CROPPING SYSTEMS

Corn and Soybean Response to Rotation Sequence, Row Spacing, and Tillage System

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ABSTRACT

Row spacing less than 76 cm for corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] is becoming more common. However, little information is available on row spacing in different rotation sequences. The objective of this study was to determine the influence of rotation sequence, row spacing, and tillage system on corn and soybean yield. Corn and soybean were planted in 19-, 38-, and 76-cm row spacing in conventional tillage and no-tillage systems. Both crops were compared in seven rotation sequences. Few interactions were found between row spacing and tillage or between row spacing and rotation sequence for corn or soybean yield. Corn grain yield decreased 11% using the 19-cm row spacing compared with the 38- and 76-cm row spacings. Corn grain yield decreased 5% using the no-tillage system compared with the conventional tillage system. Corn rotated annually with soybean and first-year corn after 5 yr of consecutive soybean yielded 15% more than continuously grown corn. Soybean yield was not affected by row spacing. No-tillage soybean yield was 6% higher than the conventional tillage system. First-year soybean after 5 yr of consecutive corn yielded 8% more than the other six rotation sequences. We concluded that corn–soybean cropping history and tillage system were not important for determining optimum row-spacing system for corn or soybean. The use of a row-spacing system less than 76 cm was not beneficial for either crop.

Considerable interest exists in the Midwest for corn and soybean planted with row spacing less than 76 cm. Narrowing row width is being used as a management tool to obtain a more uniform plant distribution in the field because current plant populations, especially for corn, have shown a positive linear yield respond to increasing plant populations (Farnham, 2001; Pedersen and Lauer, 2002).

Paszkiewicz (1996) summarized numerous university and industry studies from the 1980s and 1990s comparing 76-cm with narrower row spacings and reported a 4% average yield increase to row spacings less than 56 cm. However, corn responded more positively to narrower rows in northern latitudes, with an 8% average yield response above 44° N latitude, while narrower rows often depressed yields in the southern Corn Belt. In Iowa, Farnham (2001) reported a 2% yield loss when reducing row spacing from 76 (10.5 Mg ha^{-1}) to 38 cm (10.3 Mg ha^{-1}). However, Porter et al. (1997) found in their study from Minnesota a consistently higher yield for narrower row spacings compared with the 76-cm row spacing, with no difference between 25- and 50-cm row spacings. The yield advantage of narrow row spacing averaged 7% across nine site-years in Minnesota. All of the hybrids evaluated responded similarly, and the yield advantage occurred regardless of the plant population. In Indiana, Nielsen (1988) concluded that yield increases in the central Corn Belt have been relatively small and variable and that the risk for stalk breakage is high when using narrow rows. The advantage of growing narrow-row corn has been inconsistent over years, and in addition, the extra cost of growing narrow-row corn has often been ignored.

Numerous studies have been conducted to determine the effect of row spacing on soybean (Ablett et al., 1984; Costa et al., 1980; Herbert and Litchfield, 1984; Oplinger and Philbrook, 1992). Most of these studies have concluded that planting soybean in narrow rows will increase yields. Similar to corn, the largest increase in yield from narrow-row spacing has been in the northern Corn Belt where soybean planted in 25-cm row spacing yielded 27% more than 76-cm row spacing (Costa et al., 1980). This was also the case when planting was delayed or no-tillage was used (Boquet, 1990; Oplinger and Philbrook, 1992).

Numerous reports have been published on rotating corn and soybean and its use as a management tool to increase crop yield (Barber, 1972; Crookston et al., 1991; Meese et al., 1991; Pedersen and Lauer, 2002; Peterson and Varvel, 1989). Additionally, several studies have compared corn or soybean yield response to tillage systems (Dick and van Doren, 1985; Edwards et al., 1988; Pedersen and Lauer, 2002; Philbrook et al., 1991). However, few studies have been conducted to determine the interaction of row spacing with tillage system or cropping sequence. Most published research on row spacing in corn and soybean has been conducted under similar management systems with different seeding rates, N rates, or different cultivars and hybrids. The objective of this study was to determine the influence of row spacing, tillage systems, and various corn–soybean rotations on corn and soybean yield.

