Environment Affects the Corn and Soybean Rotation Effect

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ABSTRACT

Corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.], the backbone of Midwestern crop production, respond to rotation, but how growing conditions affect this is not well documented. Our objectives were to determine the effect of various corn and soybean cropping patterns on yields and to evaluate environmental effects on the rotation effect. The study began in 1981 at Lamberton, MN, on a Webster clay loam (fine-loamy, mixed, mesic Typic Endoaquoll), in 1982 at Waseca, MN, on a Nicollet clay loam (fine-loamy, mixed, mesic Aquic Hapludoll), and in 1983 at Arlington, WI, on a Plano silt loam (fine-silty, mixed, mesic Typic Argiudoll). Cropping sequences were (i) continuous monoculture of each crop; (ii) annual rotation of the two crops; and (iii) 1, 2, 3, 4, and 5 yr of each crop following 5 yr of the other crop. Results are based on 11 yr of data at Lamberton, 8 yr (soybean) or 9 yr (corn) at Waseca, and 9 yr at Arlington. Corn rotated annually with soybean yielded 13% more, and 1st-yr corn following multiple years of soybean yielded 15% more than continuous corn. Soybean annually rotated with corn yielded 10% more, and 1st-yr soybean following multiple years of corn yielded 18% more than continuous soybean. The crops differed in response to increasing years of consecutive planting: 2nd-yr to 5th-yr corn yields were no different from continuous corn yields; 2nd-yr soybean yielded 8% more than continuous soybean, 3rd-yr soybean yielded 3% more, and 4th- and 5th-yr soybean yielded the same as continuous soybean. Relative increase in yields of both crops in annual rotation compared with monoculture was approximately twofold greater in low-yielding than in high-yielding environments. In low-yielding environments, the yield advantage of an annual rotation of corn and soybean compared with monoculture was frequently greater than 25%. The commonly practiced annual rotation of corn and soybean maximized corn yields, but not soybean yields, relative to the other sequences studied.

A FIRST-CENTURY B.C. ROMAN TEXT states that "some crops are to be planted not so much for the immediate yield as with a view to the following year" (Varro, 1913). During the early 1980s, it was documented that corn grown on land planted to corn the previous year yielded 10 to 15% less grain than corn rotated with certain other crops (Sundquist et al., 1982), and that soybean yielded 10 to 15% more when rotated with corn rather than when grown continuously (Bhowmik and Doll, 1982). Yield increases associated with crop rotation have been referred to as the *rotation effect* (Pierce and Rice, 1988), and yield declines associated with monoculture have been referred to as *monoculture yield declines* (Sumner et al., 1990).

Several of the longest on-going studies designed to evaluate corn–soybean cropping sequences in the northern Corn Belt were initiated in the early 1980s at two locations in Minnesota and one in Wisconsin. In the Minnesota study, Crookston et al. (1991) reported that rotational cropping sequence affected both corn and soybean yields. Corn or soybean grown continuously yielded significantly less than when grown in an annual corn–soybean rotation. Likewise, corn or soybean in an annual rotation yielded significantly less than a 1st-yr crop following five consecutive years of the other crop. Follow-up research on this long-term study did not identify a cause or explanation for the corn–soybean rotation effect. It appears that root vigor of both crops was improved by rotation (Nickel et al., 1995), as was root function, as determined by nutrient and water uptake (Copeland and Crookston, 1992; Copeland et al., 1993). Neither foliar pathogens (Whiting and Crookston, 1993) nor soilborne pathogens were determined to be involved in the monoculture yield decline.

Cropping sequences in the Wisconsin study (Meese et al., 1991) were similar to those in the Minnesota study, but also included tillage, cultivar or hybrid, and N fertility components. Meese et al. (1991) reported that, for both corn and soybean, yield depressions under no-till compared with conventional tillage were less likely to occur when crops were rotated than when grown as monocultures. Soybean cultivar and corn hybrid selection affected the rotation effect. For example, a brown stem rot (BSR)–susceptible soybean cultivar was more sensitive than a resistant cultivar to annual alternation with corn and to consecutive years of soybean.

Six additional years of yield data have been collected since the analyses by Crookston et al. (1991) and Meese et al. (1991). We determined to again evaluate the yield response of both crops to rotation and focused particular attention on the effect of variations in the environment on the nature and magnitude of responses. Peterson et al. (1990) showed the effects of rainfall conditions and previous crop on crop yields. Several researchers have suggested that corn yield response to crop rotation is greater in dry or otherwise stressed environments than in more normal growing seasons (Langer and Randall, 1981; Peterson and Varvel, 1989b).

Our first objective was to determine if corn and soybean yield response to rotation sequence observed in the Minnesota and Wisconsin trials through 1995 would be consistent with the earlier reported results. Our second objective was to determine if there is a relationship between environment (stress vs. nonstress) and the response of both crops to rotation.

MATERIALS AND METHODS

The studies were established near Lamberton, MN, in 1981 on a Webster clay loam (fine-loamy, mixed, mesic Typic Endoaquoll), in 1982 at Waseca, MN, on a Nicollet clay loam (fine-loamy, mixed, mesic Aquic Hapludoll), and in 1983 at Arlington, WI, on a Plano silt loam (fine-silty, mixed, mesic

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Table 1. Corn (C) and soybean (S) sequences for 14 treatments (Trt.) at 3 locations since initiation of study.

