed capable of obtaining most of the nitrogen that it needs from soils over a wide range of organic matter-nitrogen contents, seemingly irrespective of the content of biologically active soil organic matter. Results also suggested that corn grown under conventional farming systems, and in organic small grains/clover systems squandered the organic-nitrogen resources of the soil, as they were both inefficient at turning soil organic-nitrogen into grain yields. It appeared to take up a lot more N to grow a bushel of conventional corn in a corn-corn or corn soybeans system (1.8 lbs N/bushel) than it took to grow corn in an organic system after soybeans or forages (1.4 lbs N/bushel). This inefficiency may be due to biological factors associated with rotations and soil quality, such as root disease. In any case, the most efficient systems for nitrogen and corn production appeared to involve alfalfa-grass mixtures and ruminant manure applications. These forage-and-livestock based systems also had the greatest potential for carbon retention in the soil in soil organic matter.

A major research question emerging from this research is the mechanism by which corn can extract so much N from soil organic matter and how this may or may not be coupled with the decomposition of carbon from soil organic matter. We need more information on this mechanism before we can change the budgeter to better estimate N release and Carbon decomposition from organic matter. Furthermore, it would be important to clarify whether the reasons for the efficiency of certain systems are truly due to differences in root health. Areas for fruitful future research might also include assessing whole farm nutrient and organic matter budgeting, developing methods for better assessing organic matter retention on farms, and further testing of corn production, nitrogen and organic matter dynamics in conventional systems and in farming systems that involve alfalfa-grass mixtures and manure applications.

It is difficult to think of simply one question that this research addresses, because it addresses multiple issues. Yes, organic matter is important; yes, it can be managed; yes, the budgeter is a useful tool, helping farmers to put some numbers on how their management may affect both field and whole farm nutrient and organic matter budgets. The research results points out flaws in the conventional way of thinking about N and corn growth. There appear to be important differences in the efficiency of N use in organic and conventional systems, possibly due to big differences in root health. The budgeter also predicts that farm operations may be more sustainable relative to soil organic matter if they include livestock and perennial forages.

IV. Technical Report

A. Introduction:

Corn is the crop in the Upper Midwest with the largest potential for overuse of nitrogen fertilizer. To improve the impact of farming on the environment it is necessary for us to rely more on rotations, organic manures, and soil-organic matter as the primary source of nitrogen for growing corn. Making this change implies changes in thinking. It also means that we have to better understand nitrogen release from organic matter and how using organic manures to improve soil nutrients may affect soil quality, root health, crop growth and nitrogen dynamics. To address these issues we developed farmer-friendly software called 'the organic matter and nutrient budgeter' as a tool to help farmers understand and plan their farming practices utilizing organic matter sources of nitrogen. We tested the efficacy of the tool and the assumptions that it was built on by comparing budgeter results against results derived from field level N budgets. These field budgets were constructed with information from unfertilized and manured plots on many farms. They include conventional and organic farms with and without livestock.[1] Testing the budgeter involved developing new methods for estimating N mineralization under corn crops and differentiating between N released from soil organic matter and from manure.

Farmers need to know how much N can be expected to 'mineralize' from the soil organic matter on fields that have different fertility and cropping history and from different kinds of manures. Research on organic matter in the past decades has shown that younger organic matter is more susceptible to decay and therefore releases much more N to crops than does old, passive fractions of the soil organic matter (Paul, et al., 1997). From this standpoint, the issue of the quantity of mineralization can be resolved into several research questions: 1) how much young, biologically active organic matter-N is there in the soil? 2) how quickly will it decay? 3) how does the growth of corn influence its decay? Taking this point of view, our budgeter's estimates of mineralization of organic matter are not based on the mineralization of the *total* organic matter but rather of the quantity (pool) of the *biologically active* organic matter in the soil. We attempted to measure this pool using two different methods and compared the results with actual N uptake and mineralization.

To begin to do accurate budgeting it is important to know how much N is taken up by different crops. Corn crops may play a major role by enhancing mineralization and by taking up the majority of the N that is mineralized through their rooting system (Sanchez et al., 2002). Therefore, it is important to determine relationships between root production and N uptake, and how farming systems might influence this. We also assessed the health of corn roots on farms because root health is probably important for running a tight nutrient budget. Previous trials in the Wisconsin Integrated Cropping Systems Trials showed that corn grown after corn with conventional management had more diseased roots in early stages of growth (Goldstein, 2000), and this might have induced a higher production of roots in later phases of development during grain production. The positive affect of crop rotations and manure

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[1] Funding for the research on farms was provided by the Leopold Center for Sustainable Agriculture, the National Fish & Wildlife Foundation, the Audubon Society, W.K Kellogg Foundation, USDA/SARE, USDA/EQIP, the Illinois State Dept. of Agriculture, and the Cavaliere Foundation.

appeared to be associated with healthier roots. If roots are not healthy they probably will not be effective at facilitating nutrient release and uptake. We do not understand how increased root production would affect N efficiency, but it might be associated with increased mineralization of N from soil organic matter.

Our initial problem statement and objectives were as follows:
"*Contributions plant diversity and animal manure make to the building of prairie soils are widely recognized, but conventional trends are rapidly displacing them from production agriculture. Reliance on chemical fertilizers that heavily depend on nonrenewable sources of energy for their manufacture cannot be sustained in the long term; moreover, chemical use in farming has severely impacted soil and water ecology. Modem-day processes of extracting nitrogen from air and converting it into 90 million tons of fertilizer a year have helped double the amount of nitrogen in circulation among living things in recent decades (Horton, 2000). Leaching and excessive application of nitrates are polluting ground water supplies and contributing to coastal hypoxia, which has spawned massive algae blooms that starve waters of oxygen and kill aquatic life. Acidification from excess nitrogen inputs is estimated to be wearing out our fragile prairie soils at a rate of 100 years every decade (Barak, 1999). Average annual loss of topsoil, largely from present systems of agriculture, has been put at three times the rate of formation. This bears stark implications for life and long-term sustainability when considered along side the reality that it can take 100 to 1,000 years to form 2.5 centimeters of soil (Samson, 2000).*

This project will help farmers tighten their budgeting of N for corn while maintaining yields and profitability. It will accomplish this through a system for improving organic matter and root health management. Specifically, the project's goals will be to: 1) work with 14 Iowa farms over 3 years to demonstrate nutrient and organic matter management techniques; 2) collect data to refine and validate an organic matter budgeting model; and 3) explore relationships of root health, yields and organic matter to nutrient management techniques employed on-the-farm. The project will thus demonstrate the importance of active organic matter management to water quality, soil fertility, crop health and profitable production.
Sampling from participating farms will also be compared to perennial grass and prairie remnant soils.
Objectives** the project will pursue follow **a threefold set of strategies:
1) Encourage farmers to adopt practices and tools leading to tighter N budgets on their farms (by conducting field trials and model training with the farms already recruited for this project, working with cooperators to collect and collate necessary data, publishing a practical guidebook on organic matter budgeting, organizing field days or educational programs to support the work, evaluating whether farmer cooperators improved or tightened nutrient management on their farms over the course of the project and assessing expectations of continuing farmer use at project's end and changes in farmer knowledge as a result of the project);
2) Validate a nutrient budgeting model by using both experiential and measurable data from farms (by carrying out on-farm validation tests in Iowa for a whole farm organic matter budgeting model through on-farm trials that layout experimental and test strips, measure N P K annually, track organic matter using POM and passive organic matter,

evaluate crop yields and crop residues under different organic matter conditions and use data to estimate N mineralization occurring on farm study sites; measurements of undisturbed soil sites of similar profiles through sampling for soil organic matter and mineralization potential and evaluation of N P K of soil and grasses near on-farm trials and model validation using collected data to assess the rigor of the organic budgetor model);

3) Assess relationships of root health to nutrient and organic matter practices (by evaluating impact of rotations and application of organic matter on crop root health in several on-farm situations, evaluating differences in plant uptake of organic matter nitrogen under high mot health and poor root health situations on farms, comparing root health under conditions with different rotations and organic matter inputs and estimating impacts of root health for predicted N budgets for the farm)."

B. Study Design, Methods, and Materials:

The organic matter and nutrient planning and monitoring tool:

The "Organic Matter and Nutrient Budgeter" program was developed to be a simple, friendly, end-user tool that farmers, consultants and others could use to project organic matter response and N release based on different cropping scenarios. The format is based on Microsoft Excel 2000 using Visual Basics for Applications as the programming language. The program uses menus and macros. It is still in experimental development stages and has not yet been released for general use.

The program provides worksheets that are specific for individual fields. For each field the worksheet spans eleven year, three years prior to the current year, the current year and seven years projected into the future. A new version of the tool enables the farmer or advisor to link information from all fields in a farm and gain information on the nutrient and organic matter dynamics of the whole farm.

Information that must be entered includes historical information and experience based projections. The following information must be entered:

- Crop
- The crop yield
- The production of perennial legume
- The initial size of the pool of biologically active organic matter (presently calculated from organic matter %).
- Loss of soil due to erosion (calculated from the universal soil loss equation RUSSL or estimated from experience).
- The bulk density of topsoil (8 inches)
- An estimate of the size of the P pool
- An estimate of the size of the K pool
- The application rate of manure and fertilizer

The format of the budgeter and a greater description of it are given in the section relating to whole farm budgeting. Data entry into the remaining cells is optional depending on data available. At its best, the budgeter may be integrated with a monitoring system that measures the nitrate and ammonium-N in the spring and fall, quantities of alfalfa roots that are plowed under, etc.

The initial size of the pool of biologically active organic matter may be estimated using different laboratory procedures. However, barring this information we approximated this pool size, and its turnover under different crops. We did this by using an organic matter model called CENTURY that was developed by the USDA in Colorado (Metherell, et al., 1993). The CENTURY program was used to model changes in the organic matter and nitrogen content of a cultivated prairie soil in southern Wisconsin (Koopmans and Goldstein, 1998).

The term mineralization of N implies that N is released from organic matter complexes due to microbial and biochemical action and transformed to mineral forms such as ammonium or nitrate. For the purposes of the budgeter it is crucial to be able to get good estimates of what proportion of the total N in the topsoil in biologically active and will mineralize and become available to different crops. Unfortunately, there is not at the present time an agreed upon soil test that can quantify the amount of biologically active soil organic matter. Based on our modeling with CENTURY we estimated the quantity of biologically active organic matter as a fraction of the total organic matter content of the soil. To estimate the size of the pool of biologically active organic matter in pounds/acre, the percent organic matter in the soil is multiplied by 6,909 (factor for medium textured soil). For example, a 3.2% organic matter would have 20,727 pounds of active organic matter (6,909 x 3.2 = 22,109). Multiple runs of the CENTURY model were also used to calculate mineralization rates of soil organic matter under different crops (Koopmans and Goldstein, 1998).

The rate of decomposition will vary with soil type, with lower rates expected with clay soils and higher rates expected with sandy soils. As the arable soils for the target farmers in our project were predominantly medium textured we did not adjust our mineralization rates for soil texture. Furthermore, all the farmers in our project were using conventional tillage so we did take no-tillage into account.

In addition, the pertinent scientific literature on manure and residues was reviewed. This data was used to derive coefficients to estimate how much N and C from different kinds of manures and residues will be retained and mineralized in soils. These coefficients were incorporated into the budgeter. A list of the coefficients and supportive literature is available from the author of this report and is not included here for sake of brevity.

The program output provides a graphic representation of the effects of the farming system on nitrogen surpluses and on accumulation or decline of the pool sizes of biologically active organic matter, P, and K. This data is available both for individual fields and for the linked fields up to the whole farm level.

Furthermore, functions derived from field and budget data enable the budgeter to estimate nitrate in the soil profile at harvest and the amount of surplus N that is lost (denitrification & leaching) or immobilized during the growing season. Such N estimates enable us to assess the ecological impacts of different farming systems. Declines or increases in the pool of biologically active organic matter allow us to assess the impact of the farming system on the sustainability of the farming system.

Methods for testing the budgeter by doing on-farm research trials.

The tool was tested in the context of the following projects and farms:

- 2001 EQIP project, Wisconsin, 7 farms, mostly conventional dairy; test plots were mostly set out on 2 fields/farm.
- 2001 SARE project, Wisconsin, 7 farms, mostly conventional cash grain; test plots were mostly set out on 2 fields/farm.
- 2001 Leopold project, Iowa, 12 farms were mostly organic grain-livestock farms; test plots were set out mostly on 2 fields/farm.
- 2002 Illinois Dept. of Agriculture, 5 farms which mostly were organic grain-livestock farms; treatments were mostly tested on 1 field/farm.
- 2002 Leopold project, Iowa, 11 farms mostly were organic, grain-livestock farms; plots were on 1 field/farm only.

Trials consisted of control strips with no fertilization and one or two fertilization treatments, consisting of either manure, manure + NPK mineral fertilizers, or just NPK mineral fertilizers. Plots were replicated 2 times in Iowa in 2001 and 3 times in 2002; they were replicated 3 times in Illinois in 2002. Due to a high variation within fields and plots we set out three sampling stations in each replicate of a given fertilization treatment. These three stations were visited repeatedly for sampling soils, roots, tops, and grain yields. Samples from the three stations were pooled for laboratory analysis, with the exception of root health, where we analyzed all three sub-samples individually.

We had initially intended to include prairie soils in our experimentation as a kind of check. However, this proved to be too complex an undertaking, especially when Laura Jackson, prairie expert from UNI, decided she had to withdraw from the project due to time constraints.

Soils were analyzed at the University of Wisconsin Soil Testing Lab and the USDA National Soil Tilth Lab for nutrients. Information was gathered from farmers about past and planned future rotations and fertilizer applications for each of these sites. This information was used to model treatments on these sites using our budgeter. Manure nutrient & C inputs were weighed and measured and used for budgeting. Budget predictions included projected change over time of active organic matter (AOM), P, K, and the projected surplus N in the system (N lost before harvest and nitrate N in the profile at harvest). Budget predictions for different kinds of farming systems were used to predict equilibrium levels of soil organic matter associated with the farming systems.

Relative to the crop we studied in the field in 2001 or 2002 there were 15 different sequences with preceding crops and 33 different combinations of sequences and fertilization. Many of the sequences included using small grains and clover as a green manure in order to replace the use of mineral N fertilizer. Other rotations included conventional corn-soybean sequences, and rotations with cereals, soybeans, and alfalfa. All in all we developed 132 budgets based on these results. Crops studied in the field included corn, sorghum, soybeans, timothy, and wheat, barley, and oats with and without underseedings of alfalfa or red clover. However, most of the trials were concerned with corn as it is regarded as the crop that demands the most N from the soil. Its production involves the greatest danger of pollution with excess N.