MATERIALS AND METHODS

Field research was conducted during 4 yr (1997–2001) on a Plano silt loam soil (fine-silty, mixed, mesic, Typic Argiudoll) at the University of Wisconsin Agricultural Research Station, located near Arlington, WI. The experiment was a randomized complete block in a split-split plot arrangement with four replications. Main plots were no-tillage and conventional tillage systems that were established in 1986. Conventional tillage was accomplished by a chisel plow in the fall and two passes of field cultivation in the spring before planting. For no-tillage, crops were planted directly into the undisturbed residue of the previous crop. The subplots consisted of 14 rotation sequences involving corn and soybean, which had been initiated in 1983 on land previously planted to corn (Table 1). The sequences

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Published in Agron. J. 95:965–971 (2003).

Table 1. Rotation sequences for corn (C) and soybean (S) from 1992 to 2001.

Crop sequence	Year									
Crop sequence	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
A	S	C	C	C	C	C	S	S	S	S
B	S	S	C	C	C	C	C	S	S	S
C	S	S	S	C	C	C	C	C	S	S
D	S	S	S	S	C	C	C	C	C	S
E	S	S	S	S	S	C	C	C	C	C
F	C	S	S	S	S	S	C	C	C	C
G	C	C	S	S	S	S	S	C	C	C
H	C	C	C	S	S	S	S	S	C	C
I	C	C	C	C	S	S	S	S	S	C
J	C	C	C	C	C	S	S	S	S	S
K	C	C	C	C	C	C	C	C	C	C
L	S	C	S	C	S	C	S	C	S	C
M	C	S	C	S	C	S	C	S	C	S
N	S	S	S	S	S	S	S	S	S	S
	Corn sequences				Soybean sequences					
Year in rotation†	1998	1999	2000	2001	1998	1999	2000	2001		
1	F	G	H	I	A	B	C	D		
1-C–S	M	L	M	L	L	M	L	M		
2	E	F	G	H	J	A	B	C		
3	D	E	F	G	I	J	A	B		
4	C	D	E	F	H	I	J	A		
5	B	C	D	E	G	H	I	J		
Cont.	K	K	K	K	N	N	N	N		

† For corn: 1 = first-year corn after several years of soybean; 1-C–S = first-year corn alternated annually with soybean; 2, 3, 4, and 5 = second-, third-, fourth-, and fifth-year corn, respectively; Cont. = continuous corn since the experiment was started in 1983. For soybean: 1 = first-year soybean after several years of corn; 1-C–S = first-year soybean alternated annually with corn; 2, 3, 4, and 5 = second-, third-, fourth-, and fifth-year soybean, respectively; Cont. = continuous soybean since the experiment was started in 1983.

allowed comparisons during 1998, 1999, 2000, and 2001 of (i) first-year corn and soybean (after a minimum of four consecutive years of the other crop); (ii) corn and soybean alternated annually with the other crop; and (iii) two, three, four, and five or more years of continuous corn and soybean (16th, 17th, 18th, and 19th year in 1998, 1999, 2000, and 2001, respectively). The sub-subplots were row spacings of 19, 38, and 76 cm, which were planted at recommended seeding rates for each row spacing and crop (Oplinger and Albaugh, 1996; Oplinger and Philbrook, 1992). The effect of row spacing will therefore be considered as a system and not as a combination of plant densities and row spacing because seeding rates were not consistent across row-spacing treatments. Corn was planted at 111 100, 98 800, and 86 400 seeds ha^{-1}, respectively, for the 19-, 38-, and 76-cm row spacing. The final plant population for corn averaged across years for 19-, 38-, and 76-cm row spacing was 99 700, 85 000, and 86 100 plants ha^{-1}, respectively. Soybean was planted at 555 600, 432 100, and 308 600 seeds ha^{-1}, respectively, for the 19-, 38-, and 76-cm row spacing. The final plant population for soybean across years for 19-, 38-, and 76-cm row spacing was 374 900, 373 900, and 298 700 plants ha^{-1}, respectively. The corn hybrid was DeKalb DK493RR. The soybean variety was Asgrow 2501RR in 1998 but was changed to Asgrow 2301RR from 1999 to 2001 because the former was late maturing and prone to frost damage. Both the corn hybrid and the two soybean varieties were resistant to glyphosate [*N*-(phosphonomethyl)glycine].