Trt. no.	Rotation	Crop sequence, by year and location														
	Lamberton, MN	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
	Waseca, MN	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	
	Arlington, WI	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995		
1	10-yr rotation	C	C	C	C	C	S	S	S	S	S	C	C	C	C	C
2	10-yr rotation	S	C	C	C	C	C	S	S	S	S	S	C	C	C	C
3	10-yr rotation	S	S	C	C	C	C	C	S	S	S	S	S	C	C	C
4	10-yr rotation	S	S	S	C	C	C	C	C	S	S	S	S	S	C	C
5	10-yr rotation	S	S	S	S	C	C	C	C	C	S	S	S	S	S	C
6	10-yr rotation	S	S	S	S	S	C	C	C	C	C	S	S	S	S	S
7	10-yr rotation	C	S	S	S	S	S	C	C	C	C	C	S	S	S	S
8	10-yr rotation	C	C	S	S	S	S	S	C	C	C	C	C	S	S	S
9	10-yr rotation	C	C	C	S	S	S	S	S	C	C	C	C	C	S	S
10	10-yr rotation	C	C	C	C	S	S	S	S	S	C	C	C	C	C	S
11	Continuous corn	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
12	Continuous soybean	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
13	Corn–soybean	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C
14	Corn–soybean	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S

Typic Argiudoll). Details of the soil types, soil fertility, and fertilizers and pesticides used through 1989 for the studies are described by Crookston et al. (1991) and Meese et al. (1991). Recommended practices for optimum production were followed. Nitrogen applications were designed to ensure that N was not a yield-limiting factor. These studies were managed under a conventional fall moldboard-plowing tillage system with secondary tillage before planting.

This paper will discuss 14 of the treatments, with the following general cropping sequences: (i) 5-yr consecutive corn alternated with 5-yr consecutive soybean, arranged so that during each year of the study there occurred a 1st, 2nd, 3rd, 4th, and 5th yr of each crop, (ii) continuous monoculture of each crop, and (iii) an annual rotation of each crop (Table 1). At Arlington, only the conventional tillage system, averaged across all N fertility levels, is discussed in this paper. There were four replicates of each treatment at each location. At Lamberton, 11 yr of corn and 11 yr of soybean yield data were analyzed.