Methods to monitor N budgets on farms:

Contents of nitrate-N and ammonium-N were determined in the profile early in the spring to estimate N carryover from the previous year. Cereal roots were excavated from plots at the time of flowering to determine maximum root production and root N content. Yields and the content of N in tops were determined at harvest.

The strip trial experiments were used to validate our nutrient and organic matter budgeting model. For corn crops we measured the quantities of nutrients and organic matter applied to soils in the form of fertilizer, manure, or compost, spring residual nitrate and ammonium in the soil profile, the grain yield, and the amount of nitrate left in the soil profile at harvest. Then we used our budgeter to produce N budgets for each treatment. These budgets estimated N that was released from soil organic matter and organic manures, the N that was taken up by corn, and the residual N that was left in the soil profile after harvest in the form of nitrate.

Formula used by the budgeter to calculate the N balance:

\+ spring residual nitrate and ammonium-N (measured)
\+ fertilizer N (measured)
\+ release of N from soil and residues (calculated from soil and management data using coefficients)
\+ N deposition from atmosphere and N fixation by free living bacteria (estimated at 40 lbs N acre^{-1} year^{-1})
\+ Release of N from manure (measured, analyzed, release is calculated using coefficients)
\- Uptake of N by crop (calculated on basis of yield).

= Residual, surplus N in the farming system.

Because we could not measure volatilization, denitrification, and leaching losses, the budgeter combined these losses with nitrate-N at harvest into a single estimate of surplus, residual N. In theory, the residual, surplus N in the system can be partitioned into two components:

- Nitrate-N in the soil profile at or just after harvest (measured)
- N losses due to volatilization, leaching, denitrification, and immobilization (not measured).

To estimate these two components we correlated the actual quantity of nitrate-N found in the soil profile at harvest time with the budgeter-predicted quantity of surplus, residual-N. We found that this predicted quantity of surplus N correlated very well with the actual quantity of nitrate-N found at harvest for the 33 different cropping sequences/fertilization treatments in the plots ($R^2 = 0.7613$, n=33, $p < 0.01$). We used the linear equation ($y = 0.2967 + 40$) for actual nitrate N (y) regressed on surplus N (x) to predict nitrate-N that should be available in the soil profile at harvest. The N lost due to denitrification, leaching or immobilization before harvest was estimated by subtracting the nitrate-N estimate from the total surplus N estimate. These estimates allowed us to assess the impact of different farming systems on potential N losses to the environment.

Methods for evaluating the amounts of N mineralized from soils and manures and the yield response of corn.

When we initially began to budget for the uptake of N by corn, we multiplied the actual corn yield in bushels/acre times a coefficient of 1.64 lbs of N per bushel of corn; a coefficient found in the scientific literature (Koopmans and Goldstein, 1998). To check this coefficient we measured the actual N-uptake by corn roots, stalks, and grain, and compared the actual total uptake with our coefficient based calculation of uptake. The N contribution by corn roots was determined by multiplying root N content at flowering x root dry matter x 3 (conversion factor for adjusting roots in monolith to roots in rooting zone occupied by 1 plant) x 1.38 (conversion factor for adjusting for root turnover) x plant population/acre. These relationships were determined empirically based on studies of corn root growth in the Wisconsin Integrated Cropping Systems Trials (Goldstein, 2000).

We constructed 'field-based data N budgets' to check these estimates of N mineralization from soil organic matter on the unfertilized plots and from soil organic matter and manure on the fertilized plots. The formula used was based purely on field-derived data.

Formula for calculating N mineralized during a corn cropping year on the basis of field data:

(1) For unfertilized control plots:

\+ N uptake by corn (roots, tops) and weed tops.
\- Spring nitrate and ammonium-N in the soil profile in the spring.
\+ Nitrate-N found in the soil profile at harvest.

= Total N mineralized from organic matter sources in soil.

***(2)For manured plots*:**

\+ N uptake by corn (roots, tops) and weed tops
\- Spring nitrate and ammonium-N in the soil profile in spring + ammonium-N in the manure.
\+ Nitrate-N found in the soil profile at harvest

= Total N mineralized from organic matter sources in soil.

The field-derived estimates of mineralization derived from this equation are naïve and conservatively low because they assume that corn takes up all the nitrate and ammonium in the profile that is carried over from the previous year and because they do not take into account losses due to denitrification, leaching, and volatilization. Furthermore, it proved difficult in practice to obtain spring soil samples for nitrate at an early enough time to satisfy us that mineralization had not already occurred in the soil. We were able to do this for Iowa farm sites in 2001, but for all other sites sampling took place from April to May. We could not use these values because they included not only the carryover soluble N from the previous year, but also newly mineralized N from the spring. In order to estimate N mineralization it was necessary to estimate a default value for spring nitrate and ammonium-N. To do this we first calculated the mineralization data without any value for spring soluble N in cases where the information we had for spring soluble N was dubious. Then we regressed total uptake of N by corn + weeds (y) on our calculated mineralized N (x) and obtained a linear equation ($y=0.5703X + 54.8$, $R^2 = 0.49$, $p < 0.01$). We substituted various default values for spring nitrate and ammonium-N into the equation and observed the value for the y intercept (the amount of N taken up by corn in the absence of any mineralization of organic matter). We used the value for the y intercept to approximate the quantity of carryover N. The y intercept value was relatively stable: default values ranging between 0 and 70 lbs N/acre produced y intercept values ranging between 49 and 60 lbs/acre. A default value of 52.5 produced the same y intercept value ($y = 0.6844X + 52.5$, $R^2 = 0.55$, $p < 0.01$) and we used this value in all subsequent calculations. These estimates were compared with our budgeter estimates and also were correlated with the growth of roots and the grain yields of corn.

Regarding the calculation of mineralization rates we made three assumptions: 1) that the field based calculations for N mineralized were valid estimates of total N mineralized; 2) that the time span covered was a cropping year (therefore an annual rate) and 3) that the N that was mineralized came from the native organic matter and manure that were in the top 8 inches of the soil. The formula for mineralization rates, calculated on the basis of the field based budget used N mineralization derived from formulae 1 and 2:

- *(3) for unfertilized plots* = (N mineralized from soil x 100)/ total organic N in top 8 inches of soil).
- *(4) for manure/compost fertilized plots* = (N mineralized from soil x 100)/ (total organic N in top 8 inches of soil + the organic-N added in manure/compost).

At interest whether it would be possible to simplify the procedure if simply using crop and weed uptake of N would yield valid estimates of mineralization. Therefore, mineralization rates were also calculated using formulae 3 and 4 and substituting total N uptake by corn and weeds for the N mineralization values. The two kinds of estimates were compared.

Farmers involved in the trials used a wide range of fertilization and manure rates based on their experience and practice. The pertinent questions appeared to be what kind of yield response they could expect to obtain from application of their fertilization practice, and how much N would become available from manure by mineralization. To estimate the level of response to fertilization we regressed the yields obtained on mineral fertilized or manured plots (y) on the yields obtained on the relevant control plots (x). The regression formula was used to predict the response to fertilization at different levels of yield for the controls.

It is important to be able to estimate the amount of N that becomes mineralized from the organic N in manure and available to corn crops. It is difficult to do that, even by using ^{15}N tracer studies. We used the field based N mineralization information to estimate apparent N release from the organic fraction of the manure. We assumed in doing this that the increase in mineralized N associated with the application of the manure was due to mineralization of organic N from the manure and not to the manure in some way stimulating the mineralization of N from native soil organic matter (priming effect). Furthermore, we only performed calculations for fields where matched controls and manured plots had similar (within 1,000 lbs/acre) quantities of total N in the topsoil. This decreased the number of comparisons that were made. The calculations of apparent N release from manure assumed that the fraction of N release from native soil organic matter for the manured plots was the same as that found on the control plots. Such estimates would not be accurate in cases where the control and manured plots had strongly divergent quantities of total N in their topsoils and mineralization rates were not fixed but depended on the quantity of soil N.

The ***apparent total N mineralized from manure =***
Total N mineralized during the growing season on manure plots
- ((N mineralization rate for the unfertilized checks/100)
x (N content of manured soil before manure was applied)).

and the ***apparent N mineralization of organic N from manure as a percent*** *of the total N in the manure=*
(apparent N mineralized from manure x 100)/
total amount of organic N applied in manure.

These rates are apparent and they portray total mineralization, not the uptake of manure-N by corn plants.

Measuring biologically active organic matter and its relationship to quantities of N released.

Based on our earlier computer modeling with the CENTURY model we assumed that all the soils had 42.2% of the organic matter C is in this active pool, that the C:N ratio of the active organic matter is 13:1, and that 4.7% of this mineralizes under corn to release nitrate or ammonium-N.

However, it is not easy to measure that pool size in the field. In the past we have estimated it by measuring particulate organic matter-C in the spring and multiplying it by 4. In addition to conducting soil organic matter analyses, Kevin Jensen and Cindy Cambardella from the National Soil Tilth Lab in Ames, Iowa estimated the quantity of hydrolysable, biologically active C and N using a method developed at Michigan State University (Paul et al., 1999). In this method one gram of soil is digested in 1 N HCL acid. After several hours of digestion the recalcitrant C in N is regarded as representing the amount of 'passive' on biologically inactive material. The pool of biologically active, hydrolyzable organic matter may be estimated by substraction (total C – recalcitrant C = biologically active C). Samples tested were the Wisconsin soils from 2001.

On the Iowa and Wisconsin soils in 2001, Yun Wang and Michelle Wander determined how well the estimate the pool relates to the content of amino-sugar-N in the soil using a test developed at the University of Illinois-Urbana (Khan et al., 2001). Soils that have large quantities of amino-sugar-N are known on an empirical basis to release a lot of soluble-N from their organic matter. Such soils often produce crops of corn that do not respond to N fertilizer.

Evaluate corn root health and its connections with management, and nutrient efficiency.

Our technique for analyzing root disease was a modification of the technique developed with the Wisconsin Integrated Cropping Systems Trials (Goldstein, 2000). In 2000 the technique was modified by sampling only at the flowering stage of development on 17 farms. This survey included sampling and analyzing three on-farm field trials in Illinois, two field trials run jointly by Wisconsin farmers and the University of Wisconsin Dept. of Agronomy (Dr. Joshua Posner and Janet Riester), one trial run by a farmer and the Wisconsin Nutrient and Pest Management Program (Mr. Kevin Shelley), two systems in the Wisconsin Integrated Cropping Systems trial and ten Wisconsin farm fields that were using alternative and conventional practices, many of whom would later be involved in further trials funded by EQIP and SARE. Many of the trials involved evaluating the use of small grains and green manures on the yields of corn. In 2001 and 2002 we used this same technique on all farms in Wisconsin, Iowa, and Illinois. On each plot three crown and root soil monoliths (each was 6 inches long x 6 inches wide x 8 inches deep) from individual corn plants were excavated when the corn was flowering. We sampled the corn at flowering time because this is when the maximum amount of roots are present. Roots were washed from soil, frozen, and stored frozen. When time came for analysis they were more carefully washed, photographed, dissected according to node, dried and weighed. Root disease was evaluated for root samples from each plant by a team of three people who gave independent evaluations of necrosis on roots from each node. Scores from individuals appeared to be highly correlated. An overall root score was derived by averaging the scores obtained from all the nodes by all the evaluators. We did not attempt to weight the scores on the basis of root length or mass as we had reason to believe that corn was compensating for disease on its smaller, earlier sets of roots by producing large quantities of later developing roots.

Statistical analysis of results.

To evaluate the relationships between management systems, root disease or health, and nutrient efficiency we grouped data from farms into 8 different management systems. There were four conventional systems and four organic systems. The conventional systems involved soil management with previous routine applications of mineral N fertilizer and pesticides. The four conventional systems that were represented consisted of corn following after corn, soybeans, small grains under-seeded with alfalfa or clover, and after alfalfa which had been grown for hay. The organic farms depended on organic manures and soil organic matter to supply N to corn. Mineral N fertilizers were not used when growing corn. To examine effects of disease we studied how systems affected corn grain yields, root production, root disease, and root production per bushel of corn and correlated disease with the other characteristics. To examine how systems affected the efficiency of corn and N relationships we analyzed the total uptake of N uptake by corn plants and the amount of N taken up by corn plants for every bushel of corn produced. To understand how systems affected the mineralization of N from soil organic matter we evaluated the quantity and relative portion of N mineralized from soil organic matter in the topsoil. We assumed that the soil N was obtained from soil organic matter only in the topsoil because the scientific literature suggests that little mineralization occurs below 8 inches of the profile.

To simplify the results with yields the 8 farming systems were as follows:

System 1 = corn following corn on fields with a history of conventional management practices;

System 2 = corn following soybeans on fields with a history of conventional management practices;

System 3 = corn following small grains (wheat or oats) under-seeded with clover or alfalfa on fields with a history of conventional management practices;

System 4 = corn following alfalfa on fields with a history of conventional management practices;

System 5 = corn following soybeans on fields with a history of organic practices (including perennial forages and manure);
System 6 = corn following small grains (wheat or oats) under-seeded with clover or alfalfa on fields with a history of organic management practices.
System 7 = corn following alfalfa on fields with a history of organic management practices (including manure applications);
System 8 = corn following alfalfa/grass mixtures on fields with a history of organic management practices (including manure applications).

Data was analyzed using SAS programs called PROC REG and PROC GLM for regression and general linear models analyses. Systems were compared using single degree contrasts. The contrasts were chosen in order to draw out interesting possible differences and to portray extreme treatments. They were:

1) Conventional systems vs. Organic;
2) Corn following after conventional corn or soybeans vs. after organic forages or soybeans;
3) Corn following after conventional corn vs. organic soybeans;
4) Corn following after conventional corn vs. organic alfalfa/grass;
5) Corn following after perennial forages vs. after a small grain/legume green manure;
6) Corn following after soybeans vs. after a small grain/legume green manure;
7) Corn following after organic alfalfa vs. after organic alfalfa/grass.