Sub-subplot experimental units were 3 by 9 m. Corn was planted at 5-cm depth. The 19-cm row spacing was planted with a John Deere 750 Drill (John Deere, Moline, IL) because of row-spacing limitations on our standard plot planter. A Kinze 2000 Interplant planter (Kinze Manufacturing, Williamsburg, IA) was used for the 38- and 76-cm row spacing. The planter was equipped with a notched coulter positioned directly in front of the seed disc openers plus unit-mounted, notched-disc row cleaners. Corn plots were planted on 11 May 1998, 4 May 1999, 2 May 2000, and 2 May 2001. During 1998 to 2000, all corn plots were fertilized after planting with 28% urea ammonium nitrate at a rate of 168 kg N ha^{-1}. In 2001, rate of ammonium nitrate for corn was raised to 195 kg N ha^{-1}. During 1999 to 2001, 1.12 and 1.12 kg a.i. ha^{-1} glyphosate and 2,4-D [2,4-(dichlorophenoxy)acetic acid], respectively, were applied preplanting for weed control. In 1998, 2.24 and 1.12 kg a.i. ha^{-1} glyphosate and 2,4-D, respectively, were applied preplanting for weed control. Postemergence weed control was done with 1.12 kg a.i. ha^{-1} glyphosate. Chlorpyrifos [0,0-diethyl 0-(3,5,6-trichloro-2-pyridinyl)phosphorothioate] was applied in-furrow to all corn plots at planting to control corn rootworm (*Diabrotica* spp.) at a rate of 1.7 kg a.i. ha^{-1}.

Soybean plots were planted using the same planters used for corn on the same date at 4-cm depth. Soybean plots were replanted in 2000 on 9 June because of soil crusting and poor emergence. During 1999 to 2001, 1.12 and 1.12 kg a.i. ha^{-1} glyphosate and 2,4-D, respectively, were applied preplanting for weed control. In 1998, 2.24 and 1.12 kg a.i. ha^{-1} glyphosate and 2,4-D, respectively, were applied preplanting for weed control. One postemergence weed control treatment was applied with 1.12 kg a.i. ha^{-1} glyphosate every year except in 2000 when a follow-up treatment of glyphosate at 1.12 kg a.i. ha^{-1} was applied at V2 (second trifoliate unfolded).

Data collected from soybean plots included grain yield, preharvest plant population, 100-seed weight, plant height, and lodging. Lodging was based on a 1 (no lodging) to 5 (completely lodged) scale. Corn measurements included grain yield, grain moisture, preharvest plant population, and lodging. Lodging was measured by counting number of lodged stalks (>45°) per plot (as a percentage of the final plant population).

The center seven, four, and two rows of the 19-, 38-, and 76-cm corn plots were harvested on 20 Oct. 1998, 14 Oct. 1999, 10 Oct. 2000, and 8 Oct. 2001 with a Kincaid Plot Combine (Kincaid Equipment Manufacturing, Haven, KS). The center seven, four, and two rows of the 19-, 38-, and 76-cm soybean plots were harvested with an Almaco Plot Combine (Allen Machine Co., Nevada, IA) on 1 Oct. 1998, 1 Oct. 1999, 11 Oct. 2000, and 8 Oct. 2001. Grain yields were adjusted to moisture content of 155 g kg^{-1} (corn) and 130 g kg^{-1} (soybean).

All data were subjected to an analysis of variance using the

MIXED procedure of SAS (Littell et al., 1996). The restricted maximum likelihood method was used for variance component estimation, and data were analyzed across years after determining homogeneous error variances. All effects except replicates were considered fixed in determining the expected mean squares and appropriate F tests in the analysis of variance. Year was treated as a fixed effect rather than a random effect to determine interactions involving year. Mean comparisons were made using Fisher's protected LSD test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Growing conditions varied considerably over years. Average precipitation during the growing season (May to September) was greater than the 20-yr average for 1998 and 2000 and close to the 20-yr average for 1999 and 2001. Temperatures were lower or equal to the 20-yr average during the 1999 and 2000 growing seasons and higher than the 20-yr average in 1998 and 2001. In the combined analysis, few differences were observed for the final plant population of corn and soybean, and the results will therefore not be presented.

Corn

Grain Yield

Impact of tillage system, rotation sequence, and row spacing varied with year (Table 2). Despite observing no interactions between tillage system and row spacing and between rotation sequence and row spacing, the results were not consistent across years (Table 3). A tillage system × rotation sequence interaction was observed (Table 2). No differences were found between tillage systems for second-year corn and annually rotated corn. First-year corn after 5 yr of consecutive soybean benefited from no-tillage practices, producing 4% greater yields than those from conventional tillage. The remaining four rotations produced 6% more yield in the conventional tillage systems than the no-tillage systems.

