IS THE CORN-SOYBEAN ROTATION IN TROUBLE? EVIDENCE FROM THE LANCASTER ROTATION EXPERIMENT

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Sustainable agriculture is a practice that over the long term enhances environmental quality and the resource base on which agriculture depends, provides for basic human food and fiber needs, is economically viable, and improves the quality of life for farmers and society (White et al., 1994). Generally, 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).

Many reports show yield benefit for rotated corn over continuous corn. Raimbault and Vyn (1991) reported that first-year corn grown in rotation yielded 4% more than continuous corn under fall moldboard plow and 8% more than continuous corn under fall chisel. Peterson and Varvel (1989b) found that corn grown in a 4-yr rotation and fertilized with 160 lb N A^{-1} yielded 22% more than continuous corn fertilized at the same rate. Katsvairo and Cox (2000a, b) showed that under high chemical inputs and chisel plow, a 3-yr rotation (that included a legume) yielded 16% more than continuous corn, while under moldboard plow, the 3-yr rotation yielded 22% more than continuous corn.

The merits of extended crop rotations that include forage or pasture crops have been debated for centuries (Karlen et al., 1994). The key benefits of including a forage or pasture crop consist of increase carbon retention in the surface horizon and a more 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, 1989a; Raimbault and Vyn, 1991). Karlen et al. (2006) and Wienhold et al. (2006) have also suggested that extended rotations have a positive impact on soil quality. Wienhold et al. (2006) found that reduced tillage and the incidence of fallow combined with more diversified crop rotations improved soil function by supporting plant growth, providing a reservoir for essential plant nutrients, storing and purifying water, and providing a site for biological activity such as decomposing and recycling of plant and animal materials. Extended rotations involving forage crops may be more sustainable than current short-term agricultural practices (Randall, 2003).

Despite these benefits, the infrastructure developed and devoted to corn and soybean has resulted in a 500% increase in harvested area and 800% increase in soybean production between 1950 and 2003 (USDA-NASS, 2004). The dominant agricultural land use throughout the northern Corn-Soybean Belt became a 2-yr corn and soybean rotation during the last half of the 20th century. 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% (Karlen et al., 2006). 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). It also coincided with major changes in the livestock industry that decreased demand for oat and alfalfa.

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In 1965, a group of young crop scientists laid out plots at the College of Agriculture and Life Science's Lancaster Agricultural Research Station. In 1966, a multiple crop rotation experiment was established to evaluate which rotations were the most profitable and sustainable for farmers in this region. This experiment was a joint collaboration between the University of Wisconsin, Iowa State University, University of Illinois, and the University of Minnesota. The emphasis was on corn grain production. It was established to compare the benefits of growing corn continuously using commercial N fertilizer, with those of rotating corn with alfalfa; with alfalfa supplying the N.

Forty years later, the original researchers have since retired, but the plots are still yielding data for what has become one of the longest running rotation studies in the U.S. To our knowledge, this is the only long term rotation experiment of its kind, making it not only unique but extremely valuable in the information that it can provide. The objective of this paper was to determine the effect of crop rotation and applied N on first phase corn grain yield in corn-soybean rotations and selected extended rotations.

MATERIALS AND METHODS

A long-term crop rotation study located in southwestern Wisconsin at the University of Wisconsin Agricultural Research Station near Lancaster, WI (42°51' N, 90°43' W)] was originally established to evaluate crop rotation and N fertilization rate effects on crop yield and soil N mineralization, retention, and availability (Vanotti and Bundy, 1994, 1995). The study was located on Rozetta (fine-silty, mixed, superactive, mesic Typic Hapludalfs) soil, which consists of very deep well-drained soils formed in loess on uplands (USDA-SCS, 1961). Permeability is moderate, and slopes range from 0 to 25%. Mean annual temperature and precipitation are 51 °F and 36 inches, respectively. The site is located in the driftless area of Major Land Resource Area (MLRA) 105 found in southwest Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois (USDA-SCS, 1981). The deep, rugged valleys and karst topography that characterize this 36.3 million acres region were carved into the sedimentary bedrock of a Paleozoic plateau by glacial runoff. The productive silt loam and loam soils were formed primarily from a deep loess layer overlying limestone, dolomite, sandstone, and shale bedrock (Prior, 1991). The steeply sloping land has very high erosion potential if not properly managed. Crop rotations, especially those with high residue production and including perennial crops like alfalfa, are important for comprehensive soil and crop management programs within this region (Karlen et al., 2006).

