# Organic maize, organic matter management, root health, and nitrogen.

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## X.1 Introduction

Maize is the cornerstone crop of North American agriculture but it is also the crop with the largest potential for overuse of nitrogen fertilizer. State Land-Grant universities in the Midwestern USA give recommendations how to fertilize based on empirical experiments carried out under conventional farming systems. Historically, some Universities give credits for N release from manure, but little (Anon. 1999) or no credit for soil organic matter (Hoeft. and Nafziger, 2006). Despite having some of the richest soils in the Midwest, farmers in Illinois for many decades have estimated that they need 21.4 kg of N for every ton of maize grain they predict they will harvest. If they grew soybeans the previous year they credited 16.7 kg of N/ha for every ton of beans harvested the previous cropping year. They then supplied N fertilizer to supply the rest. Unfortunately, such yield-based N recommendations are inaccurate because they do not account for N that is mineralized from soil organic matter, resulting in under or over-fertilization (Mulvaney, et al., 2004). Recently there has been some effort to credit higher production soils for more N (Laboski et al., 2006). However, maize grown on many soils simply does not respond economically to N (Mulvaney, et al., 2004), irrespective of production level, Laboski et al., 2006).

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 cereals even when fertilizers are applied. Many trials with the natural $^{15}N$ isotope have shown that empirical field trials often overestimate N uptake efficiency both from mineral and organic fertilizers. Hence N crediting in the way it has been done in the past is obsolete. The scientific literature shows that N uptake efficiency from $^{15}N$ labeled fertilizers is generally about 1/3rd of that applied (Raun and Johnson, 1999). Uptake from ruminant animal manure is 5-16% of total N applied. Similarly, several $^{15}N$ studies have shown N efficiency from green manures to range from 10-23% (Jensen, 1994, Haynes, 1997, Ma, et al, 2001). The rest of N taken up by cereal crops probably comes mostly from soil organic matter (Jensen, et al., 1999, Thomsen, 2004, Munoz, et al. 2006, Quiroga, et al., 2006).

In attempting to explain why N uptake from mineral N fertilizers was less by the $^{15}N$ technique than by the empirical, standard difference method, Hoeft et al., (1999) stated: *"This differential in results between the two techniques is probably due to the fact that addition of N stimulates plant and root growth, and thus the treated plants are better able to utilize soil N than is the case with the control plots."* In the case of maize, roots strongly enhance mineralization of N from soil organic matter (Sanchez et al., 2002; Ma, et al., 2001). A 'rhizosphere priming effect' due to root exudation and rhizodeposits can cause changes in microbial biomass that accelerate the decomposition of soil organic matter (Kuzyakov, et al., 2000; Kuzyakov, 2002). Fertilization of maize with mineral N (Liljeroth, et al. 1994; Amos and Walters, 2006) or farm yard manure (Ma, et al., 1999) can increase the priming effect, probably by increasing root activity. Loehnis (1926) discovered the priming effect while

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studying the effect of green manures on uptake of N by cereals on rich and poor soils. Janzen and Schaalje (1992) concluded their $^{15}N$ study of the N value of green manures with the following remarks: "*The presence of non-nutritional benefits observed in this study demonstrates that the agronomic value of green manure is not limited to N release and casts doubt on the assumptions inherent to calculation of fertilizer equivalents.*"

The senior author has experienced that organic farmers generally consider conventional soil testing and fertilizer recommendations to be mostly irrelevant to their situations. In general the organic philosophy is to feed the soil with high quality organic matter. It is thought that if this is done the soil will adequately feed all crops. Nitrogen coming from soil organic matter is thought to be important, and some organic farmers may estimate credits from it and from animal manure or green manure crops when they plan how to meet the N need of their crops. Sometimes they credit the full N content of those manures.

The stimulatory effect on yield that is sometimes observed with mineral and organic fertilizers causes both conventional and organic agronomists and farmers to believe that fertilizers are providing the nutrients to grow crops rather than the whole soil. This thinking leads to practices that cause excessive nutrient application and pollution.

