Corn/Soybean Rotation Effect as Influenced by Tillage, Nitrogen, and Hybrid/Cultivar

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Information from the northern Corn Belt comparing tillage systems and corn (*Zea mays* L.)/soybean [*Glycine max.* (L.) Merr.] rotations over years is limited. Field studies were conducted near Arlington, WI for 3 yr (1987–1989) on a Plano silt loam soil (fine-silty, mixed, mesic Typic Argiudoll). The objectives were to determine the influence of tillage, N fertilizer level, and hybrid/cultivar on growth and grain yield of corn and soybean grown in various rotation sequences. Yields of both corn and soybean declined with consecutive years of monocropping, but only soybean had 15% lower yields with annually alternating corn and soybean than for the 1st yr of production following several years of the other crop. For the least "monocropping-sensitive" hybrid (Pioneer 3737) or cultivar (BSR 101) evaluated and for either corn hybrid under conventional tillage (CT), the yield benefit of 1st yr compared to continuous cropping was similar for corn and soybean at about 15%. But with corn hybrid DeKalb 524 under no-till (NT), and the brown stem rot (BSR) (caused by *Phialophora gregata*) susceptible soybean cultivar in 1987 and 1989, yields were more than 25% higher for 1st yr crop production. Average NT yields were similar to CT for both crops with 1st yr or alternate corn and soybean, but yields were usually lower under NT with monocropping.

CORN yield benefits due to crop rotation in the Midwest have been attributed to the symbiotic N_2 fixation of a previous legume crop (Baldock et al., 1981; Nafziger et al., 1984; Shrader et al., 1966). Yield increases above that accounted for by N have also been reported (Voss and Shrader, 1982; Welch, 1976). Typical yield reductions in the Midwest for corn following corn compared to corn following other crops range from 5 to 15%, even when N fertilizer is supplied at recommended levels (Benson, 1985). Planting soybean after another crop or after fallow has also resulted in consistently higher yields than when grown in monoculture (Dabney et al., 1988; Edwards et al., 1988; Crookston, 1984).

Reasons cited for improved crop response to rotation above that attributed to N include reduced insect and disease pressure, improved soil physical properties, and growth promoting or inhibiting substances in the residue of the previous crop. For continuous corn, allelopathy (Yakle and Cruse, 1984; Anderson et al., 1988) or other unexplained "negative effects" that persist in continuous cropping (Crookston et al., 1988) have been suggested as factors causing the reduced yield potential. Crookston and Kurle (1989) found that aboveground previous-crop residue had little influence on corn and soybean yield response to rotation.

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Published in J. Prod. Agric. 4:74–80 (1991).

The use of reduced tillage systems for erosion control and government compliance programs increases the need for information on interaction between crop rotation and tillage systems for corn and soybean production. Corn and soybean yield response to different tillage systems varies depending on previous crop and soil drainage characteristics (van Doren et al., 1976; Dick and van Doren, 1985; Griffith et al., 1988; Guy and Oplinger, 1989; Erbach, 1982). No-till yields are least likely to equal or exceed those for CT with poorly drained soils, but yield reductions under NT are usually minimized by rotating corn and soybean. Residue cover is greater following corn compared to soybean, therefore NT planting into corn residue usually results in cooler and wetter soils than when following soybean, which can reduce rates of growth and development (Johnson and Lowery, 1985; Johnson et al., 1984).

Most of the published research from the northern Corn Belt comparing tillage systems has been conducted under continuous corn (Al-Darby and Lowery, 1986; Carter and Barnett, 1987). Little information is available in northern areas comparing tillage systems under corn/soybean cropping systems. Also few studies have considered whether corn and soybean differ in sensitivity to continuous cropping, or increased frequency within a rotation. If there are differences, rotation sequences could be developed which include the relatively "monocropping-insensitive" crop more frequently than the "monocropping-sensitive" crop. This study was conducted to determine the influence of tillage, N fertilizer level, and hybrid-cultivar, on the growth and grain yield of corn and soybean grown the initial year following several years of the other crop and following a progression of consecutive years of monocropping in the northern Corn Belt.

