Tillage and Crop Rotation Affect Corn, Soybean, and Winter Wheat Yields

M.G. Lund, P.R. Carter, and E.S. Oplinger

Research Question

Grain producers are converting to reduced tillage systems to reduce soil erosion and field-work time requirements, and to remain eligible for government programs. Little research has been conducted evaluating tillage systems in crop rotations including corn, soybean, and wheat.

The two objectives of this study were to (i) evaluate the influence of tillage on performance of corn, soybean, and winter wheat in rotations with each other and (ii) determine whether corn or soybean yields could be increased in 3-yr rotations with wheat compared with those in an annual corn/soybean rotation.

Literature Summary

In northern regions, grain yields for both corn and soybean are generally lower under no-till than moldboard plow systems when growing either crop continuously, but yields are often similar for these tillage systems when the two crops are rotated. There is little published research available regarding winter wheat response to tillage systems in corn/soybean rotations or of corn/soybean response to tillage following winter wheat.

Results of several studies indicate that both corn and soybean yields are limited in 2-yr, corn/soybean sequences compared with those in rotations in which the two crops are grown less frequently than every other year.

Study Description

This study was conducted for 3 yr on Plano silt loam soil at Arlington, WI.

Treatments:
- A. Tillage systems (2)
  - Moldboard plow and no-till
- B. Crop rotation sequences (6)
  - Corn/soybean
  - Corn/soybean/wheat
  - Corn/wheat/soybean
  - Continuous corn, soybean, and wheat
- C. Hybrids/cultivars (2)
  - Corn (Pioneer 3737, Kaltenberg K4000)
  - Soybean (BSR 101, Ozzie)
  - Wheat (Caldwell, Argee)

Fertility: Univ. of Wisconsin recommendations

Weed control:
- Corn (cyanazine, metolachlor, alachlor, thifensulfuron)
- Soybean (metolachlor, alachlor, thifensulfuron)
- Wheat (glyphosate, post-harvest)
- Hand weeding

Insect control:
- Corn (terbufos, fenvalerate)

Growing season moisture:
- Adequate for average to above-average crop yields per year.

Full scientific article from which this summary was written begins on page 207 of this issue.

Applied Questions

How do crop yields compare in no-till vs. moldboard plow systems in corn, soybean, wheat rotations?

For corn and soybean, yields were similar under no-till and moldboard plow systems when the two crops were grown following any crop other than themselves (Table 1). But yields for no-till continuous corn were 8% lower than for moldboard plowing, and continuous soybean yields were 7% less with no-till than with moldboard plowing.

Winter wheat yields were depressed by several factors including (i) the relatively late planting necessary when following corn and soybean, (ii) winter injury in 1989 (especially with moldboard plowing), and (iii) leaf diseases in 1991 (especially with no-till). Although 3-yr average wheat yields for no-till were similar to, or slightly higher than, those with moldboard plowing (Table 1), wheat response to tillage was inconsistent. Yields were higher for no-till in 1989, but greatest yields occurred with moldboard plowing in 1991.

Can corn or soybean yields be increased in 3-yr rotations with wheat compared with an annual rotation with each other?

Three-crop rotations did not result in greater soybean or corn yields than corn-soybean rotations (Table 1). Our previous studies had shown 15 to 20% lower soybean yields in corn-soybean rotations than in first year soybean after 5 yr of corn, when the brown stem rot disease was prevalent. Brown stem rot had less overall influence on soybean yields in the current study. Adding a crop (such as wheat) to corn-soybean rotations may be more beneficial when soybean diseases reduce yields more than in this study.

Table 1. Three-year average grain yields for corn, soybean, and winter wheat for four crop rotation sequences and two tillage systems.

		Crop rotation sequence			
Crop	Tillage system	C/S†	C/W/S	C/S/W	Continuous
		bu/acre			
Corn	Moldboard plow	173	175	172	162
	No-till	176	172	163	149
Soybean	Moldboard plow	53	54	53	46
	No-till	52	53	51	43
Wheat	Moldboard plow	–	40	40	33
	No-till	–	40	45	40

†C = corn, S = soybean, W = winter wheat.

Tillage and Crop Rotation Affect Corn, Soybean, and Winter Wheat Yields

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There is little research in northern regions on tillage systems in corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr], and wheat (*Triticum aestivum* L.) rotations. The objectives of this study were to (i) evaluate the influence of tillage on performance of corn, soybean, and winter wheat in rotations with each other, and (ii) determine whether corn or soybean yields could be increased in 3-yr rotations with wheat compared with an annual rotation with each other. Field studies were conducted near Arlington, WI, for 3 yr (1989 to 1991) on a Plano silt loam soil (fine-silty, mixed, mesic Typic Argiudoll) under both moldboard plow (MP) and no-till (NT). Six crop sequences evaluated were: corn/soybean, corn/soybean/wheat, corn/wheat/soybean, and continuous corn, soybean, or wheat. Grain yields for both corn and soybean were similar regardless of crop sequence when these crops were in rotation, with no advantage for 3-yr vs. 2-yr sequences. Average yields were reduced 10% (corn) and 15% (soybean) for continuous cropping compared with rotations, with greater yield reductions under NT than MP. Tillage did not influence grain yield for soybean or corn in rotation, but yields were reduced under NT for both crops with monocropping. Grain yields for NT continuous corn were 8% lower than MP, and continuous soybean yields were 7% less with NT than MP. Wheat yields were low and response to tillage and rotation was inconsistent. In this study we found no clear advantage for three-crop corn, soybean, and wheat rotations compared with an annual rotation of corn and soybean.