In some cases there were missing data for farms, especially for constructing N budgets. In this report analyses are shown for as many farms as we had good data for rather than pruning results down to a single data set with complete data for all parameters. For root disease results obtained for the project for 2000, 2001, and 2002 we averaged the results obtained from different fertilization treatments on a site for a given farming system and considered each average as a data point, (there were 79 experimental entries with n = 9, 15, 21, 2, 13, 4, 12, and 3 for systems 1 to 8, respectively). In our fertilization trials two kinds of fertilization were applied, but the rates and kind varied from farm to farm. Using GLM we compared the response of corn to mineral fertilizers vs. manure or we compared the farming systems in general for how they responded to fertilization (total number of entries was 91 with n = 9, 16, 7, 5, 22, 6, 20, and 6 for systems 1 to 8, respectively). For our studies involving nitrogen budgeting we evaluated N uptake, N mineralization, and their relationships to corn yield and roots. As we focused on N mineralization from soil organic matter we considered only unfertilized plots or plots where manure had been applied and for which we had a full set of data on N associated parameters. For analyzing corn yield, root production, and the quantity of roots produced per bushel we had 100 experiment entries (n = 11, 16, 8, 5, 22, 7, 21, and 10 for systems 1 to 8, respectively). For soil and corn N data and for root necrosis we had 91 experimental entries (n = 9, 16, 7, 5, 22, 6, 20, and 6 entries for systems 1 to 8, respectively). Where pertinent, regressions were run that tested linear, quadratic, and cubic responses to x variables. Statistical levels of significance are reported according to the international system as NS, +, *, **, ***, and **** which mean non significant ($P > 10\%$), or $P < 10\%$, 5%, 1%, 0.1%, and 0.01%, respectively (i.e., security levels of 90%, 95%, 99%, 99.9%, and 99.99%). Graphs showing results were produced using Microsoft EXCEL packages.

Methods for whole farm budgeting for organic matter, P, and K.

The primary objective of the third year of our project was to extend the budgeting and monitoring system (the OMB Model) from beyond a single field to the whole farm. Actual field data collected from participating farmers helped us fine-tune the OMB Model. Our goal is to have the OMB Model be a valuable tool in aiding farmers to tighten their nitrogen (N) budgets for crops while maintaining good yields, and to help farmers to have an overview of how their management practices affect the whole farm. Objectives in this third year are 1) to integrate the results of our fieldwork into changes in the budgeter; 2) to work with a subset of the farmers to do whole-farm nutrient budgeting; 3) to evaluate the value of the budgeting process and results for those farmers and to integrate necessary changes into the budgeter and process.

Farm and field data collection

In early 2004, the original participating Iowa farmers were contacted and asked to provide additional information about the history and future plans for crop rotations on individual field units of their farms. Of those queried, 10 found the time to work with us. Field surveys completed by the farmers included historical field information on crop rotation, fertilizer and amendment applications, and results of soil nutrient testing. In addition, field slope, bulk density, and percent organic matter were estimated if actual values were unavailable. A copy of the three-page field/farm survey is provided (see Appendix I). If available, manure or amendment analyses records were recorded. In most cases, a farm site visit was conducted to address questions about the information provided on the field input sheets. Most of the farmers recorded information for all the fields that they farmed; others provided information for only certain sections of their farms.

The Organic Matter Budgeter Model format was based on Microsoft Excel 2000 using Visual Basics for Applications as the programming language. The program was developed to be a simple end-user tool that farmers, consultants and others could use to project organic matter response and nitrogen release based on different cropping scenarios. The program spans eleven years, three years prior to the current year, the current year and seven years projected into the future. A sample copy of the OMB Model worksheet and subsequent report charts are provided in Figures 1, 2, and 3.

Data entry

Field information was collected in early 2004, therefore data was entered into the OMB Model based on 2003 as the “current year”. There were a minimum of six and a maximum of thirty-one fields entered to represent ten respective farms. Farms were given a generic farm number (1–10) to preserve individual farm identity.

OMB Model worksheet field entries and calculations are described below. The numbered items (1-10) describe the interactive cells where field data was entered.

Field worksheet entries:

1. *‘Crop’* – selected from a drop down list. The OMB Model currently has 50 field and vegetable/fruit crops in its database (Table 1).

Table 1. Field and vegetable crops currently included in the Organic Matter Budgeter Model.

Field crops		Vegetable/Fruit crops	
Alfalfa	Orchard grass	Asparagus	Onion
Barley	Red clover	Brussels sprouts	Peas
Barley, alfalfa	Spring wheat	Bean	Pepper
Barley, legume-grass	Spring wheat, alfalfa	Beet	Potato
Barley, red clover	Spring wheat, legume-grass	Broccoli	Pumpkin
Bromegrass	Spring wheat, red clover	Cabbage	Snap beans
Corn, silage	Soybean	Carrot	Spinach
Corn, grain	Sweet clover	Cauliflower	Squash
Legume-grass	Timothy	Celery	Sweet corn
Oats	Winter wheat	Cucumber	Sweet potato
Oats, alfalfa	Winter wheat, alfalfa	Lettuce	Tomato
Oats, legume-grass	Winter wheat, legume-grass	Melon	Turnip
Oats, red clover	Winter wheat, red clover		

2. *'Yield: crop (bu/a); vegetables (tons/a)'* - Yield for grain crops are entered as bushels per acre (bu/a) and vegetable crop yields are entered as tons per acre (t/a).

3. *'Yield of forage (lbs/acre DM basis)'* - Yield of forage crops are entered as pounds per acre (lbs/a) on a dry matter basis for all forages except corn silage, which is reported in lbs/a on an as is basis.

4. *'Initial size of active pool'* - If the organic matter percent (OM%) was known, it was multiplied by a factor of 6,909 (factor for medium textured soil) to obtain the estimated initial size of the active organic matter pool. If OM% was unknown, 22,000 was used as a default value (based on an assumed 3.2% organic matter value).

5. *'Loss of soil due to erosion (t/acre)'* - Soil loss (t/a) was based on the relative slope of the field. Entries were based on the values listed in Table 2.

Table 2. Estimated soil loss in tons per acre based on the degree of slope.

General Crop Type	**Level I** Flat or level (0–2% slope) (t/a)	**Level II** Slightly hilly (2–6% slope) (t/a)	**Level III** Hilly (> 6% slope) (t/a)
Corn	3.00	4.50	6.00
Soybean	2.00	3.50	5.00
Oats/Legume	1.50	2.00	2.50
Legume	0.25	0.50	1.00

6. *'Bulk density of 8 in. soil (g cm^{-3})'* - In most cases, a default value of 1.3 g cm^{-3} was entered.

7. *'N mineral fertilizer applied in **FALL**'*
*'N analysis of **FALL** applied N'*
*'N mineral fertilizer applied in **SPRING 1st**'*
*'N analysis of **SPRING 1st** applied N'*
*'N mineral fertilizer applied in **SPRING 2nd**'*

'N analysis of ***SPRING 2nd*** *applied N'*

Fertilizer applications were entered in terms of rate (lbs/a) and percent of N, P_2O_5, and K_2O analyses.

8. *'Manure application type'*
   'Manure rate (tons/acre)'

   Manure applications were entered by type from a drop down list and by rate. Rates were entered as tons or 1,000 gallons per acre. The OMB Model currently has 11 different manure types in its database (Table 3).

   Table 3. Manure types currently listed in the Organic Matter Budgeter Model.

Compost	**Solid**	**Liquid**
Beef	Beef	Beef
	Dairy	Dairy
	Poultry	
Sheep		
	Swine	Swine
Garden		

   Manure analysis values were entered for current and previous application history, but future projections were based on default values for the manure type. Manure types other than those listed were utilized, but only if the nutrient analysis was known.

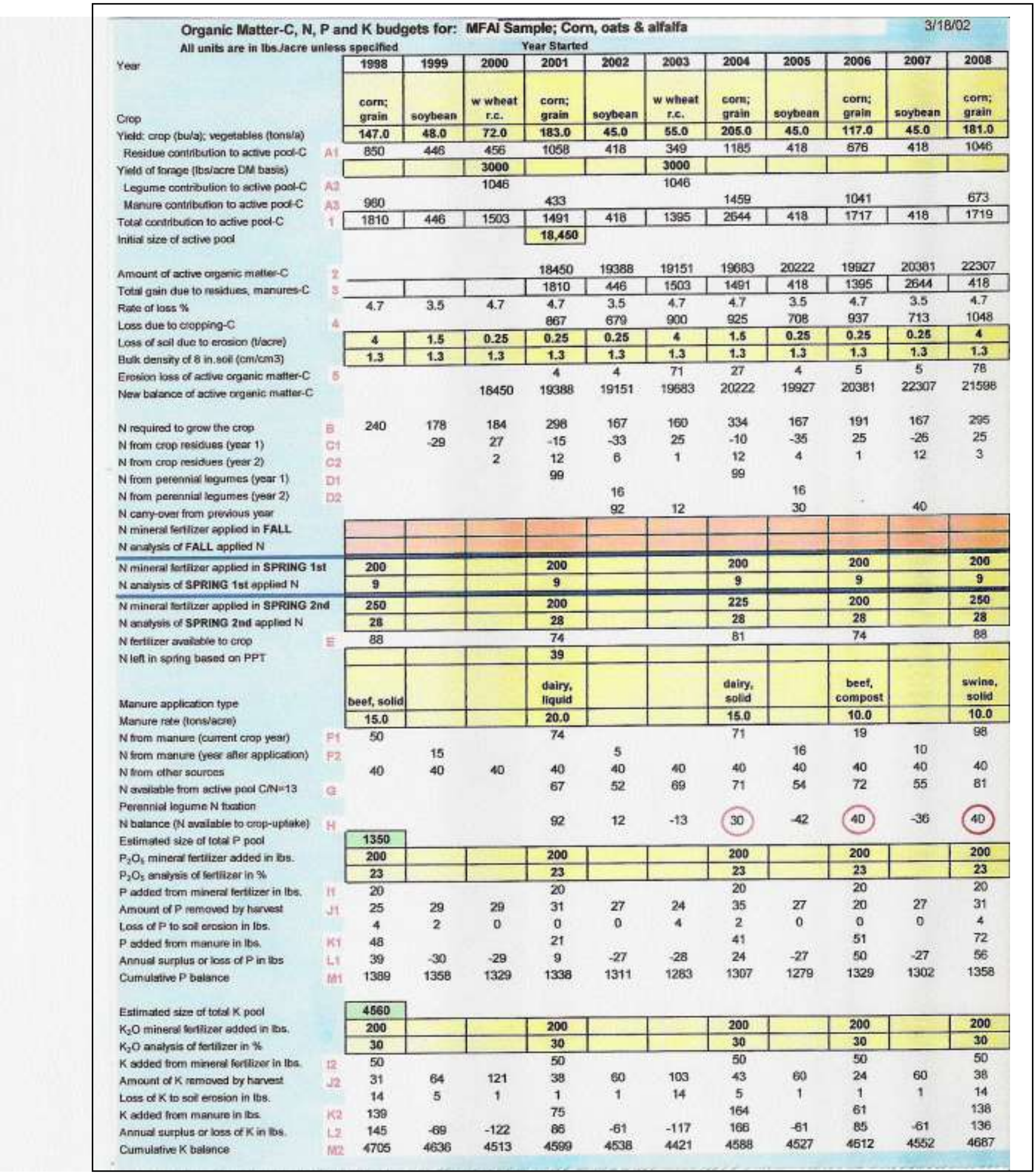
9. *'Estimated size of total P pool'* - In all cases, the default value of 1,200 was entered. This number was used as a starting point to monitor soil P over time. Though this value probably differs from the actual starting point, the idea of the budgeting was to examine the effects of the cropping strategies on the net loss or gain of P rather than the actual size of the total P pool.

10. *'Estimated size of total K pool'* – In all cases, the default value of 2,800 was entered. This number was used as a starting point to monitor total soil K over time. Though this value probably differs from the actual starting point, the idea of the budgeting was to examine the effects of the cropping strategies on the net loss or gain of K rather than the actual size of the total K pool.

The organic matter calculations start with the initial size of the active organic matter pool. Mineralization contributions of crop residues, legume residues, and manure are added (lines A1 to A3, Figure 1) and losses due to cropping and soil erosion are subtracted. The OMB Model calculates a running balance of active organic matterC (AOMC) as either positive or negative depending upon the cropping system strategy.

The nitrogen balance was calculated by summing N carryover from the previous year, N mineralization credits from crop residues (lines C to D, Figure 1), manure applications (lines F, Figure 1), N mineralized from the active, 'slow' organic matter pool (lines G, Figure 1), and N from the crop (line B, Figure 1) at the given yield level, which left either a positive or negative N balance for crop uptake. If an early spring N test is taken, any nitrogen carryover that the program calculated from the previous year was ignored in favor of the measured value. Farmers may use available N to calculate a probable yield level for cereal crops such as corn and wheat. A buffer value was used for excess N needed to realize yield under a given farming system. For a rotation where corn follows soybeans or wheat, the buffer was 40 lbs N/a remaining at the end of the growing season. For a corn – soybean - cereal grain w/cover crop rotation, the buffer was 30 lbs N/a and if a manure application and forage crop were included in the rotation, the buffer was 25 lbs N/a (line H, Figure 1 - highlighted by red circles).

Phosphorus and potassium budgets were calculated based on estimated initial values. Phosphorus and potassium values from mineral fertilizer (lines I, Figure 1) and/or manure (lines K, Figure 1) were added to the initial values; P and K values removed by the crop (lines J, Figure 1) and lost by soil erosion were subtracted. The running cumulative P and K balance (lines M, Figure 1) included the initial P and K balance plus the annual surplus or loss (lines L, Figure 1) of P and K.