The effect of organic manures is not only due to the mineral nutrients that they provide. Organic manures feed soil flora and fauna and the resulting dynamic creates healthy, well structured soils that suppress various root rot problems caused by pathogens such as *Pythium, Phytophthora and Fusarium* ssp (Mazzola 2004). Organic matter additions have also been shown to be effective against root rot nematodes (Abawi and Widmer 2000, Anon. 2006a). Conversely, poor soil quality resulting from compaction and depleted organic matter reserves reduces plant health and increases susceptibility to disease (Bailey and Lazarovits 2003).

Key to the development of suppressive conditions is the supply of young, readily decomposable organic matter such as particulate organic matter (POM) that is colonized with certain non-pathogenic microorganisms (Stone and Hoitink 2001). Compost provides the soil with POM that suppresses diseases (Abawi and Widmer 2000, Stone et al 2004). Such general suppression is thought to last from 5 months to two years (Hoitink, 1977; Darby et al. 2006, Stone et al 2004, Rotenberg, 2005). Suppression of disease can also be created by green manures, but the effect may be of shorter duration.

Increased yields as a result of adding organic matter to soil can be substantial. In a study conducted by Abbas and Hoitink (2002) organic tomatoes amended with compost yielded 33% higher and had greater disease control than plots that did not receive compost. Drinkwater et al. (1995) found that organically managed tomatoes had less corky rot in their roots. There is evidence animal manure composts are particularly effective with 10% increased yields of vegetables over use of plant matter alone (Killeen 2000).

Root disease probably influences uptake of nutrients and organic matter dynamics by affecting root health and root turnover. In the Wisconsin Integrated Cropping Systems Trials root rot in maize was associated with a complex of both *Pythium* and *Fusarium* species (Voland and Rouse, 1992). The positive affect of crop rotations and manure appeared to be associated with healthier roots. Maize grown after maize with conventional management had more diseased roots in early stages of growth than organic maize (Goldstein, 2000). This early disease probably induced a higher production of roots in later phases of development during grain production.

Pertinent to organic farmers is the issue of what kind and how much organic matter and rotations are necessary to maintain healthy soils and productive crops. Based on a preliminary synthesis of knowledge in the field of soil organic matter dynamics, we developed a Organic Matter Budgeter Model to help farmers to plan their use of organic matter and nutrients (Koopmans and Goldstein, 1998). Coefficients for residue production, organic matter retention, turnover, and nitrogen release were based on our data, the scientific literature and multiple runs of the CENTURY model for soil organic matter dynamics (Metherell, et al., 1993). The budgeter was developed from 1988-2004 in conjunction with the USDA-Soil Tilth Lab, Iowa State University, the University of Illinois-Urbana, and cooperating farmers in three states. It is field specific. The model helps farmers identify how farm field balances of active organic matter, total phosphorus, and total potassium 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. It also predicts 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 based on fixed percentages of N mineralization of organic matter under different crops. 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 needed to test and validate our budgeter on real farms. The budgeter was weak on several important pieces of knowledge. First we needed more information on how much N is taken up by different crops. Second, we needed more information on root production for organic matter budgeting. Third, we needed more information on root health and how it affects the availability and uptake of N. This paper will focus on results obtained on these three questions from on-farm trials.

## X.2 Experimental design and site conditions

Tests were carried out in the context of the following projects and farms:

- Year 2000: Root samples were taken on 17 farms in Wisconsin and Illinois with the objective of adapting root analysis techniques developed in plot work for on-farm research. We sampled and analyzed 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. Some of these farms were involved in further trials funded by EQIP and SARE in 2001. Farmers included conventional cash grain and dairy farms and organic dairy farms.
- 2001 EQIP and SARE projects, Wisconsin: 7 farms each, mostly conventional dairy or conventional cash grain; test plots were mostly set out on 2 fields/farm.
- 2001 Leopold Center project, Iowa: 12 farms were organic and conventional grain-livestock and conventional cash grain 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 Center project, Iowa, 11 farms: organic and conventional grain-livestock and conventional cash grain farms; plots were on 1 field/farm only.