To accommodate all possible phases of the rotations and four fertilizer treatments, 168 plots (6.1 by 9.1 m) were established in 1966 in a randomized complete block in a split-plot design with two replications of 21 treatments to test the rotation effect by having each phase of every rotation represented each year. Thus, for continuous corn (CC), there were one plot within each statistical block, and for corn-soybean (CS) there was one corn plot and one soybean plot within each block. The crop sequence plots were split to accommodate four N rate treatments. From 1967 to 1976, N rates were 0, 75, 150, and 300 lb N A^{-1}, but since 1977, the annual rates have been 0, 50, 100, and 200 lb N A^{-1} for corn only (Table 1). N fertilizer treatments were applied in spring as ammonium nitrate (NH_4NO_3). Rotation treatments have changed over time (Table 1). Tillage has varied over time. 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, whether seeded alone or with oat, has not been harvested during the seeding year following oat harvest. For rotations with 1-yr alfalfa, the alfalfa was killed during the fall of the same year using appropriate herbicides or prior to 1999 the alfalfa was plowed under. For rotations with 2- or 3-yr of alfalfa, two or three harvests were taken depending on if it was a direct seeding year or established prior with oats, respectively.

Table 1. Crop rotations and nitrogen rates at Lancaster, Wisconsin used to evaluate the influence of crop rotation and nitrogen on the rotation effect of first year corn.†

1966-1976	1977-1986	1987-2004
Crop Rotation Treatments		
CC	CC	CC
CSCOaA	CSCOaA	CSCOaA
CCCOaA	CCCAA	CCCAA
CCOaAA	CCOaAA	CCOaAA
COaAAA	CCAA	CA
COaAAA	CCAA	CS
COaAAA	AA	
Nitrogen Treatments (lb N A^{-1})		
0	0	0
75	50	50
150	100	100
300	200	200

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

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 years, and CSCOaA takes 5 yrs (Table 1). However, the traditional analysis using years can be expanded to analyze both spatial and temporal trends based on the average yields produced in the period it took to accomplish the cycle. By doing this, we can see how the rotations preformed when they returned to the same piece of ground allowing data analysis across both time and space. Hence, we analyzed the data in groups of either 2- or 5-yrs depending on the length of the rotation cycle using CC as our control.

RESULTS AND DISCUSSION

Regression slopes of each phase 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. We compared each regression slope to 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 different (Fig. 2).

5-yr Rotations – First Corn Phase (1970 – 2004)

Corn grain yields increased from 1.1 to 1.6 bu A^{-1} yr^{-1} with increasing N rates (0 and 200 lb N A^{-1}, respectively) for corn that was rotated (Table 2). Relative yield trends for continuous corn did not improve over time no matter the N rate. Thus, there was no yield gain with adopting improved hybrids during the 35-yr of this study. This suggests two things, either hybrids have not improved since 1970, or that improved hybrids have kept continuous corn yield trends from declining over time. Currently, with the rapid turnover of hybrids there is no way to answer this question.

Rotating corn significantly improved corn grain yield over time for the first phase of corn when compared to CC (Table 2). For the 0 lb N A^{-1} treatment, grain yield for *C*CCAA, *C*COaAA, and *C*SCOaA rotations improved 1.2 to 1.3 bu A^{-1} yr^{-1}, respectively. In the 50 lb N A^{-1} treatment where N was applied but limiting, *C*CCAA, *C*COaAA, and *C*SCOaA improved grain yield by 1.1 to 1.2 bu A^{-1} yr^{-1}, respectively. For the 100 lb N A^{-1} treatment, *C*CCAA, *C*COaAA, and *C*SCOaA improved grain yield 1.4 to 1.5 bu A^{-1} yr^{-1}, respectively. Overall, within a diversified crop rotation and with adequate N (200 lb N A^{-1}), corn yields improved by 1.6 bu A^{-1} yr^{-1}or 1.4 % yr^{-1}, which is similar to the national average (USDA-NASS, 2006).

