Soil Organic Matter Dynamics in the North American Corn Belt: The Arlington Plots

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Site Description

The plots are located at the University of Wisconsin Arlington Agricultural Research Station in south central Wisconsin, USA, approximately 25 km north of Madison (43°18'N; 89°21'W). The climate is cool temperate and arable crops form the present ecosystem. Monthly mean temperatures are -9.1 and 21.8°C for January and July, respectively. Mean annual precipitation totals 79.1 cm. The climate of this area normally provides 47.2 cm of precipitation and 2,570 growing degree days (50°F base) from May 1 to September 30, which closely matches the normal frost-free period of 172 days (data for 1961-1990). Meteorological data from the site (1958-1991) includes daily rain and air temperature. Daily records containing solar radiation, wind speed, relative humidity, dew point and potential ET data are provided from Madison.

Prairie vegetation originally covered the area. Soil at the site is a Plano silt loam (fine-silty, mixed, mesic, Typic Argiudolls) developed from loess deposits 90 cm or more in depth over calcareous loam glacial till. These dark, well-drained soils are some of the most fertile and productive in the U.S. Corn Belt region. The soil at the site was poorly managed for approximately 25 years before establishment of the experiment in 1958; corn stalks were even burned to facilitate plowing. The site has been maintained in continuous corn with residues returned to the soil since 1958. Visual observations and penetrometer

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measurements as well as workability of the soil indicated the soil tilth improved during the continuous corn experiment.

Continuous Corn Nitrogen Fertilization Study (1958-1983)

Fertility treatments during 1958 through 1962 involved three rates of fertilizer N (0, 56, and 112 kg N ha^{-1} as ammonium nitrate) and use of differential rates of starter NPK fertilizer (6-24-24). Beginning in 1963, annual N application rates were 0, 92-140 and 184-280 kg N ha^{-1} for the control, medium and high rate treatments respectively, applied as anhydrous ammonia. Since 1963, all plots received 224 kg ha^{-1} yr^{-1} of starter fertilizer (6-24-24) providing 13 Kg N ha^{-1} yr^{-1}. These three long-term N fertilizer treatments (LTN1, LTN2 and LTN3) were continued until the 1983 growing season without lime applications. The initial average soil test values (1958 data) at the site were: pH 6.75; available P, 20 mg kg^{-1}; exchangeable K, 87 mg kg^{-1}; and soil C, 18.8 g kg^{-1}. Corn was harvested for grain each year, and the residues were returned to the soil. Yield parameters were determined all years except for the 1963-1967 period. Average grain yields in treatments receiving recommended rates were 5,700 kg ha^{-1} at the beginning of the study (1958-1962) and gradually increased with time (8,200 kg ha^{-1} for 1979-1983) due to improved corn hybrids, soil tilth, and cultural practices (Vanotti *et al.*, 1995). Corn grain yields were markedly affected by N application rate (Fig. 1). Responses to fertilizer N applied above the standard recommendation (LTN2) were usually small.

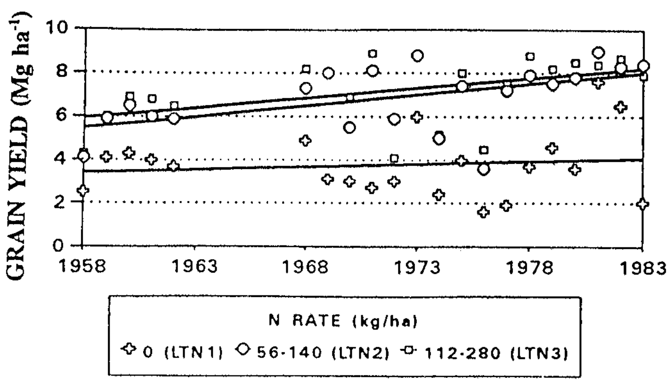

Figure 1. *Corn grain yields at three long-term N fertilizer rates. Arlington Plots. 1958-1983.*

Soil Organic Nitrogen

Total soil N was significantly affected by LTN treatment ($LSD_{0.05}$=0.14 g kg^{-1}) (Table 1). The high LTN treatment resulted in 735 and 206 kg N ha^{-1} (0-20 cm) more soil N content than LTN1 and LTN2, respectively. These values are similar to differences in total stover N returned to soil during the same period. Although net N inputs (N applied - grain N harvest) were markedly different, the final (1984) soil C/N ratios were not affected by treatment. This suggests that soil N stabilization processes in this study were regulated by C input availability.

