Influence of Rotation Sequence on the Optimum Corn and Soybean Plant Population

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ABSTRACT

Rotation sequence and plant population are important management considerations for maximum yield. Response of corn (*Zea mays* L.) and soybean [*Glycine max* L. (Merr.)] to changes in plant population, rotation sequences, and tillage system was evaluated for 3 yr. Corn was planted in 76-cm rows and had a final plant population of 56 300, 65 800, and 75 200 plants ha^{-1}; soybean was planted in 19-cm rows with a final plant population of 294 200, 450 400, and 518 500 plants ha^{-1} using conventional tillage and no-tillage systems. Both crops were compared in seven rotation sequences. For corn yield there were no interactions of plant population with tillage or rotation sequence. Averaged over years, tillage did not affect corn yield. Corn rotated annually with soybean and first-year corn after 5 yr of consecutive soybean yielded 12% more than continuous grown corn. Corn yields increased 11% as plant population increased from 56 300 to 75 200 plants ha^{-1}, regardless of tillage or rotation treatment. Averaged over years, no interactions of plant population with tillage or rotation sequence on soybean yield were found. Soybean yields were 8% higher in conventional tillage than in the no-tillage systems. First-year soybean after 5 yr of consecutive corn yielded 8% more compared with the other six rotation sequences. Plant population within the studied range did not affect soybean yield. It was concluded that neither corn–soybean cropping history nor tillage system were important for determining optimum plant population for corn or soybean.

ROTATING corn and soybean and its beneficial effects have been recognized and exploited for centuries as a management practice to increase crop yields (Bhowmik and Doll, 1982; Peterson and Varvel, 1989). Barber (1972) reported that corn yields declined with increasing frequency of corn in the rotation. However, other results indicate that the type of crop in the rotation may not be important, as long as corn does not follow itself (Peterson and Varvel, 1989). Crookston et al. (1991) reported a 5% yield advantage for first-year corn after several years of soybean compared with corn rotated annually with soybean. Planting soybean in rotation has also resulted in consistently higher yields than when grown in monoculture (Dabney et al., 1988; Edwards et al., 1988; Meese et al., 1991). In Wisconsin, soybean yields in an alternating corn and soybean rotation were 15 to 20% lower (depending on the tillage system and cultivar) compared with first-year soybean after several years of corn (Meese et al., 1991).

Corn and soybean yield response to different tillage systems varies depending on previous crop and soil drainage characteristics (Dick and van Doren, 1985; Philbrook et al., 1991). No-tillage corn yields are least likely to equal or exceed those for conventional tillage with poorly drained soils (Dick and van Doren, 1985), but rotating corn and soybean usually minimizes yield reductions under no-tillage systems. Soybean yields in no-tillage systems are often lower than yields in conventional tillage systems (Philbrook et al., 1991). Reduced emergence and final plant stands from comparable seeding rates may account for part of the yield reductions (Guy and Oplinger, 1989; Philbrook et al., 1991).

Information is not available in the literature on the corn–soybean rotation effect on different plant populations. Numerous papers published on plant populations for corn and soybean indicate that year, location, and hybrid/variety influences optimum plant population (Nafziger, 1994; Oplinger and Philbrook, 1992; Porter et al., 1997). Soybean yields often increase, up to a point, with increasing plant population (Ablett et al., 1984; Oplinger and Philbrook, 1992). However, soybean yield responses to plant population are generally small and often inconsistent (Lehman and Lambert, 1960). In general, increasing plant populations has increased mature plant height and resulted in greater yield losses from lodging (Weber and Fehr, 1966). Devlin et al. (1995) reported that as plant population increased plant mortality increased, and final plant population compared to seeding rate decreased.

The objective of this experiment was to determine the optimum plant population with continuous corn or soybean compared with various corn–soybean rotations using different tillage systems.

MATERIALS AND METHODS

Field research was conducted during 3 yr (1995–1997) on a Plano silt loam soil (fine-silty, mixed, mesic Typic Argiudolls) 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 allowed comparisons to be made during 1995, 1996, and 1997 of (i) first-year 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 (13th, 14th, and 15th year in 1995, 1996, and 1997, respectively). The sub-subplots were plant populations. Corn was planted in 76-cm rows at 62 700, 74 100, and 86 400 plants ha^{-1}; soybean was planted in 19-cm rows at 432 200, 555 600, and 679 000 plants ha^{-1}. The three seeding rates for both corn and soybean represent a low, medium, and a high seeding rate for the specific planting date and region. The corn hybrid was Pioneer Brand 3769 and the soybean variety was Northern King Brand S24-92.