MATERIALS AND METHODS

Field research was conducted during 3 yr (1987–1989) on a Plano silt loam soil near Arlington, WI. The experiment was established in a split-split-split plot randomized complete block arrangement of treatments with four replicates. Main plots were NT systems and CT systems which were established in 1986. Tillage operations for CT were moldboard plowing in the fall and field cultivation in the spring before planting. For NT, crops were planted directly into the residue of the previous crop. Subplots consisted of 14 rotation sequences involving corn and soybean (Table 1). The sequences were initiated in 1983 on land previously planted to corn. The sequences allowed comparisons to be made during 1987, 1988 and 1989 of

Table 1. Rotation sequences for corn (C) and soybean (S).

Crop sequence	1983	1984	1985	1986	1987	1988	1989
A	C	C	C	C	C	S	S
B	S	C	C	C	C	C	S
C	S	S	C	C	C	C	C
D	S	S	S	C	C	C	C
E	S	S	S	S	C	C	C
F	S	S	S	S	S	C	C
G	C	S	S	S	S	S	C
H	C	C	S	S	S	S	S
I	C	C	C	S	S	S	S
J	C	C	C	C	S	S	S
K	C	C	C	C	C	C	C
L	C	S	C	S	C	S	C
M	S	C	S	C	S	C	S
N	S	S	S	S	S	S	S

Year in rotation†	Corn sequences 1987	Corn sequences 1988	Corn sequences 1989	Soybean sequences 1987	Soybean sequences 1988	Soybean sequences 1989
1	E	F	G	J	A	B
1-C/S	L	M	L	M	L	M
2	D	E	F	I	J	A
3	C	D	E	H	I	J
4	B	C	D	G	H	I
5	A	B	C	F	G	H
Cont.	K	K	K	N	N	N

† For corn: 1 = 1st-yr corn, after several years of soybean; 1-C/S = 1st-yr corn, alternated annually with soybean; 2,3,4,5 = 2nd, 3rd, 4th, and 5th-yr corn respectively; Cont. = 5th-yr corn in 1987, 6th-yr corn in 1988, and 7th-yr corn in 1989. For soybean: 1 = 1st-yr soybean, after several years of corn; 1-C/S = 1st-yr soybean, alternated annually with corn; 2,3,4,5 = 2nd, 3rd, 4th, and 5th-yr soybean respectively; Cont. = 5th-yr soybean in 1987, 6th-yr soybean in 1988, and 7th-yr soybean in 1989.

(i) 1st yr corn and soybean (after a minimum of 4 consecutive years of the other crop); (ii) corn and soybean alternated annually with the other crop; and (iii) 2, 3, 4, and 5 or more years of continuous corn and soybean (Table 1). Nitrogen fertilizer levels of 100 and 200 lb/acre for corn and 0 and 30 lb/acre for soybean were assigned to sub-subplots. Nitrogen in the form of NH_4NO_3 was surface applied after planting. Sub-sub-subplots were two corn hybrids or soybean cultivars. Corn hybrids were Pioneer brand 3737 (P3737) and Dekalb-Pfizer Genetics brand DK524 (DK524). One soybean cultivar was susceptible to BSR and the other cultivar was resistant to the disease. The BSR-resistant cultivar was BSR 101 all 3 yr, and the BSR-susceptible cultivar was Hodgson 78 in 1987 and Corsoy 79 in 1988 and 1989.

Plot size was 7.5 ft by 30 ft. Corn was planted with a Kinze (Kinze Manufacturing Inc., Williamsburg, IA)[1] six-row planter at a 2-in. depth in 30-in. wide rows. The planter was equipped with rippled coulters in front of double disk openers with dual press wheels for planting under NT conditions. Corn plots were planted at 31 000 seeds/acre on 5 May 1987, 4 May 1988, and 27 Apr. 1989. A 6–10–20 (N-P-K) starter fertilizer was applied at planting at the rate of 225 lb/acre. Terbufos insecticide was applied at an 8 lb/acre rate at planting to control corn rootworm (*Diabratica* spp.). Two quarts per acre alachlor and 2 lb/acre cyanazine were applied preemergence for weed control.

