Corn Grain Yield Response to Crop Rotation and Nitrogen over 35 Years

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ABSTRACT

Crop rotation and N are management methods that can increase corn (*Zea mays* L.) grain yields. Our objective was to determine the corn grain yield response to six crop rotation sequences and four N rates in a long-term (35-yr) study. The rotations were continuous corn (CC), corn–alfalfa (*Medicago sativa* L.) (CA), corn–soybean [*Glycine max* (L.) Merr.] (CS), corn-corn-corn-alfalfa-alfalfa (CCCAA), corn-corn-oat (*Avena sativa* L.) with alfalfa seeding-alfalfa-alfalfa (CCOaAA), and corn-soybean-corn-oat with alfalfa seeding–alfalfa (CSCOaA). From 1970 to 2004, first-yr corn grain yields (*C*CCAA, *C*COaAA, and *C*SCOaA) increased from 79 to 100 kg ha^{-1} yr^{-1}. Increasing N rates did not influence grain yield trends, indicating that an alfalfa crop produced the N required by first-yr corn. However, 224 kg N ha^{-1} was needed to improve second and third-yr grain yield trends 69 and 58 kg ha^{-1} yr^{-1}, respectively. Grain yield trends for CC did not improve despite increasing N treatments, although grain yield tended to increase over time at 224 kg N ha^{-1} ($P < 0.10$). From 1989 to 2004, corn grain yield trends of CA and CS decreased by 161 kg ha^{-1} yr^{-1} if no N was added. The 2-yr rotation was not sufficient to improve grain yield trends, whereas the 5-yr rotation was able to enhance corn grain yield and decrease the need for fertilizer N. Effects on pathogens and insects were not evaluated but warrant further investigations. Overall, this data shows that extended rotations involving forage crops reduce N inputs, increase corn grain yields, and are more agronomically sustainable than current short-term rotations.

Agricultural productivity gains since the 1950s resulted from the development of farming systems that rely extensively on external inputs of energy and chemicals to replace management and on-farm resources (Oberle, 1994). Cropping sequence in the midwestern United States has increasingly evolved to a greater reliance on the CS rotation and even CC over the last half of the century. There are many reasons for this, among them the development of effective fertilizers and pesticides, government policies, and favorable economics (Porter et al., 2003).

Nitrogen has been considered one of the best crop-input investments that a farmer can make in terms of return on dollars spent (Pikul et al., 2005); however, N is the most expensive nutrient for growing grain crops. Bundy et al. (1999) estimated that in the 12-states of the north central United States, at least 3.6 Tg of N fertilizer were applied annually to corn at a cost of $800 million.

Many crops respond dramatically to applications of N fertilizer. Nitrogen fertilizer is universally accepted as a key input to high corn grain yield and optimum economic return. In the Midwest, the primary philosophical approach to developing an N fertilizer recommendation for corn is to consider, as independent variables, yield goal, economic return, management level, and some measure of the inherent differences in soil productivity (Oberle and Keeney, 1990). Overapplication is more frequent since producers have an economic incentive to err more frequently in that direction. From a crop production perspective, the cost of unneeded N fertilizer in areas of overapplication is less than the cost of lost yield potential in areas of underapplication (Scharf et al., 2005). This is not true from an environmental perspective (Hallberg, 1989; Yadav, 1997).

According to Heichel (1978) and Pimentel et al. (1978), continuous rotation of corn and soybean cannot be sustained without substantial additions of fertilizers. Recent statistics (USDA-National Agricultural Statistics Service, 2006a) show for example that corn grown in the United States receives around 4.5 Tg of N annually. These high application levels result in low N use efficiency (NUE), currently estimated at only 33% (Raun and Johnson, 1999) for world cereal grain production systems. In addition to economic losses, N overapplication results in environmental contamination through nitrate N runoff or leaching, making nitrate N the most common contaminant found in the surface and ground water of the Corn Belt (Council for Agricultural Science and Technology, 1999).

Increased diversity of crops grown in rotation enhances sustainability of agriculture systems because crops grown in rotation, with similar off-farm inputs, have greater yield than those grown in monoculture (Mannering and Griffith, 1981; Dick et al., 1986; Higgs et al., 1990). Other key benefits of including a forage or pasture crop consist of improved soil quality (i.e., increased C retention in the surface horizon) and a more

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Abbreviations: CA, corn-alfalfa; CC, continuous corn; CCCAA, corn-corn-corn-alfalfa-alfalfa; CCOaAA, corn–corn-oat with alfalfa seeding-alfalfa-alfalfa; CS, corn-soybean; CSCOaA, corn-soybean-corn-oat with alfalfa seeding-alfalfa; NUE, nitrogen use efficiency. *Italics in a rotation code indicate the year of the rotation under discussion.*

Table 1. Crop rotations and N rates at Lancaster, WI, used to evaluate the influence of crop rotation and N on the rotation effect of corn.†

Crop rotation treatments			N Treatments	
1966–1976	1977–1986	1987–2004	1967–1976	1977–2004
			kg N ha^{-1}	
CC‡	**CC**	**CC**	0	0
CSCOaA	**CSCOaA**	**CSCOaA**	84	56
CCCOaA	**CCCAA**	**CCCAA**	168	112
CCOaAA	**CCOaAA**	**CCOaAA**	336	224
COaAAA	CCAA	**CA**		
	AA	**CS**		
		AA		

† C, corn; S, soybean; Oa, oat with alfalfa seeding; A, alfalfa.

‡ The rotations in bold were included in the analysis.

even distribution of labor needs and risk due to climate or market conditions than those involving only grain or fiber crops (Magdoff and van Es, 2000).

Crop rotations that include legumes also increase soil N levels (Peterson and Varvel, 1989; Raimbault and Vyn, 1991). Crop rotation has also been shown to improve NUE by reducing requirements for external input of fertilizer N. Bruulsema and Christie (1987) found that a single-year of alfalfa or red clover (*Trifolium pretense* L.) resulted in corn yields (8.8 and 8.5 Mg ha^{-1}, respectively) equivalent to that obtained from applying 90 to 125 kg ha^{-1} of fertilizer N. Fox and Piekielek (1988) extended the evaluation period to 3 yr of alfalfa managed as hay and reported that there was no significant grain yield response (10.3 Mg ha^{-1}) to fertilizer N for first-year corn.