Tillage system influenced corn grain yield, with the conventional tillage system yielding 5% (12.3 Mg ha^{-1}) more than the no-tillage system (11.7 Mg ha^{-1}). However, no differences were found between tillage systems and corn grain yield in 1998, 1999, and 2001. In 2000, the conventional tillage system yielded 16% more than the no-tillage system. A cool, wet spring in 2000 resulted in runoff and N deficiency symptoms in the no-tillage system, which may explain the yield difference. Our data is consistent with the results reported by Dick and van Doren (1985) and Meese et al. (1991), who observed similar results regarding tillage effect on corn grain yield, and by Pedersen and Lauer (2002), who did not observe a tillage effect on corn grain yield in 2 out of 3 yr evaluated.

Corn grain yield responded similarly to rotation sequences each year, with first-year corn after 5 yr of consecutive soybean and annually rotated corn producing 17% more grain yield than continuous corn. Meese et al. (1991) and Pedersen and Lauer (2002) found similar results. However, Crookston et al. (1991) found that annually rotated corn produced about 10% greater yield

Table 2. Tillage, rotation sequence, and row spacing influence on corn grain yield, grain moisture, and lodging, 1998–2001.

Main effect	Yield	Moisture	Lodging
	Mg ha^{-1}	g kg^{-1}	%
Tillage (T)			
No-tillage	11.7	195	4.8
Conventional tillage	12.3	183	4.2
LSD (0.05)	0.2	3	NS†
Rotation sequence (R)‡			
First-year corn	13.6	179	4.2
Corn–soybean	13.2	185	2.6
Second-year corn	11.8	191	4.2
Third-year corn	11.2	190	6.3
Fourth-year corn	11.6	193	4.5
Fifth-year corn	11.4	192	5.4
Cont. corn	11.5	190	4.1
LSD (0.05)	0.4	6	NS
Row spacing (S)			
19 cm	11.1	195	3.4
38 cm	12.5	184	4.9
76 cm	12.5	187	5.2
LSD (0.05)	0.2	4	1.2
ANOVA			
Year (Y)	***	***	***
T	***	***	NS
Y × T	***	**	NS
R	***	***	NS
Y × R	***	NS	NS
T × R	***	*	NS
Y × T × R	NS	NS	NS
S	***	***	*
Y × S	***	NS	NS
T × S	NS	NS	NS
Y × T × S	***	**	NS
R × S	NS	NS	**
Y × R × S	**	NS	NS
T × R × S	NS	NS	**
Y × T × R × S	NS	NS	NS

* Significant at the $P = 0.05$ probability level.
** Significant at the $P = 0.01$ probability level.
*** Significant at the $P = 0.001$ probability level.
† NS = no significant differences at $P \leq 0.05$.
‡ Following 5 yr of soybean except for alternate corn–soybean and continuous corn.

and first-year corn after 5 yr of soybean produced 15% greater yield than continuous corn.

The effect of row spacing on grain yield was consistent, except for 2000 when no difference was found among the three row spacings. Grain yields were 11% lower in the 19-cm row spacing compared with the other two row spacings. This may be due to a stress from higher final plant population in the 19-cm row spacing compared with the other two row spacings. Further research is needed to document this. However, our data is in line with data from Iowa (Farnham, 2001) that demonstrated a significant advantage of only 0.2 Mg ha^{-1} using 76- vs. 38-cm row spacing across six locations and 3 yr. Our data and the data from Iowa contradict previous research findings that corn grown in 38-cm rows produces higher yield than corn in 76-cm rows (Nielsen, 1988; Paszkiewicz, 1996; Porter et al., 1997). The contradictory results from around the Midwest indicate that other factors influence row spacing effect on corn grain yield.

Grain Moisture

Year variability had an influence on grain moisture at harvest (Table 2). A year × tillage system × row spacing interaction was observed as a result of higher

Table 3. Rotation sequence × row spacing and tillage system × row spacing influence on corn grain yield, 1998–2001.