Table 1. *Nitrogen balance for continuous corn after long-term N fertilization*

	Total Nitrogen (1958-1983), kg ha^{-1}				Soil Organic Matter(1984)	
Treatments	Applied	Grain	Stover	Net	Nitrogen, g kg^{-1}	C/N
LTN1	315	1053	676	-738	1.56	12.6
LTN2	3088	2038	1404	1050	1.74	12.7
LTN3	5825	2180	1534	3645	1.81	12.3

Soil Organic Carbon

Initial soil C was very low at 18.8 g kg^{-1} compared with an uncultivated site which had 22.6 g kg^{-1} soil C (Vanotti *et al.*, 1995). Under continuous corn, removal of corn residues can severely deplete organic matter content of Corn Belt prairie-derived soils (Larson *et al.*, 1972). After 26 years of corn monoculture with residues returned to soil, the soil C content increased in all N treatments ($LSD_{0.05}$=1.7 g kg^{-1}) (Table 2). Changes in soil C were proportional to the amount of residue returned, increasing at an annual rate of 0.045 g kg^{-1} for every 1,000 kg ha^{-1} yr^{-1} of corn stover above 5100 kg ha^{-1} yr^{-1} (Fig. 2). This is in agreement with data reported by Larson *et al.* (1972) after 11 years of continuous corn production on an Iowa Mollisol with an initial soil C content similar to that of the Arlington plots. In the Iowa experiment, soil C increased at an annual rate of 0.043 g kg^{-1} per 1,000 kg ha^{-1} yr^{-1} of corn stover returned in excess of 5,700 kg ha^{-1} yr^{-1}. It was estimated that net soil C losses will occur for quantities of corn residues returned below 5,700 kg ha yr^{-1} (Larson *et al.*, 1972).

Table 2. *Changes in soil organic carbon as affected by plant carbon inputs. 1958-1984*

Treatments	Stover Biomass, Mg ha^{-1} yr^{-1}	Total Plant C to Soil, g kg^{-1}	Soil Organic C, g kg^{-1} 1958	Soil Organic C, g kg^{-1} 1984	Soil C Stabilization Efficiency, %
LTN1	5.7	23	18.8	19.6	--
LTN2	7.7	31	18.8	22.0	30
LTN3	8.0	32	18.8	22.2	29

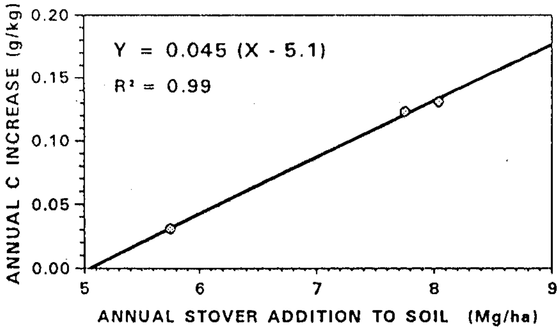

Figure 2. *Relationship between the amount of corn residue returned to soil and the annual rate of soil carbon increase.*

We calculated the soil C stabilization efficiencies for the fertilized treatments by comparing changes in soil C and plant C inputs for these treatments with changes in control (LTN1) levels over the 1958 to 1984 period. Values obtained (Table 2) are slightly higher than efficiencies of 25 to 27 % obtained by Parton & Rasmussen (1994) at the Pendleton site in plots receiving high N fertilizer treatment.

Residual N Effects of Long-term N Fertilization (1984-1991)

In 1984, the long-term N treatments were discontinued and each of the original plots was subdivided to determine the residual effects of the LTN treatments on corn response to N fertilization (Motavalli *et al.*, 1992). Urea N was applied at 0, 84, 168, and 252 kg N ha^{-1} and immediately incorporated by tillage in each of the LTN treatments from 1984 through 1991. These short-term N fertilizer treatments will be referred to as N0, N84, N168, and N252, respectively. As expected, the long history of N application increased soil acidity because of nitrification of ammonia fertilizer. The resulting pH values in 1984 were 6.1, 5.5

and 5.0 for LTN1, LTN2 and LTN3 plots, respectively. Lime was imposed as an additional split treatment in spring 1985, to study its influence on yield in response to applied and residual soil N (Bundy *et al.*, 1988). Variable lime rates were applied to raise soil pH to 6.9. Samples taken in 1990 indicated that all limed plots had a uniform pH of 6.6. Ten treatments were selected for the SOMNET dataset, which include limed and unlimed plots receiving continuous N treatment from 1958 through 1991 (Check= LTN1-N0; medium rate LTN2-N84; and high rate= LTN3-N168), and LTN plots that received no N fertilizer after 1983 (LTN2-N0 and LTN3-N0).