Despite the benefits of crop rotations that include legumes, the infrastructure developed and devoted to corn and soybean has resulted in a 500% increase in harvested area of these crops in the United States between 1950 and 2003 (USDA-National Agricultural Statistics Service, 2004). During that same period, oat production declined 90%, and although hay production increased because of better yields, the land area devoted to it decreased more than 15%. This occurred for several reasons including simplicity and similar equipment requirements as farm size increased, commodity programs that emphasized short-term profit, public and private research and development efforts devoted to genetic improvement of corn and soybean, and increased food and industrial uses for both corn and soybean oils and various by-products (Karlen, 2004). Expansion of the simplified CS system has tremendous economic and world trade benefits because of the many products and materials developed from those crops (Karlen et al., 2006).

In 1966, a multiple crop rotation experiment was established to evaluate the profitability and agronomic sustainability of corn-based crop rotations. Forty years later, the experiment has become one of the longest running rotation studies in the United States. Previous papers published from this experiment have looked at the effect of legumes on subsequent corn crops (Baldock et al., 1981), corn N recommendations based on yield goals vs. soil specific data (Vanotti and Bundy, 1994a, 1994b), the frequency of N fertilizer carryover (Vanotti and Bundy, 1994c), soybean effects on soil N availability (Vanotti and Bundy, 1995), and the effect of extended rotations improving soil quality and profitability (Karlen et al., 2006). The objective of this paper was to determine the effect of crop rotation and applied N on corn grain yield trends for a 35-yr period.

MATERIALS AND METHODS

Data from a long-term crop rotation study located in southwestern Wisconsin [University of Wisconsin Agricultural Research Station-Lancaster (42°50' N, 90°47' W; elevation 324 m above mean sea level)] near Lancaster was used for this study. A randomized complete block in a split-plot design with two replications of 21 treatments was established to test the rotation effect by having each crop phase of every rotation represented each year. To accommodate all possible crop phases of the rotations and four fertilizer treatments, 168 plots (6.1 by 9.1 m) were established in 1966. Thus, for CC, there was one plot within each replication, and for CS there was one corn plot and one soybean plot within each replication. Rotation treatments have changed over time (Table 1). The crop sequence plots were split to accommodate four N rate treatments. From 1967 to 1976, N rates were 0, 84, 168, and 336 kg N ha^{-1}, but since 1977, the annual rates have been 0, 56, 112, and 224 kg N ha^{-1} for corn only (Table 1). Nitrogen fertilizer treatments were broadcast by hand each spring as ammonium nitrate (NH_4NO_3).

Tillage has varied over time. Corn following corn and oat and alfalfa seedbed preparation has always been fall chisel plowed followed by spring disking and cultimulching before planting. Corn following soybean has been no-till since 1994, while corn following alfalfa and soybean following corn have been no-till since 1999. Soil fertility samples were collected and analyzed every 3 yr, and uniform rates of P and K fertilizers were applied as needed to maintain optimum to high soil-test levels. Herbicides and cultivation were used for weed control as needed. Cultivars varied over time but were always improved selections developed for the region. The alfalfa, which was seeded with oat, has not been harvested during the seeding year following oat harvest. For alfalfa that was independently established, two harvests were taken during the seeding year, except for rotations with 1-yr alfalfa, where the alfalfa was killed during the fall of the same year following a third cutting by plowing (before 1999) or through the use of appropriate herbicides (2000 onward). For rotations with 2 or 3 yr of alfalfa following establishment, three harvests were taken.

We chose to focus only on corn yields using a subset of crop rotations to test our objective regarding crop rotation. The rotations of interest were CC, CS, CA, CSCOaA, CCCAA, and CCOaAA. Italics in a rotation code indicate the year of corn in the rotation under discussion. We treated CCCOaA and CCCAA in this analysis as one continuing rotation (see Table 1). The only difference was that in CCCAA, oats were not used as a nurse crop and the alfalfa was independently established.

The Lancaster cropping systems study is comprised of multiple crop rotations that take varying amounts of time to complete a rotation sequence. For example, CC takes 1 yr, CS takes 2 yr, and CSCOaA takes 5 yr (Table 1). Previous rotation experiments have always analyzed the data on a year by year basis. However, the traditional analysis using years can be expanded to analyze both spatial and temporal trends based on the average grain yields produced in the period it took to complete the cycle. By doing this, we can see how the rotations per-