Soybean was drilled in 8-in. wide rows with a Tye Pasture Pleaser drill (The Tye Company, Lockney, TX) equipped with rippled coulters in front of double disk openers and dual press wheels. Soybean plots were planted 13 May 1987, 4 May 1988, and 11 May 1989 at 180 000 seeds/acre. Weeds were controlled in soybean plots with 2 qt/acre alachlor and 4 qt/acre chloramben applied pre-emergence. Hand weeding was used where necessary to maintain weed free plots. Phoshorous and K were broadcast-applied annually as needed from the beginning of the study to maintain high soil test levels.

In 1987 and 1988, data collected from both corn and soybean plots included: residue cover, soil temperature, days to emergence, and both early- and late-season plant height and stand density. Additional measurements for corn were days to silk and root damage ratings. For soybean, days to maturity (Growth Stage R8, Ritchie et al., 1982) and preharvest lodging ratings were determined. Soybean lodging was based on a 1 (no lodging) to 5 (completely lodged) scale.

Residue cover was measured after planting using the photographic technique described by Hartwig and Laflen (1978). Midday soil temperature was measured with a digital probe thermometer in the row at a 2-in. depth for 3 wk after planting. Corn root samples were collected from five randomly selected plants at silking from nonharvest rows, and washed for visual rootworm damage inspection. Root damage was rated on a scale of 1 (no damage) to 6 (very severe damage) based on the rating scale of Hills and Peters (1971).

Two corn rows from each plot were harvested on 2 Oct. 1987, 27 Sept. 1988, and 29 Sept. 1989 with an Almaco (Allen Machine Co., Nevada, IA) SPC 20 combine for grain yield determination. A plot combine was also used to harvest the six middle soybean rows from each plot on 1 Oct. 1987, 29 Sept. 1988, and 28 Sept. 1989. Grain yields were adjusted to 15.5 (corn) and 13% (soybean).

Data were analyzed over years using a split-split-split plot analysis of variance, and mean comparisons were made using the LSD test and orthogonal polynomial contrasts. All effects except replicates were considered fixed in determining the expected mean squares and appropriate *F*-tests in the combined analysis of variance.

RESULTS AND DISCUSSION

Corn

Highest corn yields occurred the year following soybean, with similar yields for annually alternated corn

[1]Mention of trade names does not imply endorsement by the authors or their institution.

as for 1st-yr corn following 4 or more years of soybean (Fig. 1 and 2). Crookston et al. (1989) in Minnesota found that annually alternated corn produced about 7% lower yields than 1st yr corn after several years of soybean. Monocropped corn yields often decreased with additional years of consecutive corn in our study (Fig. 1 and 2), but Crookston et al. (1989) reported similar yields for 2-, 3-, 4-, and 5-yr periods of monocropping compared to continuous (8-yr) corn, in research conducted at a single, optimum N fertilizer level and using CT.

The rate of yield loss with more than 2 consecutive years of monocropped corn was reduced in 1987 with application of 200 compared to 100 lb N/acre (Fig. 1), but even at the high N rate, 3-yr average yields were 15% lower for continuous corn compared to 1st-yr corn. Lack of yield differential between the two N rates in 1988 and 1989 may have been due to drought conditions in 1988, that reduced yields about 50% compared to 1987 and 1989. The low yields limited response to fertilizer N in 1988 and likely resulted in substantial carry-over of soil N, which was available for crop use in 1989 (Bundy and Malone, 1988).