The farm fields chosen were all on loams, and mostly silty loams. In 2000, most of the trials involved replicated strip plots (randomized, complete block design) evaluating the use of small grains and green manures on the yields of maize with treatments replicated 1 to 3 times. Our measurements included root production, and root health. Trials in 2001 and 2002 involved sampling for root production and health, but we also analyzed roots, tops, and grain for their N content. In these later two years, treatments consisted of control strips with no fertilization and one or two fertilization treatments, consisting of either of manure, manure + NPK mineral fertilizers, or just NPK mineral fertilizers. Treatments were replicated 2 times on each farm 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 at parallel distances between treaments.

These three stations were visited repeatedly for sampling soils, roots, tops, and grain yields. Yield samples consisted of two one thousandth of an acre samples taken adjacent to each sampling area. Samples from the three stations were pooled for laboratory analysis, with the exception of root health, where we analyzed all three sub-samples individually.

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. Budget predictions included projected change over time of active organic matter, P, K, and the projected surplus mineral N 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. Data from budgets from individual farms were clustered into the following categories: 1) conventional grain cropping without mineral fertilizer; 2) conventional grain cropping with mineral fertilizer; 3) conventional grain cropping with manure; 4) grain cropping that included a small grain + clover green manure; 5) grain cropping that included a small grain + clover green manure + mineral fertilizer; 6) grain cropping that included a small grain + clover green manure + animal manure; 7) grain cropping + a high percent of perennial forages, no fertilizer; and 8) grain cropping + a high percent of perennial forages + manure.

Using the budgeter we calculated gains or losses in active organic matter C on an annual basis over the period for each site. Data from each farming system group was then regressed against the initial C contents of the soils within a group. This enabled us to predict the break even point of total soil organic matter where the soil would be at equilibrium neither gaining nor losing active C for that given farming system.

Farmers involved in the trials used a wide range of fertilization and manure rates based on their experience, practices, type of livestock, and stocking rate and it was not possible to standardize them. The average mineral N application was 128 kg N/ha but varied between 45 and 191 kg N/ha. The pertinent question appeared to be what kind of yield response they could expect to obtain from application of their fertilization practice and how much it would contribute to N uptake.

Contents of nitrate-N and ammonium-N were determined in the top 91.4 cm or the soil profile early in the spring to estimate N carryover from the previous year and again at harvest to estimate residual mineral N. An attempt was made to sample soils in the spring as soon as the frost was out of the profile in order to estimate carryover of mineral N from the previous year, but this only proved possible for Iowa farms in 2001. Soils were analyzed at the University of Wisconsin Soil Testing Lab and the USDA National Soil Tilth Lab for nutrients, and total C and N content. Manure nutrient & C inputs were weighed and measured and used for budgeting.

We measured the actual N-uptake by maize roots, stalks, and grain and by weeds. Grain yields and the content of N in stalks, leaves, and grain was determined at harvest, and grain yields are expressed at 15.5% grain moisture. The N contribution by maize 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 over the season) x plant population/hectare. These relationships were determined empirically based on studies of maize root growth in the Wisconsin Integrated Cropping Systems Trials (Goldstein, 2000).

Our technique for analyzing root disease was the same as that used in the Wisconsin Integrated Cropping Systems Trials (Goldstein, 2000) but it was modified by sampling only at the flowering stage of development. On each plot three crown and root soil monoliths (each was 15.2 cm long x 15.2 cm wide x 20.3 cm deep) from individual maize plants were excavated when the maize was flowering. We sampled the maize at flowering time because this is when the maximum amount of roots are present in the topsoil (Goldstein, 2000). Roots were washed from soil using a spray gun on a hose. All wash material was passed through a 0.5 mm sieve. The intact crown and roots and any displaced roots collected on the sieve were 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 maize was compensating for disease on its smaller, earlier sets of roots by producing large quantities of later developing roots (Goldstein, 2000).

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 maize following after maize, 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 maize. Mineral N fertilizers were not used on organic farms when growing maize. To examine effects of disease we studied how systems affected maize grain yields, root production, root disease, and root production per ton of maize grain and correlated disease with the other characteristics. To examine how systems affected the efficiency of maize and N relationships we analyzed the total uptake of N uptake by maize plants and the amount of N taken up by maize plants for every ton of maize produced.

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

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

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

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

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

System 5 = maize following soybeans on fields with a history of organic practices (including perennial forages and manure);

System 6 = maize following small grains (wheat or oats) under-seeded with clover or alfalfa on fields with a history of organic management practices.