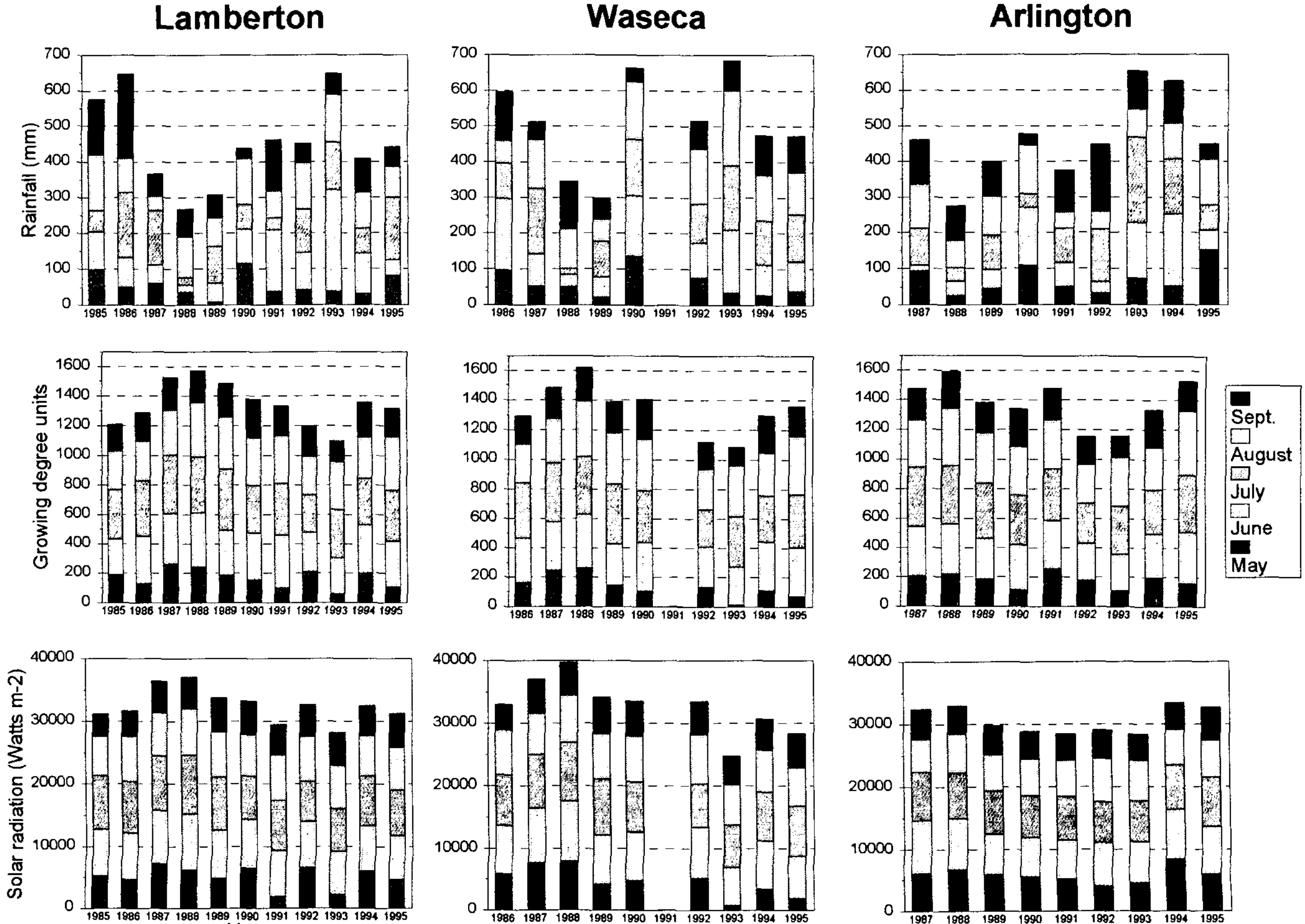

Fig. 1. Monthly rainfall, growing degree units, and solar radiation at Lamberton, MN, Waseca, MN, and Arlington, WI, from corn planting through September. Growing degree units were calculated each day as $[(T_{max} - T_{min})/2] - T_{base}$, where $10°C \leq T_{max}$ and $T_{min} \leq 30°C$ and $T_{base} = 10°C$.

Table 2. Corn yield of seven cropping sequences and yield advantage or disadvantage relative to continuous corn at Lamberton, MN.

Sequence†	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1985–1995
	Mg ha^{-1}											
continuous corn	7.58	8.80b‡	8.01	5.26	8.97b	8.42c	6.95b	7.64cd	3.63b	6.98	7.43ab	7.24b
5th-yr corn	7.43	8.04c	8.05	5.31	8.87b	8.34c	6.87b	7.97bc	3.21b	7.52	6.61b	7.11b
4th-yr corn	7.63	7.96c	8.35	5.01	9.46ab	8.58bc	8.23a	7.01d	3.12b	8.59	6.87b	7.35b
3rd-yr corn	7.58	7.87c	8.44	5.62	9.54ab	8.75abc	6.91b	7.85cd	3.26b	7.94	7.18b	7.36b
2nd-yr corn	7.33	7.53c	7.58	5.23	9.44ab	8.98ab	7.25b	8.41ab	3.25b	7.63	7.52ab	7.29b
1st-yr corn	8.06	10.86a	8.42	6.25	10.06a	8.99ab	7.29b	9.27a	5.11a	7.70	8.33a	8.21a
soybean–corn	8.39	10.63a	8.04	5.38	10.30a	9.12a	7.43ab	8.80abc	4.70a	9.10	8.28a	8.20a
Mean	7.71	8.81	8.13	5.44	9.52	8.74	7.28	8.14	3.75	7.92	7.46	7.54
Pr > F	0.16	<0.01	0.18	0.51	0.07	0.02	0.04	<0.01	<0.01	0.18	0.02	<0.01
CV, %	7.3	4.8	5.8	15.6	7.0	3.6	7.5	7.5	14.1	13.8	9.4	8.6
	Yield advantage or disadvantage,§ %											
5th-yr corn	−2	−9	0	1	−1	−1	−1	4	−12	8	−11	−2
4th-yr corn	1	−10	4	−5	5	2	18	−8	−14	23	−7	1
3rd-yr corn	0	−11	5	7	6	4	−1	3	−10	14	−3	2
2nd-yr corn	−3	−14	−5	−1	5	7	4	10	−10	9	1	1
1st-yr corn	6	23	5	19	12	7	5	21	41	10	12	13
soybean–corn	11	21	0	2	15	8	7	15	29	30	11	13

† Sequence descriptions are as follows: continuous corn since 1981; 5th-yr, 4th-yr, 3rd-yr, 2nd-yr, and 1st-yr corn following 5 yr of soybean; soybean–corn, in rotation since 1981.
‡ Within columns, means followed by the same letter are not significantly different at $P = 0.05$.
§ The yield advantage, in percent, was calculated by taking the difference in yield between cropping sequence and continuous corn, dividing by the yield of continuous corn, then multiplying by 100.

Table 3. Corn yield of seven cropping sequences and yield advantage or disadvantage relative to continuous corn at Waseca, MN.

Sequence†	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1986–1995
	Mg ha^{-1}										
continuous corn	7.54ab‡	10.94ab	4.58	10.58c	9.08	—§	9.21cd	4.05b	9.30c	7.86	8.13b
5th-yr corn	7.33b	10.66b	4.81	10.64c	9.94	—	9.40cd	4.57b	9.21c	8.43	8.33b
4th-yr corn	7.01b	10.59b	5.40	10.45c	9.38	—	9.06cd	4.12b	9.24c	8.36	8.18b
3rd-yr corn	6.73b	9.77c	5.32	10.84bc	9.25	—	8.74d	4.49b	9.51c	8.39	8.12b
2nd-yr corn	6.85b	10.52bc	4.73	9.67c	10.03	—	9.71bc	4.56b	9.64bc	8.69	8.27b
1st-yr corn	8.23a	11.65a	5.96	12.50a	9.87	—	10.77a	4.57b	10.68a	8.78	9.22a
soybean–corn	6.84b	10.63b	6.12	12.29ab	9.63	—	10.27ab	5.37a	10.41ab	8.70	8.92a
Mean	7.22	10.68	5.27	11.00	9.60	—	9.59	4.53	9.71	8.46	8.45
Pr > F	0.02	<0.01	0.30	<0.01	0.19	—	<0.01	0.06	<0.01	0.41	<0.01
CV, %	8.0	4.8	20.0	9.1	6.0	—	5.8	11.8	5.7	7.1	8.2
	Yield advantage or disadvantage,¶ %										
5th-yr corn	−3	−3	5	1	10	—	2	13	−1	7	3
4th-yr corn	−7	−3	18	−1	3	—	−2	2	−1	6	0
3rd-yr corn	−11	−11	16	2	2	—	−5	11	2	7	0
2nd-yr corn	−9	−4	3	−9	11	—	5	13	4	11	2
1st-yr corn	9	6	30	18	9	—	17	13	15	12	13
soybean–corn	−9	−3	34	16	6	—	12	33	12	11	10

† Sequence descriptions are as follows: continuous corn since 1982; 5th-yr, 4th-yr, 3rd-yr, 2nd-yr, and 1st-yr corn following 5 yr of soybean; soybean–corn, in rotation since 1982.
‡ Within columns, means followed by the same letter are not significantly different at $P = 0.05$.
§ Data records from 1991 at Waseca were lost.
¶ The yield advantage, in percent, was calculated by taking the difference in yield between cropping sequence and continuous corn, dividing by the yield of continuous corn, then multiplying by 100.