Average CT yields were 9 and 3% higher than NT in 1987 and 1989, respectively, but yields were similar for CT and NT in 1988 (data not shown). Drought and heat stress resulted in delayed plant growth and leaf rolling for long periods in June, July, and early August in 1988, and visual stress symptoms appeared more severe for plants grown under NT compared to CT. By mid-August, temperatures became cooler and rainfall was more abundant. Corn grown under NT may have been better able to benefit from the more favorable late-season environment, due to delayed growth compared to CT (Table 2).

Three-year average yields under CT vs. NT were similar with 1st-yr corn following soybean for both hybrids, although DK524 had 7% greater average 1st-yr yields than P3737 (Fig. 2). But with consecutive years of monocropping, NT yields were lower for DK524 than for P3737. For P3737 under both CT and NT and DK524 under CT, 1st-yr corn yields were 12 to 14% higher than those for continuous corn. How-

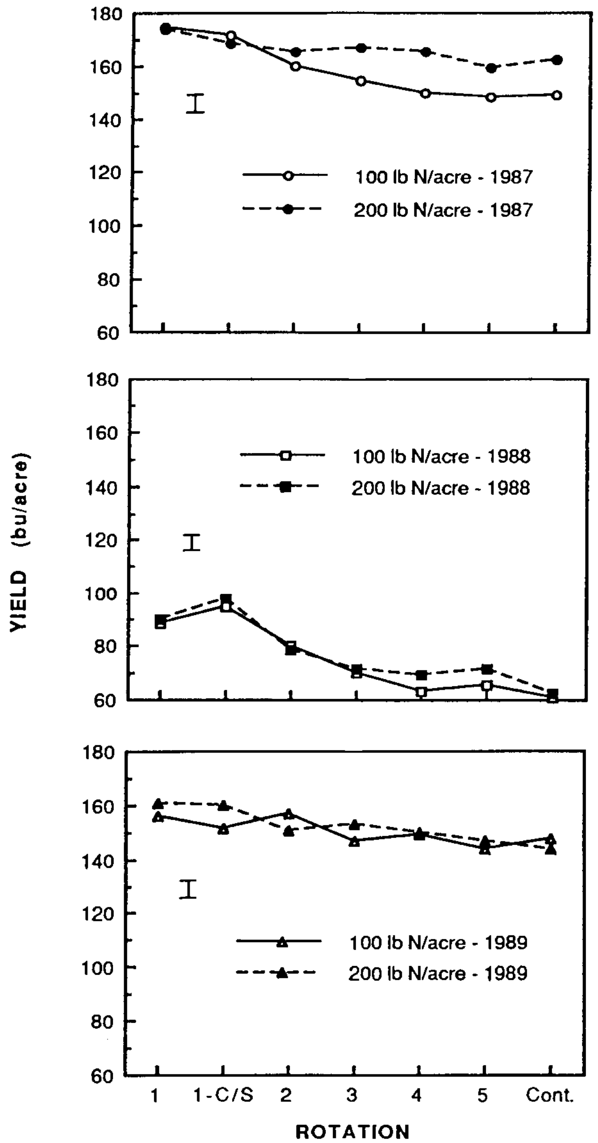

Fig. 1. Corn yield as influenced by year in rotation, N fertilizer rate and year, averaged over tillage systems and hybrids. Years in rotation are: 1 = 1st-yr corn after 4 or 5 yr of soybean; 1-C/S = corn alternated annually with soybean; 2,3,4,5 = 2nd-, 3rd-, 4th-, and 5th-yr corn, respectively, following 1 or more years of soybean; Cont. = 5th-, 6th-, and 7th-yr corn in 1987, 1988, and 1989, respectively. Vertical bar represents LSD (0.05).