System 7 = maize following alfalfa on fields with a history of organic management practices (including manure applications);

System 8 = maize 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) Maize following after conventional maize or soybeans vs. after organic forages or soybeans;
3) Maize following after conventional maize vs. organic soybeans;
4) Maize following after conventional maize vs. organic alfalfa/grass;
5) Maize following after perennial forages vs. after a small grain/legume green manure;

6) Maize following after soybeans vs. after a small grain/legume green manure;
7) Maize 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 maize to mineral fertilizers or 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 and its relationships to maize yield and roots. Because we were particularly interested in acquisition of N from decaying organic matter we focused our analysis on control plots and plots which had received organic manures. For analyzing maize yield, root production, and the quantity of roots produced per ton of grain we had 100 experiment entries (n = 11, 16, 8, 5, 22, 7, 21, and 10 for systems 1 to 8, respectively). For soil and maize 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 sometimes 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%).

## X.3 Key results

### X.3.1 Soils:

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 (Table 1). 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 mineral fertilizers and animal manure were 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 (see Table 4). The cash grain systems generally had lower organic matter and N contents. Where maize was grown after conventional maize or soybeans the soil N contents in the top 20 cm of the soil averaged 5,000 kg of N/ha, while maize grown after organic soybeans or forages had 5,609 kg of N/hectare (P<0.1%). Perhaps the largest difference was found between maize that followed conventional maize (4,124 kg N/ha) and maize that followed organic alfalfa/grass (6,878 kg N/ha) (P<0.01%). 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.

Studies in Iowa in 2001 on mostly livestock farms suggested that on average the carry-over quantities of mineral N in the soil profile in the spring (65 kg N/ha) were the same as that found in the fall after harvest of the maize for grain (69 kg N/ha).

Table 1. Results of budgeting organic matter for all farms in 2001 and 2002; the correlation between the initial organic matter content and the predicted annual change in active organic matter; the predicted equilibrium level for soil organic matter.

| | Grain Crop rotations no fertilizer | Grain Crops rotations mineral fertilizer | grain crop rotations mineral & manure fertilizer | grain + green manure rotation | grain + green manure rotation + mineral fertilizer | grain + green manure rotation + animal manure | grain + high % of perennial hay no fertilizer | grain + high % of perennial hay + manure |
|---|---|---|---|---|---|---|---|---|
| Number of fields budgeted | 18 | 11 | 14 | 13 | 9 | 8 | 16 | 22 |
| Initial Organic Matter % | 2.96 | 2.25 | 3.11 | 2.5 | 1.98 | 2.24 | 3.52 | 3.3 |
| Predicted average annual change in active organic matter kg/ha | -325 | -17 | 104 | -118 | 15 | 250 | 55 | 390 |
| equilibrium level of soil organic matter % | 1.72 | 2.17 | 3.31 | 2.13 | 2.02 | 2.99 | 3.88 | 5.35 |
| Coefficient of determination ($R^2$) | 0.7 | 0.43 | 0.58 | 0.77 | 0.75 | 0.56 | 0.47 | 0.33 |
| Significance level P | 0.01 | 0.05 | 0.01 | 0.05 | 0.01 | 0.01 | 0.01 | 0.01 |

## X.3.2 Crops:

In the 2001 and 2002 trials, maize plants took up less nitrogen from fertilizers and more nitrogen from native soil organic matter sources than we had expected. The yield response to fertilization was also far lower than we had expected. A total of 20 trials were carried out with unfertilized controls and fertilization with mineral fertilizers on conventional fields. Fertilization increased root production 8% (from 5555 and 6112 kg/ha), N uptake by 13% (233 to 263 kg/ha), and yield by 8% (6984 to 7551 kg/ha). A total of 47 trials were carried out on organic and conventional farms with unfertilized controls and different organic manures. Fertilization increased root production by 2% (5203 to 5318 kg/ha), N uptake by 10% (190 to 209 kg/ha), and yield by 4% (7676 to 7991 kg/ha).