Plot size of the sub-subplot experimental units was 3 by 9 m. Potassium was applied to all plots at a rate of 0–0–270 kg

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Table 1. Rotation sequences for corn (C) and soybean (S) from 1988 to 1997.

	Year									
Crop sequence	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
A	S	S	S	S	S	C	C	C	C	C
B	C	S	S	S	S	S	C	C	C	C
C	C	C	S	S	S	S	S	C	C	C
D	C	C	C	S	S	S	S	S	C	C
E	C	C	C	C	S	S	S	S	S	C
F	C	C	C	C	C	S	S	S	S	S
G	S	C	C	C	C	C	S	S	S	S
H	S	S	C	C	C	C	C	S	S	S
I	S	S	S	C	C	C	C	C	S	S
J	S	S	S	S	C	C	C	C	C	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

	Year					
Year in rotation†	1995	1996	1997	1995	1996	1997
	Corn sequences			Soybean sequences		
1	C	D	E	H	I	J
1-C/S	L	M	L	M	L	M
2	B	C	D	G	H	I
3	A	B	C	F	G	H
4	J	A	B	E	F	G
5	I	J	A	D	E	F
Cont.	K	K	K	N	N	N

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

N–P–K in 1995. Corn was planted with a John Deere JD7000 MaxEmerge Planter (Moline, IL) at a 5-cm depth. 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 5 May 1995, 22 May 1996, and 7 May 1997. All corn plots were fertilized after planting with 28% urea ammonium nitrate at a rate of 168 kg N ha^{-1}. In 1995, 1.12 kg a.i. ha^{-1} of glyphosate [*N*-(phosphonomethyl)glycine], 3.36 kg a.i. ha^{-1} of metolachlor [2-chloro*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide], and 0.56 kg a.i. ha^{-1} of dicamba (3,6-dichloro-2-methoxybenzoic acid) were applied preemergence for weed control. A postharvest burndown was done with 2.24 kg a.i. ha^{-1} of glyphosate and 1.12 kg a.i. ha^{-1} of 2,4-D [2,4-(dichlorophenoxy)acetic acid]. In 1996, 2.24 kg a.i. ha^{-1} of glyphosate and 1.12 kg a.i. ha^{-1} of 2,4-D were applied preplant and 1.68 kg a.i. ha^{-1} of glyphosate and 2.24 kg a.i. ha^{-1} of metolachlor were applied preemergence for weed control. In 1997, 2.24 kg a.i. ha^{-1} of glyphosate, 1.12 kg a.i. ha^{-1} of 2, 4-D, and 1.50 kg a.i. ha^{-1} of dimethenamid [2-chloro-*N*-(1-methyl-2-methoxy)ethyl-*N*-(2,4-dimethyl-thien-3-yl)acetamide] were applied preemergence and 0.02 kg a.i. ha^{-1} of rimsulfuron [*N*((4,6-dimethoxypyrimidin-2-yl)aminocarbonyl)-3-(ethylsulfonyl)-2-pyridinesulfonamide] and thifensulfuron methyl [methyl 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylate] was applied postemergence. Chlorpyrifos [*O*,*O*-diethyl *O*-(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 was drilled with a John Deere 750 no-tillage drill (Moline, IL) at a 4-cm depth. Soybean plots were planted on 5 May 1995, 25 May 1996, and 5 May 1997. In 1995, 1.12 kg a.i. ha^{-1} of glyphosate and 3.36 kg a.i. ha^{-1} of metolachlor were applied preemergence, and 0.27 kg a.i. ha^{-1} of imazethapyr [(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] and 0.17 kg a.i. ha^{-1} of thifensulfuron methyl were applied postemergence with a nonionic surfactant mixed at 5.0 mL L^{-1} and 4.67 L ha^{-1} of 28% urea ammonium nitrate. A postharvest burndown was done with 2.24 kg a.i. ha^{-1} of glyphosate and 1.12 kg a.i. ha^{-1} of 2,4-D. In 1996, 2.24 kg a.e. ha^{-1} of glyphosate and 1.12 kg a.i. ha^{-1} of 2,4-D were applied preplant and 1.68 kg a.i ha^{-1} of glyphosate, 2.24 kg a.i. ha^{-1} of metolachlor, 0.10 kg a.i. ha^{-1} of imazethapyr, and 0.09 kg a.i. ha^{-1} of thifensulfuron methyl were applied postemergence for weed control. In 1997, 2.24 kg a.i. ha^{-1} of glyphosate, 1.12 kg a.i. ha^{-1} of 2,4-D, and 1.50 kg a.i. ha^{-1} of dimethenamid were applied preemergence and 0.10 kg a.i. ha^{-1} of imazethapyr and 0.09 kg a.i. ha^{-1} of thifensulfuron methyl were applied postemergence.