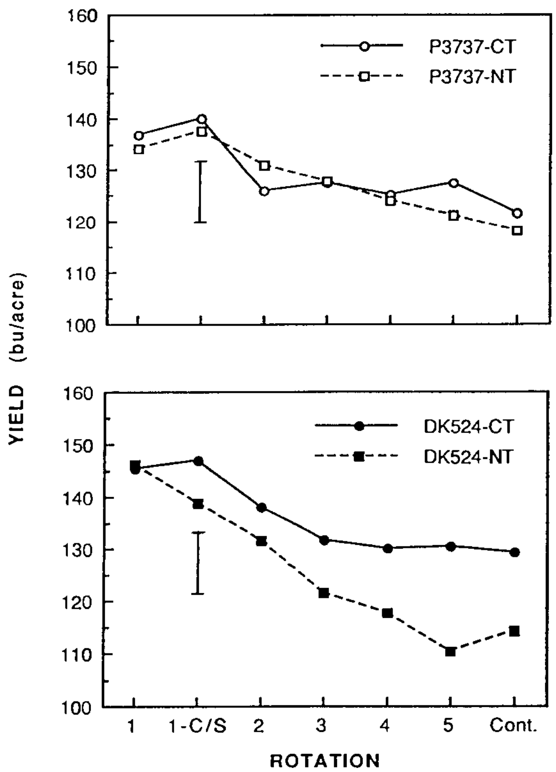

Fig. 2. Corn yield as influenced by year in rotation, tillage, and hybrid, averaged over N fertilizer rates and years. Years in rotation are: 1 = 1st-yr corn after 4 or 5 yr of soybean; 1-C/S = corn alternated annually with soybean; 2,3,4,5 = 2nd-, 3rd-, 4th-, and 5th-yr corn, respectively, following 1 or more years of soybean; Cont. = 5th-, 6th-, and 7th-yr corn in 1987, 1988, and 1989, respectively. Vertical bar represents LSD (0.05).

ever, 1st-yr NT corn yield of DK524 was 28% higher than continuous corn (Fig. 2).

The reasons for the increased sensitivity of DK524 to monocropping under NT are not clear. There was a 2-d delay for DK524 compared to P3737 in days to silk with NT continuous corn compared to NT 1st-yr corn (data not shown), but there were no other consistent differences between hybrids for other growth measurements. Other researchers have found that some corn hybrids yielded less when monocropping the same hybrids compared to annually rotating hybrids (Hicks and Peterson, 1981; Anderson et al., 1988). The design in our experiment did not allow a comparison of rotating vs. repeating hybrids when monocropping, but the increased negative response to continuous corn under NT for DK524 indicates this hybrid might respond favorably to hybrid rotation.

Increased residue cover under NT resulted in cooler soil temperatures at planting, which delayed season-long plant growth (Table 2). Although tillage system-induced differences in these parameters usually occurred for both 1st-yr and continuous corn, differences were smaller for corn following soybean. This was likely due to less residue cover with NT planting into soybean residue and consequently warmer soil temperatures (Table 2). Residue cover for annually alternated corn was intermediate between 1st-yr corn and continuous corn, but differences in growth and yield response to tillage system between 1st-yr corn and annually alternated corn were small (Table 2 and Fig. 2).

Root damage was not influenced by tillage systems (data not shown), but there was increased damage for continuous corn compared to 1st-yr corn (Table 2).

Soybean

The BSR-susceptible-soybean cultivar was more sensitive than the resistant cultivar to annual alternation with corn and to consecutive years of soybean (Fig. 3). Yields for both soybean cultivars were usually 15 to 20% greater for 1st-yr soybean after several years of corn than for annually alternated soybean. An exception occurred in 1987, when yields for the BSR-resistant cultivar were similar for 1st-yr and alternated soybean (Fig. 3). Crookston et al. (1989) also found lower yields for soybean annually alternated with corn compared to 1st-yr soybean after several years of corn.

Although the soybean yield response to additional years of consecutive soybean varied with cultivar and year, yields generally decreased with 2 or more years of consecutive soybean, before stabilizing or increasing slightly after more than 5 yr (Fig. 3 and 4). In 1989, yields of the BSR-resistant cultivar did not change with more than 2 yr of consecutive soybean (Fig. 3).