CORN, SOYBEAN, and winter wheat yield less following themselves than when rotated with another crop (Meese et al., 1991; Crookston e tal., 1991; Edwards et al., 1988). There are many factors that contribute to the yield advantage that occurs from rotating crops. Legumes in a rotation provide N for ensuing non-legume crops, but crop rotations may also provide weed, disease, insect, and nematode control (Benson, 1985), as well as improved soil physical properties (Raimbault and Vyn, 1991).

Even when crop rotation is practiced, yields can be limited if particular crops are grown frequently. In Wisconsin, soybean yields in annual corn/soybean rotations were 15 to 20% lower (depending on the tillage system and cultivar) compared to first-year soybean after several years of corn (Meese et al., 1991). A similar study in Minnesota showed soybean yield reductions of 8% when alternated annually with corn compared with first-year soybean after several years of corn (Crookston et al., 1991). Crookston et al. also reported a 5% yield advantage for first-year corn after several years of soybean compared with corn rotated annually with soybean. These results indicate a need to add crops to the prevalent corn and soybean rotation to obtain the maximum yield benefit from rotation for all crops.

Peterson and Varvel (1989a), in Nebraska, evaluated a 4-yr rotation of corn/oat (*Avena sativa* L.) + clover [80% *Melilotus officinalis* (L.) Lam., 20% *Trifolium pratense* L.]/grain sorghum [*Sorghum bicolor* (L.) Moench]/soybean and found a 5% soybean yield increase in this rotation compared with annually rotating soybean and corn. In Alabama (Edwards et al., 1988), soybean yields were increased 6% in a corn/wheat/soybean sequence compared with those in a corn/soybean rotation under MP. In contrast, under NT conditions, soybean yields in a corn/wheat/soybean rotation were 19% lower than with corn/soybean rotation.

For corn, Peterson and Varvel (1989b) reported a 9% increase in grain yield when grown in the 4-yr rotation with grain sorghum, oat + clover, and soybean compared with corn rotated annually with soybean. In another Nebraska study, corn yield increased 20% in a soybean/wheat/corn rotation as compared with continuous corn (Peterson et al., 1991). Research to evaluate corn and soybean response in northern latitudes in grain crop rotations with other crops such as wheat is limited.

Many farmers are converting to reduced tillage systems to reduce soil erosion and field-work time requirements, and to remain eligible for government programs. Little research has been done evaluating tillage systems in crop rotations including corn, soybean, and wheat. On silt loam or finer soil textures, grain yields for both corn and soybean are generally lower under NT than MP systems when monocropping (Dick and Van Doren, 1985; Carter and Barnett, 1987; Griffith et al., 1988; Meese et al., 1991). But these yield reductions can often be at least partially offset by rotating crops (Dick and Van Doren, 1985; and Griffith et al., 1988). Meese et al. (1991) reported that while continuous corn and soybean yields were about 10% greater for MP than NT, MP and NT yields were generally similar for annually rotated corn and soybean.

There have been few studies evaluating winter wheat performance in various tillage systems and crop rotations in northern regions. Vyn et al. (1991) in Ontario, found that wheat yields were reduced 20% for continuous wheat compared with wheat after soybean, barley (*Hordeum vulgare* L.), or alfalfa (*Medicago sativa* L.), but tillage practices (MP, minimum tillage, and NT) did not influence grain yield. In Kentucky, wheat grain yields were similar for NT and MP systems when wheat was grown following either ryegrass (*Lolium perenne* L.), sorghum-sudan grass (*Sorghum* x. *drumondii*; syn. *S. sudanense* [Piper] stapf), or corn (Ditsch and Grove, 1991). In the western US and Canada, wheat is often planted NT be-

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Abbreviations: MP, moldboard plow; NT, no-till.

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

	Year					
Crop rotation sequence	1986	1987	1988	1989	1990	1991
1. S-C	S	C	S	C	S	C
2. C-S	C	S	C	S	C	S
3. W-S-C	W	S	C	W	S	C
4. C-W-S	C	W	S	C	W	S
5. S-C-W	S	C	W	S	C	W
6. S-W-C	S	W	C	S	W	C
7. C-S-W	C	W	S	C	W	S
8. W-C-S	W	C	S	W	C	S
9. Cont. corn	C	C	C	C	C	C
10. Cont. soybean	S	S	S	S	S	S
11. Cont. wheat	W	W	W	W	W	W

cause the increased soil residue catches more snow, which results in greater soil insulation and less winter injury (Fowler and Gusta, 1977; Loeppky et al., 1989; Cox et al., 1986). Currently, most growers in the northern Corn Belt seed winter wheat in early to mid September following corn silage, plow-down alfalfa, or short-season canning crops such as pea (*Pisum sativum* L.) or sweet corn, rather than delaying wheat planting until after corn or soybean grain harvest.

This study was initiated to evaluate the influence of tillage on the growth and grain yield of corn, soybean, and wheat when grown in rotations with each other in the northern Corn Belt. We were also interested in determining whether corn or soybean yields could be increased in 3-yr rotations with wheat compared with annually alternated corn and soybean.

METHODS AND MATERIALS

Field research was conducted during 3 yr (1989 to 1991) on a Plano silt loam soil near Arlington, WI. Soil tests indicated a pH of 6.4, 30 ppm P/acre, 250 ppm K/acre, and 3.3% organic matter (Kelling et al., 1991).