Organic Matter-C, N, P and K budgets for: MFAI Sample; Corn, oats & alfalfa 3/18/02

All units are in lbs./acre unless specified

Year Started

Year		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Crop		corn; grain	soybean	w wheat r.c.	corn; grain	soybean	w wheat r.c.	corn; grain	soybean	corn; grain	soybean	corn; grain
Yield: crop (bu/a); vegetables (tons/a)		147.0	48.0	72.0	183.0	45.0	55.0	205.0	45.0	117.0	45.0	181.0
Residue contribution to active pool-C	A1	850	446	456	1058	418	349	1185	418	676	418	1046
Yield of forage (lbs/acre DM basis)				3000			3000					
Legume contribution to active pool-C	A2			1046			1046					
Manure contribution to active pool-C	A3	960			433			1459		1041		673
Total contribution to active pool-C	1	1810	446	1503	1491	418	1395	2644	418	1717	418	1719
Initial size of active pool					18,450							
Amount of active organic matter-C	2				18450	19388	19151	19683	20222	19927	20381	22307
Total gain due to residues, manures-C	3				1810	446	1503	1491	418	1395	2644	418
Rate of loss %		4.7	3.5	4.7	4.7	3.5	4.7	4.7	3.5	4.7	3.5	4.7
Loss due to cropping-C	4				867	679	900	925	708	937	713	1048
Loss of soil due to erosion (t/acre)		4	1.5	0.25	0.25	0.25	4	1.5	0.25	0.25	0.25	4
Bulk density of 8 in.soil (cm/cm3)		1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Erosion loss of active organic matter-C	5				4	4	71	27	4	5	5	78
New balance of active organic matter-C				18450	19388	19151	19683	20222	19927	20381	22307	21598
N required to grow the crop	B	240	178	184	298	167	160	334	167	191	167	295
N from crop residues (year 1)	C1		-29	27	-15	-33	25	-10	-35	25	-26	25
N from crop residues (year 2)	C2			2	12	6	1	12	4	1	12	3
N from perennial legumes (year 1)	D1				99			99				
N from perennial legumes (year 2)	D2					16			16			
N carry-over from previous year						92	12		30		40	
N mineral fertilizer applied in **FALL**												
N analysis of **FALL** applied N												
N mineral fertilizer applied in **SPRING 1st**		200			200			200		200		200
N analysis of **SPRING 1st** applied N		9			9			9		9		9
N mineral fertilizer applied in **SPRING 2nd**		250			200			225		200		250
N analysis of **SPRING 2nd** applied N		28			28			28		28		28
N fertilizer available to crop	E	88			74			81		74		88
N left in spring based on PPT					39							
Manure application type		beef, solid			dairy, liquid			dairy, solid		beef, compost		swine, solid
Manure rate (tons/acre)		15.0			20.0			15.0		10.0		10.0
N from manure (current crop year)	F1	50			74			71		19		98
N from manure (year after application)	F2		15			5			16		10	
N from other sources		40	40	40	40	40	40	40	40	40	40	40
N available from active pool C/N=13	G				67	52	69	71	54	72	55	81
Perennial legume N fixation												
N balance (N available to crop-uptake)	H				92	12	-13	30	-42	40	-36	40
Estimated size of total P pool		1350										
P_2O_5 mineral fertilizer added in lbs.		200			200			200		200		200
P_2O_5 analysis of fertilizer in %		23			23			23		23		23
P added from mineral fertilizer in lbs.	I1	20			20			20		20		20
Amount of P removed by harvest	J1	25	29	29	31	27	24	35	27	20	27	31
Loss of P to soil erosion in lbs.		4	2	0	0	0	4	2	0	0	0	4
P added from manure in lbs.	K1	48			21			41		51		72
Annual surplus or loss of P in lbs	L1	39	-30	-29	9	-27	-28	24	-27	50	-27	56
Cumulative P balance	M1	1389	1358	1329	1338	1311	1283	1307	1279	1329	1302	1358
Estimated size of total K pool		4560										
K_2O mineral fertilizer added in lbs.		200			200			200		200		200
K_2O analysis of fertilizer in %		30			30			30		30		30
K added from mineral fertilizer in lbs.	I2	50			50			50		50		50
Amount of K removed by harvest	J2	31	64	121	38	60	103	43	60	24	60	38
Loss of K to soil erosion in lbs.		14	5	1	1	1	14	5	1	1	1	14
K added from manure in lbs.	K2	139			75			164		61		138
Annual surplus or loss of K in lbs.	L2	145	-69	-122	86	-61	-117	166	-61	85	-61	136
Cumulative K balance	M2	4705	4636	4513	4599	4538	4421	4588	4527	4512	4552	4687

Figure 1. Field data worksheet - Page 1 of the OMB Model field report (Sample copy).

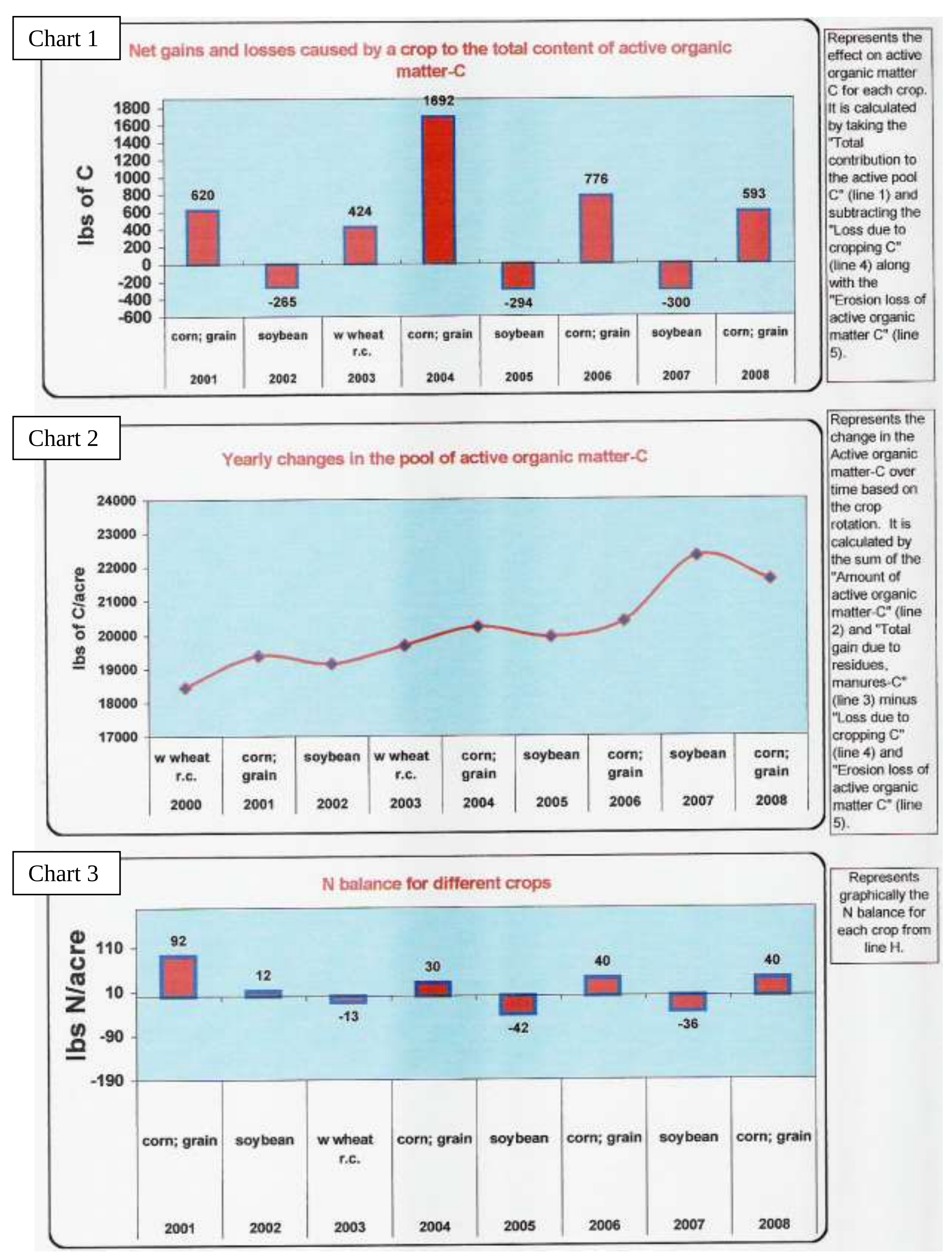


Chart 1

Net gains and losses caused by a crop to the total content of active organic matter-C

Represents the effect on active organic matter C for each crop. It is calculated by taking the "Total contribution to the active pool C" (line 1) and subtracting the "Loss due to cropping C" (line 4) along with the "Erosion loss of active organic matter C" (line 5).

Chart 2

Yearly changes in the pool of active organic matter-C

Represents the change in the Active organic matter-C over time based on the crop rotation. It is calculated by the sum of the "Amount of active organic matter-C" (line 2) and "Total gain due to residues, manures-C" (line 3) minus "Loss due to cropping C" (line 4) and "Erosion loss of active organic matter C" (line 5).

Chart 3

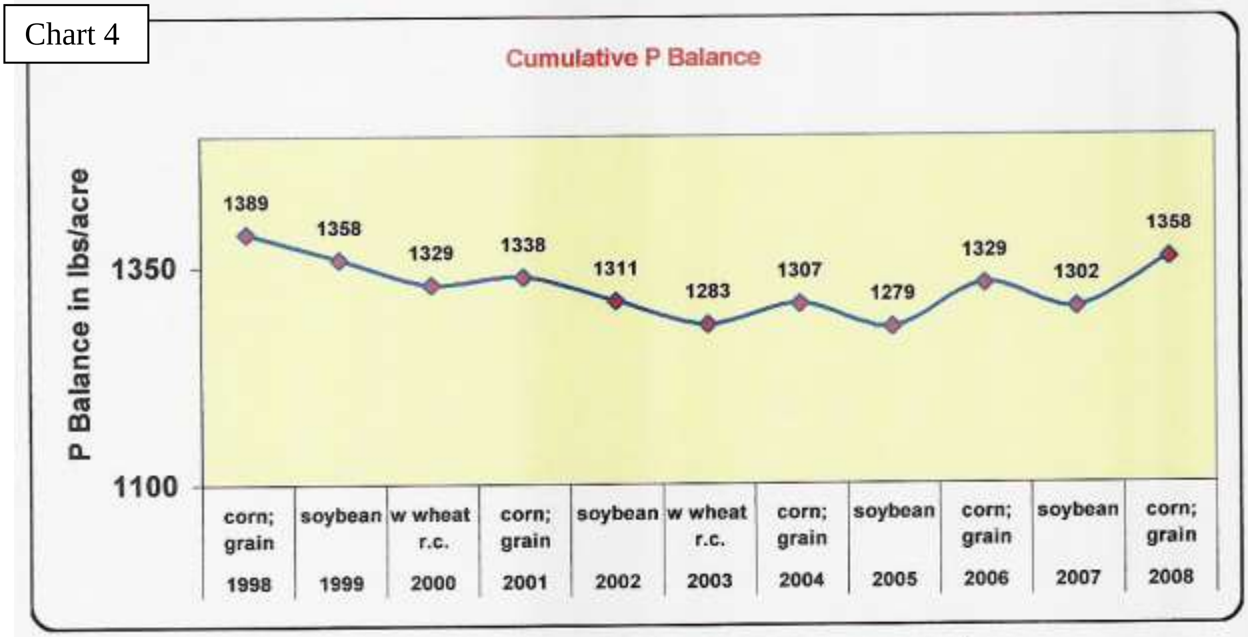
N balance for different crops

Represents graphically the N balance for each crop from line H.

Figure 2. Charts 1, 2, and 3 - Page 2 of the OMB Model field report (Sample copy).

Represents graphically the change in total phosphorus (line M1)

Chart 4



Represents graphically the change in total potassium (line M2)

Chart 5

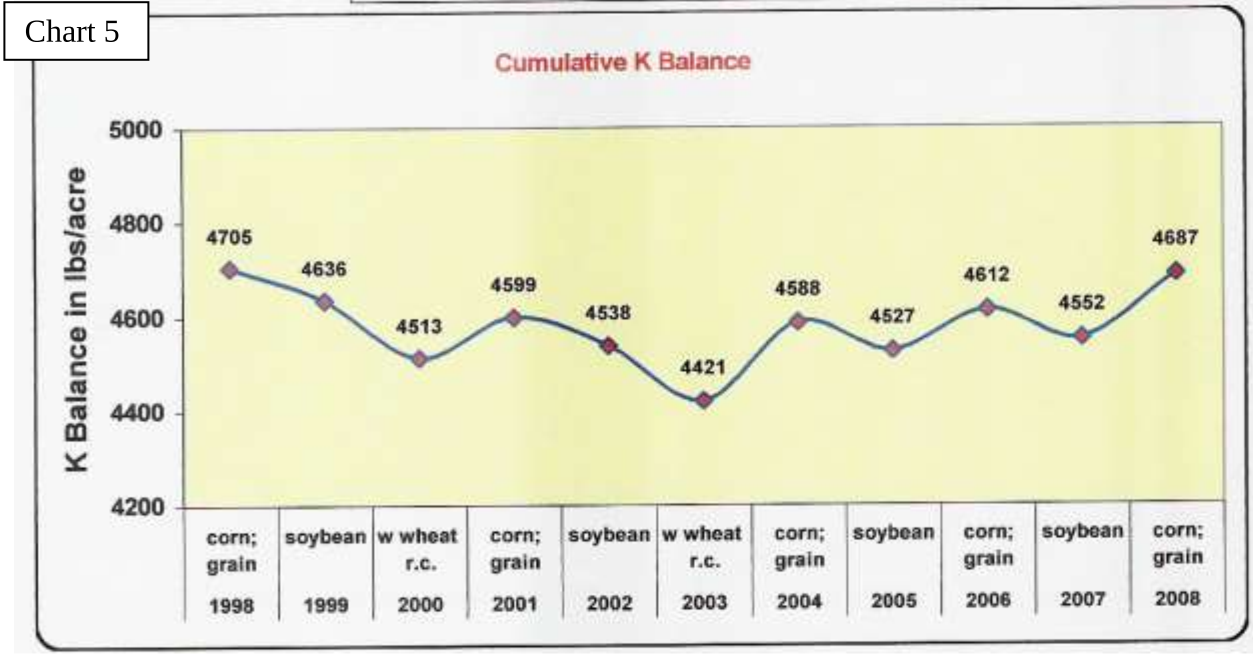


Figure 3. Charts 4 and 5 - Page 3 of the OMB Model field report (Sample copy).

The field data summary is presented in a three-page report that may be viewed onscreen or printed. The printed report includes the field data worksheet (Figure 1) and five charts (Figures 2 and 3) which track the balance of AOM-C (Charts 1 and 2), N balance for crop uptake (Chart 3), and cumulative change in P and K balances for each field (Charts 4 and 5).

Chart 1. Net gains and losses caused by a crop to the total content of AOM-C (Figure 2). This chart represents the effect on AOM-C for each crop in the rotation. It is calculated by taking the 'Total contribution to the active pool C' (Line 1, Figure 1) and subtracting the 'Loss due to cropping C' (Line 4, Figure 1) and the 'Erosion loss of active organic matter C' (Line 5, Figure 1).

Chart 2. Yearly changes in the pool of active organic matter C (Figure 2). This chart represents the change in the AOMC over time based on the crop rotation. It is calculated by the sum of the 'Amount of active organic matterC' (Line 2, Figure 1) and the 'Total gain due to residues, manuresC' (Line 3, Figure 1) less the 'Loss due to cropping C' (Line 4, Figure 1) and the 'Erosion loss of active organic matter C' (Line 5, Figure 1).