There was no difference in slope for the first phase of corn when comparing the 2, 3, and 4-crop rotation sequences at each N rate (Table 2). These results suggest as long as the previous crop is not corn, each rotation sequence in this study is equally effective in breaking the yield depression caused by monoculture.

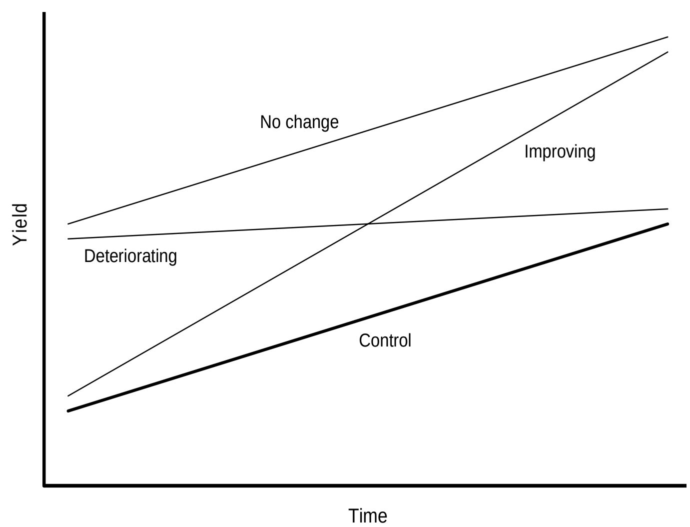

Fig. 2. Theoretical changes over time in cropping systems relative to the control cropping system.

2-yr Rotations (1989 – 2004)

Through 16 years (eight 2-yr cycles) CC grain yield at all N-rate levels was not affected over time and thus did not improve or deteriorate (Table 3). Corn grain yield in the CS rotation at 0 lb N A^{-1} decreased by 3 bu A^{-1} yr^{-1}. A similar trend was found for the CA rotation. Rotating corn with a legume improves corn grain yield over time only when additional N is added to the system.

5- vs. 2-yr 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 are not significantly different from a zero slope, except for the decreasing slopes of CA and CS rotations at 0 lb N A^{-1} (Table 4). Since 1990, in the 0 lb N A^{-1} treatment, grain yields have actually declined by 2.5 and 2.8 bu A^{-1} $yr^{-1}$for the CA and CS rotations, respectively. For the 50 lb N A^{-1} treatment, the CS rotation decrease grain yields over time by 2.5 and 2.7 bu A^{-1} $yr^{-1}$when compared to the *C*CCAA and *C*COaAA rotations, respectively (Table 5). For the 100 lb N A^{-1} treatment, the CC rotation decrease grain yields over time by 2.5 bu A^{-1} $yr^{-1}$when compared to the *C*CCAA rotation. Since 1990 in the 200 lb N A^{-1} treatment, the CC rotation decreased grain yields over time by 2.6 and 2.5 bu A^{-1} $yr^{-1}$when compared to the *C*CCAA and *C*SCOaA rotations, 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 sustainable than current short-term agricultural practices. However, according to Karlen et al. (2006) without the support of federal incentive programs such as the Conservation Security Program or other public and private research and development efforts, markets and uses for forage-based products developed to promote economic and environmental sustainability, farmers will hesitate to adopt more sustainable practices.