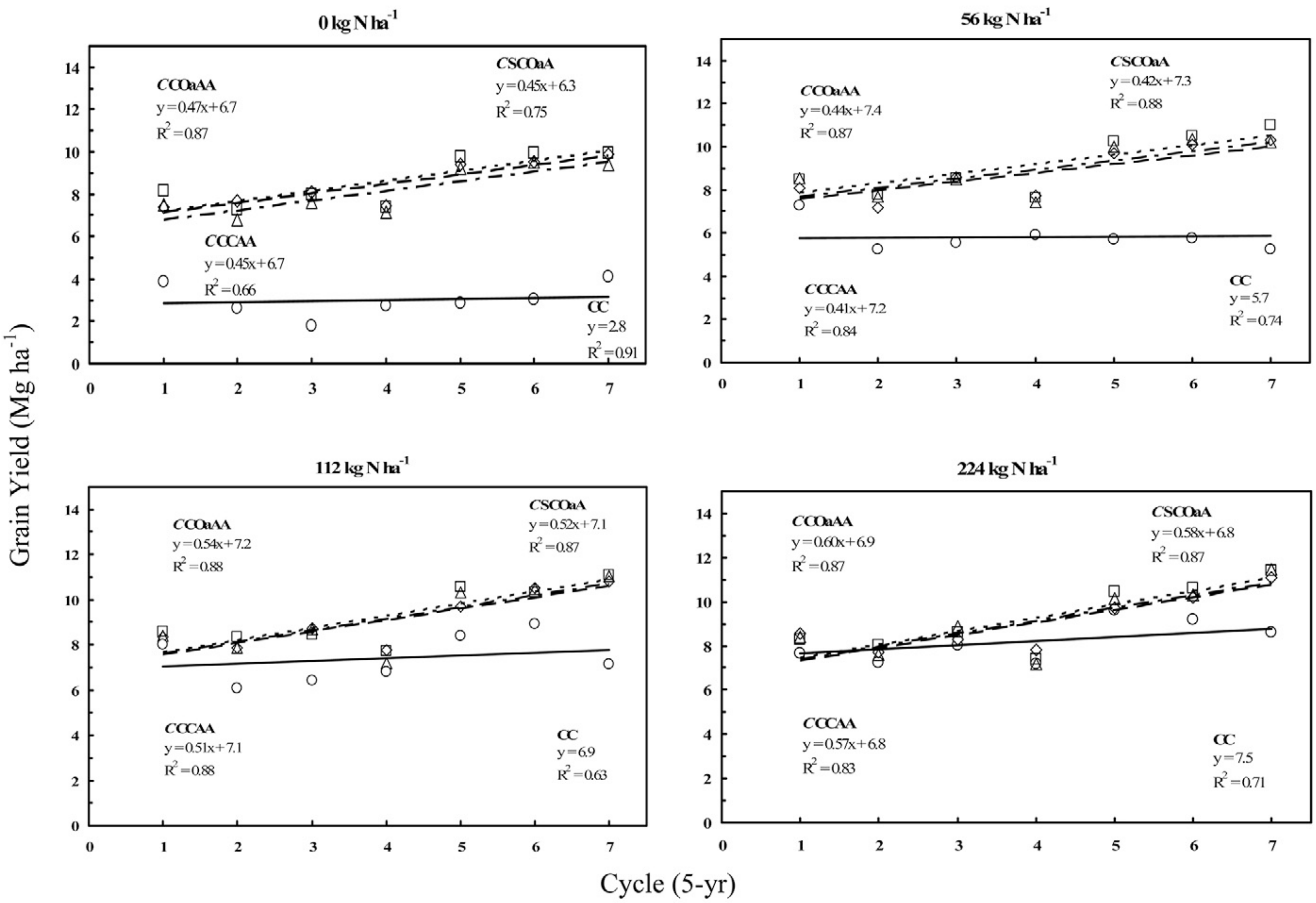

Fig. 1. Relationship between grain yield and time for each N rate and rotation sequence for the first year of corn at Lancaster, WI from 1970 to 2004. C, corn; S, soybean; Oa, oat with alfalfa seeding; A, alfalfa. CC, circle, ————; *C*CCAA, diamond, — — —; *C*COaAA, square, - - - -; *C*SCOaA, triangle, — - — - —. Cycles: 1, 1970–1974; 2, 1975–1979; 3, 1980–1984; 4, 1985–1989; 5, 1990–1994; 6, 1995–1999; 7, 2000–2004. Before 1977, N rates were 0, 84, 168, and 336 kg N ha^{-1}. Italic indicates year of rotation for the corn crop being evaluated.

formed when they returned to the same plot of land allowing data analysis across both time and space. Hence, we analyzed the data in groups of either 2- or 5-yr depending on the length of the rotation cycle using CC as our control.

Data were analyzed by covariate analysis using the PROC MIXED procedure (Littell et al., 1996) of SAS (SAS Institute, 2002). The covariate was rotation cycle using the mean grain yield from across the years for that cycle. Repeated measures analysis (SAS Institute, 2002) with the first-order autoregressive variance structure was used to evaluate time and space effects on grain yield. Regression slopes of each year of corn within each rotation sequence were evaluated to determine the long-term effects of various crop rotations and different N fertilization rates on grain yield. Each regression slope was compared to a slope of zero to determine if over time the rotation treatments were improving or deteriorating, and to each other to determine if the relative slopes of each treatment are common or not. For determining the expected mean squares, appropriate *F*-tests in the analysis of covariance and *t* tests in the analysis of slopes-equal-to-zero and common-slopes, random effects were rep(year) and year. Least square means of the fixed effects were computed, and the PDIFF option of the LSMEANS statement was used to display the differences among least square means for comparison. This option uses Fisher's protected least significant difference, and comparisons were conducted at $P \leq 0.05$. The P value was corrected for the common-slope contrasts using the Bonferroni procedure for multiple comparisons (George et al., 2005). The final model used to determine each of the regression equations was attained using backward stepwise selection. This procedure starts with the full model and sequentially deletes factors and their interactions. The factor producing the smallest F value is deleted at each stage and the model is complete when the factors remaining in the model have a $P \leq 0.05$. Intensity (kg ha^{-1} yr^{-1}) of significant yield treads was calculated from the final regression equations by calculating the difference in average yields between the first and last cycle, then dividing by the total number of years observed. The R^2 was derived using the predicted values calculated by PROC MIXED $\{R^2 = 1 - [(y_{ij} - \hat{y}_{\mathrm{Pred}})^2/(y_{ij} - y_{\mathrm{grand\ mean}})^2]\}$.