The experiment was established in a split-split plot randomized complete block arrangement of treatments with four replicates. Whole plots were NT and MP which were established in 1986. Tillage operations for MP were MP in the fall and field cultivation prior to planting. For NT, crops were planted into the undisturbed residue of the previous crop. Sub-plots consisted of six rotation sequences involving corn, soybean, and winter wheat (Table 1), which also were initiated in 1986. Crop sequences were corn-soybean, corn-wheat-soybean, corn-soybean-wheat; and continuous corn, soybean, and wheat. Each phase of each sequence was repeated each year, resulting in a total of 11 rotation sequence treatments (Table 1). The sequences were in place by 1988, but 1988 data were not included due to variability caused by extreme drought that year. The sub-sub plots were two corn, soybean, and wheat hybrids/cultivars, selected to represent a range in maturity. Corn hybrids were Pioneer brand 3737 (P3737) (100-d) and Kaltenberg 4000 (K4000) (90-d), soybean cultivars were Ozzie (Group 0) and BSR 101 (Group I), and wheat cultivars were Caldwell (early) and Argee (late). Experimental unit size was 7.5 ft by 30 ft.

Corn was planted with a Kinze (Kinze Mfg., Williamsburg, IA) six-row planter at a 2-in. depth in 30-in. rows. The planter was equipped with rippled coulters in front of double disk openers with dual press wheels for planting under NT conditions. Corn was planted at a rate of 32 000 seeds/acre on 27 Apr. 1989, 30 Apr. 1990, and 1 May 1991. A 6-24-24 (N-P-K) starter fertilizer was row-applied at planting in all years at a rate of 200 lb/acre. Additional N was broadcast-applied in the form of ammonium nitrate. Rates were adjusted annually based on preplant soil nitrate tests, with lowest rates in 1989 and 1990 when residual nitrate levels were high, due to low rainfall in 1987 and 1988 (Bundy and Malone, 1988). In 1989, 100 lb N/acre was applied to all corn plots. In 1990 and 1991, N rates were 100 (1990) and 160 (1991) lb/acre for corn following corn and wheat. For corn following soybean, 50 (1990) and 120 (1991) lb N/acre were applied.

The corn following corn plots received terbufos (Phosphorodithioic acid S[[(1,1-dimethylethyl)thio]methyl] 0,0-diethylester) insecticide at a rate of 1 oz. a.i./1000 ft of row at planting to control corn rootworm (*Diabrotica* spp.). In 1989 and 1990, 2 lb a.i./acre cyanazine and 1.5 lb a.i./acre metalachlor herbicides were applied pre-emergence for weed control. In 1991, 2 lb a.i./acre alachlor were applied pre-emergence and 0.0625 oz a.i./acre of thifensulfuron was applied post-emergence for weed control. Also, in 1991 0.05 lb a.i./acre of fenvalerate (α-cyano-3-phenoxybenzyl α-(-4-chlorophenyl)isovalerate) was applied to control common stalk borer (*Papaipema nebris* Guenee).

Soybean was drilled in 8-in. wide rows at a depth of 1.5 in. in a Tye No-Till drill (Tye Co., Lockney, TX) equipped with rippled coulters in front of double disk openers and a double press wheel. Soybean was planted 11 May 1989, 18 May 1990, and 1 May 1991 at 225 000 seeds/acre. In 1989, 1.5 lb a.i./acre metolachlor was applied pre-emergence and 2 lb a.i./acre bentazon and oil were applied post-emergence to control weeds. In 1990, 1.5 lb a.i./acre of only metolachlor was applied pre-emergence. In 1991, 2 lb a.i./acre alachlor was applied pre-emergence and 0.0625 oz a.i./acre of thifensulfuron was applied post-emergence for weed control. Hand weeding also was used if necessary to maintain weed-free corn and soybean plots.

Wheat was drilled in 8-in. rows with the same drill used for soybean. Wheat was planted following corn and soybean harvest on 13 Oct. 1988, 10 Oct. 1989, and 4 Oct. 1990 at a rate of 36 seeds/sq ft. Glyphosate was applied at a rate of 0.75 lb a.i./acre after harvest to control weeds and wheat regrowth. Each year N was applied to wheat in the spring at a rate of 50 lb/acre as ammonium nitrate.

In 1989, 1990, and 1991 data collected for corn plots included; final plant population, grain moisture, and grain yield. Soybean data collected all 3 yr included: preharvest plant height and lodging, grain moisture, and grain yield. Wheat measurements taken for all 3 yr included: late-season plant height, grain moisture, and grain yield. Additional measurements taken only in 1991 for corn and soybean plots included: residue cover and soil temperature after planting, days to emergence, early-season plant population, and early-season plant height. Days to 50% silk for corn was also measured in 1991 only.

Table 2. Monthly precipitation and mean air temperature for 1989 to 1991 growing seasons in Arlington, WI.

Month	Year 1989	1990	1991
	Precipitation		
	in.		
May	1.8 (−1.4)†	4.3 (1.1)	1.9 (−1.3)
June	2.0 (−2.1)	6.3 (2.2)	2.6 (−1.5)
July	3.8 (0.3)	1.6 (−1.9)	8.0 (0.3)
August	4.3 (0.3)	5.4 (1.4)	1.8 (−2.2)
September	3.8 (0.2)	1.2 (−2.4)	4.4 (0.8)
Five-month total	15.7 (−2.7)	18.8 (0.4)	14.5 (−3.9)
	Mean air temperature		
	°F		
May	57.2 (−0.2)	55.0 (−2.4)	62.8 (5.4)
June	66.3 (−0.1)	68.0 (1.6)	69.9 (3.5)
July	72.9 (1.7)	70.1 (−1.1)	71.0 (−0.2)
August	67.6 (−1.5)	70.0 (0.9)	69.5 (0.4)
September	59.4 (−1.5)	64.0 (3.1)	59.3 (−1.6)
Five-month mean	64.7 (−1.6)	65.4 (0.4)	66.5 (1.5)

† Number in parentheses indicates the departure from long-term average.