For the BSR-resistant cultivar, 1st-yr-soybean yields were 13 to 16% higher for 1st-yr soybean than for continuous soybean (Fig. 3). However, soybean yields were influenced more by monocropping with the susceptible cultivar, with 25 to 40% greater yields for 1st-yr soybean than for continuous soybean. Brown stem rot susceptibility of cultivars had the greatest influence in 1987 and 1989, when the disease was most prevalent. Cultivar yields were within 3 (1987) and 12% (1989) with 1st-yr soybean, but yields were 14 (1987) and 36% (1989) higher for the BSR-resistant cultivar with continuous soybean. Yields of soybean cultivars were similar in 1988. These results indicate that soybean is more sensitive to monocropping than corn. This observation has been reported in previous studies (Edwards et al., 1988; Crookston et al., 1989) and may be related to build-up of BSR or other diseases in continuous soybean. In our study, relative corn vs. soybean response to monocropping was generally similar when corn and BSR-resistant soybean were compared (Fig. 1, 2 and 3).

Averaged over rotations, soybean yields under CT were 8 to 10% higher than those with NT in 1987 and 1989, but CT yields were 18% lower than NT under the dry, hot conditions in 1988. Soybean growth was delayed under NT (Table 3), which may have allowed

Table 2. Residue coverage, soil temperature, and plant growth parameters for corn as influenced by tillage system and year in rotation, 1987 to 1988.

	Residue cover			Soil temperature			Days to emergence			Plant height (6 wk)			Days to silk		
Year in rotation†	CT‡		NT	CT		NT	CT		NT	CT		NT	CT		NT
	%			°F						in					
1	1	*	28	72	*	71	12		12	26	*	24	72	*	73
1-C/S	1	*	44	–		–	–		–	26	*	22	72	*	74
Cont.	3	*	74	72	*	68	12	*	15	24	*	18	73	*	79
LSD (0.05)§		7			1			1			1			1	

	Grain moisture			Final plant population				
	CT		NT	CT		NT	Mature plant height	Root damage rating¶
	%			plants/acre × 1000			ft	
1	21.2		21.9	26.3	*	28.1	6.2	1.2
1-C/S	20.8	*	22.9	26.1	*	28.1	6.3	1.4
Cont.	21.1	*	25.2	26.3		26.7	5.7	2.1
LSD (0.05)		1.5			1.2		0.2	0.3

* Difference between tillage systems is significant at the 0.05 probability level.
† 1 = 1st-yr corn, after several years of soybean; 1-C/S = 1st-yr corn, alternated annually with soybean; Cont. = 5th-yr corn in 1987 and 6th-yr corn in 1988.
‡ CT = conventional tillage; and NT = no till.
§ Least significant difference for comparisons within tillage systems.
¶ Based on a scale of 1 (no damage) to 6 (very severe damage).