CONCLUSION

Corn grain yield response data show that for extended crop rotations an alfalfa crop supplied most of the N required by the first phase of corn that improved over time. For the second phase of corn a lower but still substantial amount of the total N requirement was supplied from the previous alfalfa crop, however, additional N was needed in order to improve corn grain yields over time. With increasing years of corn following alfalfa, the differences in corn grain yield trends between rotated and continuous corn diminished. An application of 200 lb N A^{-1} was needed for grain yield improvement 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 is added, CA and CS appeared to depress corn grain yields with time. A single legume crop yr was only beneficial in maintaining corn yields over time if nitrogen was added to the system. When all rotations were compared (1990 to 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 show a long-term corn grain yield advantage of extended rotations when compared to 2-yr rotations and continuous corn. 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 with time among crop rotation-phase treatments when CC was compared to the first phase of corn in 5-yr rotations. These results support the argument that extended rotations involving forage crops may be more sustainable than current short-term agricultural practices, because time (2+ yr) along with rotation and nitrogen were required to improve corn grain yields. However, without proper incentives like the Conservation Security Program, farmers may hesitate to adopt more sustainable practices.

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Table 2. Corn grain yield rate of change for the first phase of corn (bu A^{-1} yr^{-1}) of 5-yr rotations in various N rate (lb N A^{-1}) treatments at Lancaster, WI from 1970 to 2004 (seven 5-yr cycles).

	lb N A^{-1}			
Rotation	**0**	**50**	**100**	**200**
	bu A^{-1} yr^{-1}			
CC	**NS**	**NS**	**NS**	**†**
***C*CCAA**	**1.2****	**1.1****	**1.4****	**1.6****
***C*COaAA**	**1.3****	**1.2****	**1.5****	**1.6*****
***C*SCOaA**	**1.2****	**1.1****	**1.4*****	**1.6*****

†, *, **, * Significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively**

Table 3. Corn grain yield rate of change for corn (bu A^{-1} yr^{-1}) of 2-yr rotations in various N rate (lb N A^{-1}) treatments at Lancaster, WI from 1989 to 2004 (eight 2-yr cycles).

	lb N A^{-1}			
Rotation	**0**	**50**	**100**	**200**
			bu A^{-1} yr^{-1}	
CC	NS	NS	NS	NS
CA	†	NS	NS	NS
CS	-3.0*	NS	NS	NS

†, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively

Table 4. Corn grain yield rate of change for corn (bu A^{-1} yr^{-1}) of 5-yr and 2-yr rotations in various N rate (lb N A^{-1}) treatments at Lancaster, WI from 1990 to 2004 (three 5-yr cycles).

	lb N A^{-1}			
Rotation	**0**	**50**	**100**	**200**
			bu A^{-1} yr^{-1}	
CC	NS	NS	NS	NS
CA	-2.5*	NS	NS	NS
CS	-2.8*	†	NS	NS
*C*CCAA	NS	NS	NS	NS
*C*COaAA	NS	NS	NS	NS
*C*SCOaA	NS	NS	NS	NS

†, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively

Table 5. Corn grain yield rate of change contrasts for corn (bu A^{-1} yr^{-1}) in 5-yr (first phase) and 2-yr rotations in various N rate (lb N A^{-1}) treatments at Lancaster, WI from 1990 to 2004 (three 5-yr cycles).

	lb N A^{-1}			
Rotation	**0**	**50**	**100**	**200**
			bu A^{-1} yr^{-1}	
CC vs. CA	3.8***	NS	NS	NS
CC vs. CS	4.1***	NS	NS	NS
CC vs. *C*CCAA	NS	NS	-2.5*	-2.6*
CC vs. *C*COaAA	NS	NS	NS	NS
CC vs. *C*SCOaA	NS	NS	NS	-2.5*
CA vs. CS	NS	NS	NS	NS
CA vs. *C*CCAA	-3.0***	NS	NS	NS
CA vs. *C*COaAA	-2.7*	†	NS	NS
CA vs. *C*SCOaA	-2.7*	NS	NS	NS
CS vs. *C*CCAA	-3.3***	-2.5*	NS	NS
CS vs. *C*COaAA	-3.0***	-2.7*	NS	NS
CS vs. *C*SCOaA	-2.9***	NS	NS	NS

†, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively