FIFTY YEARS OF CONTINUOUS CORN: EFFECTS ON SOIL FERTILITY

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Introduction

Long-term experiments provide an opportunity to evaluate the sustainability of agricultural practices (Jenkinson, 1991). Evidence of sustainability in continuous corn production systems would include stable or increasing productivity over time as indicated by crop yields and maintenance or enhancement of key soil fertility factors such as soil organic matter content. The objectives of this paper are to present results from a 50-yr experiment showing the effects of long-term continuous corn and N-fertilizer use on corn yields, response to applied N and lime treatments, and effects of the long-term treatments on soil organic matter content and soil pH.

Materials and Methods

This long-term continuous corn experiment is located at the Arlington Research Station (43°18'N; 89°21'W), approximately 42 km north of Madison, WI. The soil at the site is a Plano silt loam (fine-silty, mixed mesic, Typic Argiudolls) developed under prairie vegetation in loess deposits over glacial till (Vanotti and Bundy, 1996). The site has 0 to 1% slope and low soil erosion potential. Initial treatments consisted of three N rates (applied as ammonium nitrate) arranged in a randomized complete block design with four replications (Andrew et al., 1963). Subsequent N and lime treatments were incorporated into the experimental design using a split-plot treatment combination (Motavalli et al., 1992). Nitrogen was applied as anhydrous ammonia from 1963-1984 and from 1993-2007. Nitrogen rates changed over time (Table 1), and during 1984 to 1992, each long-term N treatment received N rates of 0, 84, 168, and 252 kg N ha^{-1} as urea to study the residual effects of the original N treatments on N availability to corn (Motavalli et al., 1992). During this period, data for the medium LTN rate were taken from the 168 kg N ha^{-1} treatment and data for the high LTN rate were taken from the 252 kg N ha^{-1} treatment. In 1985, one-half of each long-term N plot was limed to raise the pH to 6.5-7.0. An additional lime application was made in 1988 to achieve the desired pH range. Dolomitic limestone with a neutralizing index value of 80-89 was used for the lime applications.

Corn was grown in the experimental area each year since 1958 using adapted hybrids and recommended pest management methods. At corn planting, starter fertilizer was applied each year as a band 5 cm below and 5 cm to one side of the seed. The average (1958- 2007) annual rate of nutrients applied in starter fertilizer was 10, 19, and 37 kg ha^{-1} of N, P, and K, respectively.

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Broadcast applications of K fertilizer [as 0-0-60 ($N-P_2O_5-K_2O$)] were made to the entire experiment at a rate of 112 kg K ha^{-1} in both 1987 and 1991. Since 1984, corn was grown in 76-cm rows with seeding rates of 79,000 to 86,000 seeds ha^{-1}. The hybrids used were selected from those that performed well in the Wisconsin Corn Hybrid Trials conducted at the Arlington Research Station (see Lauer, 2010). Hybrids and soil insecticides used since 1986 are listed in Table 2. Hybrids with transgenic traits have been used since 1999. Corn was harvested for grain each year and all residues were incorporated into the soil by moldboard plowing in the spring (1958-1983) or fall (1984-2007). Although chisel plowing currently is the typical tillage practice for corn production in the region, moldboard plowing was the prevailing tillage method when the experiment was initiated in 1958, and this tillage was continued through 2007 to maintain cultural practice continuity throughout the long-term study. Grain yields are reported at a moisture content of 155 g kg^{-1}.

Initial (1958) soil test levels in the experimental area were: pH 6.5 to 7.0; available P 15 to 25 mg kg^{-1}; exchangeable K 80 to 95 mg kg^{-1}; and organic matter 30 to 35 g kg^{-1} (Andrew et al., 1963). Soil samples (0 to 15 cm) were collected periodically during the course of the experiment and were analyzed for available P, exchangeable K, pH, and organic matter (Kelling et al., 1991; Laboski et al., 2006). Soil samples (six to eight cores/plot) were obtained from four replications of each of the three LTN treatments. After lime treatments were applied in 1985, soil samples were taken from both lime treatments. Before 1991, soil organic matter was determined using the colorimetric chromic acid oxidation procedure described by Combs and Nathan (1998). Organic matter in soil samples collected in 1991 and subsequent years was measured using the loss of weight on ignition method (Combs and Nathan, 1998; Schulte et al., 1991). From 1984 to 2005, soil tests averaged 58 mg kg^{-1} for P and 140 mg kg^{-1} for K. These soil test results for P and K confirmed that levels of these nutrients equaled or exceeded the optimum levels recommended for corn production at the study site (Laboski et al., 2006).