Main effect	Grain yield						
	Rotation sequence × row spacing						
	1 yr†	C–S‡	2 yr	3 yr	4 yr	5 yr	Cont.
	Mg ha^{-1}						
Row spacing				1998			
19 cm	14.5	12.7	12.6	12.8	12.3	11.9	12.9
38 cm	15.1	14.8	14.3	13.8	13.8	14.0	13.3
76 cm	15.5	14.6	14.2	13.6	13.9	13.3	13.5
LSD(0.05)				NS§			
				1999			
19 cm	10.8	11.2	7.8	7.8	8.4	9.1	8.4
38 cm	12.5	12.9	11.8	11.4	10.8	11.8	11.2
76 cm	13.3	13.7	12.9	12.5	12.1	12.3	12.4
LSD(0.05)				1.2			
				2000			
19 cm	12.4	12.6	9.6	8.4	10.3	9.0	9.8
38 cm	13.2	11.8	10.9	9.9	9.5	9.5	9.8
76 cm	13.1	12.3	10.1	8.9	9.3	8.3	9.8
LSD(0.05)				1.1			
				2001			
19 cm	14.2	13.6	11.3	11.4	12.5	11.8	11.4
38 cm	14.5	14.4	13.3	11.8	13.5	13.1	12.0
76 cm	14.1	14.1	12.5	12.0	12.9	12.9	12.5
LSD(0.05)				NS			
	Tillage system × row spacing						
	19 cm	38 cm	76 cm				
	Mg ha^{-1}						
Tillage system		1998					
No-tillage	13.1	14.3	14.3				
Conventional tillage	12.5	14.1	13.9				
LSD(0.05)		NS					
		1999					
No-tillage	8.7	11.8	12.8				
Conventional tillage	9.4	11.8	12.7				
LSD(0.05)	NS						
		2000					
No-tillage	9.9	9.8	8.8				
Conventional tillage	10.7	11.5	11.7				
LSD(0.05)		0.9					
		2001					
No-tillage	11.8	13.1	12.9				
Conventional tillage	12.7	13.3	13.1				
LSD(0.05)		0.6					

† Following 5 yr of soybean except for alternate corn–soybean and continuous corn.
‡ C–S, first-year soybean alternated annually with corn.
§ NS, no significant differences at $P \leq 0.05$.

grain moisture content for the 19-cm row spacing in the no-tillage system than in the conventional tillage system in 1998 and 1999 (data not shown). A tillage × rotation sequence interaction was found for grain moisture (Table 2). The no-tillage system had 7% more grain moisture content than the conventional tillage system for all rotation sequences except for first-year corn after 5 yr of consecutive soybean or annually rotated corn where no difference was observed between tillage systems.

Overall, grain moisture content in the no-tillage system averaged 195 vs. 183 g kg^{-1} for the conventional tillage system. Pedersen and Lauer (2002) reported similar differences in grain moisture at harvest.

Grain moisture was influenced by rotation sequence, with first-year corn or annually rotated corn having an average of 5% lower grain moisture at harvest than continuous corn or corn in other rotation sequences.

Grain moisture content was 4% higher for the 19-cm row spacing (195 g kg^{-1}) compared with the other row-spacing treatments (average 186 g kg^{-1}). No differences were found between the 38- and 76-cm row-spacing treatments. Farnham (2001) found opposite results, with a slightly lower grain moisture content in 38-cm rows compared with 76-cm rows, whereas Porter et al. (1997) did not find a row-spacing effect on grain moisture content.

Lodging

A tillage system × rotation sequence × row spacing interaction was observed, but there was no consistent pattern for the interaction (data not shown). A rotation sequence × row spacing interaction was observed for lodging (Table 2). No differences were found between row spacing for first-year corn and annually rotated

Table 4. Tillage, rotation sequence, and row spacing influence on soybean grain yield, grain moisture, height, lodging, and seed weight, 1998–2001.