Table 4. Corn yield of seven cropping sequences and yield advantage or disadvantage relative to continuous corn at Arlington, WI.

Sequence†	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987–1995
	Mg ha^{-1}									
continuous corn	10.43	3.93	9.26c‡	9.48bcd	8.53c	9.23d	5.14c	10.17bc	7.59b	8.20c
5th-yr corn	10.17	4.61	9.50bc	9.52bcd	9.09c	9.05d	5.08c	10.59b	7.71b	8.37c
4th-yr corn	10.63	4.10	9.29c	9.35cd	9.08c	9.47cd	5.35bc	9.90c	7.60b	8.30c
3rd-yr corn	10.46	4.42	9.51bc	9.25d	8.99c	8.97d	5.31bc	10.45bc	7.69b	8.33c
2nd-yr corn	10.57	4.51	9.75abc	9.95abc	9.60bc	10.13bc	5.87b	10.50bc	7.82b	8.74b
1st-yr corn	11.20	5.39	9.94ab	10.37a	10.45ab	12.11a	7.64a	11.60a	8.86a	9.73a
soybean–corn	10.80	6.07	10.13a	10.13ab	11.04a	10.87b	7.06a	11.28a	8.26ab	9.51a
Mean	10.61	4.72	9.62	9.72	9.54	9.97	5.92	10.64	7.92	8.74
Pr > F	0.16	0.45	0.03	0.02	<0.01	<0.01	<0.01	<0.01	0.05	<0.01
CV, %	4.6	31.8	3.9	4.7	8.9	5.5	7.6	4.3	7.5	8.2
	Yield advantage or disadvantage,§ %									
5th-yr corn	−2	17	3	0	7	−2	−1	4	2	2
4th-yr corn	2	4	0	−1	6	3	4	−3	0	1
3rd-yr corn	0	12	3	−2	5	−3	3	3	1	2
2nd-yr corn	1	15	5	5	13	10	14	3	3	7
1st-yr corn	7	37	7	9	23	31	49	14	17	19
soybean–corn	4	54	9	7	29	18	37	11	9	16

† Sequence descriptions are as follows: continuous corn since 1983; 5th-yr, 4th-yr, 3rd-yr, 2nd-yr, and 1st-yr corn following 5 yr of soybean; soybean–corn, in rotation since 1983.
‡ Within columns, means followed by the same letter are not significantly different at $P = 0.05$.
§ The yield advantage, in percent, was calculated by taking the difference in yield between cropping sequence and continuous corn, dividing by the yield of continuous corn, then multiplying by 100.

At Waseca, 9 yr of corn and 8 yr of soybean yield data were analyzed. Yield data at Waseca were collected but lost in 1991 for corn and in 1991 and 1993 for soybean. At Arlington, 9 yr of corn and 9 yr of soybean yield data were analyzed. Data from the initial 4 yr, when the rotation sequences were being established, were not included in the analysis.

Planting and harvest dates varied according to seasonal conditions at each location. In general, planting occurred between late April and late May, and harvest occurred between mid-September and late October. The same corn and soybean cultivars were grown in all treatments at each location each year, but the cultivars did change over the 15-yr period of the study. Corn hybrids included Pioneer brands 'P3780,' 'P3737,' and 'P3563' and Dekalb-Pfizer Genetics brand 'DK524.' Soybean cultivars included 'Hodgson 78,' 'Parker,' 'Corsoy 79,' 'BSR100,' and Northrup King brand 'NK19-90.'

Corn was planted in 76-cm rows at all three locations. Soybean was planted in 20-cm rows at Arlington and 76-cm rows at Lamberton and Waseca. Corn was seeded at a rate of 60 000 to 75 000 and soybean at a rate of 400 000 to 450 000 viable seeds per hectare, respectively. At Lamberton, the plots were 12 rows wide and 10 m long; harvest was from 8 m of four of the center rows. At Waseca, plots were 6 rows wide and 18 m long; harvest was from 15 m of the two center rows. At Arlington, plots were 12 rows wide and 9 m long; harvest was from 6 corn rows and 18 soybean rows, 9 m in length. Plots were harvested with a plot combine.

Weather data are given in Fig. 1. Grain yields were adjusted to moisture contents of 155 g kg^{-1} for corn and 130 g kg^{-1} for soybean. Grain yield data were analyzed using the general linear model (GLM) procedure of SAS (Spector et al., 1985). Only those treatments listed in Table 1 were included in the analysis, and for the Arlington location only conventional tillage data were analyzed. Treatment mean comparisons at each location each year, at each location across all years, and combining location and year, were made when the *F*-test was significant at $P < 0.10$ using Fisher's protected least significant difference (LSD) test at the $P = 0.05$ level. Regression analysis was conducted on the yield advantage (or disadvantage) of corn or soybean in annual rotation and 1st-yr corn or soybean vs. yield of continuous corn or continuous soybean. The yield advantage, in percent, was calculated by taking the difference in yield between cropping sequence and continuous crop, dividing by the yield of the continuous crop, then multiplying by 100. The term 'environment' refers to a particular year at one location. The term 'high-yielding environment' refers to the year and location where the continuous crop yield was high (in the upper sixth of all continuous crop yields), and 'low-yielding environment' refers to the year and location where the continuous crop yield was low (in the lower sixth of all continuous crop yields).