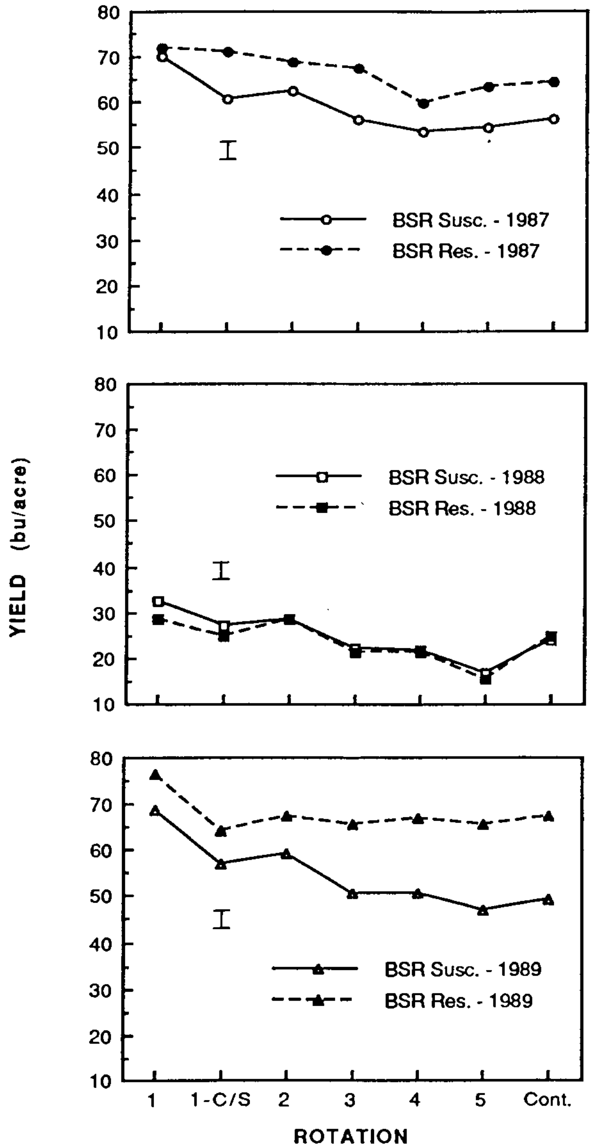

Fig. 3. Soybean yield as influenced by year in rotation, cultivar, and year, averaged over tillage systems and N fertilizer rates. Years in rotation are: 1 = 1st-yr soybean after 4 or 5 yr of corn; 1-C/S = soybean alternated annually with corn; 2,3,4,5 = 2nd-, 3rd-, 4th-, and 5th-yr soybean, respectively, following 1 or more years of soybean; Cont. = 5th-, 6th-, and 7th-yr soybean in 1987, 1988, and 1989, respectively. Vertical bar represents LSD (0.05).

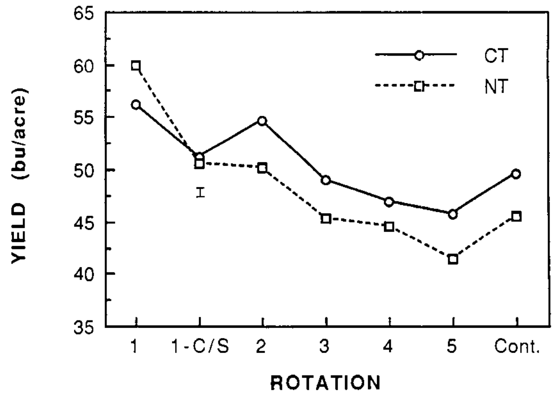

Fig. 4. Soybean yield as influenced by year in rotation, and tillage, averaged over years, N fertilizer rates, and cultivars. Years in rotation are: 1 = 1st-yr soybean after 4 or 5 yr of corn; 1-C/S = soybean alternated annually with corn; 2,3,4,5 = 2nd-, 3rd-, 4th-, and 5th-yr soybean, respectively, following 1 or more years of soybean; Cont. = 5th-, 6th-, and 7th-yr soybean in 1987, 1988, and 1989, respectively. Vertical bar represents LSD (0.05).

the crop to better use late-season rains in 1988, compared to the more advanced soybean grown under CT. Three-year-average-soybean yields were either slightly greater with NT or similar under CT and NT for 1st-yr and alternated soybean, but when soybean was monocropped CT yields were about 10% greater than those under NT (Fig. 4).

Increased residue cover and cooler soil temperatures under NT resulted in delayed early-season soybean growth and increased days to maturity (Table 3). Differences were smaller with continuous soybean compared to 1st-yr soybean, most likely due to decreased residue cover and warmer soil when planting NT into soybean vs. corn previous-crop residue.

For both tillage systems, days to maturity decreased with continuous compared to first-year soybean (Table 3). A rotation by cultivar interaction for days to maturity occurred in 1987, with 9 (BSR-susceptible cultivar) and 5 (BSR-resistant cultivar) days earlier maturity for continuous compared to first-year soybean. This indicates that earlier maturity for continuous soybean may be at least partially caused by premature death due to BSR infection.

Brown stem rot severity ratings during podfill in 1989 indicated the disease was more severe under NT than CT with continuous soybean (Dr. Craig Grau, personal communication). Evidently, BSR had a more adverse influence on NT yields than did cool early-season soil. Vasilas et al. (1988) and Dick and van Doren (1985) found that increased Phytophthora (*Phytophthora megasperma*) root rot under NT was related to decreased soybean yields compared to CT.