RESULTS AND DISCUSSION

Five-Year Rotations–First-Year Corn (1970–2004)

First-yr corn grain yields (*C*CCAA, *C*COaAA, and *C*SCOaA) increased from 79 to 100 kg ha^{-1} yr^{-1} with increasing N rates (0 and 224 kg N ha^{-1}, respectively) (Fig. 1). Grain yield trends for CC did not improve relative to a slope of zero despite increasing N treatments; although grain yield tended to increase over time at 224 kg N ha^{-1} ($P < 0.10$). These results imply that either hybrids have not improved since 1970 or that

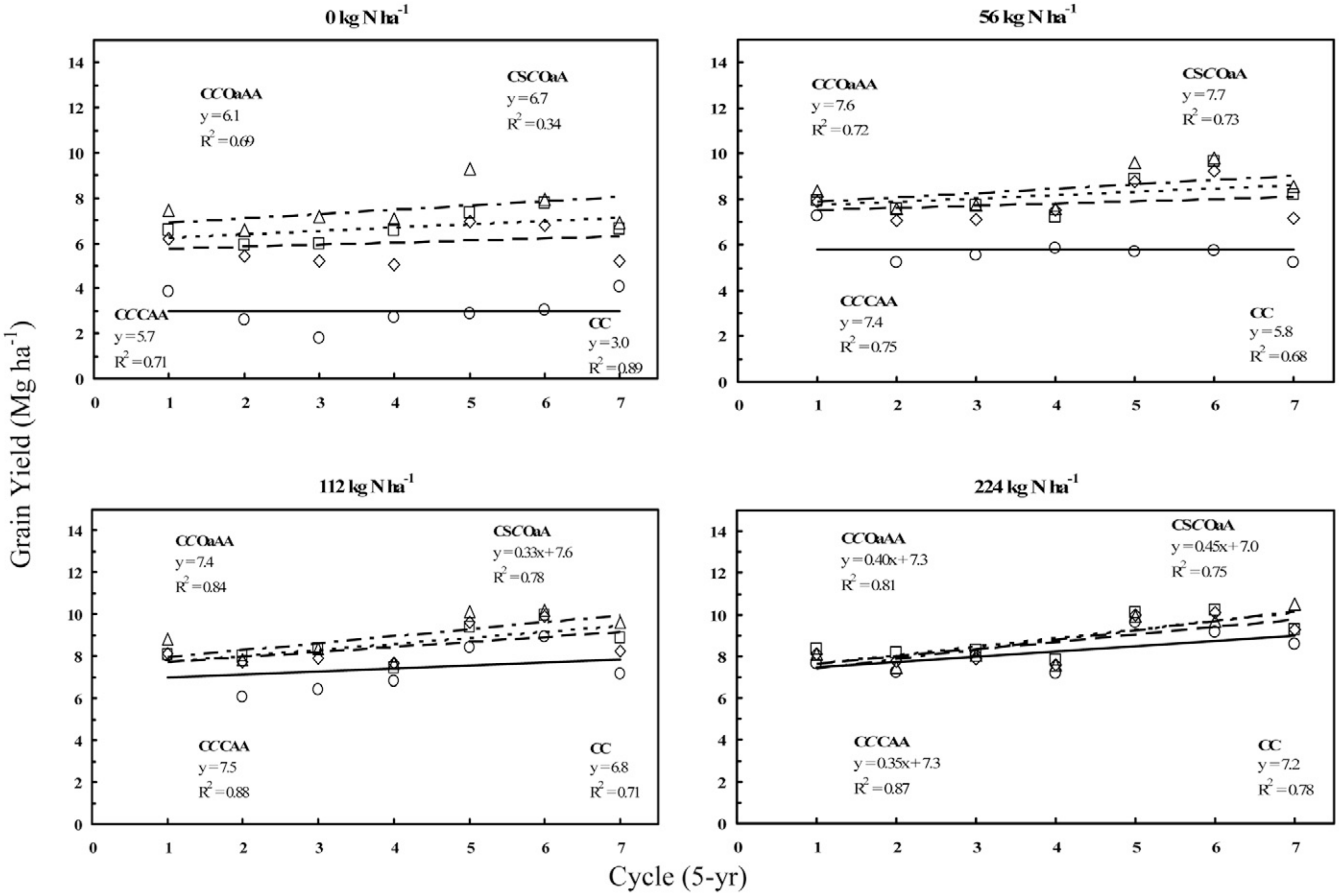

Fig. 2. Relationship between grain yield and time for each N rate and rotation sequence for the second year of corn at Lancaster, WI from 1970 to 2004. C, corn; S, soybean; Oa, oat with alfalfa seeding; A, alfalfa. CC, circle, ––––––––; C*C*CAA, diamond, –– – –––; C*C*OaAA, square, – – – –; CS*C*OaA, triangle, –·–·–·–·–. Cycles: 1, 1970–1974; 2, 1975–1979; 3, 1980–1984; 4, 1985–1989; 5, 1990–1994; 6, 1995–1999; 7, 2000–2004. Before 1977, N rates were 0, 84, 168, and 336 kg N ha^{-1}. Italic indicates year of rotation for the corn crop being evaluated.

improved hybrids have kept CC yield trends from declining over time. According to Tollenaar and Wu (1999) the genetic potential of corn hybrids have improved, however the negative effect of growing CC cancel any yield improvement. Currently, with the rapid turnover of hybrids there is no way to separate the two effects and answer this question.

Rotating corn significantly improved grain yield over time for the first-year of corn when compared to CC (Fig. 1). For the 0, 56, and 112 kg N ha^{-1} treatments, grain yield for *C*CCAA, *C*COaAA, and *C*SCOaA rotations improved 67, 72, and 69 kg ha^{-1} yr^{-1}, respectively. These findings agree with Bolton et al. (1976), Higgs et al. (1976), and Welch (1976) who found corn grown in rotation had higher yields than corn grown in monoculture, even in the presence of N, P, or K fertility levels that were not limiting yields. Corn grown in rotation with a legume receives more N than corn grown continuously with no fertilizer N. However, if N is the only cause of yield differences between rotations, then these differences would be expected to disappear if more than adequate N is applied. It appears that N fertilizers do not substitute for crop rotation (Fig. 1).

There was no difference in slope for the first-year of corn when comparing the rotations involving two, three, and four crops at each N rate (Fig. 1). These results suggest that each rotation sequence in this study is equally effective in breaking the yield depression caused by monoculture. Overall, first-year corn yields for N treatments at 224 kg N ha^{-1} of 5-yr rotations improved by 100 kg ha^{-1} yr^{-1} or 1.4% yr^{-1}, which is similar to the national average (USDA-National Agricultural Statistics Service, 2006b).