Chart 3. N balance for different crops (Figure 2). This chart graphically represents the N balance for each crop from Line H, Figure 1.

Chart 4. Cumulative P Balance (Figure 3). This chart graphically represents the change in total P over time (Line M1, Figure 1).

Chart 5. Cumulative K Balance (Figure 3). This chart graphically represents the change in total K over time (Line M2, Figure 1).

C. Data and Discussions:

Results from strip-trials.

For the on-farm trials, the results of organic matter budgeting are shown in Table 1; this table describes the system, the number of fields budgeted, the initial content in soil organic matter, the predicted change in biologically active matter, and the predicted equilibrium level for the system. The significant correlations between the predicted annual loss of biologically active organic matter (AOM) and the initial organic matter content of the soil indicates that predictions were generally consistent and valid across farms within a given farming system despite variable management practices. Budgeting suggested that conventional grain cropping systems were depleting their soil organic matter resources. These systems were predicted to eventually equilibrate at organic matter contents somewhere between 2.2 to 3.3%, with higher levels where animal manure was applied. The results were about the same for grain crop rotations that used small grains under-seeded with clover as a green manure. However, soils that employed rotations with grain crops and a high percentage of perennial forages were estimated to be accumulating organic matter. Their equilibrium level was estimated to range from 3.9 to 5.4%, depending on whether and how much animal manure was applied. The predictions made by the budgeter on how different farming systems would affect the equilibrium soil organic matter contents were reflected in the actual soils on the different farms. The cash grain systems generally had lower organic matter contents.

As was mentioned above, the budgeter's predictions of surplus N in the cropping systems correlated well with nitrate-N found in the soil profile at harvest for the different systems tested. The content of N lost before harvest was estimated by subtracting the predicted nitrate content from the predicted total surplus of N (see Table 2). There was a strong correlation between the predicted losses before harvest and the budgets prediction of surplus or deficit N in the system ($R^2 = 0.95$). Below predictions of approximately 57 lbs of surplus N/acre the budgeter under-estimated N mineralized from soil organic matter sources. The budgeter routinely underestimated the quantity of nitrogen that was mineralized from soil organic matter in the soil where cereals were grown and no fertilizer was applied. Results from field based analysis showed that our budgeter was off because it uses a fixed rate of decomposition (mineralization) to account for how much nitrogen will be released to corn from soil organic matter under different crops.

On average (number of values = 91), corn produced 120 bushels of grain per acre and took up an average of 179 lbs of N/acre. On average, 1.65 lbs of N were taken up for every bushel produced. During this process, an average of 185 lbs of N was mineralized out of soil organic matter sources. On average, 1.71 lbs of N were mineralized for every bushel produced.

The mineralization of N under corn and its uptake appeared to be relatively stable, irrespective of the preceding crop (see Diagram 1, Table 5 (column, N mineralized from soil organic matter), and Table 6). In short, corn seems to have a hitherto underestimated ability to mine N from soil organic matter sources. The richer the soil was in total organic nitrogen, the lower the percent of total nitrogen that was released (Diagram 2 and 3, Table 5, last two columns). Assuming that the N that came out of organic sources was obtained from the topsoil, the average percent of the total topsoil organic N that mineralized was 4.3%. This was much higher than the 1-2% that is commonly assumed when calculating N release from topsoil organic matter. Actually, the quantity generally ranged from 1 to 8% and on very poor soils with low quantities of total N, the mineralization of N was greater than 8% of the total N content of the soil. Diagram 3 shows how the results were affected by state. Wisconsin's soils were most variable and had high rates of mineralization on some of the poorer soils. The relationship between the N content of the topsoil and the percent mineralization was little affected by manuring (see Diagram 2). Soil texture may have had an effect, as further examination of results showed that clay loam soils appeared to have somewhat lower mineralization than loams, sandy loams, and silty loams.

Results of the amino-sugar-N analyses were compared with yield responses to manure found on our plots, with mineralization of N from organic matter in unmanured and manured soils, and with N uptake by corn. The test appeared to work for predicting whether corn crops would respond to fertilization with manure but not to mineral fertilizers on Wisconsin farms in 2001. There also might have been a positive finding for the test on Iowa farms in 2001 for predicting response to manure applications. However, there was no significant correlation between the quantities of amino sugar N and the quantity of N that was mineralized during a corn cropping year either in Wisconsin or in Iowa. Furthermore, the Paul test for biologically active soil organic C and N did not correlate any better with N mineralization ($R^2 = 0.31$**) than did total C ($R^2=0.35$**) content of the soil. Thus neither test appeared to be especially useful for predicting the pool of biologically active N that will mineralize during the growing season. Our field test with corn itself provides a real life bioassay for N mineralization from organic sources, however we do not yet know a lot about the repeatability of the test as it is probably affected by climatic factors that regulate the growth of the corn.

In Wisconsin and Iowa in 2001 we found significant positive correlations between the amount of root growth on the one hand, and the quantity of N that was mineralized from soil organic matter and taken up by corn plants. Over all sites, root production appeared to correlate in a positive fashion with yield for conventional systems where corn followed corn or soybeans ($R^2 = 0.41$ **) but not for organic systems where corn followed after perennial forages or soybeans.

Wisconsin trials with fertilizers suggested that fertilizers had greater effects on N uptake and grain yields on those sites where the unfertilized controls produced relatively low yields. On average, corn plants took up less nitrogen from fertilizers and more nitrogen from native soil organic matter sources than we had expected. Twenty trials comparing unfertilized controls with fertilizers (applied at normal rates for the farm) indicated that fertilization with mineral nitrogen fertilizer increased nitrogen uptake in corn on average only by 11%. Furthermore, 47 trials comparing unfertilized controls with normal farm fertilization practices indicated that fertilization with manure or manure compost increased nitrogen uptake in corn on average only by 10%. Despite this, field budgets involving calculation of nitrogen mineralization rates from manure suggested that there was an apparent release (mineralization) of 43%, 36%, and 14% of the organic nitrogen from solid livestock manure, composted livestock manure, and liquid manure (see Table 3). This release was relatively independent of the rotation or system. There was a wide variation in mineralization of manure-nitrogen from farm to farm.

In our farm trials in 2000, 2001, and 2002 the root disease scores were highest in 2000 (see Table 7). Overall, there were also striking differences in root health according to management practices. On 47 sites where conventionally managed corn was grown in rotation with cash grains (corn, soybeans and small grains/legumes), the root disease scores were 30, 27, 23, and 24%, respectively. The average root disease at flowering for the conventional sites was 26%. For 28 organic sites, where corn followed soybeans or perennial forages with a history of use of animal manure, the root disease score averaged 13%. Where corn followed after small grains with clover on organically managed soil (4 sites) the root disease at flowering time averaged 15 %. Differences were significant for contrasts (at the $p < 0.001$ level) between where corn was grown on conventional and organic, between where corn was grown after conventional corn and soybeans vs. after organic forages or soybeans, and between where corn was grown after conventional corn vs. after organic soybeans.

Tables 5 and 6 summarize results obtained for the different farming systems in 2001 and 2002 with respect to root production and N dynamics. Results are averaged only for treatments where no fertilizers were applied or manure was applied. Yields were slightly lower in conventional systems, but not significantly. Corn yields for the different systems were comparable with two exceptions. Corn grown organically after small grains/clover produced unusually low yields (79 bushels/acre). These low yields appeared in most cases to be associated with unusually low root production and problems with weed competition. On the other hand, corn grown on organic fields after alfalfa-grass mixtures produced exceptionally high yields (153 bushels/acre). Corn grown organically had less root disease than corn grown conventionally (15% vs. 21, $p < 1\%$), while corn grown conventionally produced more roots than organic corn (4910 vs. 4337, $p < 5\%$). Corn grown after corn or soybeans in conventional systems produced 5,252 lbs of roots/acre, while corn grown on organic fields after forages or soybeans produced 4,442 lbs of roots/acre (difference significant at $p < 1\%$).

The ratio between root production and grain yield was reflected in differences in lbs of dry roots per bushel of corn grain produced. On average, corn grown conventionally after corn and soybeans on 27 sites had root/bushel ratios of 65:1, while corn grown organically after forages or soybeans on 53 sites had root/bushel ratios of 38:1. The highest average root/bushel ratios were found with corn following corn on conventional fields (90 lbs/bushel) and the lowest ratios were found where corn followed alfalfa/grass mixtures on organic fields (33 lbs/bushel) (difference significant at $p < 5\%$).

Ratio data is not normally distributed, and isolated crop failures resulted in extremely high root/grain ratios. This probably was the case where corn followed small grain/clover mixtures under organic production. In this situation, corn growth appears to be stunted, root production was low, and corn seems susceptible to weed competition.

Possibly because it shifted its resources away from grain production and towards root production, the conventional corn also took up more N from the soil than the organic corn (202 vs. 164 lbs N/acre, $p < 1\%$). Corn grown after corn or soybeans in conventional systems needed an average of 1.8 lbs of N for every bushel of grain produced, while corn grown after soybeans or forages in the organic systems needed 1.4 lbs of N for every bushel of grain produced (difference significant at $p < 5\%$). Corn that followed corn on conventional fields needed 2.02 lbs of N/bushel, while corn that followed alfalfa/grass mixtures on organic fields needed 0.9 lbs of N/bushel ($p < 1\%$). Corn grown after small grain/legume green manures was also highly inefficient at converting N to yield (2.24 lbs of N/bushel), while corn after soybeans was intermediate (1.57 lbs N/bushel). The results with the quantities of N mineralized from soil organic matter and N mineralized per bushel of grain were generally similar in tendency to results obtained with N uptake but differences between systems were mostly not significant.

The N contents of the topsoil found on the different farms reflected the difference predicted by the budgeter for equilibrium levels of organic matter associated with the long-term use of different farming systems. Corn grown after conventional corn or soybeans had N contents in the top 8 inches of 4,465 lbs of N/acre, while corn grown after organic soybeans or forages had 5,009 lbs of N/acre (Table 6). Perhaps the largest contrast was found between corn that followed conventional corn (3,683 lbs of N/acre) and corn that followed organic alfalfa/grass (6,142 lbs of N/acre). The C:N ratio of these soils mostly fell between 10:1 and 11:1, and the C content of the soil also was higher for the more established organic systems.

Because conventional soils had lower N contents, and because conventional corn had higher N uptake requirements and more roots, the rates of mineralization from soil organic matter were higher for corn grown in the conventional systems. For corn grown conventionally after corn or soybeans, 5.2% of the total N content may have been mineralized, while for corn grown organically after organic forages or soybeans, 4% was estimated to have been mineralized. These results again appear to underscore that corn has the ability to obtain what it needs of N from soil organic matter.

Whole Farm Budgeting Results

Crop rotations ranged from simple, conventionally managed corn and soybean rotations to organically managed six year rotations that included corn, soybeans, and legume-grass mixtures. Livestock systems included a number of legume-grass pasture fields. One farm had vegetables, fruits, and cover crops rotations. All but one of the participating farms was or was transitioning to organic systems.

A whole-farm summary worksheet was utilized to consolidate the fields for each farm. Individual field information was converted to a per acre basis for field to field comparisons within the whole farm. The field summary charts represented the average annual change in AOM-C, TP and TK over time for 9 farms (Figure 4). The 10th farm involved in vegetable production was excluded from these comparisons.
These charts were also used to represent the differences between the participating farms.

For the majority of the farms, the Budgeter indicated an annual increase for AOM-C (Figure 4). The range of annual AOM-C increase was 42 to 759 lbs/a with an average increase of 69 lbs/a. Most of the increase in AOM-C was attributed on a per farm per field basis to the years with legume crops included in multi-year rotations and to fields that were kept in long term legume-grass crops for pasture. Examples of these AOM-C graphs for are shown in Figures 2 and 3. Above average increases were indicated for farms 4 and 6. The crop rotations on these farms were similar to the other farms, but these two tended towards heavier manure application rates (10 – 30 tons/a) than the others.

Chart 1. Average Annual Change in AOM-C for 9 farms (over 8 year time period).

Chart 2. Average Annual Change in Total P for 9 farms (over 11 year time period).

Chart 3. Average Annual Change in Total K for 9 farms (over 11 year time period).

The data presented in Figure 4 illustrates the differences between nine Iowa farms rather than individual field differences within a farm.

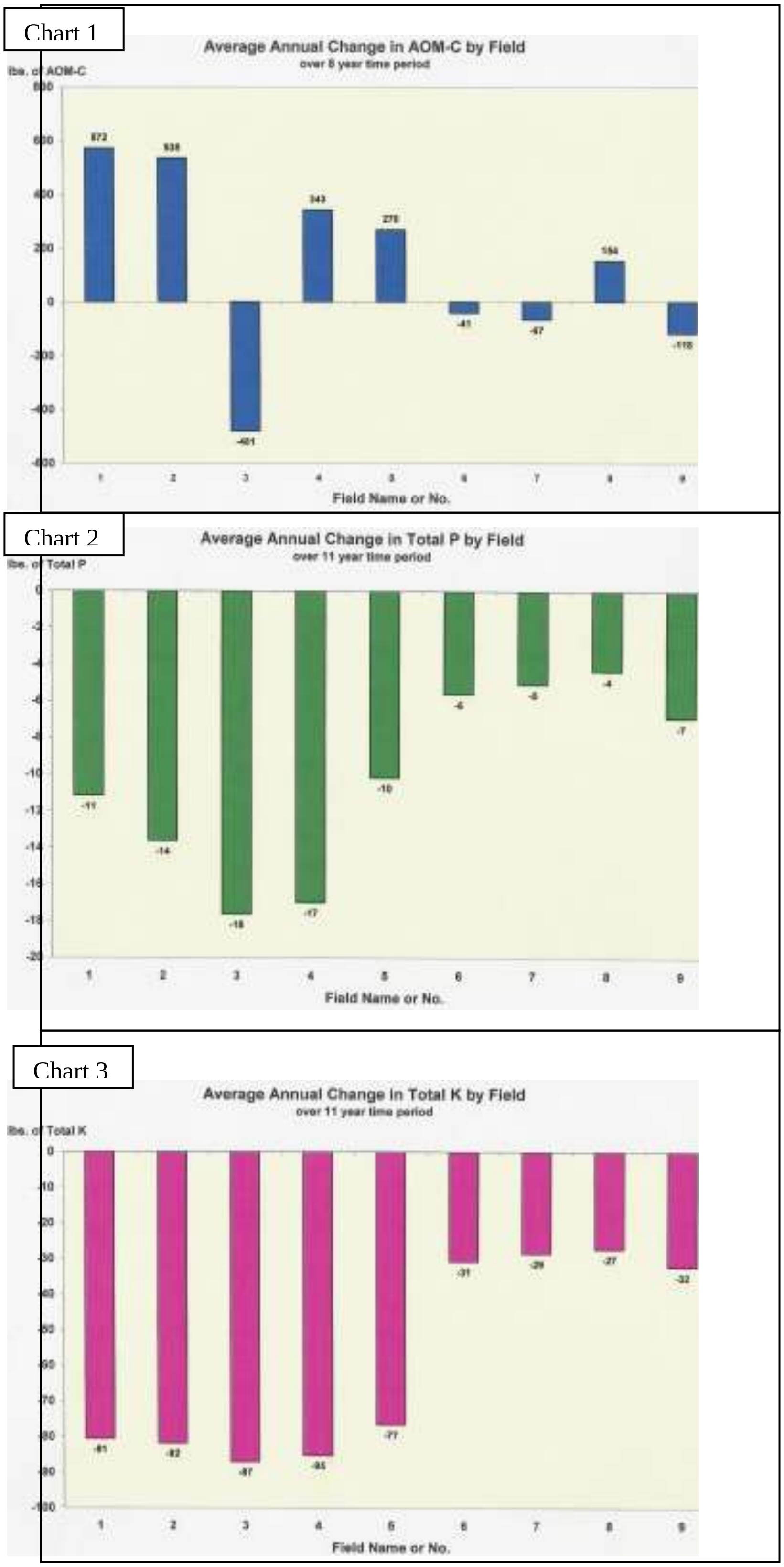


Figure 4. Whole farm summary charts – highlighting field differences for AOM-C, TP, and TK.