RESULTS

Corn

When averaged across all years, corn yields at both Lamberton (11 environments) and Waseca (9 environments) were greater for the corn–soybean and 1st-yr corn cropping sequences than for any of the other five cropping sequences (Tables 2 and 3). At Arlington (9 environments), corn yields were higher for the corn–soybean and 1st-yr corn cropping sequences than for 2nd-yr corn, which in turn had higher yields than the remaining four cropping sequences (Table 4).

Combining the data from all 29 environments, 1st-yr corn and corn in the corn–soybean rotation yielded significantly more than the other cropping sequences (Fig. 2). There was a 15% increase in 1st-yr corn yield relative to continuous corn. Corn yield from the soybean–corn rotation was 13% greater than yield from continuous corn. Yields of 2nd-, 3rd-, 4th-, and 5th-yr corn yields were not different from those of continuous corn.

In 15 of 29 environments, there was a positive yield effect observed for both 1st-yr and annually rotated corn relative to continuous corn (Tables 2, 3, and 4). In no environment was there a significant negative effect of rotations compared with continuous corn. There was a linear negative relationship between the relative yield advantage of corn in the annual rotation and 1st-yr corn vs. the yield of continuous corn: as the yields of corn increased, the yield advantage of rotation declined (Fig. 3). In low-yielding environments, the yield advantages for 1st-yr corn and corn grown in annual rotation were often greater than 25%, but in high-yielding environments the yield advantages for 1st-yr corn and corn grown in annual rotation were generally less than 15%.

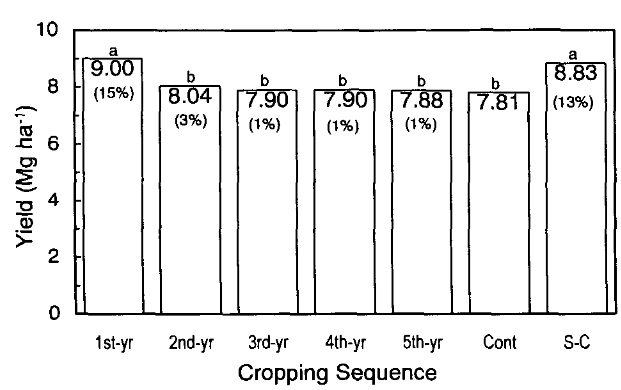

Fig. 2. Corn (C) grain yield from 3 locations representing 29 environments grown under corn monoculture or with soybean (S) in the following sequences: 1st-yr, 2nd-yr, 3rd-yr, 4th-yr, and 5th-yr corn after 5 yr of soybean; Cont (continuous corn); and S–C (alternating S–C). Values not assigned the same letter are significantly different at the 0.05 probability level. Numbers in parentheses are the percent yield advantage of the sequence compared with continuous corn.

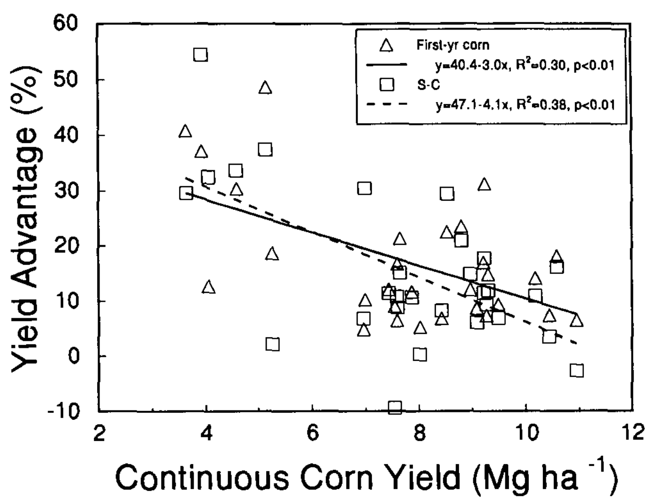

Fig. 3. Relationship between the yield advantage of corn in a soybean–corn (S–C) rotation and 1st-yr corn after 5 yr of soybean compared with continuous corn for 29 environments.

Table 5. Soybean yield of seven cropping sequences and yield advantage or disadvantage relative to continuous soybean at Lamberton, MN.