Results and Discussion

At the medium and high LTN rates, yields increased during the 1958 to 1983 period (Fig. 1). Some of this increase could be due to the increase in the LTN rates during this time period. From 1984 through 2007, medium and high LTN rates significantly increased corn yields every year compared to the control LTN rate (Fig. 1). When the data was combined over years, yields were significantly increased ($p<0.01$) by LTN additions, but were not significantly different between the medium and high LTN rate treatments. Yields at both medium and high LTN rates increased dramatically (100%) over time with little difference between the two rates (Fig.1). For the 50-yr period (1958-2007), yields in the medium and high LTN treatments increased linearly by about 150 kg ha^{-1} yr^{-1} while yields in the control LTN treatment have remained relatively constant over time. After 1985, data shown in Fig.1 are from the with lime treatment. A similar pattern of increasing yields over time occurred when data from the without lime treatment were analyzed separately. The annual yield increase over the 50-yr period for the un-limed treatment was 142 kg ha^{-1} yr^{-1} for the medium LTN rate and 124 kg ha^{-1} yr^{-1} for the high LTN treatment.

A major source of this yield gain is likely the genetic improvement of corn hybrids. Several studies comparing the simultaneous yield performance of corn cultivars from various eras from 1930 to present (Hallauer et al., 1988) show that newer hybrids have consistently greater yields likely due to improve-ments in genetic potential and adaptation to improved cultural practices (Castleberry et al., 1984; Duvick, 1984; Lauer et al., 2001). In some of these studies, much of the yield gain is attributed to genetic improvements in the modern hybrids. Lauer et al. (2001) showed that since 1930, corn forage and stover yields increased by 1.4 and 0.7% yr^{-1}, respectively while ear yields increased by 2.4% yr^{-1}. In our experiment, hybrid genetic improvement undoubtedly contributed to the observed yield gain at the medium and high LTN rates by enhancing apparent NUE and by increasing resistance to stresses such as greater plant density and unfavorable climatic conditions (Fig. 1). The relatively stable yields over time in the control LTN (0 kg N ha^{-1}) treatment suggest that hybrid genetic improvement alone does not account for the long-term yield gain. Improved management techniques such as appropriate fertilizer additions, increased plant densities (consistent with increasing hybrid tolerance), effective pest control techniques, optimum planting dates, and selection of improved hybrids over the course of the experiment were also probable contributors to yield gain.

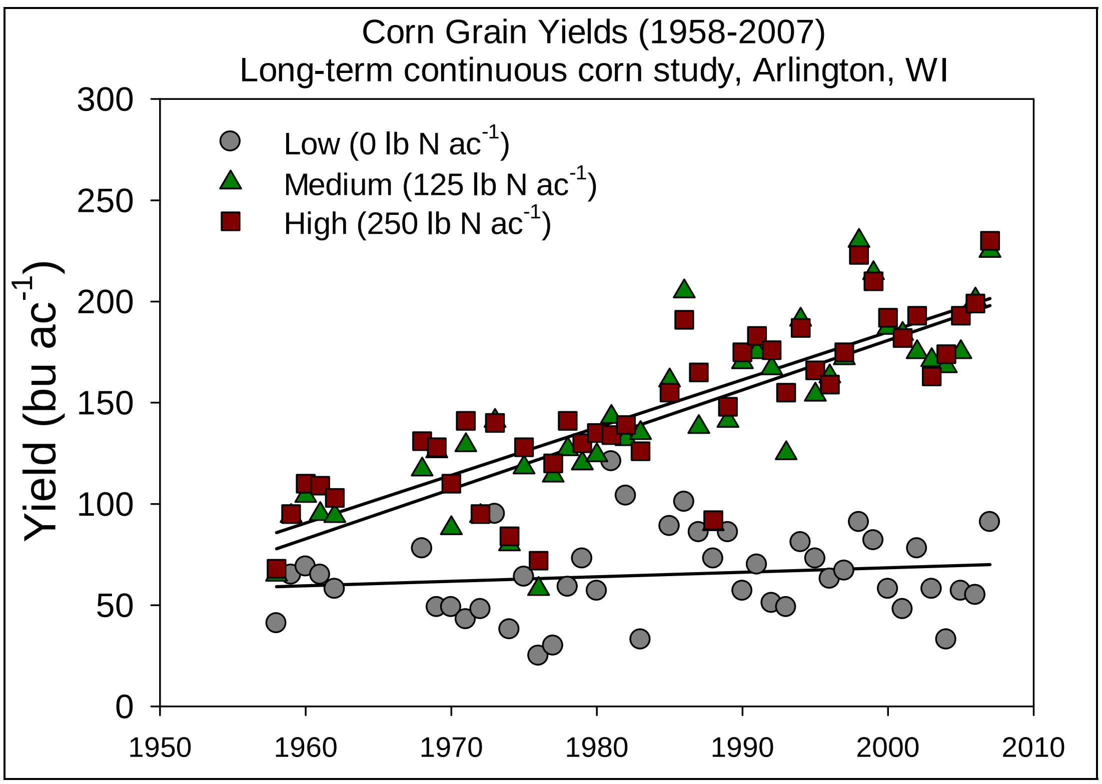

Figure 1. Corn yields from 1958 to 2007 with 0, 125, and 250 lb a^{-1} of N.