The Budgeter indicated a minimal annual decrease for all farms in soil Total P (lb/a) balance except for #7 which may be attributable to conventional fertilizer applications (Figure 1). Farm #7 was the only farm for which the Budgeter indicated an annual increase in the soil Total K (lbs/a) balance (Figure 1). This may be due to the use of conventional fertilizer applications.

On most farms, P and K losses were minimal to moderate. However, within these farms there were fields or management units with greater losses or buildups than others. Again the predominant tendency was for buildup of fertility or lower losses in manured fields that included pasture or hay cropping. Conversely, areas of the farm that were in grain-crop rich rotations showed greater losses of nutrients and lower accumulation rates of soil organic matter. Almost every farm had management units with contrasting losses or gains in these nutrients, suggesting that even within individual farms, there were wide differences in losses.

As had been true for the budgets on individual fields, the losses and gains of soil organic matter on individual farms were generally proportional to the original organic matter content of the soil. It was more difficult to maintain soil organic matter where native levels were high than where native levels were low. Only half of the farms that we worked with had measured values of organic matter for all their field soils. The whole-farm equilibrium levels for soil organic matter were calculated. Fields were predicted to lose organic matter above those levels and to gain it below them, depending on the native level of soil organic matter. Diagram 4 shows that equilibrium levels varied from 3.4 to 4% for three organic farmers that included perennial forages in their rotations and used animal manures, to 2.9% for a farm that was using underseeding green manure clover crops into small grains, to 1.5% for a cash grain farmer employing a conventional, corn and soybean rotation.

D. Summary and Recommendations.

Many of these results parallel empirical evidence gained from studying yields and root health for different farming systems on the Wisconsin Integrated Cropping Systems Trials (Goldstein, 2000). Our present study confirms those results and also links soil and root health to the N dynamics of the corn plant/soil system. Some results of this study challenge both common thinking and the budgeter’s assumptions of how soil fertility and management work.

The growth of corn roots is important because they actively facilitate the decay of organic matter in the soil by feeding soil microorganism with root exudates. Farmers and agronomists often think of available N as being the driving element that determines the yield of corn. It is not often thought that the corn may itself play a major role in determining the availability of N through its rooting system. Results of this study suggest that the mineralization of N on both the manured and unmanured plots may be partly driven by corn roots. This confirms results by Sanchez et al (2002) who found that mineralization of N was increased more than 50% in the presence of corn roots.

Furthermore, despite indubitable evidence that mineral and organic fertilizers can cause large increases in yield under some conditions our results suggested that on average the vast majority of nitrogen taken up by corn probably comes from soil organic matter even where fertilizers are applied. Corn seemed quite capable of obtaining most of the nitrogen that it needs from soils over a wide range of organic matter-nitrogen contents, seemingly irrespective of the content of biologically active soil organic matter. Results also suggested that corn grown under conventional farming systems, and in organic small grains/clover systems squandered the organic-nitrogen resources of the soil, as they were both inefficient at turning soil organic-nitrogen into grain yields. It appeared to take a lot more N to grow a bushel of conventional corn in a corn-corn or corn soybeans system (1.8 lbs N/bushel) than it took to grow corn in an organic system after soybeans or forages (1.4 lbs N/bushel). This inefficiency may be due to biological factors associated with rotations and soil quality, such as root disease.

The data also suggests that organic farmers are able to achieve a practical level of soil-borne antagonism. Three years of field trials indicated that corn had almost twice as high disease scores where it was grown under conventional systems relative to grown in organic systems, with the highest disease incidence was found where corn followed corn (30%) and the least disease was found where corn followed organic soybeans (15%). Increased root disease in the early stages of growth of corn has been linked with enhanced, compensatory root growth in the late phases of growth (Goldstein, 2000). This may account for ‘the rotation effect’ or lower yield associated with poor rotations as root formation takes place at the same time as grain fill and there is competition for internal plant resources. By shifting its resources away from grain production and towards root production, this conventional corn apparently also mineralized more nitrogen from soil organic matter, took up more nitrogen, and needed more nitrogen for every bushel of grain produced than did the other systems. In trials conducted in 2001 and 2002, corn grown after corn or soybeans in conventional systems produced more roots and less yield than corn grown in the organic systems after soybeans or forages. On average, corn grown conventionally after corn and soybeans on 27 sites had root/bushel ratios of 65:1, while corn grown organically after forages or soybeans on 53 sites had root/bushel ratios of 38:1. Greater root production was possibly caused by poorer soil quality and greater root disease problems (see Tables 5 and 6).

Corn grown after small grains with under-seeded green manure legumes such as red clover had low root and grain production and also showed poor nitrogen efficiency. The green manure system seemed to be associated with a lowered ability for corn to compete with weeds and with a lowering of yield potential. The most efficient systems for transforming soil organic nitrogen into grain were where corn followed after alfalfa, alfalfa + grass, or after soybeans in an organic rotation that included perennial forages and routine applications of animal manure. These forage-and-livestock based systems also had the greatest potential for carbon retention in the soil in soil organic matter.

A major research question emerging from this research is the mechanism by which corn can extract so much N from soil organic matter and how this may or may not be coupled with the decomposition of carbon from soil organic matter. We need more information on this mechanism before we can change the budgeter to better estimate N release and Carbon decomposition from organic matter. Furthermore, it would be important to clarify whether the reasons for the efficiency of certain systems are truly due to differences in root health.

Areas for fruitful future research might also include assessing whole farm nutrient and organic matter budgeting, developing methods for better assessing organic matter retention on farms, and further testing of corn production, nitrogen and organic matter dynamics in conventional systems and in farming systems that involve alfalfa-grass mixtures and manure applications. Future research should involve whole farm nutrient and organic matter budgeting, developing methods for better assessing organic matter retention on farms, and further testing of corn production, nitrogen and organic matter dynamics in conventional systems and in farming systems that involve alfalfa-grass mixtures and manure applications.

The budgeter should receive greater use in helping farmers to convert to environmentally friendly farming practices because it is useful for planning and relevant. A spread in its use will demand sponsorship by relevant organizations and interest by consultants. It may have a future in helping design whole farm plans that ensure greater environmental stewardship.

E. Impact of the Results.

Impacts are as follows:

- An organic matter and nutrient budgeter was developed that help farmers to make utilize organic matter resources to improve the sustainability of their farms. The budgeter helps to make coherent plans and to calculate organic matter and nutrient losses and gains due to different practices, both on a field basis and a whole farm basis. The budgeter has been used to help about 60 farmers to make budgets.

- Budgeting results also suggested that integrated livestock systems were the most sustainable with respect to maintaining or enhancing soil organic matter levels. Conventional grain cropping systems with mineral fertilization and grain crop/green manure systems were predicted to gradually reduce soil organic matter to levels around 1.5-2.2%. Systems which utilized forages and green manures plus animal manures were predicted to have an equilibrium point of 3-5.4%, depending on the proportion of the rotation in forages and on rates of animal manure applications. These results may have large implications for global warming, as the sustainable farming systems probably will store more C.

- Results from on-farm trials indicated that corn was capable of extracting large quantities of N from soil organic matter sources. These results have helped scientists and farmers to start to change the way they think about soil fertilization from being fertilizer based to being root driven in the case of corn. This is an important step in getting away from the use of mineral fertilizers.

- Limitations to efficiency in converting N to grain appeared to be associated with corn grown in conventional grain cropping systems and grain/green manure systems. Corn in these systems also had greater root growth and about double as much root disease as systems that included perennial forages and a history of manuring. Our present farming culture addresses mineral nutrition of corn from a chemical mindset while not realizing that biological issues associated with root health may actually be key regulators. This probably causes inefficient use of resources and pollution due to over use of N fertilizer.

F. Outreach and Information Transfer.

Outreach activities included:

- visits, discussions, and individual farm reports for individual fields and for whole farms to individual participating farmers in all three states;
- reports on overall results at the Practical Farmers of Iowa Annual conference and at their Research Planning meetings in 2002/3 and 2003/4;
- reports and budgeting workshops with individual farmers at the Upper Midwest Organic Farming Conference in Lacrosse, Wisconsin;
- A report on the results at the annual researcher/farmer meeting of the Wisconsin Integrated Cropping Systems Trials in 2002.
- reports on results during courses on Organic soil management at the Organic University in Lacrosse, Wisconsin in February 2004 and 2005.
- An invited presentation at the American Society of Agronomy Organic Symposium in the Fall of 2003.

G. Publications.

W. A. Goldstein. 2003. Developing and testing nutrient and organic matter budgeting and practies that will reduce the leaching of nutrients into surface and groundwaters. Wisconsin Integrated Cropping Systems Trials 9th Report. Pp. 82-105.

H. Education and Outreach.

Section F. gives a listing of education events. These were primarily farmer oriented. The presentation at the American Society of Agronomy was primarily researcher oriented.

I. Cooperative Efforts and Student Support.

Research involved graduate work by a graduate student in the Dept. of Agronomy (Kevin Jensen) at ISU. Dr. Michelle Wander and her graduate students also tested soils using the new Illinois N test.

J. Evaluation.

We did not acquire or keep workshop evaluations on our outreach efforts, but review of evaluation of our PFI presentations by farmers was favorable. The project objectives were largely met. There were a few things that we did not achieve. One was to compare our farm soils with prairie soils. As described above that was largely because our prairie expert needed to withdraw from the project. Furthermore, we developed our budgeter as a computer program but did not develop a second version of a workbook on it due to time and financial constraints. For the sake of improving the budgeter there is one major loose end: we need to do more research in order to be able to better clarify whether the greater than predicted N extraction by corn is coupled with greater C losses from soil organic matter.

K. Bibliography.

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V. Budget Report

A. The total request of our budget was $116,787. Expenditures year one - $37,255; year two $39,532; year three $40,000.

B. The primary expenditure areas for the grant were salaries, contract work, travel, materials and supplies, farmer stipends, telephone, administration and occupancy, and lab fees.

C. Other agencies involved in funding the research were:

National Fish and Wildlife $95,000.
Caviliere Foundation $15,000.
Illinois Dept of Agriculture $88,800.
Audubon Society $2,000
W.K. Kellogg Foundation $2,000
USDA/SARE $98,400.
USDA/EQIP $25,000.

Table 1. Results of budgeting changes in organic matter for all farms, 2001, 2002, and the correlation between the initial organic matter content and the predicted annual loss or gain in active organic matter (AOM).

Farming System	number of fields	initial organic matter %	predicted annual change in AOM	equilibrium level of soil organic matter	coefficient of determination (R^2)	Significance level of p
grain crop rotations without fertilization	18	2.96	-290	1.72	0.70	0.01
grain crop rotations with mineral fertilizer	11	2.25	-15	2.17	0.43	0.05
grain crop rotations with manure	14	3.11	93	3.31	0.58	0.01
grain crops and small grain/legume green manure	13	2.50	-105	2.13	0.77	0.05
grain crops and small grain/legume green manure + mineral fertilizer	9	1.98	13	2.02	0.75	0.01
grain crops and small grain/legume green manure + animal manure	8	2.24	223	2.99	0.56	0.01
high percent of perennial hay and grain no fertilizer	16	3.52	49	3.88	0.47	0.01
high percent of perennial hay and grain with manure	22	3.30	348	5.35	0.33	0.01

Table 2. Budget predictions of surplus N in the system, N-losses or underestimation of N mineralization, and nitrate-N in the soil profile at harvest, and the relationship between predicted and actual values for nitrate-N at harvest. Data summarizes results from 132 field trials and budgets with 15 crop sequences and 30 combinations of fertilization and rotations in 3 states from 2001 to 2002.