Sequence†	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1985–1995
	Mg ha⁻¹											
continuous soybean	2.57b‡	2.51bc	2.79	1.87	1.87c	2.70c	2.99c	1.64c	1.91c	2.54	2.76c	2.38d
5th-yr soybean	2.46b	2.51bc	2.80	2.25	2.12bc	2.90bc	3.03bc	2.10ab	2.37b	2.52	2.79c	2.53c
4th-yr soybean	2.53b	2.34c	2.85	1.94	2.13bc	2.94b	3.10bc	1.86bc	2.55ab	2.70	2.94bc	2.53c
3rd-yr soybean	2.46b	2.52bc	2.92	2.04	2.08bc	2.98b	3.10bc	1.85bc	2.47b	2.49	2.89bc	2.53c
2nd-yr soybean	2.49b	2.60bc	3.12	1.96	2.24ab	3.36a	3.32a	2.10ab	2.59ab	2.56	3.26a	2.69b
1st-yr soybean	2.94a	3.21a	3.13	2.09	2.48a	3.38a	3.36a	2.24a	2.74a	2.67	3.03b	2.84a
corn–soybean	2.88a	2.89ab	3.12	2.23	2.48a	3.26a	3.21ab	2.05ab	2.73a	2.49	2.89bc	2.75ab
Mean	2.62	2.65	2.96	2.06	2.20	3.07	3.16	1.97	2.48	2.57	2.94	2.61
Pr > *F*	<0.01	<0.01	0.13	0.49	<0.01	<0.01	<0.01	<0.01	<0.01	0.99	<0.01	<0.01
CV, %	7.5	10.5	7.7	14.6	9.5	4.8	4.5	9.7	7.0	17.0	5.1	9.1
	Yield advantage or disadvantage,§ %											
5th-yr soybean	−4	0	1	20	13	7	1	28	24	−1	1	7
4th-yr soybean	−2	−7	2	4	14	9	4	13	34	7	7	7
3rd-yr soybean	−4	0	5	9	11	10	4	13	29	−2	5	7
2nd-yr soybean	−3	4	12	5	20	24	11	28	36	1	18	13
1st-yr soybean	14	28	13	12	33	25	13	36	43	5	10	20
corn–soybean	12	15	12	19	33	21	7	25	43	−2	5	16

† Sequence descriptions are as follows: continuous soybean since 1981; 5th-yr, 4th-yr, 3rd-yr, 2nd-yr, and 1st-yr soybean following 5 yr of corn; corn–soybean, in rotation since 1981.
‡ Within columns, means followed by the same letter are not significantly different at $P = 0.05$.
§ The yield advantage, in percent, was calculated by taking the difference in yield between cropping sequence and continuous soybean, dividing by the yield of continuous soybean, then multiplying by 100.

Table 6. Soybean yield of seven cropping sequences and yield advantage or disadvantage relative to continuous soybean at Waseca, MN.

Sequence†	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1986–1995
	Mg ha⁻¹										
continuous soybean	2.31cd‡	2.86cd	1.86	2.46bc	2.87c	—§	1.82	—‡	2.81c	2.74bcd	2.47d
5th-yr soybean	2.43bcd	2.76d	2.10	2.42c	3.05bc	—	1.86	—	3.05bc	2.55cd	2.53cd
4th-yr soybean	2.13d	3.14ab	1.86	2.29c	3.27b	—	1.99	—	3.02bc	2.42d	2.51d
3rd-yr soybean	2.76b	2.81cd	1.82	2.48bc	3.24b	—	1.81	—	2.76c	2.67bcd	2.54cd
2nd-yr soybean	2.59bc	2.86cd	2.21	2.66ab	3.23b	—	1.92	—	3.18b	2.85bc	2.69bc
1st-yr soybean	3.18a	3.23a	2.24	2.85a	3.67a	—	2.47	—	3.57a	3.31a	3.06a
corn–soybean	2.61bc	3.00bc	1.71	2.78a	3.36ab	—	2.40	—	2.98bc	2.99ab	2.73ab
Mean	2.57	2.95	1.97	2.56	3.24	—	2.04	—	3.05	2.79	2.65
Pr > *F*	<0.01	<0.01	0.17	<0.01	<0.01	—	0.13	—	<0.01	<0.01	<0.01
CV, %	9.5	5.2	16.1	6.0	7.1	—	19.6	—	7.3	8.3	9.7
	Yield advantage or disadvantage,¶ %										
5th-yr soybean	5	−3	13	−2	6	—	2	—	9	−7	3
4th-yr soybean	−8	10	0	−7	14	—	9	—	7	−12	2
3rd-yr soybean	19	−2	−2	1	13	—	−1	—	−2	−3	3
2nd-yr soybean	12	0	19	8	13	—	5	—	13	4	9
1st-yr soybean	38	13	20	16	28	—	35	—	27	21	24
corn–soybean	13	5	−8	13	17	—	32	—	6	9	11

† Sequence descriptions are as follows: continuous soybean since 1982; 5th-yr, 4th-yr, 3rd-yr, 2nd-yr, and 1st-yr soybean following 5 yr of corn; corn–soybean, in rotation since 1982.
‡ Within columns, means followed by the same letter are not significantly different at $P = 0.05$.
§ Data records from 1991 and 1993 at Waseca were lost.
¶ The yield advantage, in percent, was calculated by taking the difference in yield between cropping sequence and continuous soybean, dividing by the yield of continuous soybean, then multiplying by 100.

Table 7. Soybean yield of seven cropping sequences and yield advantage or disadvantage relative to continuous soybean at Arlington, WI.

