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ORGANIC PRODUCTION

Utility of Interseeded Winter Cereal Rye in Organic Soybean Production Systems

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ABSTRACT

Soybean [*Glycine max* (L.) Merr.] growers using organic production systems have predominately been limited to mechanical cultivation for weed control. Interseeded cover crops such as winter cereal rye (Secale *cereale* L.) have been used in conventional soybean production systems in conjunction with herbicides to reduce tillage and cultivation operations. The objective of this study was to determine if high soybean planting populations in drill-planted (19-cm row) systems or a single mechanical cultivation in row-planted (76-cm row) systems could facilitate the use of interseeded rye in organic soybean production systems. Interseeded winter cereal rye decreased soybean grain yield in 2 of 3 yr in the drill-planted system by 22 and 17%, respectively, and in all 3 yr of the row-planted system by 23, 27, and 23%, respectively. Moisture stress from the interseeded rye was a predominate factor in soybean grain yield reduction. In 2000, the soybean planting population was inversely correlated with late-season biomass of interseeded rye. However, during the drier years of 2001 and 2002, increasing soybean planting density did not significantly reduce late-season biomass of interseeded rye. The interseeded rye reduced late-season weed biomass in both the drill-planted and row systems in 2001. Removal of the interseeded rye with mechanical cultivation in the row system when the soybean was at the V4 growth stage was ineffective in 2000 but increased soybean grain yield by 1142 and 746 kg ha^{-1}, respectively, in 2001 and 2002. These results suggest that some means of controlling winter cereal rye growth is necessary for effective management across a range of precipitation levels.

ORGANIC GROWERS typically rely on tillage for weed control in soybean production systems. Disadvantages with crop systems that rely on tillage include increased erosion risk (Edwards et al., 1993; McGregor et al., 1999), loss of soil structure, decrease in soil organic C levels (Studdert and Echeverria, 2000), and increases in machinery and fuel costs (Lu et al., 1999). Weil et al. (1993) found that mineralizable N decreased with increasing intensity of tillage in five Maryland cropping systems.

Spring-planted winter cereal rye, interseeded with soybean, has been identified as a possible alternative weed control method in conventional soybean production systems. Unlike fall-planted winter cereal rye, spring-planted winter cereal rye remains vegetative and does not rapidly elongate (Ateh and Doll, 1996). The less aggressive growing pattern of spring-planted winter rye makes it more appealing as an interseeded cover crop than fall-planted winter rye. Conceivably, a high soybean planting density could be used to further reduce the competitive effect of the interseeded winter cereal rye.

The use of cereal rye in field cropping systems has many advantages, including increased surface residue for erosion control (Kessavalou and Walters, 1997), reduced soil compaction (Raper et al., 2000), and suppressed weed emergence (Blum et al., 1997). In conventional soybean production systems, the availability of herbicides to control the interseeded rye affords the grower a management option in the event that the rye becomes too competitive with interseeded soybean. The objective of this study was to determine if interseeding winter cereal rye in the spring with soybean is a viable management practice in organic drilled and row-planted soybean production systems.

MATERIALS AND METHODS

Field research was conducted at the W.K. Kellogg Biological Station in Hickory Corners, MI. The soil is a mixture of Kalamazoo (fine-loamy, mixed, mesic Typic Hapludalfs) and Oshtemo (coarse-loamy, mixed, mesic Typic Hapludalfs) sandy loams. The depth of the Ap horizon is 20 to 25 cm, and pH ranged from 6.3 to 6.8. The experimental fields are certified organic by the Organic Crop Improvement Association (OCIA Int., Lincoln, NE). Corn (*Zea mays* L.) was the previous crop each year.

Two separate experiments were conducted. One experiment investigated a drill-planted system using 19-cm row spacing, and the second experiment involved a row-planted system using 76-cm row spacing. The experimental design for each study was a randomized complete block with four replications. The treatment design in each study was a two-factor factorial. In the drill-planted system, the first factor was soybean planting density (444 600, 889 200, and 1 333 800 plants ha^{-1}), and the second factor was the presence or absence of interseeded winter cereal rye. In the row-planted system, the first factor was whether or not row cultivation was used, and the second factor was the presence or absence of interseeded rye. Plot size in the 19-cm-row drill system was 46 by 3 m, 34 by 3 m, and 15 by 3 m in 2000, 2001, and 2002, respectively. In the 76-cm-row system, plot size was 46 by 5 m, 34 by 5 m, and 15 by 5 m, respectively, in 2000, 2001, and 2002. In both systems, the interseeded winter cereal rye treatments consisted of 125 kg ha^{-1} rye ('Wheeler', Michigan Agric. Exp. Stn., East Lansing, MI) planted with a drill in 19-cm row widths the same day the soybean was planted. In the row-planted experiment, row cultivation (Model 183 cultivator, Case Int., Racine, WI) was conducted on the indicated treatments when the soybean was approximately at the V4 growth stage.