Addition of N fertilizer increased 3-yr average soybean yields by 2% in 1987 and 1988, and 6% in 1989 (data not shown). Both soybean rotation and tillage effects were not influenced by N fertilizer. Others have reported only limited soybean response to N application (Baldock et al., 1981; Welch et al., 1973).

INTERPRETIVE SUMMARY

The results of this study indicate several considerations that could be used by growers in the northern Corn Belt when developing corn/soybean cropping systems:

1. Corn and soybean must be rotated to obtain highest yields. For both crops, yield decreases occurred beyond the 2nd yr of monocropping.
2. Withholding corn for 1 yr was sufficient to obtain the maximum "rotation effect," but for soybean rotating for just 1 yr was not enough to obtain maximum yield.
3. The level of yield decrease with continuous soybean was doubled with BSR-susceptible compared to BSR-resistant cultivars, when the BSR disease was severe.

Table 3. Residue coverage, soil temperature, and plant growth parameters for soybean as influenced by tillage system and year in rotation, 1987 to 1988.

	Residue cover			Soil temperature			Days to emergence			Plant height (6 wk)			Days to maturity		
Year in rotation†	CT‡		NT	CT		NT	CT		NT	CT		NT	CT		NT
	%			°F						in.					
1	3	*	74	72	*	68	16	*	19	7.8	*	5.7	128	*	134
1-C/S	2	*	71	–		–	–		–	7.5	*	5.8	125	*	130
Cont.	1	*	28	72	*	71	14	*	16	7.4	*	6.5	125	*	126
LSD (0.05)§		7			1			3			0.2			2	

	Mature plant height			Lodging			Plant population (V5)			Plant population (maturity)		
	CT		NT	CT		NT	CT		NT	CT		NT
	in.			1–5			plants/acre × 1000					
1	34		35	1.1	*	1.4	137		139	126	*	116
1-C/S	34		34	1.1	*	1.3	153	*	134	141	*	119
Cont.	33	*	31	1.0	*	1.1	152		156	136	*	129
LSD (0.05)		3			0.2			19			12	

* Differences between tillage systems is significant at the 0.05 probability level.
† 1 = 1st-yr soybean, after several years of corn; 1-C/S = 1st-yr soybean, alternated annually with corn; Cont. = 5th-yr soybean in 1987 and 6th-yr soybean in 1988.
‡ CT = conventional tillage; and NT = no till.
§ Least significant difference for comparisons within tillage systems.

4. Corn hybrids varied in sensitivity to monocropping under NT, but had similar responses to crop sequence with CT.
5. The relative sensitivity of corn and soybean to monocropping was similar when the least "monocropping-sensitive" corn hybrid and BSR-resistant soybean were compared.
6. For both corn and soybean, yield depressions under NT compared to CT were less likely to occur when crops were rotated rather than grown continuously.

Based on these results, a proposed 3-yr-corn/soybean rotation to maximize yields and minimize tillage would be corn-corn-soybean, using NT for soybean and corn-following-soybean, and CT for the corn-following-corn year. However, corn and soybean producers seldom settle on particular rotations for long-term periods. Rather, selection of crop sequences is usually a complicated annual process based on (i) current or anticipated crop prices, (ii) changes in government programs, and (iii) the previous year's growing conditions (which may influence water and/or N availability, and herbicide carryover susceptibility of subsequent crops). We believe the results described should help growers with this yearly decision-making effort by providing expected corn and soybean yield potentials for a range in crop history, tillage system, N management, and hybrid/cultivar backgrounds to apply to specific economic, environmental, and government policy scenarios.

ACKNOWLEDGMENTS

This research was supported in part by grants from The Wisconsin Soybean Marketing Board, The Wisconsin Fertilizer Research Council, and Pioneer Hibred International, Inc.

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