Nitrogen fertilizer rate had a significant effect on grain yield slopes of CC (Fig. 1). Although, yield trends for CC by N rate did not improve relative to a slope of zero, the data did show the 112 and 224 kg N ha^{-1} treatments improved grain yield trends by 17 and 28 kg ha^{-1} yr^{-1} when compared to the 56 kg N ha^{-1} treatment, respectively. For the two, three, and four-crop rotation sequences there was no difference in relative grain yield trends as N fertilizer rates increased from 0 to 224 kg N ha^{-1}. First-year alfalfa can supply 134 to 168 kg N ha^{-1} for a subsequent corn crop (Bundy et al., 1990). Because N was never limiting for first-year corn, no differences in grain yield trends with increasing N rates were observed.

Five-Year Rotations–Second-Year Corn (1970–2004)

The benefits of crop rotation in relation to corn grain yield improvement diminished following the first year of corn. Grain yields for the C*C*CAA, C*C*OaAA, and CS*C*OaA rotation at 224 kg N ha^{-1} increased 60, 69, and 77 kg ha^{-1} yr^{-1}, respectively (Fig. 2). The CS*C*OaA rotation also showed a grain yield improvement of 57 kg ha^{-1} yr^{-1} at 112 kg N ha^{-1}. This improvement in corn grain yield appears to be the result of adding 1 yr of soybean between the first and second year of corn in

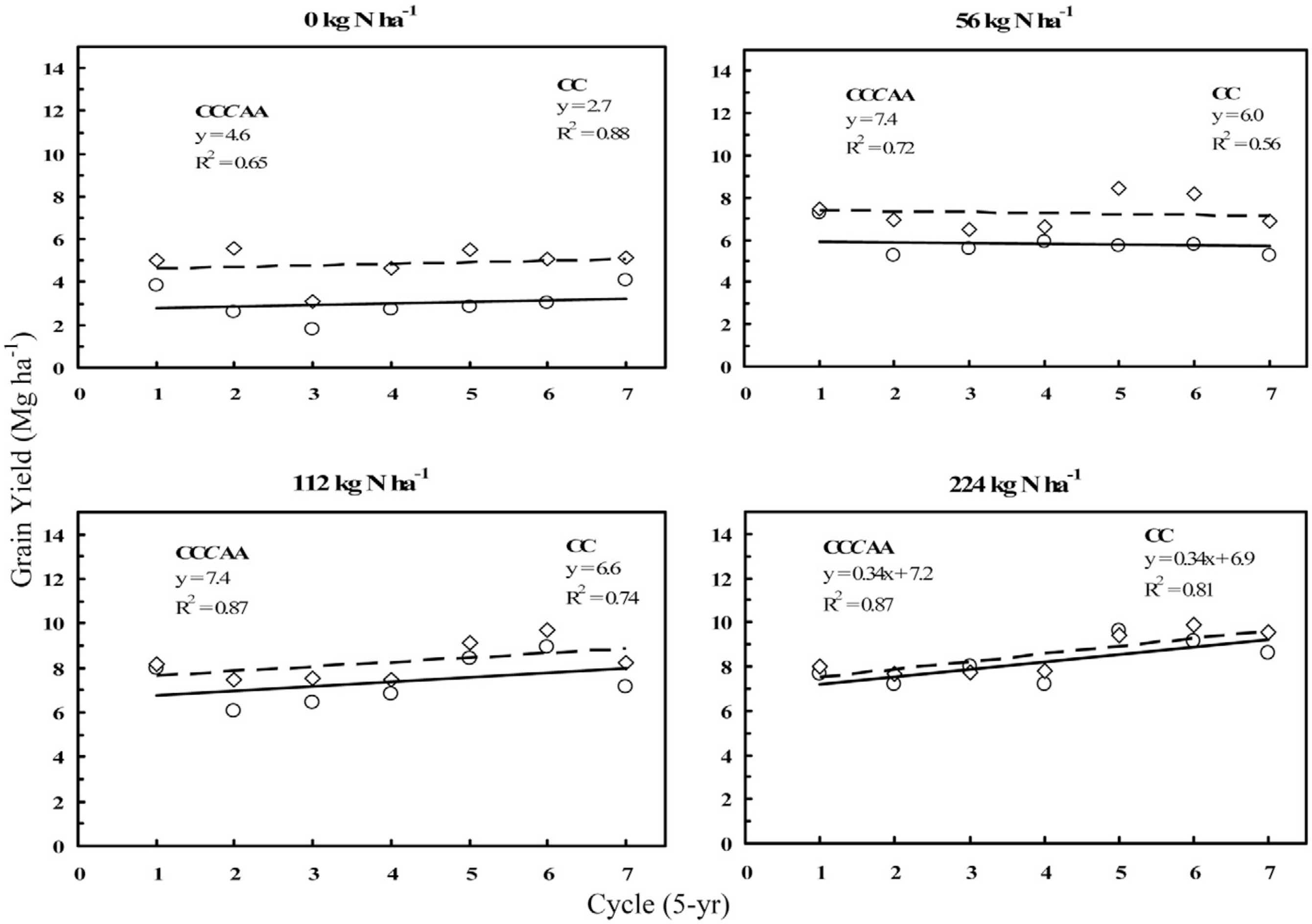

Fig. 3. Relationship between grain yield and time for each N rate and rotation sequence for the third year of corn at Lancaster, WI from 1970 to 2004. C, corn; A, alfalfa. CC, circle, ————; CCCAA, diamond, — — —. Cycles: 1, 1970–1974; 2, 1975–1979; 3, 1980–1984; 4, 1985–1989; 5, 1990–1994; 6, 1995–1999; 7, 2000–2004. Before 1977, N rates were 0, 84, 168, and 336 kg N ha^{-1}. Italic indicates year of rotation for the corn crop being evaluated.

this rotation (Fig. 2). Soybean can supply up to 45 kg N ha^{-1} for a subsequent corn crop (Bundy et al., 1990), explaining the yield improvement at the 112 kg N ha^{-1} rate. Previous research has demonstrated that when corn is grown in rotation with soybean, it yields greater than corn following corn (Baldock et al., 1981; Crookston et al., 1991; Meese et al., 1991; Porter et al., 1997; Pedersen and Lauer, 2002, 2003).