There were striking differences in root health according to management practices. Root disease affected crop yield potential and N use efficiency (Table 2, 3, and 4)**.** Three years of field trials (see Table 2 for data from 2000, 2001, and 2002) indicated that maize had almost twice as high disease scores where it was grown under conventional systems (26% necrotic roots) relative to grown in organic systems (15% necrotic roots) (difference significant at P<0.08%). The highest disease incidence was found where maize followed maize (30%) and the least disease was found where maize followed organic soybeans (15%) (difference significant at P<0.01%). Maize grown after maize or soybeans in conventional systems also had more disease than maize grown after soybeans or perennial forages in organic systems (difference significant at P<0.3%).

**Table 2. Root disease found in different fields from 2000 to 2002. Values represent specific farming systems on specific fields and are averages across fertilization treatments.**

| Farming System | Preceding crop | Number of experiments | % Root disease |
|---|---|---|---|
| conventional | maize | 9 | 30 |
| conventional | soybeans | 15 | 27 |

| | | | |
|---|---|---|---|
| conventional | small grains/clover | 21 | 23 |
| conventional | alfalfa | 2 | 24 |
| organic | soybeans | 13 | 14 |
| organic | small grains/clover | 4 | 15 |
| organic | alfalfa | 12 | 15 |
| organic | alfalfa/grass | 3 | 21 |
| Total or average | | 79 | 21 |

Tables 3 and 4 summarize results obtained for the different farming systems in 2001 and 2002 for yield, root production, root disease, and N uptake. These tables show results only from unfertilized control plots and plots that received animal manures. The intent is to show uptake of N by maize under conditions where N could largely be obtained only from decaying organic matter. Yields were slightly lower in conventional systems, but not significantly. Maize yields for the different systems were comparable with two exceptions. Maize grown organically after small grains/clover produced unusually low yields (4,954 kg/ha). These low yields appeared in most cases to be associated with unusually low root production and problems with weed competition. On the other hand, maize grown on organic fields after alfalfa-grass mixtures produced exceptionally high yields (9,595 kg/ha).

Table 3. Relationships between grain yield, root production of maize, root disease, and N content of topsoil. Maize was either not fertilized or fertilized with manure, and grown on conventional and organic farms in Iowa, Illinois, and Wisconsin in 2001 and 2002.

| Farming System | Preceding crop | Number of experiments | Grain yld kg/ha | Roots kg/ha | Root disease % | kg root/kg grain | N uptake maize kg/ha | N uptake kg/ton of grain | Total organic N in topsoil kg/ha |
|---|---|---|---|---|---|---|---|---|---|
| conventional | maize | 11 (9) | 6459 | 5187 | 23 | 1.61 | 236 | 36 | 4124 |
| conventional | soybeans | 16 | 7713 | 6320 | 21 | 0.86 | 223 | 30 | 5493 |
| conventional | small grains/clover | 8 (7) | 6961 | 4175 | 19 | 0.82 | 218 | 36 | 4300 |
| conventional | alfalfa | 5 | 7713 | 5670 | 19 | 0.80 | 227 | 30 | 6666 |
| organic | soybeans | 22 | 7713 | 4835 | 13 | 0.64 | 197 | 27 | 6315 |
| organic | small grains/clover | 7 (6) | 4954 | 3966 | 11 | 1.09 | 161 | 44 | 4574 |
| organic | alfalfa | 21(20) | 7337 | 4984 | 15 | 0.77 | 188 | 26 | 4454 |
| organic | alfalfa/grass | 10 (6) | 9595 | 5260 | 21 | 0.59 | 141 | 16 | 6878 |
| Total or average | | 100 (91) | 7337 | 5044 | 18 | 0.89 | 199 | 31 | 5351 |

Table 4. Summary of comparisons for maize grown on conventional and organic farms in different cropping sequences from 2001 to 2002 in Iowa, Illinois, and Wisconsin.