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

Two corn rows from each plot were harvested on 4 Oct. 1995, 26 Oct. 1996, and 1 Nov. 1997 with a Kincaid Plot Combine (Kincaid Equipment Manufacturing, Haven, KS). The center seven rows of each soybean plot were harvested with an Almaco Plot Combine (Allen Machine Co., Nevada, IA) on 27 Sept. 1995, 14 Oct. 1996, and 10 Oct. 1997. Grain yields were adjusted to moisture content of 155 g kg^{-1} (corn) and 130 g kg^{-1} (soybean).

All of the data were subjected to an analysis of variance using the MIXED procedure of SAS (SAS Inst., 1995) at $P \leq 0.05$. Data were analyzed by years after determining error variances were heterogeneous. Mean comparisons were made using Fisher's protected LSD test. All effects except replicates were considered fixed in determining the expected mean squares and appropriate *F*-tests in the analysis of variance. Grain yield was regressed on final plant population using the maximum likelihood estimation procedure in PROC MIXED.

RESULTS AND DISCUSSION

Growing conditions varied considerably over years, which resulted in yield variability among the 3 yr. Additionally, the corn crop was heavily infested with European Corn Borer [*Ostrinia nubilalis* (Hübner)] in 1995 that resulted in lower corn yield because of stalk breakage, lodging, and ear droppage.

Influences of tillage system, rotation sequence, and plant population on soybean plant height and seed weight were relatively small and inconsistent for the 3 yr and the results will therefore not be presented. Final plant populations were averaged across years because of the small variability for the three seeding rates (Tables 2 and 7), which were 56 300, 65 800, and 75 200 plants ha^{-1} for corn and 294 200, 450 400, and 518 500 plants ha^{-1} for soybean.

Corn

Grain Yield

Significance of *F*-values from analysis of variance of grain yield, grain moisture, and lodging are shown in Table 2. Impact of tillage system, rotation sequence, and plant population varied with year. No interactions were found between grain yield, tillage system, rotation sequence, and plant population. No differences were found between tillage systems and corn grain yield in 1995 and 1997 (Table 3). However, the conventional tillage system yield was 7.7% (10.9 Mg ha^{-1}) higher in 1996 than the no-tillage system yield (10.1 Mg ha^{-1}). A cool and wet spring in 1996 resulted in cooler soil temperatures at planting that delayed season-long plant growth. Dick and van Doren (1985) and Meese et al. (1991) observed similar results regarding tillage and climate effect on corn grain yield.

Corn grain yield responded similarly to rotation sequences for all 3 yr (Table 3). First-year corn after 5 yr soybean and annually rotated corn produced the highest yield averaging 8.8, 11.6, and 10.1 Mg ha^{-1} for the 3 yr, respectively. In general, no differences were found between the remaining five rotation sequences that averaged 12% less or 7.5, 10.1, and 9.2 Mg ha^{-1} for the 3 yr, respectively. Meese et al. (1991) found similar results. However, Crookston et al. (1991) found that annually rotated corn produced about 5% lower yields than first-year corn after 5 yr of soybean.