Residue cover was measured using a line transect method as described by Wollenhaupt and Pingry (1991). Midday soil temperature was measured at a 2-in. depth in the row on alternating days for 10 d after planting. Soybean lodging was measured on a 1 (no lodging) to 5 (completely lodged) scale.

Two corn rows from each plot were harvested on 2 Oct. 1989 and 1990, and 30 Sept. 1991 with a Gleaner (Allis Chalmers Co., Milwaukee, WI) K2 modified plot combine equipped with electronic scale and moisture meter for grain yield and moisture determination. An Almaco (Allen Machine Co., Nevada, IA) plot combine was used to harvest the six middle soybean rows from each plot on 29 Sept. 1989, 1 Oct. 1990, and 26 Sept. 1991. The Almaco plot combine also was used to harvest the six middle wheat rows from each plot on 20 July 1989 and 1990, and 21 July 1991. Grain yields were adjusted to 15.5% (corn), 13% (soybean), and 13% (wheat) moisture.

Data were analyzed over years using a split-split plot analysis of variance, and mean comparisons were made using the LSD test. Replicates were considered fixed effects while all other effects were random in determining the expected mean squares and appropriate F-tests in the combined analysis of variance.

RESULTS AND DISCUSSION

Corn

Although growing season precipitation was about 3 to 4 in. below average in 1989 and 1991 and near average only in 1990 (Table 2), conditions were favorable for high corn yields all 3 yr. Average yields were 161 (1989), 167 (1990), and 178 (1991) bu/acre. Yields for P3737 averaged 7 bu/acre higher than those for K4000, but grain yield responses to tillage and rotation were similar all 3 yr for both hybrids. Therefore, average values will be discussed (Fig. 1).

There were no grain yield differences for corn in soybean/corn, wheat/soybean/corn, and soybean/wheat/corn rotations (Fig. 1). But, continuous corn yields were reduced an average of 13% under NT and 7% with MP compared with rotated corn. Meese et al. (1991) also reported that continuous corn yield reductions were greater under NT. Corn yields were similar for NT and MP when corn was grown in crop rotations, but with continuous corn NT yields were 8% less than MP (Fig. 1).

Increased residue cover and lower soil temperature were related to delayed plant growth under NT compared with MP (Table 3). Plant growth differences between crop rotations were small under MP. But with NT, corn growth responses were generally related to the amount of previous crop residue on the soil surface at planting (Table 3). Corn grown after soybean (soybean/corn and wheat/soybean/corn) had the least residue cover, followed by corn after wheat (soybean/wheat/corn), and continuous corn. Under NT, soil temperature at planting for continuous corn averaged 5 °F lower than for rotated corn and time to emergence and silk was delayed about 2 d. Harvest grain moisture was nearly 2 percentage units higher for NT continuous corn than for NT corn following soybean (Table 3).

Early-season plant height averaged 9.5 and 7.5 in. shorter for NT continuous corn and NT corn after wheat than for NT corn after soybean (Table 3). For NT continuous corn, reduced early plant height and delayed silking probably were caused by cool seed-zone soil temperatures, which delayed emergence and early plant growth rate (Table 3). But for NT corn after wheat, soil temperature after planting and days to emergence were not different than for NT corn after soybean. Even under MP, corn plants were shorter and silking was delayed for corn following wheat compared with following soybean (although the magnitude of height reduction and silk delay was less than under NT) (Table 3). Therefore, delayed growth for corn following wheat was apparently related to factors other than soil temperature or seed placement.

Raimbault and Vyn (1990) and Raimbault et al. (1991) in Ontario reported that a winter rye (*Secale cereale* L.) cover crop delayed corn development and reduced corn biomass yield, with greater negative effects on corn under NT than MP. They suggested that allelopathic effects

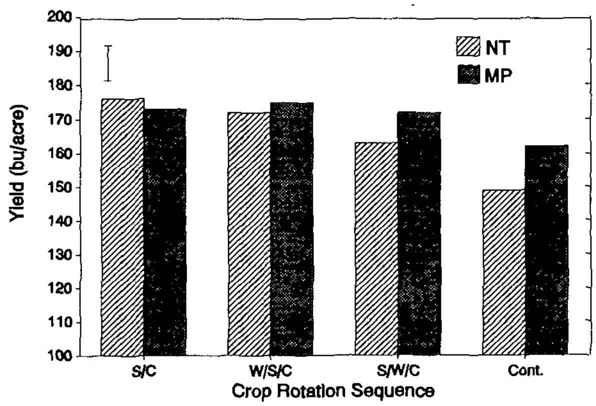

Fig. 1. Relationship between crop rotation sequence and corn grain yield for no-till (NT) and moldboard plow (MP). Values are averaged over 3 yr and two hybrids. Crop rotation sequences: Alternating soybean and corn (S/C), wheat-soybean-corn (W/S/C), soybean-wheat-corn (S/W/C), and continuous corn (Cont.). Vertical bar indicates LSD (P = 0.10).