Sequence†	1987	1988	1989	1990	1991	1992	1993	1994	1995	1987–1995
	Mg ha⁻¹									
continuous soybean	4.27cd‡	1.57	4.16cd	4.10bc	4.45	2.89b	2.96b	2.97bc	4.21	3.511cd
5th-yr soybean	4.06d	1.17	3.99d	3.92c	4.35	2.83b	3.24b	2.62e	4.09	3.366d
4th-yr soybean	4.07d	1.23	4.15cd	4.31abc	4.33	2.73b	3.15b	2.75cde	4.10	3.424d
3rd-yr soybean	4.32cd	1.38	4.20cd	4.42ab	4.56	2.74b	3.06b	2.66e	4.14	3.497cd
2nd-yr soybean	4.60ab	1.94	4.49b	4.18abc	4.36	2.87b	3.15b	2.94cd	4.07	3.621bc
1st-yr soybean	4.84a	1.64	4.86a	4.59a	4.66	3.40a	3.83a	3.35a	4.27	3.940a
corn–soybean	4.53bc	1.44	4.32bc	4.38ab	4.38	3.32a	3.31b	3.23ab	4.37	3.699b
Mean	4.39	1.48	4.31	4.27	4.44	2.97	3.24	2.93	4.18	3.580
Pr > *F*	<0.01	0.23	<0.01	0.06	0.74	<0.01	<0.01	<0.01	0.35	<0.01
CV, %	4.1	28.7	4.1	6.7	7.3	5.9	8.4	6.6	4.9	7.3
	Yield advantage or disadvantage,§ %									
5th-yr soybean	−5	−25	−4	−4	−2	−2	9	−12	−3	−4
4th-yr soybean	−5	−22	0	5	−3	−6	6	−8	−3	−3
3rd-yr soybean	1	−12	1	8	2	−5	3	−11	−2	0
2nd-yr soybean	8	24	8	2	−2	1	6	−1	−3	3
1st-yr soybean	13	4	17	12	5	18	29	13	1	13
corn–soybean	6	−8	4	7	−2	15	12	9	4	5

† Sequence descriptions are as follows: continuous soybean since 1983; 5th-yr, 4th-yr, 3rd-yr, 2nd-yr, and 1st-yr soybean following 5 yr of corn; corn–soybean, in rotation since 1983.
‡ Within columns, means followed by the same letter are not significantly different at $P = 0.05$.
§ The yield advantage, in percent, was calculated by taking the difference in yield between cropping sequence and continuous soybean, dividing by the yield of continnous soybean, then multiplying by 100.

High-yielding corn environments were characterized by high but not excessive rainfall, temperatures, and solar radiation during the growing season (Fig. 1). The lowest yielding environments occurred in the hottest, driest, and sunniest growing season (in 1988 at all three locations) and in the coolest, wettest, and cloudiest growing season (in 1993 at all three locations).

Soybean

When averaged across all years, 1st-yr soybean yields were the greatest of any soybean cropping sequence at all three locations (Fig. 4). At Lamberton (11 environments) and Waseca (8 environments), 1st-yr soybean yields were no different from soybean yields in the corn–soybean rotation (Tables 5, 6, and 7). Yields from continuous soybean were lowest at all three locations, but at Waseca continuous soybean yields were no different from the 3rd-, 4th-, and 5th-yr soybean yields and at Arlington (9 environments) continuous soybean yields were no different from the 2nd-, 3rd-, 4th-, and 5th-yr soybean yields.

Across all three locations and all years (28 environments) there was an 18, 8, and 3% increase in 1st-, 2nd-, and 3rd-yr soybean yields, respectively, relative to continuous soybean (Fig. 4). Yields from the 4th- and 5th-yr soybean were not different from those in soybean monoculture. Soybean yield in the corn–soybean rotation was 10% greater than that in continuous soybean. First-year soybean yielded more than any other cropping sequence. Second-year soybean yielded the same as soybean rotated annually with corn, and these two cropping sequences yielded more than the 3rd-, 4th-, and 5th-yr soybean.

In 20 of 28 environments, there was a positive yield effect for 1st-yr soybean compared with continuous soybean, whereas in only 9 of 28 environments was there a positive yield effect for annual rotation compared with continuous soybean (Tables 5, 6, and 7). In no environment was there a significant negative yield effect of rotations compared with continuous soybean. As continuous soybean yields increased, the advantage of rotation declined (Fig. 5). In low-yielding environments, the yield advantages of 1st-yr soybean and soybean grown in annual rotation varied greatly and often exceeded 25%, but in high-yielding environments the yield advantages for 1st-yr and annually rotated soybean were generally less than 15%. Regardless of the magnitude of the continuous soybean yield, the yield advantage of 1st-yr soybean was approximately eight percentage points greater than the yield advantage of the soybean grown in annual rotation (Fig. 5).

High-yielding soybean environments were characterized by moderate rainfall, temperatures, and solar radiation (Fig. 1). Low-yielding soybean environments included low early-season rainfall (1988 at Lamberton and Waseca, 1989 at Lamberton) or low early-season temperatures (1992 at Lamberton and Waseca, 1993 at Lamberton). Seasons with a large rotation effect included those when growing degree units from planting through July were low (1992 and 1993 at Lamberton and Arlington, and 1992 at Waseca).

DISCUSSION

In an earlier analysis of nine Minnesota environments (data through 1989), Crookston et al. (1991) found corn yields in an annual rotation and 1st-yr crop to be increased by 9 and 14%, respectively, compared with continuous corn. Our later analysis of 29 environments determined corn yields in annual rotation and 1st-yr crop to be increased by 13 and 15%, respectively, compared with continuous corn. The decrease (of 4%) in 2nd-yr corn relative to continuous corn observed by Crookston et al. (1991) was not observed in our analysis. Both the initial data set through 1989 and the expanded data set through 1995 showed yield from 3rd-, 4th-, and 5th-yr corn to be equivalent to yield of continuous corn.