| | Grain yield kg/ha | Roots kg/ha | Root disease % | Kg roots/kg grain | N uptake by maize kg/ha | N uptake kg/ton of grain | total organic N in topsoil kg/ha |
|---|---|---|---|---|---|---|---|
| conventional management vs Organic management systems | 7212 | 5495 | 21 | 1.05 | 226 | 33 | 5093 |
| | 7588 | 4854 | 15 | 0.73 | 184 | 27 | 5495 |
| P | NS | * | ** | NS | ** | NS | NS |
| | | | | | | | |
| after conv maize & soy vs after organic soybeans | 7212 | 5856 | 22 | 1.16 | 227 | 32 | 5000 |
| | 7901 | 4972 | 15 | 0.68 | 186 | 25 | 5609 |
| P | NS | ** | ** | * | ** | * | *** |
| | | | | | | | |
| after conv maize vs after organic soybeans, forages | 6459 | 5184 | 23 | 1.61 | 236 | 36 | 4124 |
| | 7713 | 4833 | 13 | 0.64 | 197 | 27 | 6315 |
| P | NS | + | *** | * | NS | NS | *** |
| | | | | | | | |
| after conv maize vs after | 6459 | 5184 | 23 | 1.61 | 236 | 36 | 4124 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| organic alfalfa/grass | 9595 | 5257 | 21 | 0.59 | 141 | 16 | 6878 |
| P | NS | NS | NS | * | ** | ** | **** |
| | | | | | | | |
| after forages vs after small grain/legume | 8027 | 5153 | 17 | 0.73 | 185 | 25 | 5280 |
| | 6020 | 4075 | 15 | 0.95 | 193 | 40 | 4427 |
| P | * | + | NS | NS | NS | *** | ** |
| | | | | | | | |
| after soybeans vs after small grain/legume | 7713 | 5457 | 17 | 0.73 | 208 | 28 | 5969 |
| | 6020 | 4075 | 15 | 0.95 | 193 | 40 | 4427 |
| P | + | * | NS | NS | * | ** | * |
| | | | | | | | |
| after organic alfalfa vs after organic alfalfa/grass | 7337 | 4982 | 15 | 0.77 | 188 | 26 | 4454 |
| | 9595 | 5257 | 21 | 0.59 | 141 | 16 | 6878 |
| P | * | NS | * | NS | * | NS | **** |

In trials conducted in 2001 and 2002 maize grown conventionally produced more roots than organic maize (5495 vs. 4854 kg/ha, p < 5%). Unfertilized maize grown on 27 sites after maize or soybeans in conventional systems produced more (P<1%) roots (5,856 kg/ha) than maize grown in the unfertilized organic systems on 53 sites after soybeans or forages (4,972 kg/ha). Grain yields did not differ significantly (7,212and 7,588 kg/ha for conventional and organic, respectively).

The ratio between root production and grain yield was reflected in differences in kg of dry roots per kg of maize grain produced. On average, maize grown conventionally after maize and soybeans on 27 sites had root/grain ratios of 1.16, while maize grown organically after forages or soybeans on 53 sites had root/grain ratios of 0.68. The highest average root/grain ratios were found with maize following maize on conventional fields (1.61) and the lowest ratios were found where maize followed alfalfa/grass mixtures on organic fields (0.59) (difference significant at p < 5%). This ratio data was not normally distributed, and isolated crop failures resulted in extremely high root/grain ratios. This probably especially the case where maize followed maize under conventional management and small grain/clover mixtures under organic production. In this situation, maize growth appeared to be stunted, root production was low, and maize seemed susceptible to weed competition.

By shifting its resources away from grain production and towards root production, the conventional maize took up more N from the soil than the organic maize (average 226 vs. 184 kg/ha, P < 1%). Maize plants grown after maize or soybeans in conventional systems took up 32 lbs of N for every ton of grain produced, while maize grown after soybeans or forages in the organic systems took up 25 kg of N for every ton of grain produced (difference significant at P < 5%). Maize that followed maize on conventional fields took up 36 kg of N/ton of grain, while maize that followed alfalfa/grass mixtures on organic fields yielded very well and took up only 16 kg of N/ton (P < 1%). Maize grown after small grain/legume green manures was also highly inefficient at converting N to yield (40 kg of N taken up/ton of grain), while maize after soybeans was intermediate (28 kg of N taken up/ton of grain).

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 taken up by corn plants. Over all sites, root production appeared to correlate in a positive fashion with yield for conventional systems where maize followed maize or soybeans (R2 = 0.41 **) but not for organic systems where maize followed after perennial forages or soybeans.