According to the data, the effect of rotating corn for improved corn grain yield over time has diminished when comparing the second year of corn with CC (Fig. 2). Grain yield for CC did not improve, while C*C*OaAA and CS*C*OaA improved grain yield by 25 and 33 kg ha^{-1} yr^{-1}, respectively, when compared to CC for the 56 kg N ha^{-1} treatment. No other differences among N treatments for the second year of corn compared to CC were observed. According to Meese et al. (1991) and Pedersen and Lauer (2002), little or no differences were found in grain yield of second-year corn in rotation compared to CC. For the second year of corn in these rotations, the benefits of rotation have largely disappeared.

The N fertilizer rate had a significant effect on grain yield slopes of the second year of corn within their respective rotations (Fig. 2). Similar to the first year of corn, yield trends for CC by N rate did not improve relative to a slope of zero, the data did show the 112 and 224 kg N ha^{-1} treatments improved grain yield trends by 24 and 44 kg ha^{-1} yr^{-1} when compared to the 56 kg N ha^{-1} treatment, respectively. As for the CS*C*OaA rotation, the 224 kg N ha^{-1} treatment increased grain yield by 44 kg ha^{-1} yr^{-1}, when compared to the 0 kg N ha^{-1} treatments.

Five-Year Rotations–Third-Year Corn (1970–2004)

There was no yield improvement over time for corn from crop rotation by the time the rotation has reached the third year of corn, when compared with CC (Fig. 3). At 224 kg N ha^{-1}, grain yields increased 58 kg ha^{-1} yr^{-1} for both the CC and CC*C*AA rotation.

The N fertilizer rate had a significant effect on grain yield slopes of the third year of corn within their respective rotations (Fig. 3). Similar to the first and second year of corn, yield trends for CC by N rate did not improve relative to a slope of zero, the data did show the 112 and 224 kg N ha^{-1} treatments improved grain yield trends by 41 and 64 kg ha^{-1} yr^{-1} when compared to the 56 kg N ha^{-1} treatment, respectively. For the CC*C*AA rotation, the 224 kg N ha^{-1} treatment increased grain yield by 45 kg ha^{-1} yr^{-1}, when compared to the 0 kg N ha^{-1} treatment.

Two-Year Rotations (1989–2004)

There was no yield improvement over time for corn from 2-yr crop rotations, when compared with CC. For the CS rotation at the 0 kg N ha^{-1} treatment, yields actually declined by 189 kg ha^{-1} yr^{-1} since 1989 (Fig. 4). It is unknown as to why