Soil organic matter concentration measured by routine soil test methods varied substantially among years during the 1963 to 2005 period (Fig. 2) likely due to variability in repeated soil sampling and laboratory analysis. Overall, the data indicate that soil organic matter concentrations in the 0- to 15-cm depth were maintained during the 50 yr of continuous corn production and LTN applications. Soil organic matter measurements were limited to the 0-15 cm soil depth. However, research by Jenkinson et al. (2008) and Syswerda et al. (2011) suggests that surface soil sampling may be adequate for assessing management practice effects on soil C. In our study, soil organic matter levels were not significantly affected by LTN treatments in 1984 or 1991, but soil organic matter was significantly higher at the medium and high LTN rates compared to the control LTN treatment in 1995 through 2005. Lime treatments did not affect soil organic matter levels, and there were no N by lime treatment interactions.

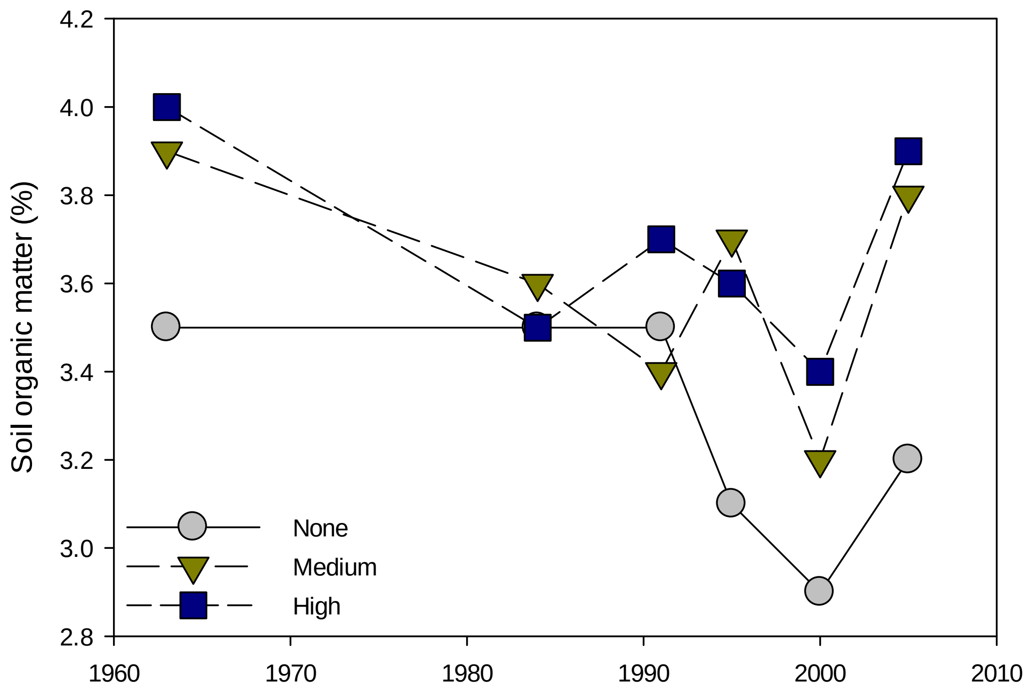

Figure 2. Soil organic matter concentrations measured between 1962 and 2005.

As expected, soil pH declined with long-term N additions due to acidity formed during nitrification of ammonium-N, and the drop in pH values was greatest in the high LTN treatment (Fig. 3). Once lime treatments were applied in 1985, soil pH in the limed plots increased while pH values in the un-limed plots remained relatively constant. Lime additions significantly increased average corn yields by 0.54 Mg ha^{-1}. There was no significant interaction between N and lime treatments on yield. In individual years, lime addition significantly ($p < 0.10$) increased corn yields in 14 of 23 years since 1985. In these years, the N by lime interaction was significant ($p < 0.10$) in only four of the 14 years suggesting that lime and N treatments usually influence yield independently. Overall, these results emphasize the importance of lime applications as part of sustainable agricultural practices, especially in high-yielding grain production systems receiving substantial N inputs.