Barber (1972) observed that corn grown in Indiana did not yield differently when grown after 1, 2, 3, or 4 yr of alfalfa (*Medicago sativa* L.), bromegrass (*Bromus inermis* Leyss.), or a mixture of the two. However, corn

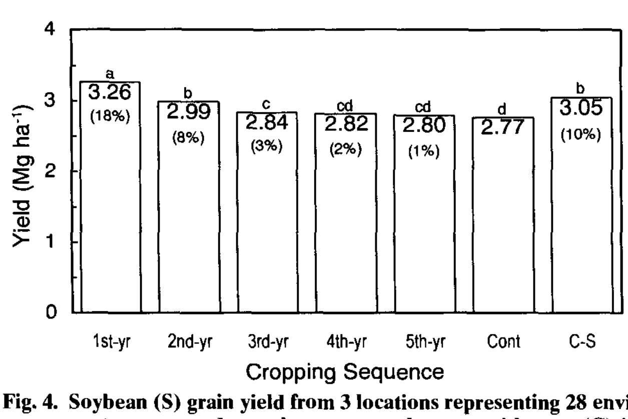

Fig. 4. Soybean (S) grain yield from 3 locations representing 28 environments grown under soybean monoculture or with corn (C) in the following sequences: 1st-yr, 2nd-yr, 3rd-yr, 4th-yr, and 5th-yr soybean after 5 yr of corn; Cont (continuous soybean); and C–S (alternating C–S). Values not assigned the same letter are significantly different at the 0.05 probability level. Numbers in parentheses are the percent yield advantage of the sequence compared with continuous soybean.

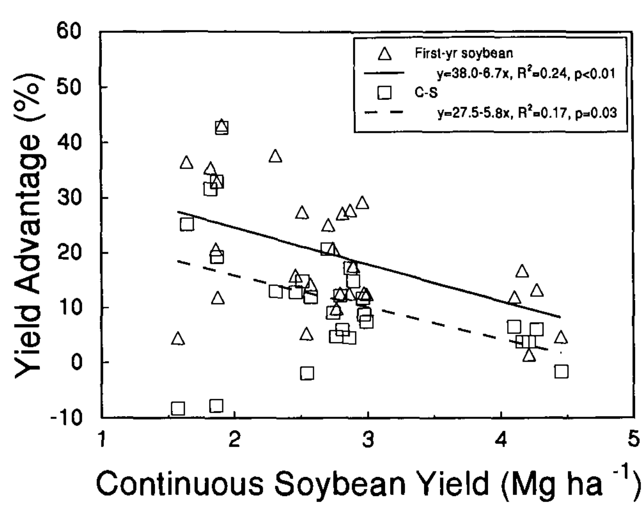

Fig. 5. Relationship between the yield advantage of soybean in a corn–soybean (C–S) rotation and 1st-yr soybean after 5 yr of corn compared with continuous soybean for 28 environments.

following these crops yielded more than continuous corn, and the greater the number of years of corn subsequent to these crops, the lower the corn yield. Barber (1972) suggested that high and low extremes in early season rainfall and higher than normal early season growing degree days contributed to the corn yield reduction. Those results are in conflict with our findings, that corn yields did not decline in the 2nd, 3rd, 4th, and 5th yr of consecutive corn following 5 yr of consecutive soybean.

Our data suggest that, following 5 yr of consecutive soybean, 1st-yr corn yield was greater than 2nd-yr corn yield, but no further yield loss would occur if corn were grown on the same land for an additional year. This statement could not be made for soybean. In the earlier analysis of nine environments, Crookston et al. (1991) determined soybean yields in annual rotation and 1st-yr soybean following 5 yr of corn to be increased by 8 and 17%, respectively, compared with continuous soybean. Our analysis of 28 environments determined soybean yields in the annual rotation and 1st-yr soybean to be increased by 10 and 18%, respectively, compared with continuous soybean yields. An increase of 8% in 2nd-yr soybean relative to continuous soybean was observed by Crookston et al. (1991) and also in this present analysis of 28 environments. Although Crookston et al. (1991) found no difference between the continuous soybean yield and the soybean yield from 3rd-, 4th- and 5th-yr soybean, our extended data set showed 3rd-yr soybean to have a 3% yield increase over continuous soybean, while the 4th- and 5th-yr soybean were equivalent in yield to continuous soybean.

Our results showed a 6% decrease in soybean yield when soybean was grown in an annual corn–soybean rotation compared with 1st-yr soybean after multiple years of corn. These results show the prevailing practice of annually rotating corn and soybean does not give maximum soybean yields.

These results do not support the statement by Peterson and Varvel (1989a) that the rotation effect is less pronounced for soybean than for cereal crops. Our results showed corn and soybean grown in annual rotation yielded 13% and 10% more, respectively, than when grown as a continuous crop. However, the yield increase for 1st-yr corn and soybean following 5 yr of the other crop was 15 and 18% more, respectively, than under continuous cropping.

The yields obtained in our study translated to an economic benefit for the annual corn–soybean rotation at Lamberton. This conclusion was based on averages of yields, total costs, and cash prices for farmers in the Southwestern Minnesota Farm Business Management Association for 1985 through 1995. Net returns per hectare were estimated to be $18 for continuous corn, $82 for continuous soybean, and $131 for the corn–soybean rotation. This comparison was made using historical prices and costs, but does not include government program payments. With the elimination of support levels and acreage restrictions in the 1995 Farm Bill, farmers are able to shift their acreage between crops without losing government payments. Such a shift could affect the relative prices and net returns of corn and soybean. Farmers' future choices therefore cannot be accurately predicted using historical prices and returns. Complete economic analysis of the yield data from all three locations coupled with possible future market conditions is the subject of other work in progress.

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