Table 3. Residue cover, soil temperature, and plant growth parameters for corn as influenced by tillage and crop rotation sequence, 1991.

	Residue cover			Soil temperature‡			Days to emergence			Plant height (6 wk)			Days to silk			Grain moisture#			Final plant population#		
Crop rotation sequence	MP§		NT	MP		NT	MP		NT	MP		NT	MP		NT	MP		NT	MP		NT
		%			°F						in.						%			plants/ acre × 1000	
Alternating soybean-corn	2	†	31	65	†	63	15	†	17	57	†	48	46	†	48	22.8		23.4	30.7		30.7
Wheat-soybean-corn	7	†	43	66	†	64	14	†	16	56	†	47	46	†	48	23.3		23.7	31.0		29.3
Soybean-wheat-corn	2	†	58	65	†	63	15	†	17	52	†	40	47	†	49	23.0	†	24.5	30.1	†	27.0
Continuous corn	5	†	69	65	†	58	16	†	19	53	†	38	47	†	50	22.7	†	25.5	30.6	†	27.7
LSD (0.10)¶		15			1			2			4			1			1.1			2.1	

† Difference between tillage systems within crop rotation sequences is significant at the 0.10 probability level.
‡ In-row soil temperature at seeding depth measured at mid-day. Values are the average of measurements taken on alternate days for 10 d after planting.
§ MP = moldboard plow and NT = no-till.
¶ Least significant difference for comparisons between crop rotation sequences within tillage systems.
# Average data from 1989–1991.

from the rye may have inhibited corn growth. They also cited researchers (Freyman and Schaalje, 1983; and Cochran et al., 1977) who attributed adverse effects of crop growth after wheat to the presence of phytotoxic compounds secreted by, or produced during, decomposition of wheat residues. We also speculate that allelopathy may have at least partially caused the growth delays for corn following wheat in this study. We did not remove wheat straw following harvest, but many farmers in dairy regions bale this straw for bedding. This may reduce the potential for allelopathic effects on subsequent crop growth. Grain yield was affected relatively little by the growth delay for corn following wheat, with no yield loss under MP and a 6% yield reduction for NT corn following wheat compared with corn following soybean (Fig. 1).

Plant populations at harvest were lower for NT continuous corn and corn following wheat than for corn after soybean and all MP treatments (Table 3). For NT corn following wheat, limited post-emergence stand reduction was caused by common stalk borer before these insects were chemically controlled. The plant population range was from 27 000 to 30 700 plants/acre, but this 5% difference in final stand probably did not affect yields. A 1988 to 1991 study at a nearby site (Hudelson and Carter, data not published) found little difference in corn yield within this range of plant populations.

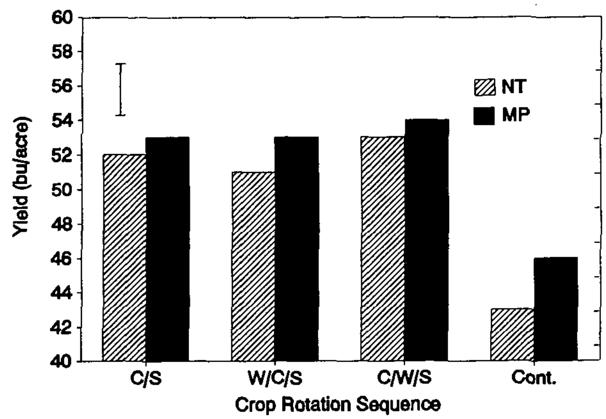

Fig. 2. Relationship between crop rotation sequence and soybean grain yield for no-till (NT) and moldboard plow (MP). Values are averaged over 3 yr and two cultivars. Crop rotation sequences: Alternating corn and soybean (C/S), wheat-corn-soybean (W/C/S), corn-wheat-soybean (C/W/S), and continuous soybean (Cont.). Vertical bar indicates LSD ($P = 0.10$).

Soybean

Similar to corn, soybean yield levels each year were relatively high and responses to tillage and rotation were similar. Consequently, only average values over years will be presented and discussed (Fig. 2). Soybean yields averaged 51 (1989), 58 (1990), and 43 (1991) bu/acre. Soybean yields in 1991 were uniformly reduced by soybean mosaic virus, which was prevalent throughout southern Wisconsin on early planted soybean. Cultivar BSR 101 yields averaged 10 bu/acre higher than those for Ozzie, but responses to tillage and rotation were not different between cultivars.

There were no yield differences for soybean in corn/soybean, corn/wheat/soybean or wheat/corn/soybean rotations (Fig. 2). Continuous soybean yield losses averaged 17% for NT and 14% for MP compared with those in rotation. Other studies also have reported lower yields for monocropped soybean than for soybean in rotations (Meese et al., 1991; Crookston et al., 1991).

For all three crop rotations (when soybean followed corn or wheat), NT yields were similar to, or within 5% of, MP yields (Fig. 2). Lueschen et al. (1992) also found no consistent soybean yield differences between MP, chisel plowing, and NT when soybean followed corn. When soybean followed wheat, NT yields were similar to those for MP and chisel plowing in 3 of 4 yr. In this study, continuous soybean yields were 7% lower under NT than MP (Fig. 2). Meese et al. (1991) found that monocropped NT soybean yields averaged 10% lower than MP yields.