Main effect	Yield	Moisture	Height	Lodging†	Seed weight
	Mg ha^{-1}	g kg^{-1}	cm		g 100 seed^{-1}
Tillage (T)					
No-tillage	4.1	131	90.4	1.2	15.4
Conventional tillage	3.9	129	88.4	1.1	15.1
LSD(0.05)	0.1	1	1.0	0.1	0.1
Rotation sequence (R)‡					
First-year soybean	4.3	132	89.9	1.3	15.7
Soybean–corn	4.1	131	90.2	1.3	15.6
Second-year soybean	4.1	131	91.4	1.3	15.2
Third-year soybean	3.9	130	89.9	1.2	15.3
Fourth-year soybean	3.9	129	88.4	1.1	15.0
Fifth-year soybean	3.8	129	87.1	1.1	15.1
Cont. soybean	3.8	129	88.1	0.9	15.0
LSD (0.05)	0.1	2	1.5	0.2	0.2
Row spacing (S)					
19 cm	4.0	131	90.7	1.4	15.3
38 cm	4.0	131	89.4	1.1	15.3
76 cm	4.0	129	87.9	0.9	15.2
LSD (0.05)	NS§	1	1.0	0.1	NS
ANOVA					
Year (Y)	***	***	***	***	***
T	***	*	***	*	***
Y × T	*	**	NS	***	NS
R	***	**	**	***	***
Y × R	NS	NS	NS	***	**
T × R	***	NS	***	NS	***
Y × T × R	NS	NS	NS	NS	NS
S	NS	***	***	***	NS
Y × S	***	NS	NS	***	***
T × S	NS	NS	NS	NS	NS
Y × T × S	NS	NS	NS	NS	NS
R × S	*	NS	NS	NS	NS
Y × R × S	***	***	NS	*	*
T × R × S	NS	NS	NS	NS	NS
Y × T × R × S	NS	NS	NS	NS	NS

* Significant at the $P = 0.05$ probability level.
** Significant at the $P = 0.01$ probability level.
*** Significant at the $P = 0.001$ probability level.
† Lodging score extends from 1 to 5, where 1 = erect and 5 = flat.
‡ Following 5 yr of corn except for alternate soybean–corn and continuous soybean.
§ NS = no significant differences at $P \leq 0.05$.

corn; however, lodging was 4% higher for the remaining five rotation sequences as row spacing decreased.

Tillage system and rotation sequence did not influence lodging. However, row spacing influenced lodging percentage, with lowest lodging percentage observed in the 19-cm row spacing (3.4%), and no differences were found between the 38- and 76-cm row spacings averaging 4.9 and 5.2%, respectively. Nielsen (1988), however, reported 2.5% more broken plants when row width was narrowed from 76 to 38 cm.

Soybean

Grain Yield

A tillage system × rotation sequence interaction was found for grain yield (Table 4). Tillage did not have an impact on yield of first-year soybean and second-year soybean after 5-yr corn. However, in the remaining five rotation sequences, no-tillage yielded 8% greater than the conventional tillage system. Except for 1999 and 2001, a rotation sequence × row spacing interaction was observed for grain yield (Table 5). Averaged across years, yield increased 4% by increasing the row width from 19 to 76 cm in first-year soybean after 5-yr corn and decreased 5% in continuously grown soybean. No difference was found between row spacing and the remaining five rotation sequences.

Grain yield was influenced by tillage system, except for 1998 where no difference was found among the different rotation sequences. Averaged across years, soybean planted in the no-tillage system yielded 6.1% more than soybean planted in the conventional tillage system. This observation and the tillage × rotation sequence interaction do not correspond to previous soybean grain yield observations (Pedersen and Lauer, 2002). Preliminary data collected in the spring of 2001 suggests that soybean cyst nematode (*Heterodera glycines* Ichinohe) has infested the plots, which could explain the deviation from previous work. This is in agreement with results reported by Workneh et al. (1999), who observed a tillage effect on *H. glycines*.

Rotation sequence influenced soybean yield, with first-year soybean after 5-yr corn producing 8% higher yield than the other rotation sequences. Pedersen and Lauer (2002), Crookston et al. (1991), and Meese et al. (1991) found similar results.

Significant year interactions indicated inconsistent response to row spacing. In 1998 and 1999, yield in the 19-cm row spacing averaged 4% (4.6 Mg ha^{-1}) higher than the other two row spacings. The opposite was the

Table 5. Rotation sequence × row spacing influence on soybean grain yield, 1998–2001.