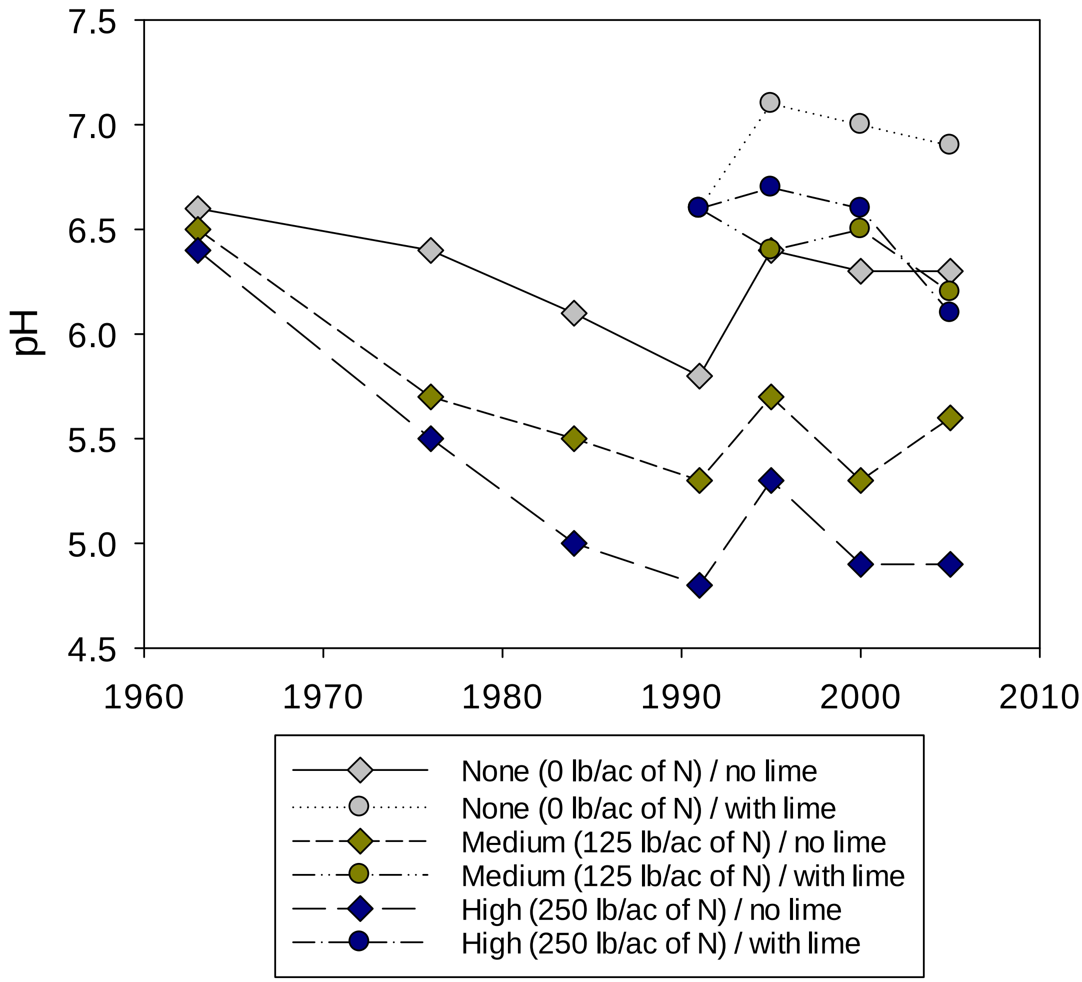

Figure 3. pH levels measured between 1962 and 2005

Conclusions

Continuous corn yields with N fertilizer additions increased dramatically (100 %) during the 50-yr experiment with much of the yield gain likely due to genetic improvements of the corn hybrids used and improved management practices. Highest yields were obtained in the most recent years of the experiment, and did not require greater fertilizer N applications indicating an apparent improvement in corn N use efficiency. Soil organic matter levels were maintained or increased in the medium and high LTN treatments, providing evidence that long-term N fertilizer additions do not inherently reduce soil organic matter. Without lime addition, soil pH declined in the N fertilizer treatments and liming increased corn yields in most years. Lime and N treatments usually influenced yield independently and both inputs are required to maintain the sustainability of this cropping system. Results from this long-term study demonstrate the value of improved corn hybrids, appropriate N application rates, and use of liming materials for the long-term agronomic sustainability of continuous corn cropping systems in the northern Corn Belt. No evidence of a decline in productivity from long-term corn monoculture or N fertilizer use was detected when lime applications were used to maintain soil pH levels.

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