Previous research in Wisconsin (Meese et al., 1991) and Minnesota (Crookston et al., 1991) indicated that soybean yields were lower in an annual corn/soybean rotation than in first-year soybean after 5 yr of corn. Based on these studies, we suspected that soybean yields might be increased when grown less frequently (every third year in three-crop rotation sequences (wheat/corn/soybean and corn/wheat/soybean) than every other year in corn/soybean rotations. Results of this study indicate that increasing the interval between soybean crops in rotation from 1 yr to 2 yr may be inadequate to achieve maximum yields.

Meese et al. (1991) found that the level of yield depression for both annually rotated and continuous soybean compared to first-year soybean was related to the severi-

Table 4. Residue cover, soil temperature, and plant growth parameters for soybean as influenced by tillage and crop rotation sequence, 1991.

Crop rotation sequence	Residue cover			Soil temperature‡			Plant population (6 wk)			Plant height (6 wk)		
	MP		NT	MP		NT	MP		NT	MP		NT
		%			°F			plants/ acre × 1000			in.	
Alternating soybean-corn	2	†	67	64	†	59	185	†	129	18	†	15
Wheat-soybean-corn	7	†	71	64	†	59	192		152	19	†	16
Corn-wheat-soybean	2	†	66	64	†	60	216	†	140	19	†	16
Continuous soybean	5	†	30	63	†	62	208		171	19	†	16
LSD (0.10)¶		15			1			43			2	

† Difference between tillage systems within crop rotation sequences is significant at the 0.10 probability level.
‡ In-row soil temperature at seeding depth measured at mid-day. Values are the average of measurements taken on alternate days for 10 d after planting.
§ MP = moldboard plow and NT = no-till.
¶ Least significant difference for comparisons between crop rotation sequences within tillage systems.

ty of the brown stem rot (*Phialophora gregata*) disease. Greater yield reductions occurred for a brown stem rot susceptible cultivar than for a resistant cultivar. In this study, resistant (BSR 101) and susceptible (Ozzie) cultivars were evaluated, but cultivar responses to crop rotation were not different. Although Ozzie is susceptible to brown stem rot, the disease is most prevalent late in the growing season, therefore early maturing cultivars (such as Ozzie) usually escape severe infestations (Waller et al., 1992). Advantages for soybean in a 3-yr (compared with an alternate-year) cropping system may be more apparent when the brown stem rot disease has greater yield-limiting effects than in our study.

Residue cover differences only occurred under NT, with greater values when soybean followed corn or wheat than when soybean was grown continuously (Table 4). Soil temperature differences were also small under MP, but under NT values were 2 to 3 °F lower for soybean following corn or wheat than for monocropping. Soybean annually alternated with corn and soybean following wheat had lower early season plant population under NT than under MP (Table 4). These plant population differences apparently did not influence soybean yield response, since MP and NT yields were similar for soybean grown in these sequences (Fig. 2). Early-season plant height averaged 3 in. lower for NT than for MP. Soybean grain moisture, late-season plant height, and late-season lodging did not differ between rotations or tillages (data not shown).

Wheat

Wheat response to tillage and rotation varied with year, therefore results for 1989 to 1991 are shown separately (Fig. 3). In contrast to corn and soybean yields (which were 20 to 30% above the 1989 to 1991 state average), wheat yields were about 25% below state average levels. Although several factors were responsible for the relatively low wheat yields, a major factor was delayed planting, which occurred in early October after corn and soybean harvest. This is nearly 4 wk later than the optimum wheat seeding date in Wisconsin (Dahlke and Oplinger, 1991). For wheat following corn or soybean, growers may have to sacrifice some corn or soybean yield potential by planting earlier maturities to allow for earlier wheat seeding. Another option may be to aerially seed wheat into soybean in late August, before leaf drop occurs.

In 1989, averaged over rotations, wheat grain yields under the MP system were 35% lower than for NT (Fig. 3A). There were no differences in yields between rotations in NT, but with MP, continuous wheat yielded 9% lower than wheat in rotation. Variable MP stands, due to both a cloddy, loose seed bed (which hindered optimum seed placement resulting in reduced and slowed germination) and to winter injury, were primarily responsible for the reduced yields. Visual ratings in spring 1989 indicated an average 33% stand loss due to winter killing for wheat under MP compared with only 14% loss with NT. Increased residue cover with NT probably resulted in retention of greater snow cover during the winter. Cox et al. (1986) also found that in severe winters, residue on the soil surface with NT retained snow provided insulation for the crop and decreased stand losses.

In 1990 under NT, yields for wheat following soybean were similar to those for continuous wheat (Fig. 3B). But, wheat following corn yielded 23% lower than these treatments. Under MP, continuous wheat yields again averaged 36% lower than wheat following corn and soybean.

In 1989 and 1990, NT wheat yields were always similar to, or greater than, those for MP (Figs. 3A and 3B). But in 1991, NT yields were lower than yields with MP for both rotation treatments (Fig. 3C). Yield losses with NT were even greater for continuous wheat. In 1991, NT continuous wheat yields were 36% lower than for wheat following corn or soybean, but there were no differences between rotations under MP conditions (Fig. 3C). Above-average temperatures during May and June in 1991 (Table 2) contributed to reduced wheat yields in 1991. Also, a high incidence of wheat diseases (primarily Septoria [*Septoria* spp.], leaf rust [*Puccinia recondita*], and soil borne mosaic virus) further reduced yields. Although foliar disease ratings were not obtained, we observed more leaf disease symptoms under NT. Greater surface residue with NT may have harbored more inoculum and increased the severity of leaf diseases compared with MP. Sutton and Vyn (1990) in Ontario found that crop sequence and tillage systems influenced severity of specific wheat diseases, but total foliar disease severity was not influenced by these factors. In their work, NT and/or continuous wheat promoted severity of some diseases but suppressed other pathogens.