Fertilization	**Preceding crop**	**Main Crop**	**Number of Fields**	**Budgeter predicted surplus of N in the system (lbs N/acre)**	**Predicted loss of N (+) or underestimate of N mineralization (-) (lbs N/acre)**	**Predicted quantity of nitrate-N in soil profile at harvest (lbs N/acre)**	**Actual Nitrate-N in the profile (lbs N/acre)**	**Predicted minus actual nitrate in profile (absolute value lbs N/acre)**
control	alfalfa	corn	11	130	50	79	75	27
manure	alfalfa	corn	9	173	81	92	85	45
NPK	alfalfa	corn	4	248	134	114	66	52
control	corn	corn	7	14	-31	45	54	37
manure	corn	corn	3	48	-8	55	61	30
NPK	corn	corn	6	100	30	71	63	42
biosolids	legume-grass	corn	3	645	415	230	238	23
control	legume-grass	corn	4	106	33	72	113	40
manure	legume-grass	corn	3	142	59	83	119	36
control	oats	corn	2	-22	-56	35	37	19
compost	oats	corn	1	-19	-55	36	45	9
control	oats/clover	corn	2	-23	-58	35	24	14
control	soybeans	corn	21	42	-12	54	67	29
manure	soybeans	corn	7	132	52	80	88	71
NPK	soybeans	corn	8	84	18	66	45	30
control	wheat	corn	2	4	-39	42	71	29
manure	wheat	corn	2	85	18	66	86	19
NPK	wheat	corn	1	97	27	70	107	37
control	wheat/clover	corn	7	20	-27	47	48	21
manure	wheat/clover	corn	5	62	3	59	57	14
NPK	wheat/clover	corn	6	33	-18	51	52	12
control	soybeans	oats/clover	3	73	11	63	32	31
control	soybeans	sorghum	1	-61	-84	23	22	1
compost	soybeans	sorghum	2	-24	-58	34	28	6
control	corn	soybeans	5	59	0	59	39	20
control	wheat	timothy	1	10	-34	44	4	40
control	corn	wheat/clover	1	59	0	59	55	4
control	soybeans	wheat/clover	1	79	15	64	35	29
control	soybeans	barley +/- alfalfa	2	39	-14	53	56	3
compost	soybeans	barley +/- alfalfa	2	75	11	63	55	10
		total/average	**132**	**80**	**15**	**65**	**64**	**26**
		control tot/ave	**70**	**35**	**-16**	**52**	**49**	**23**
		manure tot/ave	**29**	**107**	**34**	**73**	**83**	**36**
		compost tot/ave	**5**	**11**	**-34**	**44**	**43**	**9**
		NPK fert tot/ave	**5**	**112**	**38**	**74**	**67**	**35**

Table 3. The amounts of organic-N applied with manure and its effect on N mineralization.

Farm-Field & Year	Type of manure	The preceding crop	Amount of organic-N applied with manure (lbs/acre)	N apparently made available by manuring (lbs/acre)	% of organic N in the manure that was mineralized
11-1 01	dairy solid	alfalfa	143	25	17
4 01	dairy compost	alfalfa	235	-2	-1
9 01	dairy solid	alfalfa	167	77	46
8 01	dairy solid	alfalfa	141	129	91
24-1 01	beef solid	alfalfa	111	118	107
26-1 01	beef solid	alfalfa	131	-1	-1
26-2 01	beef solid	alfalfa	131	24	18
35 02	beef liquid	alfalfa	96	-18	-19
35 02	beef solid	alfalfa	54	58	107
33 02	sheep solid	alfalfa	82	26	31
23-3 02	beef solid	alfalfa/grass	107	50	47
6 01	dairy liquid	corn	163	78	48
21-3 02	beef solid	corn	221	94	43
29-1 01	beef solid	oats/clover	291	48	16
23-1 01	beef solid	oats/clover	126	17	14
17 01	beef solid	w.wheat/clover	235	100	42
19-2 01	chicken manure compost	soybeans	69	0	-1
20-1 01	beef solid	soybeans	86	1	1
20-2 01	beef solid	soybeans	119	-17	-14
29-2 01	beef solid	soybeans	88	36	41
31-1 01	beef, hog & municipal manure	soybeans	168	13	8
22-3 02	beef compost	soybeans	195	81	42
24-3 02	beef solid	soybeans	81	125	155
29-4 02	beef solid	soybeans	262	93	36
11-2 01	dairy solid	soybeans	189	71	37
21-1 01	beef solid	soybeans	93	102	109
21-2 01	beef solid	soybeans	83	-2	-2
18-3 02	beef compost	soybeans	65	68	105
Average	all	29 sites	140	50	40
	solid	23 sites	141	54	43
	liquid	2 sites	129	30	14
	compost	4 sites	141	37	36

Diagram 1. The relationship between the N content of the topsoil and the quantity of N that is mineralized where corn followed different crops.

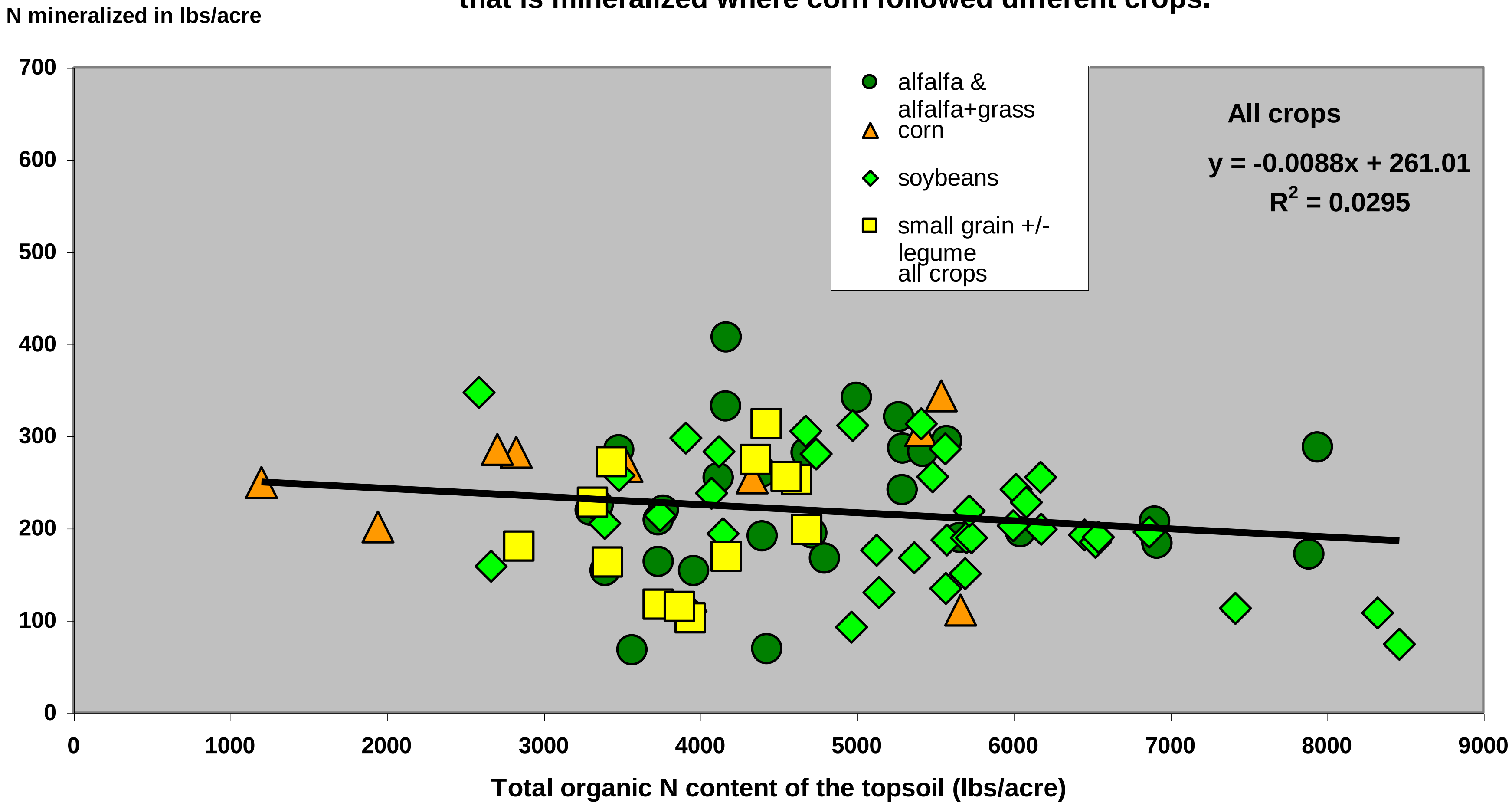

Diagram 2. The relationship between the N content of the topsoil in the spring and the % N mineralized in a corn cropping year for manured and unmanured fields all sites, 2001, 2002.

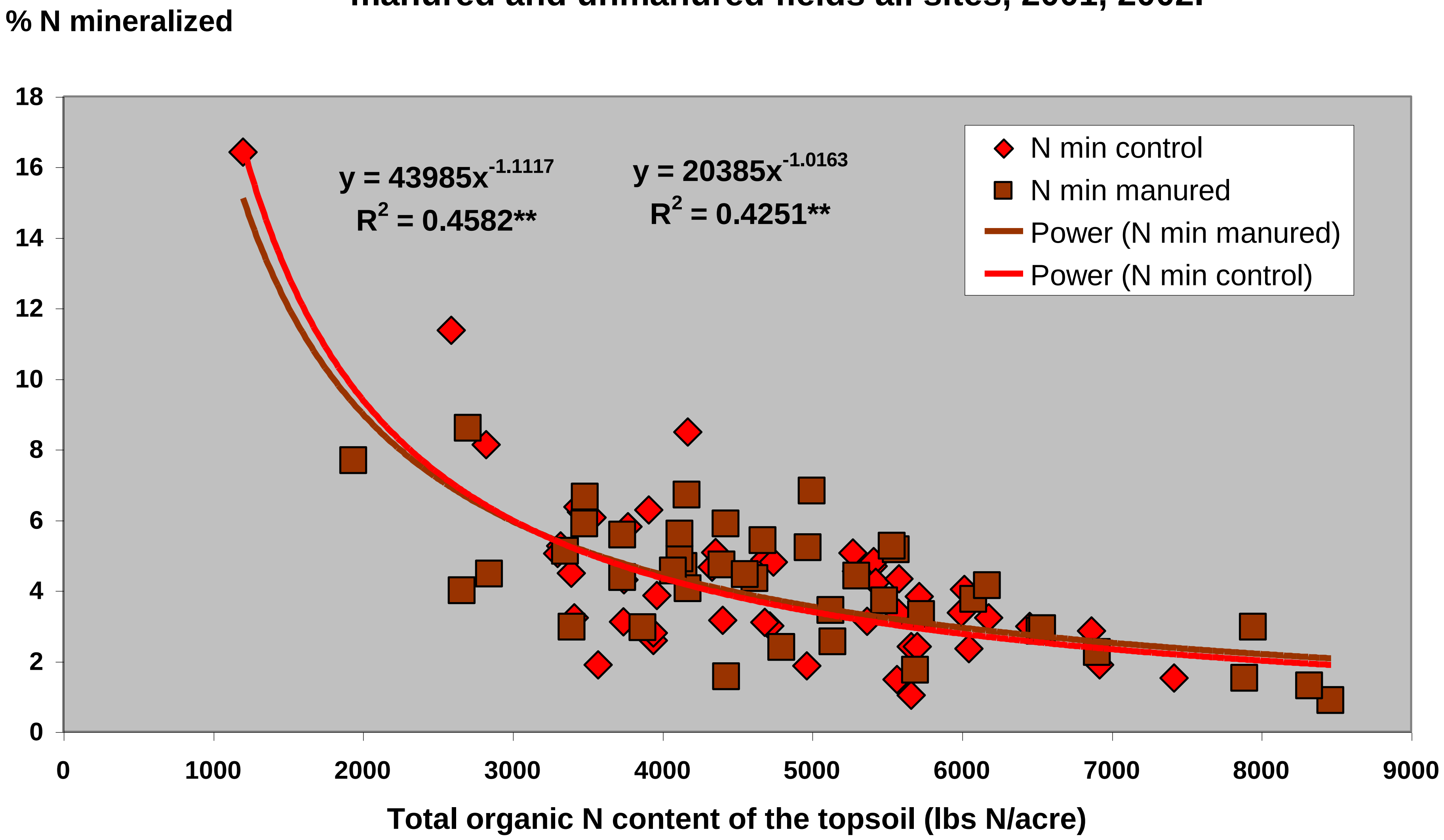

Diagram 3. The relationship between total N content of the soil in the spring and the % N mineralized during a corn cropping year in different states

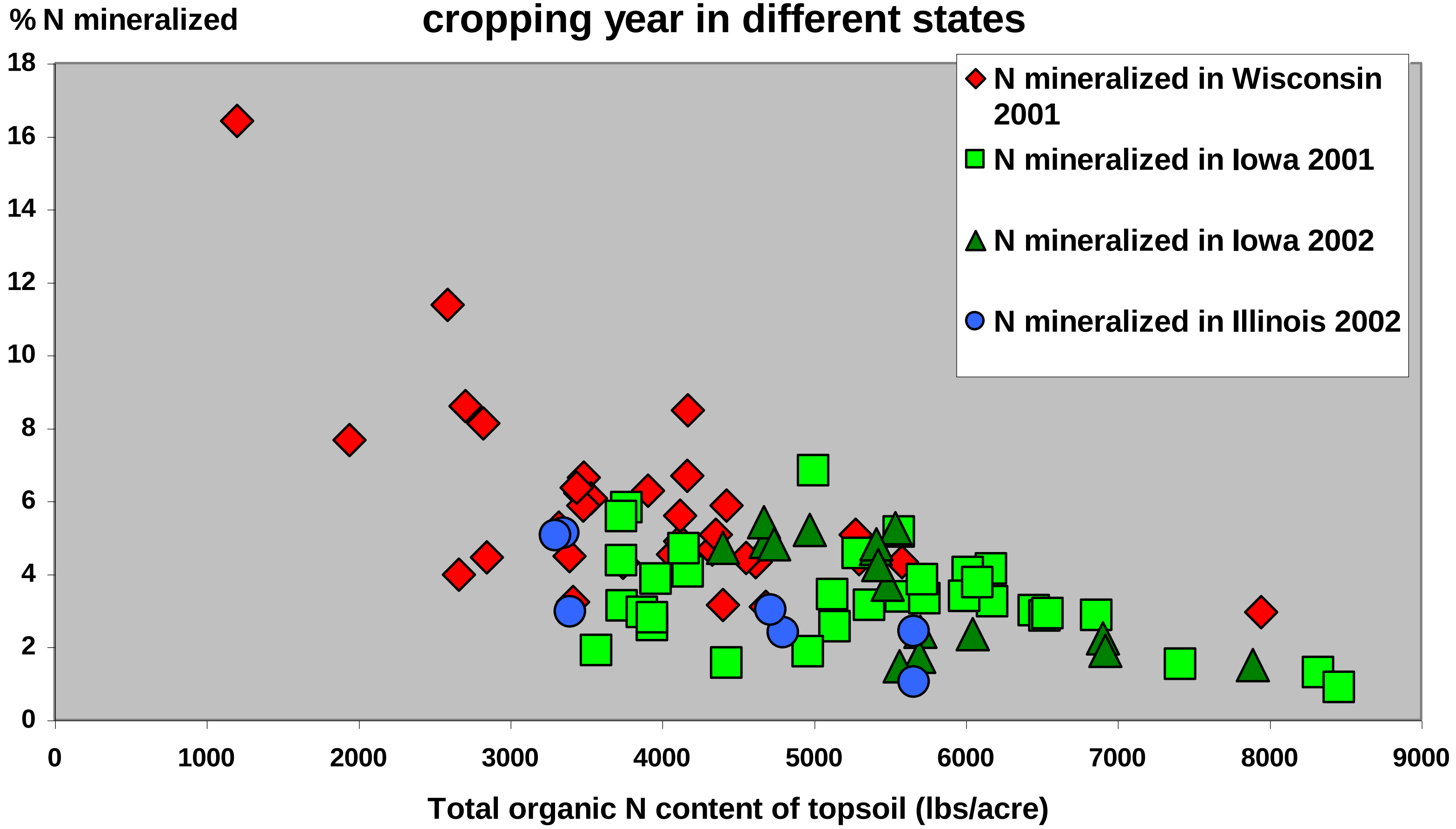

Diagram 4. Relationship between initial soil organic matter content and calculated annual gain or loss of active soil organic matter (AOM) for fields from different Iowa farms