Effects on Corn Productivity

On plots where long-term additions were halted, the supply of mineralized N was an important factor affecting corn yields in subsequent harvests. In 1984, this response was likely a result of residual inorganic N carryover from previous fertilizer addition (86, 176 and 306 kg nitrate-N ha^{-1}, 0-90 cm, in LTN1, LTN2 and LTN3 treatments, respectively).

Table 3. *Residual effects of long-term nitrogen fertilization on corn productivity*

	Grain Yield Mg ha^{-1} yr^{-1}		Grain N Removal kg ha^{-1} yr^{-1}		Plant N uptake, kg ha^{-1} yr^{-1}		NO_3-N* kg ha^{-1} yr^{-1}
Treatments	- Lime	+ Lime	- Lime	+ Lime	- Lime	+ Lime	+ Lime
				<u>1985-1989</u>			
LTN1-N0	4.66	5.42	48	56	90	104	52
LTN2-N0	6.17	6.07	62	59	120	111	60
LTN3-N0	6.74	7.88	72	86	131	145	70
				<u>1990-1991</u>			
LTN1-N0	3.79	3.94	37	39	71	70	42
LTN2-N0	4.34	5.63	52	59	91	100	50
LTN3-N0	4.55	6.38	47	70	88	123	51

* in profile

However, differences in profile inorganic-N content in subsequent years were not large enough to account for the marked response to LTN treatments observed (Motavalli *et al.*, 1992). These responses were more likely due to changes in the soil's mineralizable N pool after long-term N fertilizer additions. Treatments with a history of high N fertilization but with a 0 N rate during 1984 through 1991 (LTN3 N0) produced average grain yields 2110 kg ha^{-1} yr^{-1} higher than plots receiving no N since 1958 (LTN1 N0) (Table 3). Total N uptake and grain N removal were also affected by the residual effects of long-term N fertilization, with an average increase for the same treatments of 40 and 26 kg N ha^{-1} yr^{-1}, respectively.

Corn productivity was also enhanced by the 1985 lime application. Responses to liming were greatest at the high LTN treatment and low 1985-1991 N rate. Addition of N fertilizer offset most of the lime effect, suggesting that yield response to liming was in part due to differences in soil N availability. Since the effect of liming on corn productivity was more pronounced in plots where corn N nutrition depended on soil N reserves, it is possible that liming provided a better environment for microbial activity and N cycling, resulting in higher N mineralization rates. Cornfield (1952) compared the mineralization rates of numerous acid soils in Great Britain having a range of pH values and found that the positive response to liming decreased as original soil pH increased. Results from field experiments on newly cultivated acid soils in Canada showed that, although liming increased mineralization, it is generally a temporary effect lasting no more than 3 years (Nyborg & Hoyt, 1978). In the Arlington plots, however, the liming effect on N cycling, as measured by corn N uptake and grain removal, was still noticeable 6 years after lime application (Table 3).

Effects on Soil Organic Matter

Split treatments imposed in 1984 (N rates) and 1985 (lime) provided information on the stability of SOM pools formed after long-term N fertilization. Total soil N was much more sensitive to changes in management practices than total soil C (Fig. 3). Soil N content was significantly reduced 6 years after discontinuing N fertilization, consistent with the residual effects on corn production observed during the same period (Table 3). In the -N treatments, soil N changes between 1984 and 1990 were similar in magnitude to those produced after 32 years of differential N fertilization. For example, 1990 soil N level in LTN3 -N plots decreased to that found in 1984 LTN2 plots, while soil N level in LTN2 -N plots approached the 1984 LTN1 level (Fig. 3b).

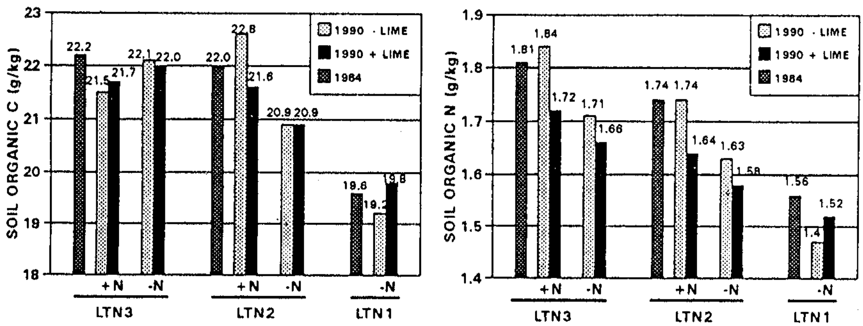

Figure 3. *Short-term N and lime treatments effect on total soil organic carbon (a) and nitrogen (b).*