The effect of plant population on grain yield was not consistent each year (Table 3). Grain yields increased with increasing plant population for 1995 and 1997, but no differences were found between the three plant populations in 1996. In general, the highest plant population tested resulted in the highest yield, and was higher than the current recommended final plant population of 69 000 to 75 000 plants ha^{-1} (Cusicanqui and Lauer, 1999). This indicates the highest plant population (75 200 plants ha^{-1}) was too low to represent the maximum attainable corn yield. Newer hybrids have improved stress tolerance associated with the above-optimum plant population (Duvick and Cassman, 1999) and the risks of a too high plant population are not as high today as it might have been a few years ago. In this case, the recommended optimum plant population was not high enough and may need to be reevaluated. Regression analysis of yield vs. final plant population was significant for all 3 yr (Table 4). The log-linear regression model gave a better fit than the linear and quadratic models. Nafziger (1994) and Porter et al. (1997) found the quadratic model to be the best fitting model. Our low coefficient of determination value shows the variability in this study and the effect of climate on corn grain yield. It also indicates the variability among the different rotation sequences (Table 3). The yield differ-

Table 2. Significance of *F*-values from analysis of variance of corn grain yield, grain moisture, and lodging from 1995 to 1997.

Source of variation	Grain yield	Grain moisture	Lodging†
		1995	
Tillage (T)	NS‡	**	–
Rotation (R)	***	***	–
T × R	NS	*	–
Final plant population (P)	***	***	–
T × P	NS	NS	–
R × P	NS	NS	–
T × R × P	NS	NS	–
		1996	
Tillage (T)	**	*	NS
Rotation (R)	***	NS	***
T × R	NS	NS	NS
Final plant population (P)	NS	***	***
T × P	NS	NS	NS
R × P	NS	NS	***
T × R × P	NS	NS	NS
		1997	
Tillage (T)	NS	NS	NS
Rotation (R)	***	NS	***
T × R	NS	NS	NS
Final plant population (P)	*	NS	***
T × P	NS	NS	*
R × P	NS	NS	NS
T × R × P	NS	NS	NS

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.
† Lodging was not measured in 1995.
‡ NS, no significant differences at $P \leq 0.05$.

Table 3. Tillage, rotation sequence, and final plant population influence on corn grain yield, 1995–1997.

Main effect	Grain yield 1995	1996	1997
		Mg ha^{-1}	
Tillage			
No-till	7.8	10.1	9.6
Conv. till	8.0	10.9	9.3
LSD (0.05)	NS†	0.2	NS
Rotation sequence			
First-year corn	8.9	11.7	9.9
Corn–Soybean	8.6	11.4	10.3
Second-year corn	8.1	10.3	9.3
Third-year corn	7.6	10.1	8.9
Fourth-year corn	7.4	9.9	9.1
Fifth-year corn	7.4	9.9	9.3
Cont. corn	7.1	10.3	9.2
LSD (0.05)	0.7	0.7	0.6
Final plant population, plants ha^{-1}			
56 300	6.6	10.4	9.2
65 800	8.2	10.5	9.4
75 200	8.9	10.6	9.8
LSD (0.05)	0.4	NS	0.4

† NS, no significant differences at $P \leq 0.05$.

Table 4. Regression equations and predicted corn yields for selected final plant populations, 1995–1997.

Year	Log-linear regression†	Model significance	R^2‡	Predicted yield at a final plant population of 56 300	65 800	75 200
				Mg ha^{-1}		
1995	$Y = -47\,081 + 5\,050.2\ln(P)$	$P < 0.0001$	0.56	8.2	8.9	9.6
1996	$Y = -21\,691 + 2\,870.8\ln(P)$	$P = 0.05$	0.09	9.7	10.2	10.5
1997	$Y = -25\,045 + 3\,072.6\ln(P)$	$P = 0.03$	0.21	8.6	9.0	9.5

† Y, corn grain yield in Mg ha^{-1}; P = final plant population in plants per hectare.
‡ R^2, coefficient of determination.

ence between the lowest plant population and the highest plant population was 25.3% in 1995, 1.9% in 1996, and 6.4% in 1997. No data has been published on the effect of plant population on European Corn Borer infestation. However, the data indicate that the heavy infestation of European Corn Borer in 1995 and the relatively large yield difference was related to plant population.

Grain Moisture

Year variability had an influence on grain moisture content at harvest (Table 5). Grain moisture content decreased with tillage in 1995 and 1996. No difference was found between tillage systems in 1997. Grain moisture was also influenced by rotation sequence. Corn following a minimum of 1 yr of corn tended to have higher grain moisture at harvest. Averaged over years, grain moisture content was lowest in the first-year corn after 5 yr of consecutive soybean. Grain moisture content at harvest for the different plant populations was not consistent across years. Grain moisture content increased as plant population increased in 1995, whereas the opposite was the case in 1996. Plant population did not affect grain moisture in 1997. Tillage by rotation sequence interaction was found on grain moisture in 1995. The no-tillage system was more sensitive to the different rotation sequences and had higher grain moisture content than the conventional tillage system (data not shown).

Lodging

Lodging was not measured in 1995. Lodging varied over years but was not influenced by tillage (Table 6). However, rotation sequence had a similar impact on lodging in both years. Lowest lodging percentages were found in first-year corn after 5 yr of soybean and for annually rotated corn averaging 7.0% in 1996 and 7.2% in 1997. Growing a minimum of 2 yr consecutive corn increased lodging percentage significantly. The remaining five rotation sequences averaged 46.8% in 1996 and 29.5% in 1997. The majority of the lodged plants had broken stalks and was associated with stalk and root rot pathogens. Williams and Schmitthenner (1963) studied the effect of crop rotation over a 7-yr period and concluded that corn planted in a rotation was less affected by stalk and root rot pathogens than continuous planted corn. In this study, plant population influenced lodging percentage for both years since an increase in plant population increased lodging percentage. Wilcoxson and Covey (1963) found similar results and concluded that corn grown at high populations have smaller diameter stalks, and therefore, the stalks break easier when weakened by the pathogen. A rotation sequence × plant population interaction was found in 1996, and a tillage × plant population interaction was found in 1997, but there is no consistent explanation for these interactions (data not shown).

Table 5. Tillage, rotation sequence, and final plant population influence on corn grain moisture, 1995–1997.

Main effect	Grain moisture 1995	1996	1997
	g kg^{-1}		
Tillage			
No-till	20.2	21.3	23.4
Conv. till	18.9	21.1	23.2
LSD (0.05)	0.5	0.2	NS†
Rotation sequence			
First-year corn	18.6	20.4	22.6
Corn–soybean	18.7	21.1	23.0
Second-year corn	19.3	21.6	23.6
Third-year corn	19.9	21.6	24.4
Fourth-year corn	20.4	21.1	23.7
Fifth-year corn	20.2	21.7	23.0
Cont. corn	19.5	20.9	23.0
LSD (0.05)	0.5	1.2	1.5
Final plant population, plants ha^{-1}			
56 300	19.2	21.5	23.2
65 800	19.7	21.4	23.3
75 200	19.6	20.8	23.5
LSD (0.05)	0.3	0.3	NS

† NS, no significant differences at $P \leq 0.05$.

Table 6. Tillage, rotation sequence, and final plant population influence on corn lodging, 1996–1997.

Main effect	Lodging 1996	1997
	%	
Tillage		
No-till	32.8	25.7
Conv. till	38.0	20.6
LSD (0.05)	NS†	NS
Rotation sequence		
First-year corn	5.9	4.8
Corn–soybean	8.0	9.5
Second-year corn	57.7	37.4
Third-year corn	47.0	41.7
Fourth-year corn	49.3	24.1
Fifth-year corn	56.5	26.9
Cont. corn	23.5	17.5
LSD (0.05)	13.8	11.4
Final plant population, plants ha^{-1}		
56 300	26.0	17.1
65 800	37.1	24.1
75 200	43.1	28.2
LSD (0.05)	4.1	5.3

† NS, no significant differences at $P \leq 0.05$.

Table 7. Significance of *F*-values from analysis of variance of soybean grain yield, moisture, and lodging from 1995 to 1997.

Source of variation	Grain yield	Grain moisture	Lodging
	1995		
Tillage (T)	**	NS†	*
Rotation (R)	**	NS	***
T × R	*	*	NS
Final plant population (P)	NS	NS	NS
T × P	NS	NS	NS
R × P	NS	*	NS
T × R × P	NS	NS	NS
	1996		
Tillage (T)	***	NS	*
Rotation (R)	***	*	**
T × R	**	NS	NS
Final plant population (P)	***	NS	***
T × P	NS	NS	NS
R × P	**	NS	*
T × R × P	NS	NS	NS
	1997		
Tillage (T)	***	**	***
Rotation (R)	***	NS	**
T × R	*	NS	*
Final plant population (P)	*	***	***
T × P	NS	NS	NS
R × P	NS	NS	NS
T × R × P	NS	NS	NS

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.
† NS, no significant differences at $P \leq 0.05$.

Soybean

Grain Yield

Significance of *F*-values from analysis of variance of grain yield, grain moisture, lodging, and final plant population are shown in Table 7. Tillage system, rotation sequence, and plant population effect on grain yield varied with year. A tillage system × rotation sequence interaction was found for grain yield in all years (Table 8). However, results were not consistent across years except for the annually rotated soybean that produced greater yield in the conventional tillage system. Averaged across years, no tillage system difference was found for first-year soybean after 5 yr of corn. The data indicate the no-tillage system was more variable under the different rotation sequences and yielded less than the conventional tillage system.

Soybean grown in the conventional tillage system produced greater yield than the no-tillage system for all years. Averaged over years, soybean planted in the conventional tillage system yielded 7.7% (3.9 Mg ha^{-1}) greater than soybean planted in a no-tillage system (3.6 Mg ha^{-1}).

Soybean yield responded similar to rotation sequence during all 3 yr. First-year soybean after 5 yr corn produced the highest yield during all years and had greater yields than the other rotation sequences. The differences between first-year soybean after 5 yr corn and the additional six rotations for 1995, 1996, and 1997 were 6.3, 9.8, and 6.9%, respectively. Crookston et al. (1991) and Meese et al. (1991) found similar results. A rotation sequence × plant population interaction was observed in 1996, but with variable results (data not shown).

Grain yield decreased with increased plant population in 1996 and 1997. However, the yield difference between the lowest plant population (294 200 plants ha^{-1}) and the highest plant population (518 500 plants ha^{-1}) was <3% for both years. No difference was found between plant population and grain yield in 1995. Regression analysis of yield vs. final plant population was not significant for any year.

Grain Moisture

Grain moisture content was influenced by year (Table 9). Rotation sequence and plant population influenced

Table 8. Final plant population and tillage × rotation sequence influence on soybean grain yield, 1995–1997.

Main effect	Grain yield (Mg ha^{-1})						
	1995	1996	1997				
Final plant population, plants ha^{-1}							
294 200	4.0	3.8	3.4				
450 400	4.0	3.8	3.4				
518 500	4.1	3.7	3.3				
LSD (0.05)	NS†	0.1	0.1				
	Tillage × Rotation sequence						
	1995						
Tillage	1-yr	C/S	2-yr	3-yr	4-yr	5-yr	Cont.
No-till	4.4	3.9	3.7	4.0	4.0	3.9	3.8
Conv. tillage	4.3	4.4	4.1	4.1	4.1	4.1	4.2
LSD (0.05) = 0.3							
	1996						
Tillage	1-yr	C/S	2-yr	3-yr	4-yr	5-yr	Cont.
No-till	4.0	3.7	3.7	3.0	3.4	3.5	3.5
Conv. tillage	4.1	4.1	3.8	4.0	3.9	3.9	3.9
LSD (0.05) = 0.3							
	1997						
Tillage	1-yr	C/S	2-yr	3-yr	4-yr	5-yr	Cont.
No-till	3.7	3.1	3.4	3.1	3.1	3.2	3.4
Conv. tillage	3.5	3.5	3.6	3.4	3.4	3.5	3.4
LSD (0.05) = 0.2							

† NS, no significant differences at $P \leq 0.05$.

Table 9. Tillage, rotation sequence, and final plant population influence on soybean grain moisture, 1995–1997.

Main effect	Grain moisture 1995	1996	1997
	g kg^{-1}		
Tillage			
No-till	13.9	15.4	14.5
Conv. till	13.8	15.7	14.1
LSD (0.05)	NS†	NS	0.1
Rotation sequence			
First-year soybean	14.2	15.8	14.7
Soybean–corn	13.9	15.9	14.1
Second-year soybean	13.6	15.2	14.2
Third-year soybean	13.9	15.6	14.2
Fourth-year soybean	13.7	15.4	14.3
Fifty-year soybean	13.9	15.4	14.1
Cont. soybean	13.8	15.5	14.4
LSD (0.05)	0.4	0.5	0.5
Final plant population, plants ha^{-1}			
294 200	13.9	15.5	14.6
450 400	13.8	15.5	14.2
518 500	13.8	15.7	14.1
LSD (0.05)	NS	0.2	0.2

† NS, no significant differences at $P \leq 0.05$.

Table 10. Tillage, rotation sequence, and final plant population influence on soybean lodging, 1995–1997.

Main effect	Lodging 1995	1996	1997
	1–5‡		
Tillage			
No-till	1.6	2.3	2.9
Conv. till	1.2	2.0	3.4
LSD (0.05)	0.3	0.3	0.4
Rotation sequence			
First-year soybean	1.5	1.8	3.2
Soybean–corn	1.9	2.5	3.3
Second-year soybean	1.3	2.7	3.2
Third-year soybean	1.5	2.1	3.5
Fourth-year soybean	1.4	2.1	3.2
Fifth-year soybean	1.2	2.4	3.3
Cont. soybean	1.2	1.6	2.5
LSD (0.05)	0.3	0.6	0.5
Final plant population, plants ha^{-1}			
294 200	1.4	1.7	2.1
450 400	1.4	2.3	3.5
518 500	1.4	2.5	3.9
LSD (0.05)	NS†	0.2	0.2

† NS, no significant differences at $P \leq 0.05$.
‡ Lodging score: the range extends from 1 = erect to 5 = flat.

grain moisture content in 1995 (data not shown). Grain moisture content was variable and not consistent across rotation sequence, tillage system, plant population, and year. No interactions were found in 1996 and 1997.

No-tillage had higher grain moisture content than conventional tillage in 1997. However, tillage did not affect grain moisture content in 1995 and 1996.

Rotation sequence had an impact on grain moisture content. In general, highest grain moisture content was found in first-year soybean after 5 yr of corn and annually rotated soybean. No differences were found between the remaining five rotation sequences. The reason for this could be the improved plant health from additional years of corn and its influence on the soybean senescence rate and grain moisture content from pathogens such as brown stem rot of soybean, caused by *Phialophora gregata* (Allington and Chamberlain) W. Gams (Adee et al., 1994). Plant population had an impact on grain moisture content but responded differently every year. During 1996, an increase in plant population increased grain moisture content, whereas the opposite was observed in 1997. Plant population did not affect grain moisture content in 1995. A rotation sequence × plant population interaction was observed in 1995, but the data was inconsistent (data not shown).

Lodging

Plant lodging at harvest varied among the 3 yr (Table 10). Plant lodging was influenced by tillage and was higher in the no-tillage system in 1995 and 1996 compared with the conventional tillage system but lower in 1997.

Rotation sequence influenced lodging scores during the years. In general, the lowest lodging score was found in the continuous grown soybean sequence, whereas the highest lodging score was found for annually rotated soybean. An explanation to the low lodging scores for continuous grown soybean could be the lower yield and plant height at harvest. A rotation sequence × plant population interaction in 1996 and a tillage × rotation sequence interaction in 1997 were found but with variable results (data not shown).

Plant population affected lodging score. Lodging score for 1996 and 1997 increased with increasing plant population, which corresponded well with previous observations (Weber and Fehr, 1966). Plant population did not influence lodging in 1995.

CONCLUSION

The optimum plant population was not influenced by various corn and soybean rotations. Highest corn yields were obtained at the highest plant population, regardless of tillage system and cropping rotation sequence, indicating that the risks of maintaining high plant populations are not as high today as it might have been a few years ago.

The absence of significant interaction between grain yield and plant population for soybean indicates that soybean plant population is not affected by rotation sequence or tillage system, and that soybean performed as well at the lowest as at the highest plant population.

For most agronomic characteristics, plant population × tillage system or plant population × rotation sequence was not different for either corn or soybean. This suggests that each of the three plant populations reacted similarly to changes in tillage system and rotation sequence.

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