## X3.3 Discussion

The results of this trial challenge the common paradigm of fertilizer N, N uptake by maize, and organic matter. They also challenge a central tenet of our budgeter.

The overall grain yield response to fertilization in 67 trials was only 5% which was much lower than we expected, even for a single year without use of fertilizer. These results are of practical concern to farmers and the public because low N fertilizer responses by maize have large financial and environmental implications. Fertilizer trials like these should be repeated on working farms rather than on test plots where soils of poor condition may be chosen for giving clear fertilizer responses. The trials confirm that the vast majority of N taken up by maize on these medium textured soils is coming from non-fertilizer sources. Many of the farms had a history of being supplied with organic manures in the past. These soils probably correspond to the fertilizer unresponsive soils characterized by Mulvaney, et al., (2004) and Laboski et al. (2006).

Parallel studies with continuous maize rotation in the year 2000 in the Wisconsin Integrated Cropping Systems trial indicated a classical, large quadratic response to levels of fertilization with mineral N. However, under on the farms we tested such strong effects of fertilization on yield were not predominant.

Disease probably affected resource allocation by the maize plants and their need for nitrogen. Conventional maize grew more roots under unfertilized conditions than organic maize. This may have been to compensate for poorer soil quality and greater root disease problems (Goldstein, 2000). Increased root disease in the early stages of growth of corn has been linked with enhanced, compensatory root growth in the later phases of growth (Goldstein, 2000). This may account for 'the rotation effect' or lower yield associated with poor rotations as additional root formation for the conventional maize takes place at the same time as grain fill and there is competition for internal plant resources.

Adding mineral N fertilizer to conventional systems stimulated root growth. A major role of N fertilizer may be to help maize to outgrow root disease and thereby access more N from soil organic matter. Hoeft et al's. (1999) explanation of the priming affect of N fertilizers on maize yields is in line with this but they did not address the potential role of root disease in the response to N fertilizer.

The practical disease suppression achieved by some of the organic farmers appeared to be an accumulative effect associated with history of organic matter use. Maize grown in different organic-type systems had variable amounts of root disease. Farms with a history of manure use generally had less rot, especially where manure was composted. On one organic/biodynamic farm that had a history of over 60 years of good rotations and compost application we found no significant visible symptoms of root rot in two fields. However, on several farms, where farmers were either organic or were trying out organics, maize grown after small grains with under-seeded green manure legumes such as red clover had greater amounts of root disease, and lower root and grain production. Maize grown after green manures was also highly inefficient at converting N to yield and competed poorly with weeds.

The most efficient systems for transforming soil organic N into grain were where maize followed after alfalfa, alfalfa + grass, or after soybeans in an organic rotation that included perennial forages and routine applications of animal manure. The budgeter predicted that these forage-and-livestock based systems also had the greatest potential for carbon sequestration in soil organic matter.

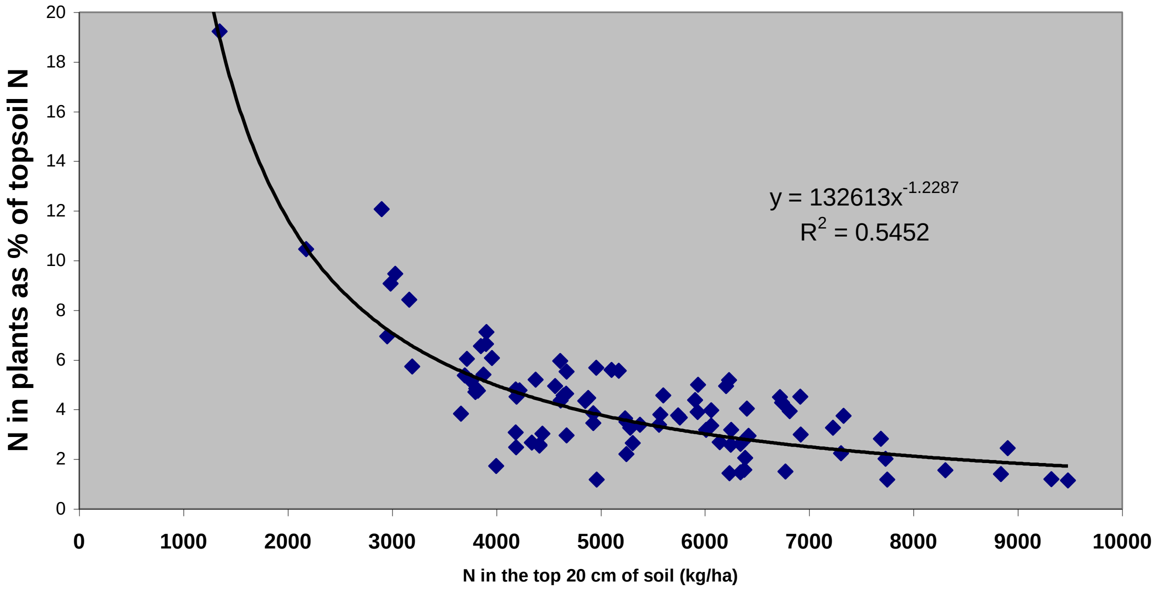
The average amount of residual N available in the spring was almost exactly equal to the amount found after harvest. The region is characterized with dry cold winters and probably little leaching occurs during those months.