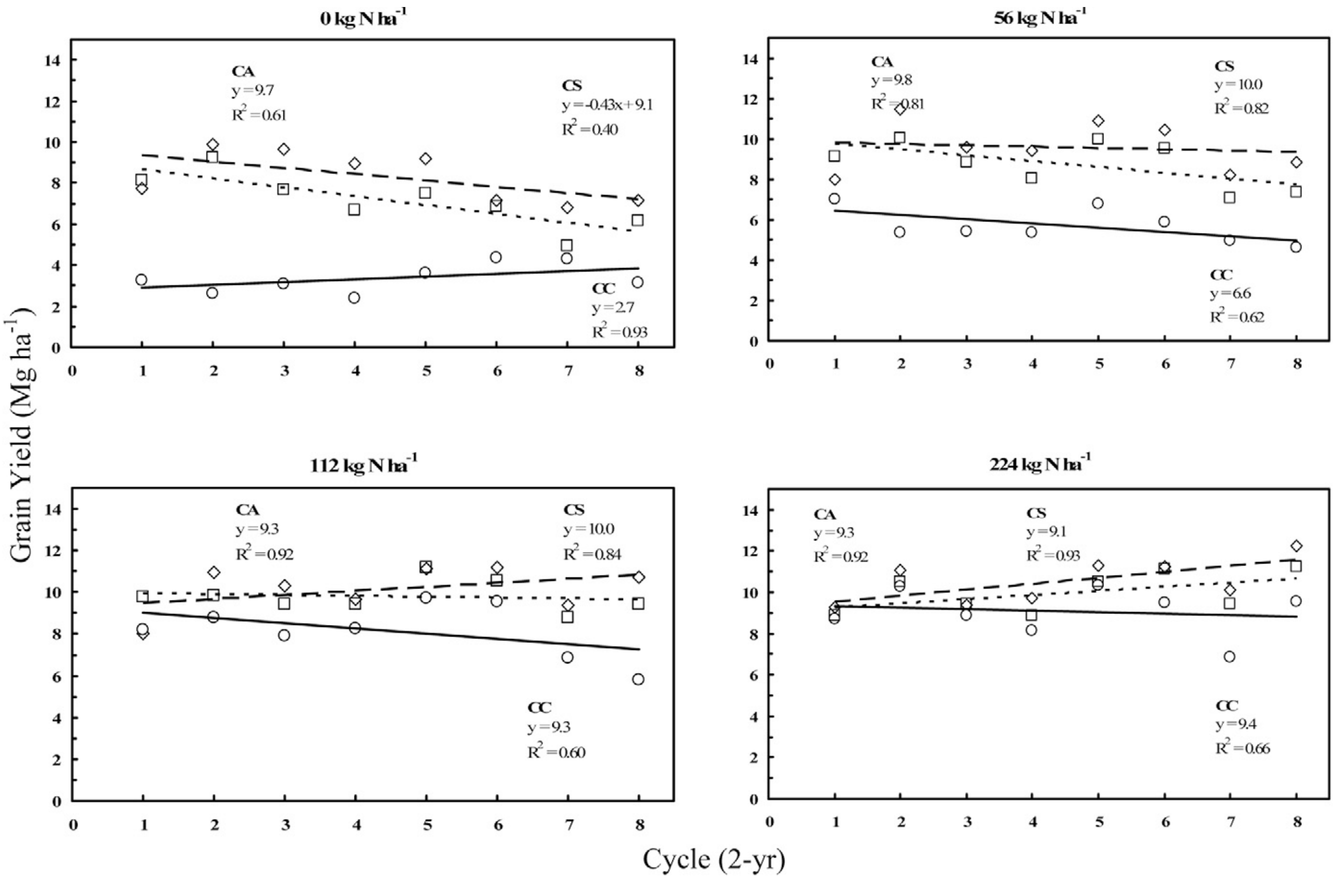

Fig. 4. Relationship between grain yield and time for each N rate and rotation sequence of corn at Lancaster, WI from 1989 to 2004. C, Corn; A, Alfalfa; S, Soybean. CC, circle, ————; CA, diamond, — — —; CS, square, - - - -. Cycles: 1, 1989–90; 2, 1991–1992; 3, 1993–1994; 4, 1995–1996; 5, 1997–1998; 6, 1999–2000; 7, 2001–2002; 8, 2003–2004.

this response was observed. A possible explanation is that corn grain yields in the CS rotation with zero inputs are hampered by lack of adequate N (Porter et al., 2003).

The data suggests the effect of alternating corn with a legume for improved corn grain yield over time appears only when additional N is added to the system (Fig. 4). These 2-yr rotations are not agronomically sustainable, meaning that a single year break between corn crops may not be adequate to eliminate the monoculture yield decline, but only reduce it. The use of N only appears to mask this decline in corn grain yields.

For the 0 kg N ha^{-1} treatment, CC improved grain yield by 249 kg ha^{-1} yr^{-1} when compared to CS (Fig. 4). While alternating corn with soybean at 0 kg N ha^{-1} appears to decrease corn yields over time, adding N fertilizer significantly improved corn grain yield of rotated corn, especially with alfalfa, when compared to CC. For the 112 kg N ha^{-1} treatment, CA improved grain yield by 196 kg ha^{-1} yr^{-1} when compared to CC.

The N fertilizer rate had a significant effect on grain yield slopes for corn that was rotated (Fig. 4). In the CA rotation, the 0 kg N ha^{-1} treatment decreased grain yields over time by 218 and 256 kg ha^{-1} yr^{-1} when compared to the 112 and 224 kg N ha^{-1} treatments, respectively. Likewise, in the CS rotation, the 0 and 56 kg N ha^{-1} treatments decreased grain yields over time by 277 and 211 kg ha^{-1} yr^{-1} when compared to the 224 kg N ha^{-1} treatments, respectively.

These results indicate external inputs of fertilizer mask the true value of crop rotation. According to Porter et al. (2003), one potential way of reducing the amount of external inputs (and associated costs) in a cropping system is to expand the crop rotation into a more diversified crop sequence pattern, thereby taking full advantage of the benefits of crop rotation.

Five-Year vs. Two-Year Rotations (1990–2004)

A comparison was made of both the 5-yr rotations with the 2-yr rotations from 1990 to 2004, on a 5-yr cycle. The slopes of the rotations at each of the N rates were not significantly different from a zero slope, except for the slopes of CA and CS rotations at 0 kg N ha^{-1}, which decreased (Fig. 5). Since 1990, grain yields have declined in the 0 kg N ha^{-1} treatment by 158 and 174 kg ha^{-1} yr^{-1} for the CA and CS rotations, respectively.

In the 0 kg N ha^{-1} treatment, the 2-yr rotations (CA and CS) decreased grain yields over time by 247 and 183 kg ha^{-1} yr^{-1} when compared to CC and the 5-yr rotations, respectively (Fig. 5). For the 56 kg N ha^{-1} treatment, the CS rotation decreased grain yields over time by 159 and 167 kg ha^{-1} yr^{-1} when compared to the *C*CCAA and *C*COaAA rotations, respectively. For the 112 kg N ha^{-1} treatment, the CC rotation decreased grain yields over time by 155 kg ha^{-1} yr^{-1} when compared to the *C*CCAA rotation. Since 1990, in the 224 kg N ha^{-1} treatment, the CC rotation decreased grain yields over time by 160 and 155 kg ha^{-1} yr^{-1} when compared to the *C*CCAA and *C*SCOaA rotations, respectively.

Nitrogen fertilizer rate had a significant effect on grain yield slopes for the CA, CC, and CS rotations (Fig. 5). In the CA rotation, the 0 kg N ha^{-1} treatment decreased grain yields over