In plots receiving continuous N treatments from 1958 through 1989 (LTN2 N84 and LTN3 N168), the soil N content between 1984 and 1990 was maintained in unlimed plots, but reduced by 6% where lime was added (Fig. 3b). Fu *et al.* (1987) found a two-fold reduction in N turnover from corn residues mixed and incubated with three Iowa soils that were adjusted to pH 4 relative to the same soils adjusted to pH 6. The rapid decline in soil N levels observed in the limed plots at Arlington suggest that a significant fraction of the soil N formed after a long history of NH_3-N fertilization is made up of highly labile materials, and its N turnover is limited by a fertilizer induced acid environment.

Labile Fractions of Soil Organic Matter

Fractions of SOM involved in rapid C and N turnover in soil are expected to have the greatest sensitivity to N management and cropping practices. Microbial biomass was determined by chloroform fumigation incubation method (10 d fumigated minus control, 25 °C, k_c = 0.45). Total net C and N mineralization was determined by aerobic leachingincubation procedure at 35 °C and 80 kPa (Vanotti *et al.*, 1995). Where lime was applied, less mineralizable N was recovered in 1990, which corresponds with the higher organic N released and removed in grain during the previous 5 yr. The effect of long-term N fertilization on C and N mineralization was more pronounced than its effect on total soil C and N. The difference in soil C mineralization between the highest and lowest LTN treatments was about six times as much as the observed difference in soil C, while for N components mineralization is three times as sensitive as total N (Table 4).

Table 4. *Effect of long-term N fertilization on total and labile soil organic matter (1990 data).*

	Total Soil Organic Matter, g kg^{-1}		Net Mineralization, mg kg^{-1}	
Treatment	Carbon	Nitrogen	Carbon	Nitrogen
LTN1-N0	19.2	1.47	2234	83
LTN3-N168	21.5	1.84	3721	140
Increase (%)	12.0	25.2	66.6	68.7

The biomass-C level in 1990 was significantly affected by the liming treatment ($P < 0.01$), but it was insensitive to N treatment (limed plots = 202 mg C kg^{-1} or 0.9 % of soil C; unlimed plots = 155 mg C kg^{-1} or 0.7 % of soil C) (Fig. 4). Nitrogen content of the biomass was similar across lime and N treatment (mean = 24 mg N kg^{-1} or 70 kg N ha^{-1}, 0-20 cm).

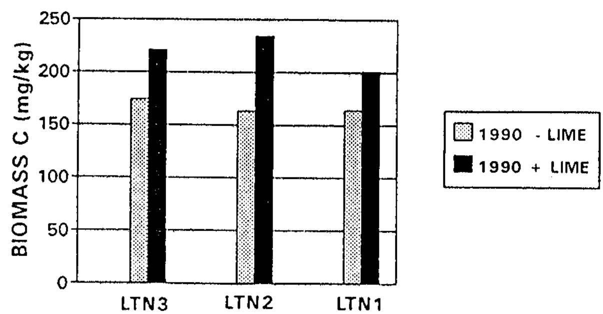

Figure 4. *Liming provided a better soil environment for microbial growth (1990 data).*

Summary

Our objective was to analyze the interactions between N fertilization and crop productivity as they affect SOM dynamics and soil N reserves in a long-term continuous corn experiment in the U.S. Corn Belt. We also contribute soil, crop production, and climatic data needed to integrate the numerous factors affecting SOM in temperate regions, and to evaluate models designed to predict land use effects on SOM and global carbon cycling. Soil management practices at the Arlington plots had a major influence on the changes in SOM content. A shift in corn stover residue management from burning to soil incorporation resulted in a net gain in SOM. Changes in soil C were linear with respect to annual C input rates, which were associated with N fertility management. Long-term NH_3 fertilizer additions significantly increased soil organic N reserves. This practice also increased soil acidity. On plots where long-term N additions were halted, the supply of mineralized N was an important factor affecting corn yields in subsequent harvests. Lime amendments resulted in higher N mineralization rates, and consequently in a more rapid decline in soil N levels. Microbial biomass was also higher in the lime amended plots. The magnitude of soil N changes after 6 years without N fertilization at optimum soil pH were equivalent to those realized after 32 years of differential N fertilization. This indicated that most of the fertilizer N was stored in relatively labile soil organic fractions. Mineralizable C and N pools measured in aerobic incubations were more sensitive indicators than total C and N of the effect of previous soil management on newly formed SOM.

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