Though the vast quantity of N taken up by maize probably came from soil organic matter there was no relationship between the N content of the topsoil and quantity of N taken up by maize ($R^2 = 0.04$). Maize seemed capable of extracting N from both poor and rich soils in similar quantities. Some evidence exists that breeding maize for increased yield may have increased its ability to extract N from soil organic matter (Ma, et al. 2001).

The N taken up by maize in the unfertilized and manured plots is probably a conservatively low estimate of the N mineralized out of organic matter in the soil because it does not take into account losses due to denitrification, leaching, and volatilization of mineral N. Nevertheless, if we take the update data as a *low* estimate of mineralization, the amounts obtained from soil organic matter are still large in proportion to the total amount of N in the topsoil.  Averages range from 2.1% for maize following alfalfa/grass on rich soils to 5.7% for maize following maize on soils with lower N contents (Table 3).

Diagram 1 shows N uptake by maize and weeds, expressed as a percent of the total N content of the topsoil (y), regressed against the total content of N in the topsoil (x).  These results show a generally curvilinear relationship.  Under the conditions of our trials maize took up the N that it needed irrespective of the N content of the soil.  A central tenet of our budgeter, that mineralization of N can be expressed as a fixed percentage of organic matter, is obviously incorrect.  Root growth seems to be driving N uptake more than the quantity of soil organic N.

**Diagram 1. Relationship between N content of the topsoil and the N in maize and weeds as a percentage of the topsoil N**




The research calls into question how maize manages to extract large quantities of N from soil organic matter.  In addition to the large diameter, relatively heavy adventitious and seminal root systems we were extracting and measuring there were many fine roots (<0.5 mm in diameter) which seemed to proliferate in areas of particulate organic matter. Often it was difficult to distinguish these fine roots from particulate organic matter and they often occurred together with mucilaginous material.  According to others these fine roots make up 70 or 96-98% of total root length (Pallant et al., 1993; Costa et al., 2002) produced by maize though the mass of these roots is relatively small.  These fine roots probably constitute the active uptake region for the plant where N may be obtained from particulate organic matter in conjunction with microbial activity.

In summary, the results suggest that fertilizer effects on the grain yield of maize were not as large as is commonly imagined, at least in the first year of holding back on fertilizer. However, root disease is an epidemic problem, especially for conventional maize, and it influences N use efficiency. Organic systems, especially those associated with the use of perennial forages and animal manures, engender root health and greater N-efficiency. We hypothesize that N fertilizer may have value in conventional systems not only as a nutrient but also as a stimulant to help maize outgrow root disease.

The results also clarify that for an organic matter and nutrient budgeting system to be applicable for both conventional and organic systems if it needs to accurately model root health or disease and its implications for root growth, N uptake, and yield.

A long-term approach to managing N means making better use of the soil's ability to supply nutrients, and optimizing the health and yield potential of the crop. The results of these trials support the need for a new paradigm. This new paradigm should conceive of healthy crops as active players in obtaining N from the soil, recognize relationships between farming systems and soil health, and correctly assess the role that fertilizers play not only as nutrient providers but also as stimulants to root growth and microbial induced mineralization of N.

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