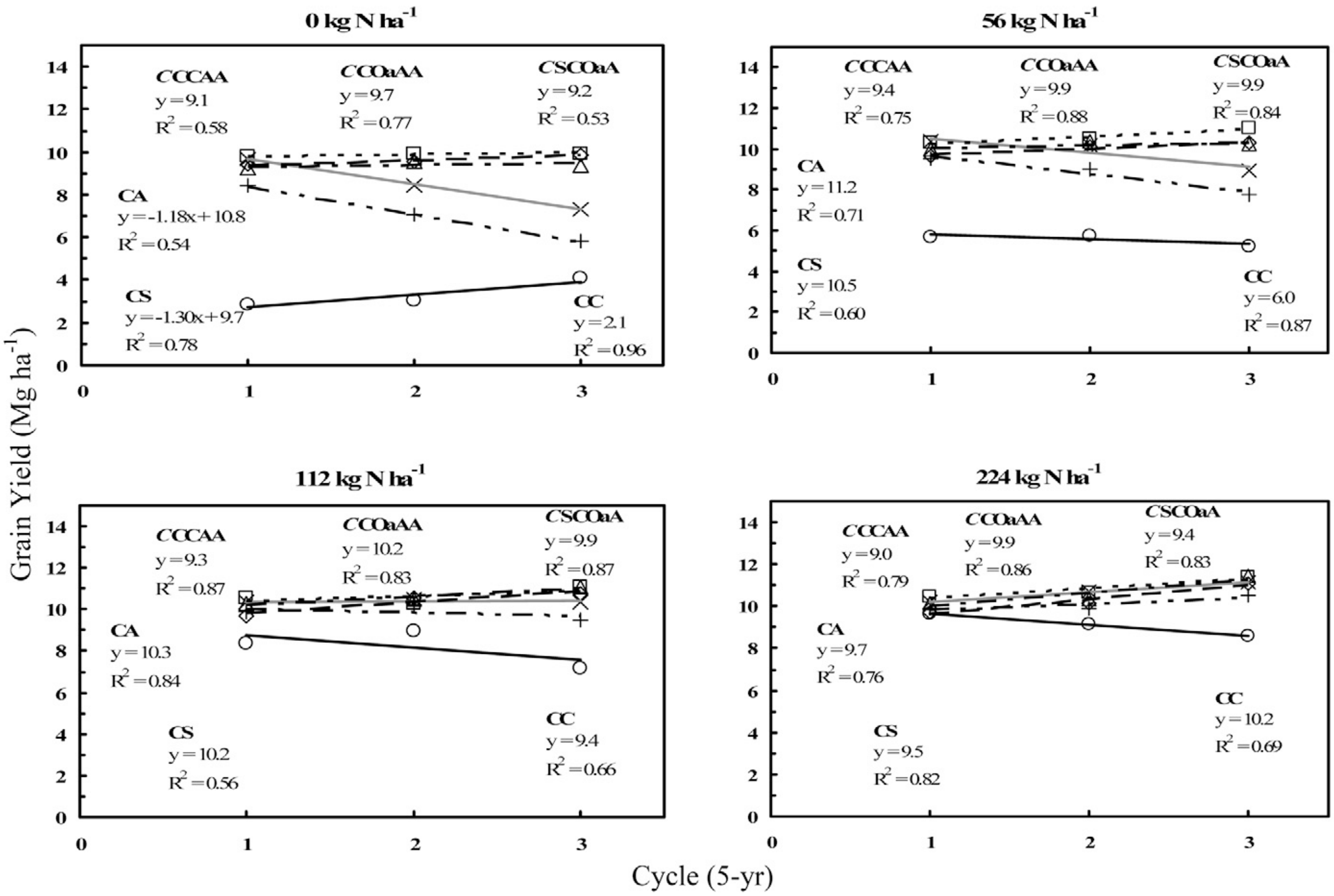

Fig. 5. Relationship between grain yield and time for each N rate and rotation sequence for the first year of corn at Lancaster, WI from 1990 to 2004. C, corn; S, soybean; Oa, oat with alfalfa seeding; A, alfalfa. CC, circle, ————; *C*CCAA, diamond, — — —; *C*COaAA, square, – – – –; *C*SCOaA, triangle, — – — –; CA, ×, ————; CS, +, — – — –. Cycles: 1, 1990–1994; 2, 1995–1999; 3, 2000–2004. Italic indicates year of rotation for the corn crop being evaluated.

time by 161 and 220 kg ha^{-1} yr^{-1} when compared to the 112 and 224 kg N ha^{-1} treatments, respectively. Grain yield trends for the 56 kg N ha^{-1} treatment decreased by 157 kg ha^{-1} yr^{-1} when compared to the 224 kg N ha^{-1} treatments. Likewise, in the CS rotation, the 0 kg N ha^{-1} treatment decreased grain yields over time by 197 and 215 kg ha^{-1} yr^{-1} when compared to the 112 and 224 kg N ha^{-1} treatments, respectively, and the 56 kg N ha^{-1} treatment grain yields decreased by 159 kg ha^{-1} yr^{-1} when compared to the 224 kg N ha^{-1} treatment. For the CC rotation, grain yields improved over time for the 0 kg N ha^{-1} treatment by 164 and 151 kg ha^{-1} yr^{-1} when compared to the 112 and 224 kg N ha^{-1} treatments, respectively.

Based on these results, time (2+ yr) along with rotation were required between corn crops to improve corn grain yields. We agree with Randall (2003) and Karlen et al. (2006) that extended rotations involving forage crops may be more agronomically sustainable than current short-term agricultural practices. However, according to Karlen et al. (2006) without the support of federal incentive programs and markets for forage-based products, farmers will hesitate to adopt extended rotations.

CONCLUSION

Extended crop rotations including an alfalfa crop improved first-year corn grain yields with time. First-year corn grain yield trends did not respond to additional N added, demonstrating that an alfalfa crop within an extended crop rotation supplied adequate N. For the second- and third-year of corn only the higher N treatments showed improved corn grain yields over time. The net effect of legumes in improving corn grain yield trends of subsequent corn was not evident for corn that was annually rotated (CA and CS). If no N was added, CA and CS appeared to decrease corn grain yields with time. A single legume crop year was only beneficial in maintaining corn yields over time if N was added to the system. When all rotations were compared (1990–2004), corn grain yields trends of 5-yr crop rotations were significantly better where no N was added and additional N was required for the 2-yr rotations to eliminate this difference. Our data showed a long-term first-year corn grain yield advantage of extended rotations when compared to 2-yr rotations and CC. Nitrogen plays a major role in maintaining and improving corn grain yields in the absence of crop rotation. The addition of N removed the corn grain yield trend differences, along with the passage of time, among crop rotation-phase treatments when CC was compared to the first-year of corn in 5-yr rotations. These results support the argument that extended rotations involving forage crops may be more agronomically sustainable than current short-term (2-yr) rotations, because time (2+ yr) along with rotation and N were required to improve corn grain yields. However, grain yield trends only show the response of long-term management practices on yields and not why this happens. With more than adequate N provided for optimum corn yields, we would expect all yield trends to be similar despite differences in rotational practices. Further research is needed regarding the influence of above- and below-ground pathogens on corn grain yields and how they may affect yield trends over time.

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