Main effect	Rotation sequence × row spacing						
	1 yr†	C–S‡	2 yr	3 yr	4 yr	5 yr	Cont.§
	Grain yield, Mg ha^{-1}						
				1998			
19 cm	4.9	4.9	4.8	4.4	4.6	4.4	4.6
38 cm	4.9	4.6	4.6	4.4	4.5	4.3	4.3
76 cm	4.8	4.7	4.6	4.5	4.4	4.2	4.4
LSD(0.05)				NS¶			
				1999			
19 cm	4.7	4.4	4.4	4.5	4.4	4.3	4.4
38 cm	4.4	4.7	4.2	4.3	4.0	4.2	4.1
76 cm	4.8	4.3	4.3	4.2	4.2	4.2	4.1
LSD(0.05)				0.3			
				2000			
19 cm	3.5	3.4	3.5	3.2	3.3	3.3	3.2
38 cm	3.7	3.5	3.5	3.1	3.3	3.2	3.3
76 cm	3.4	3.4	3.4	3.0	3.3	3.0	3.0
LSD(0.05)				NS			
				2001			
19 cm	3.9	3.7	3.9	3.5	3.5	3.6	3.2
38 cm	3.9	4.0	4.0	3.8	3.9	3.7	4.0
76 cm	4.5	4.2	4.0	3.7	3.6	3.6	3.5
LSD(0.05)				0.4			

† Following 5 yr of corn except for alternate soybean–corn and continuous soybean.
‡ C–S, first-year soybean alternated annually with corn.
§ Cont., continuous soybean since the experiment was started in 1983.
¶ NS, no significant differences at $P \leq 0.05$.

case in 2001 where the 38- and 76-cm row spacings had the highest yield. In 2000, the highest yield was found in the 38-cm row spacing (3.4 Mg ha^{-1}), and the lowest yield was found in the 76-cm row spacing (3.2 Mg ha^{-1}). Averaged across years, no differences were found among the three row spacings, all averaging 4.0 kg ha^{-1}.

Grain Moisture

Year variability had an influence on grain moisture at harvest (Table 4). Soybean grown in the no-tillage system (131 g kg^{-1}) had greater moisture content than that in the conventional tillage system (129 g kg^{-1}). Grain moisture content was influenced by rotation sequence and decreased from 132 g kg^{-1} for first-year soybean, second-year soybean, and annually rotated soybean to 129 g kg^{-1} for the remaining four rotation sequences. Grain moisture content decreased from 131 to 129 g kg^{-1} as row spacing increased from 19 to 76 cm.

Height and Lodging

Lodging was influenced by growing conditions and varied considerably over years (data not shown). Pedersen and Lauer (2002) observed similar results. A tillage system × rotation sequence interaction was found for plant height (Table 4). Plant height was 6% higher in the no-tillage system for third, fourth, and fifth year of consecutive soybean than in the conventional tillage system. No differences were found for the other four rotation sequences.

Height and lodging were influenced by tillage system (Table 4). Plant height increased 2% and lodging 9% in the no-tillage system compared with the conventional tillage system.

Height and lodging were also influenced by rotation sequence. In general, the tallest plants and the highest lodging score were found in the first-year soybean, second-year soybean, and annually rotated soybean that averaged 2% higher and had an 18% higher lodging score than the remaining four rotation sequences.

Row spacing influenced plant height and lodging score, with the highest plants (90.7 cm) and the highest lodging score (1.4) observed in the 19-cm row spacing, and height and lodging decreased as row spacing increased. Elmore (1998) found that row spacing did not influence height and lodging.

Seed Weight

A tillage × rotation sequence interaction was observed for seed weight, with 4% higher seed weight on average in the no-tillage system for three or more years of consecutively grown soybean. No differences were detected for tillage system among the remaining rotation sequences. Except for 1999, no rotation sequence × row spacing interaction was observed for seed weight.

Soybean in the no-tillage system produced 2% higher seed weight than that in the conventional tillage system (Table 4). Grain weight for the two tillage systems was consistent in most years, except for 1998 where no differences were observed between tillage systems.

Rotation sequence influenced seed weight, with first-year soybean after 5 yr of consecutive corn and annually rotated soybean producing the highest seed weight, averaging 15.7 g 100 seed^{-1} across years or 4.5% more than the remaining five rotation sequences that averaged 15.1 g 100 seed^{-1}. Grain weight for the different rotation sequences was consistent in most years, except for 1998 where no differences were observed among rotation sequences.

The effect of row spacing on seed weight was not consistent across years. During 1998, the highest and the lowest seed weight were found in the 76- and 38-cm row spacing, respectively. The opposite was observed in 2001. Row spacing did not influence seed weight in 1999 and 2000.