Cultivars Argee and Caldwell responded similarly to crop rotation, but cultivar yields were influenced differently by tillage and year (Table 5). In 1989 and 1990, Caldwell yield was reduced more (20 bu/acre in 1989; 17 bu/acre in 1990) than Argee (13 bu/acre in 1989; 0 bu/acre in 1990) under MP than under NT. We suspect the reduced yields for Caldwell under MP compared with those for Argee these 2 yr were related to lower winterhardiness of Caldwell (Oplinger and Forsberg, 1992).

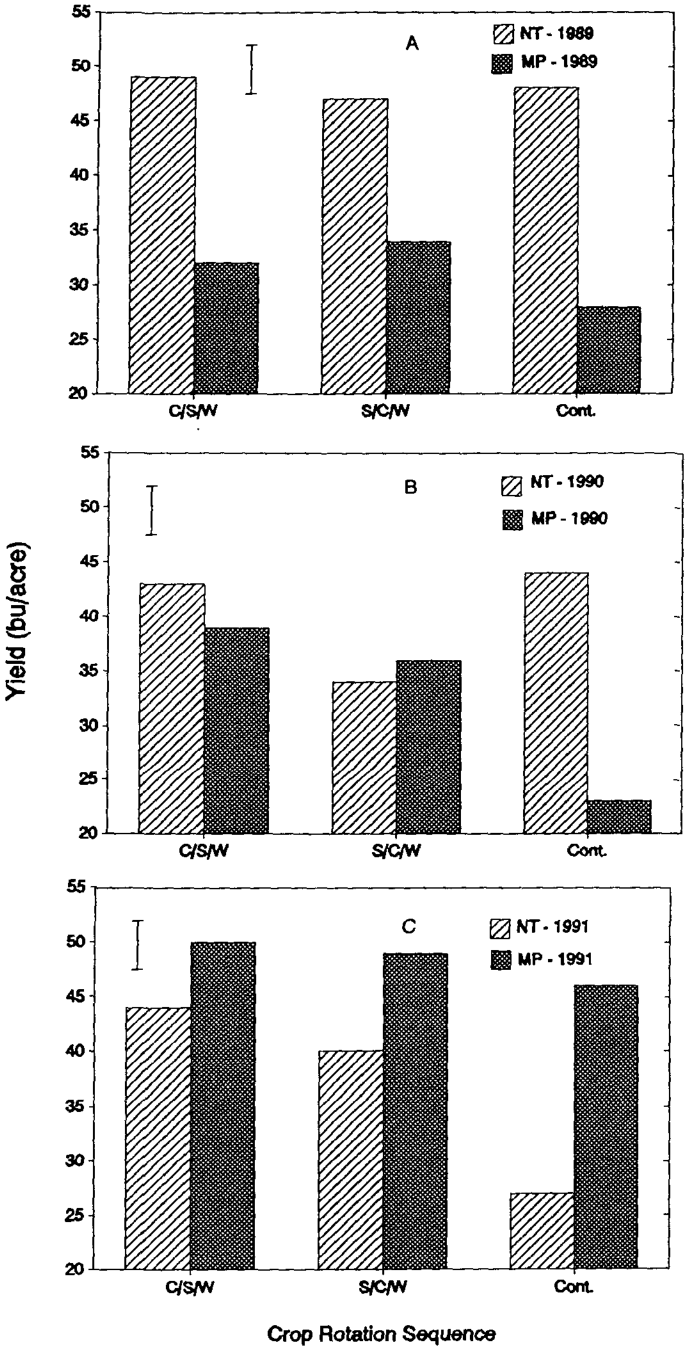

Fig. 3. Relationship between crop rotation sequence and wheat grain yield for no-till (NT) and moldboard plow (MP) for 1989 (A), 1990 (B), and 1991 (C). Values are averaged over two cultivars. Crop rotation sequences: corn-soybean-wheat (C/S/W), soybean-corn-wheat (S/C/W), and continuous wheat (Cont.). Vertical bar indicates LSD (P = 0.10).

Table 5. Grain yield for wheat as influenced by year, tillage system, and cultivar, averaged over crop rotation sequences.

	Year								
	1989			1990			1991		
Cultivar	MP†		NT	MP		NT	MP		NT
	bu/acre								
Caldwell	27	‡	47	22	§	39	50	§	42
	†			†			†		
Argee	36	§	49	43	§	42	47	§	32

† Difference between cultivars, within tillage system and year, is significant at the α = 0.10 probability level.
‡ MP = moldboard plow and NT = no-till.
§ Difference between tillage systems, within cultivar and year, is significant at the α = 0.10 probability level.

Ratings in spring, 1989 for MP indicated 51% stand loss for Caldwell compared with 15% loss for Argee. Under NT, stand loss was below 20% for both cultivars.

In 1991, Argee yields were reduced more (15 bu/acre) than Caldwell (8 bu/acre) under NT than under MP (Table 5). There is little difference in susceptibility between the two cultivars for Septoria and leaf rust diseases (Oplinger and Forsberg, 1992), but in adjacent cultivar trials we observed higher susceptibility to soil borne mosaic virus in Argee than in Caldwell.