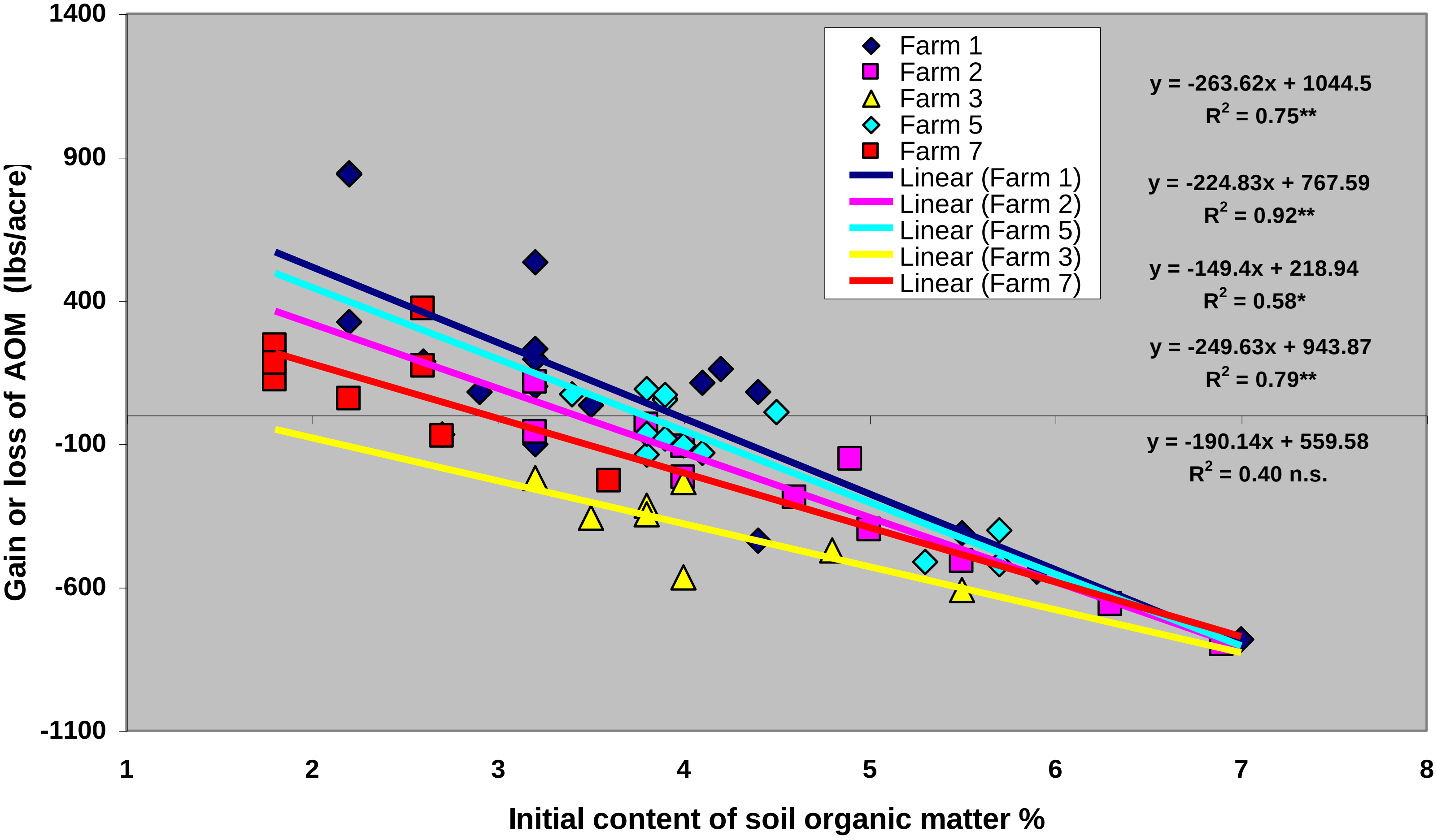

Table 4. Summary of relationships between farming systems and root disease of corn. Values represent specific farming systems on specific fields and are averages across fertilization treatments for 2000, 2001, and 2002.

Number of experi-ments	Preceding Crop and System	Root disease
number		*%*
9	corn (conventional)	30
15	soybeans (conventional)	27
21	small grains/clover (conventional)	23
2	alfalfa (conventional)	24
13	soybeans (organic)	14
4	small grains/clover (organic)	15
12	alfalfa (organic)	15
3	alfalfa/grass (organic)	21
79	total or average	21

Contrast	Root disease
after conventional vs	26
after organic	15
level of p	***
after conv. corn & soybeans vs	22
organic forages or soybeans	13
level of p	****
after conv corn vs	30
after organic soybeans	14
level of p	****
after organic alfalfa vs	15
after organic alfalfa/grass	21
level of p	NS

Contrast	Root disease
conventional corn vs	30
organic alfalfa/grass	21
level of p	NS
after forages vs	17
after small grain/legume	22
level of p	NS
after soybeans vs	21
after small grain/legume	22
level of p	NS

Table 5. Summary of relationships between the grain yield and root production of corn and N mineralization and uptake from soil organic matter. Corn was either not fertilized or fertilized with manure, and grown on conventional and organic farms in Iowa, Wisconsin, and Illinois (2001 & 2002).

Number of experi-ments	Preceding Crop and System	Grain yield	Corn roots	Root disease	Roots per bushel of grain	Total N uptake by corn	Apparent mineraliz-ation of N from soil organic matter	N taken up by plants & grain per bushel of corn	N mineralized from soil organic matter per bushel of corn	Total amount of organic N in the topsoil 8 inches	Percent of the total organic N that was apparently mineralized
		bushels/acre	*dry pounds per acre*	*%*		*pounds of N/acre*	*pounds of N/acre*	*pounds N per bushel*	*pounds N per bushel*	*pounds of N/acre*	*-%-*
11 (9)	**corn (conventional)**	**103**	**4632**	**23**	**90**	**211**	**203**	**2.02**	**1.80**	**3683**	**6.95**
16	**soybeans (conventional)**	**123**	**5644**	**21**	**48**	**199**	**180**	**1.68**	**1.54**	**4905**	**4.26**
8 (7)	**small grains/clover (conventional)**	**111**	**3728**	**19**	**46**	**195**	**168**	**2.03**	**1.88**	**3840**	**4.46**
5	**alfalfa (conventional)**	**123**	**5063**	**19**	**45**	**203**	**223**	**1.68**	**1.84**	**5953**	**3.83**
22	**soybeans (organic)**	**123**	**4318**	**13**	**36**	**176**	**189**	**1.49**	**1.56**	**5639**	**3.44**
7 (6)	**small grains/clover (organic)**	**79**	**3542**	**11**	**61**	**144**	**164**	**2.48**	**2.94**	**4085**	**3.94**
21 (20)	**alfalfa (organic)**	**117**	**4451**	**15**	**43**	**168**	**190**	**1.45**	**1.69**	**3977**	**4.87**
10 (6)	**alfalfa/grass (organic)**	**153**	**4697**	**21**	**33**	**126**	**164**	**0.90**	**1.18**	**6142**	**2.93**
100 (91)	**total or average**	**117**	**4509**	**18**	**50**	**178**	**185**	**1.72**	**1.80**	**4778**	**4.34**

Table 6. Summary of comparisons for corn grown on conventional and organic farms.

Comparison	Grain yield	Corn roots	Root disease	Roots per bushel of grain	Total N uptake by corn	Apparent mineralization of N from soil organic matter	N taken up by plants & grain per bushel of corn	N mineralized from soil organic matter per bushel of corn	Total amount of organic N in the topsoil 8 inches	Percent of the total organic N that was apparently mineralized
	bushels/ acre	*pounds per acre*	*%*		*pounds of N/acre*	*pounds of N/acre*	*pounds N per bushel*	*pounds N per bushel*	*pounds of N/acre*	*-%-*
conventional vs	115	4910	21	59	202	189	1.83	1.71	4548	4.89
organic	121	4337	15	41	164	184	1.52	1.72	4907	3.97
level of p	NS	*	**	NS	**	NS	NS	NS	NS	+
after conv corn & soybeans vs	115	5232	22	65	203	188	1.80	1.64	4465	5.23
soybeans	126	4442	15	38	166	186	1.40	1.56	5009	3.97
level of p	NS	**	**	*	**	NS	*	NS	***	***
after conv corn vs	103	4632	23	90	211	203	2.02	1.80	3683	6.95
after organic soybeans	123	4318	13	36	176	189	1.49	1.56	5639	3.44
level of p	NS	+	***	*	NS	NS	NS	NS	***	***
after conv corn vs	103	4632	23	90	211	203	2.02	1.80	3683	6.95
after organic alfalfa/grass	153	4697	21	33	126	164	0.90	1.18	6142	2.93
level of p	NS	NS	NS	*	**	NS	**	NS	****	****
after forages vs	128	4604	17	41	165	190	1.38	1.61	4715	4.33
after small grain/legume	96	3641	15	53	172	166	2.24	2.37	3953	4.22
level of p	*	+	NS	NS	NS	NS	***	**	**	NS
after soybeans vs	123	4876	17	41	186	185	1.57	1.55	5330	3.79
after small grain/legume	96	3641	15	53	172	166	2.24	2.37	3953	4.22
level of p	+	*	NS	NS	*	+	**	**	*	NS
after organic alfalfa vs	117	4451	15	43	168	190	1.45	1.69	3977	4.87
after organic alfalfa/grass	153	4697	21	33	126	164	0.90	1.18	6142	2.93
level of p	*	NS	*	NS	*	+	NS	NS	****	**

Appendix I

Individual Field Information Sheet (1)[1]

Farm Name __________________ **Field Name or No.** ___________

Year	**Crop** (Choose from list)	**Yield**[2]	**Straw Removed?**[3]	**Additional Notes**
2000				
2001				
2002				
2003				
2004 [4]				
2005				
2006				
2007				
2008				
2009				
2010				
	Soil Erosion Loss [5]	**Bulk Density**	**% OM** [6]	**PPNT** [7]
2000				
2001				
2002				
2003				
2004				
2005				
2006				

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[1] Use one **Individual Field Information Sheet (1, 2, and 3)** for each field.

[2] **Yield** If there was straw yield, include it with grain yield as tons/acre (For example, 68 bu/a and 2.2 t/a). Grain yields are reported in bu/acre; forage yields are reported as lbs/acre on a dry matter basis (includes corn silage).

[3] **Straw Removed?** If this was a crop that had straw residue remaining after harvest – Was the straw removed for bedding purposes? Enter **Yes** and enter the amount removed under **Yield**. OR Was the straw left on the field as residue? Enter **No** or leave blank.

[4] **2004+** Please list the crops you intend to plant in the future for this field. This will become the crop rotation for this field with projected yields.

[5] **Soil Erosion Loss** Estimated annual soil erosion in tons/acre. If unknown, rate your field slope by the following method: 1 = flat or level (02 % slope); 2 = slightly hilly (26 % slope); 3 = hilly (greater than 6 % slope).

[6] **% Organic Matter** Enter for any years you have OM data used to calculate Active Organic MatterCarbon.

[7] **PPNT** PrePlant Nitrogen Test done in Spring or Pre-Sidedress Nitrogen Test (PSNT) done at lay by. Please be sure to note units (%N, ppm, lbs/acre, etc.) and when the test was done.

2007				
2008				
2009				
2010				

If you have a legume or legume grass in your rotation, please indicate the average % protein you would expect for the crop for the entire year in the box after this text. If unknown, a default values of 18% will be used for alfalfa and 16% will be used for legume/grass mixtures and red clover crops.

☐

Individual Field Information Sheet (2)

Farm Name ________________ **Field Name or No.** __________

Fall or Spring Applied	Year Applied	Fertilizer	Rate (lb/a)	% N	% P_2O_5	% K_2O
	2000					
	2000					
	2001					
	2001					
	2002					
	2002					
	2003					
	2003					
	2004					
	2004					
	2005					
	2005					
	2006					
	2006					
	2007					
	2007					
	2008					
	2008					
	2009					
	2009					
	2010					
	2010					

Individual Field Information Sheet (3)

Farm Name ___________________ **Field Name or No.** ____________

Fall or Spring Year	Manure Type (Choose from list)	Rate (tons/a)	% Dry Matter [1]	Lbs. N (per ton) [2]	Lbs. P_2O_5 (per ton) [2]	Lbs. K_2O (per ton) [2]	Lbs. NH_4N (per ton) [2]	% Ash
2000								
2000								
2001								
2001								
2002								
2002								
2003								
2003								
2004								
2004								
2005								
2005								
2006								
2006								
2007								
2007								
2008								
2008								
2009								
2009								
2010								
2010								

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[1] **% Dry Matter** This value will be found on a routine manure analysis report. If the information is in different units than those listed, please specify.

[2] **Lbs. X (per ton)** This value can be either lbs. per ton or %. IF % please indicate so.

Appendix II

MICHAEL FIELDS
AGRICULTURAL INSTITUTE

January 2005

Dear Farmer,

The Michael Fields Agricultural Institute would like to thank you for your participation and the farm information you have given for this project. This report contains a preliminary Leopold Project Report and a summary of your farm based on the information gathered for the cropping and amendment history of your farm fields. In the reports, farms and fields are referred to by a generic farm number to preserve individual farm identity.

If you would like an electronic copy of the budgeter or of your file data, please contact Rhonda Graef at rlgraef@verizon.net or call 765-743-3717 and leave a message.

Sincerely,

Rhonda Graef Walter Goldstein