CONCLUSION

Our data suggest that growers should focus on optimizing other management practices rather than row-spacing systems. Highest corn yields were obtained in the 38- and 76-cm row spacing regardless of tillage system and cropping history. Corn yield decreased 11% using 19-cm row spacing compared with the 38- and 76-cm row spacings. No differences were found for soybean among the three row spacings. Corn and soybean yield was influenced by tillage system. First-year corn after 5 yr of consecutive soybean and annually rotated corn produced 14% higher yield than the remaining five rotation sequences. First-year soybean after 5 yr of consecutive corn produced 14% higher yield than the remaining six rotation sequences. Yield increased 4% by increasing the row width from 19 to 76 cm in the first-year soybean after 5-yr corn and decreased 5% in continuously grown soybean. Corn and soybean yield were influenced by tillage system. Corn yield was 5% higher in the conventional tillage system than in the no-tillage system. Soybean grown under no-tillage conditions yielded 6% higher than the conventional tillage systems. This deviates from previous work and may be due to an infestation of soybean cyst nematode. However, further research is needed to document this observation.

ACKNOWLEDGMENTS

The authors thank Dr. Edward S. Oplinger for assistance early in the development of this study and John M. Gaska, Kent Kohn, and Mark Martinka for their technical assistance. This research was partially funded by Hatch Project 142-E018.

REFERENCES

Ablett, G.R., J.C. Schleihauf, and A.D. McLaren. 1984. Effect of row width and population on soybean yield in southwestern Ontario. Can. J. Plant Sci. 64:9–15.

Barber, S.A. 1972. Relation of weather to the influence of hay crops on subsequent corn yields on a Chalmers silt loam. Agron. J. 64:8–10.

Boquet, D.J. 1990. Plant population density and row spacing effects on soybean at post-optimal planting dates. Agron. J. 82:59–64.

Costa, J.A., E.S. Oplinger, and J.W. Pendleton. 1980. Response of soybean cultivar to planting pattern. Agron. J. 72:153–156.

Crookston, R.K., J.E. Kurle, P.J. Copeland, H.J. Ford, and W.E. Lueschen. 1991. Rotational cropping sequence affects yield of corn and soybean. Agron. J. 83:108–113.

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

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.

Elmore, R.W. 1998. Soybean cultivar responses to row spacing and seeding rates in rainfed and irrigated environments. J. Prod. Agric. 11:326–331.

Farnham, D. 2001. Row spacing, plant density, and hybrid effects on corn grain yield and moisture. Agron. J. 93:1049–1053.

Herbert, S.J., and G.V. Litchfield. 1984. Growth response of short-season soybean to variations in row spacing and density. Field Crops Res. 9:163–171.

Littell, R.C., G.A. Milliken, W.W. Stroup, and W.W. Wolfinger. 1996. SAS system for mixed models. SAS Inst., Cary, NC.

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.

Nielsen, R.L. 1988. Influence of hybrids and plant density on grain yield and stalk breakage in corn grown in 15-inch row spacing. J. Prod. Agric. 3:190–195.

Oplinger, E.S., and M.J. Albaugh. 1996. Soybean plant density for optimum productivity. Agron. Advice. Field Crops 27.424. Dep. of Agron., Univ. of Wisconsin, Madison.

Oplinger, E.S., and B.D. Philbrook. 1992. Soybean planting date, row width, and seeding rate response in three tillage systems. J. Prod. Agric. 5:94–99.

Paszkiewicz, S.R. 1996. Narrow row width influence on corn yield. p. 130–138. *In* Proc. Annu. Corn and Sorghum Res. Conf., 51st, Chicago, IL. 11–12 Dec. 1996. Am. Seed Trade Assoc., Washington, DC.

Pedersen, P., and J.G. Lauer. 2002. Influence of rotation sequence and tillage system on the optimum plant population for corn and soybean. Agron. J. 94:968–974.

Peterson, T.A., and G.E. Varvel. 1989. Crop yield as affected by rotation and nitrogen rate: III. Corn. Agron. J. 81:735–738.

Philbrook, B.D., E.S. Oplinger, and B.E. Freed. 1991. Solid-seeded soybean cultivar response in three tillage systems. J. Prod. Agric. 4:86–91.

Porter, P.M., D.R. Hicks, W.E. Lueschen, J.H. Ford, D.D. Warnes, and T.R. Hoverstad. 1997. Corn response to row width and plant population in the northern Corn Belt. J. Prod. Agric. 10:293–300.

Workneh, F., X.B. Yang, and G.L. Tylka. 1999. Soybean brown stem rot, Phytophthora sojae, and Heterodera glycines affected by soil texture and tillage relations. Phytopathology 89:844–850.