We found no advantage to three-crop corn, soybean, and wheat rotations compared to corn-soybean rotations in the northern Corn Belt using conventional ground-based winter wheat planting techniques following corn or soybean harvest. Adding wheat to corn-soybean rotations may be more beneficial when (i) soybean diseases (primarily brown stem rot) limit yields to a greater extent than in this study or (ii) if alternative wheat seeding practices (such as aerial-seeding into standing soybean) are used.

REFERENCES

Benson, G.O. 1985. Why the reduced yields when corn follows corn and possible management responses? p. 161–174. *In* D. Wilkinson (ed.) Proc. 40th Corn Sorghum Res. Conf., Chicago. 11–12 Dec. American Seed Trade Assoc., Washington, DC.

Bundy, L.G., and E.S. Malone. 1988. Effect of residual profile nitrate on corn response to applied nitrogen. Soil Sci. Soc. Am. J. 52:1377–1383.

Carter, P.R., and K.H. Barnett. 1987. Corn-hybrid performance under conventional and no-tillage systems after thinning. Agron. J. 79:919–926.

Cochran, V.L., L.F. Elliot, and R.I. Papendick. 1977. The productions of phytotoxins from surface crop residues. Soil Sci. Soc. Am. J. 41:903–908.

Cox, D.J., J.K. Larsen, and L.J. Brun. 1986. Winter survival response of winter wheat: tillage and cultivar selection. Agron. J. 78:798–801.

Crookston, R.K., J.E. Kurle, P.J. Copeland, J.H. Ford, and W.E. Lueschen. 1991. Rotational cropping sequence affects yield of corn and soybean. Agron. J. 83:108–112.

Dahlke, B.J., and E.S. Oplinger. 1991. Influence of seeding date and rate on winter wheat grain yield and yield components. M.S. thesis. Univ. of Wisconsin, Madison.

Dick, W.A., and D.M. Van Doren, Jr. 1985. Continuous tillage and rotation effects on corn, soybean, and oat yields. Agron. J. 77:459–465.

Ditsch, D.C., and J.H. Grove. 1991. Influence of tillage on plant populations, disease incidence, and grain yield of two soft red winter wheat cultivars. J. Prod. Agric. 4:360–365.

Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean, and wheat. Agron. J. 80:76–80.

Fowler, D.B., and L.V. Gusta. 1977. Influence of fall growth and development on cold tolerance of rye and wheat. Can. J. Plant Sci. 57:751-755.

Freyman, S., and G.B. Schaalje. 1983. Harmful effects of worked-down winter wheat on spring-seeded wheat and rapeseed. Can. J. Plant Sci. 63:299-301.

Griffith, D.R., E.J. Kladivko, J.V. Mannering, T.D. West, and S.D. Parsons. 1988. Long-term tillage and rotation effects on corn growth and yield on high and low organic matter, poorly drained soils. Agron. J. 80:599-605.

Kelling, K.A., E.E. Schulte, L.G. Bundy, S.M. Combs, and J.B. Peters. 1991. Soil test recommendations for field, vegetable and fruit crops. Univ. of Wisconsin Est. Bull. A2809.

Loeppky, H., G.P. Lafond, and D.B. Fowler. 1989. Seeding depth in relation to plant development, winter survival, and yield of no-till winter wheat. Agron. J. 81:125-129.

Lueschen, W.E., J.H. Ford, S.D. Evans, B.K. Kanne, T.R. Hoverstad, G.W. Randall, J.H. Orf, and D.R. Hicks. 1992. Tillage, row spacing, and planting date effects on soybean following corn or wheat. J. Prod. Agric. 5:254-260.

Meese, B.G., P.R. Carter, E.S. Oplinger, and J.W. Pendleton. 1991. Corn/soybean rotation effect as influenced by tillage, nitrogen, and hybrid/cultivar. J. Prod. Agric. 4:74-80.

Oplinger, E.S., and R.A. Forsberg. 1992. Small grain varieties for grain and forage in Wisconsin. Univ. of Wisconsin Est. Bull. A3397.

Peterson, T.A., and G.E. Varvel. 1989a. Crop yield as affected by rotation and nitrogen rate. I. Soybean. Agron. J. 81:727-731.

Peterson, W.R., D.T. Walters, R.J. Supalla, and R.A. Olson. 1991. Yield and economic aspects of irrigated cropping systems in eastern Nebraska. J. Prod. Agric. 4:353-360.

Raimbault, B.A., and T.J. Vyn. 1990. Corn response to rye cover crop management and spring tillage systems. Agron. J. 82:1088-1093.

Raimbault, B.A., and T.J. Vyn. 1991. Crop rotation and tillage effects on corn growtn and soil structural stability. Agron. J. 83:979-985.

Raimbault, B.A., T.J. Vyn, and M. Tollenaar. 1991. Corn response to rye cover crop, tillage methods, and planter options. Agron. J. 83:287-290.

Sutton, J.C., and T.J. Vyn. 1990. Crop sequences and tillage practices in relation to diseases of winter wheat in Ontario. Can. J. Plant Pathol. 12:358-368.

Waller, R.S., C.D. Nickell, and L.E. Gray. 1992. Environmental effects on the development of brown stem rot in soybean. Plant Dis. 76:454-457.

Wollenhaupt, N.C., and J. Pingry. 1991. Estimating residue using the line transect method. Univ. of Wisconsin Ext. Bull. A3533.

Vyn, T.J., J.C. Sutton, and B.A. Raimbault. 1991. Crop sequence and tillage effects on winter wheat development and yield. Can. J. Plant Sci. 71:669-676.