The soybean variety used was 'NK 19-T19'. In each year of the study, all plots were rotary-hoed (Model 181MT, Case Int., Racine, WI). Consistent with local organic practices, the rotary hoeing occurred 7, 12, and 21 d after planting (DAP) in 2000; 9, 19, and 25 DAP in 2001; and 11, 13, and 19 DAP

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Abbreviations: DAP, days after planting.

Table 1. Summary of ANOVA for the drill-planted and row-planted soybean systems.

Year	Source	df	Early-season biomass Soybean	Early-season biomass Rye	Early-season biomass Weeds	Late-season biomass Soybean	Late-season biomass Rye	Late-season biomass Weeds	Yield
					19-cm row drill-planted system				
2000	Rye	1				NS	***	NS	NS
	Planting density (PD)	2				**	*	*	***
	Rye × PD	2				NS	*	NS	NS
2001	Rye	1	*	***	NS	***	***	***	***
	Planting density	2	***	NS	NS	***	NS	NS	***
	Rye × PD	2	NS	NS	NS	*	NS	NS	NS
2002	Rye	1	***	***	NS	**	NS	NS	***
	Planting density	2	*	NS	NS	NS	NS	NS	**
	Rye × PD	2	NS	NS	NS	NS	NS	NS	NS
					76-cm row-planted system				
2000	Rye	1							**
	Cultivation	1							NS
	Rye × cultivation	1							NS
2001	Rye	1	***	***	NS	***	***	***	***
	Cultivation	1	NS	NS	NS	***	**	***	***
	Rye × cultivation	1	NS	NS	NS	NS	**	***	NS
2002	Rye	1	***	***	NS	NS	NS	NS	***
	Cultivation	1	*	**	*	NS	NS	NS	***
	Rye × cultivation	1	NS	**	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

in 2002. Planting dates were 7 June, 20 May, and 30 May for 2000, 2001, and 2002, respectively. In all experiments, no herbicides were used, and management was consistent with certified production requirements (OCIA Int., Lincoln NE).

Late-season weed, soybean, and rye biomass weights were taken all 3 yr of the study, with the exception of the row-planted experiment in 2000 when biomass measurements were not taken. In 2001 and 2002, an additional early-season measurement of dry weight biomass was made on 27 June 2001 and 17 July 2002. The late-season weed, soybean, and rye biomass samples were taken on 18 Aug. 2000, 20 Aug. 2001, and 13 Sept. 2002. Plant biomass was determined by hand-clipping plants at ground level from one, four, and two quadrants per plot in 2000, 2001, and 2002, respectively. Quadrant sizes were 0.35 m^2 for soybean and 0.37 m^2 for weed in the 19-cm-row width soybean plots. In the 76-cm-row soybean plots, quadrant sizes were 0.37 m^2 for weed and 0.46 m^2 for soybean. Plants were separated, weighed, and placed in a forced-air dryer until a constant weight was observed. The dry plant material was then reweighed to calculate total dry matter. Soybean was harvested with a plot combine (Wintersteiger Nurserymaster, Zentrale, Austria) from the center 1.2-m transect of each plot, and yield was adjusted to 13% moisture. All data were analyzed with analysis of variance (ANOVA) using the PROC GLM procedure in the SAS Statistical Software Package version 8.2 (SAS Inst., 2002). Mean separation between variables was obtained by Tukey's Least Significant Difference Test. Effects were considered significant at $P < 0.05$.

Table 2. Soybean yield as affected by soybean planting density and interseeded winter cereal rye in a 19-cm drill-planted system. Effect of soybean planting density is averaged across rye treatments, and effect of rye planting is averaged across all soybean planting densities.

Soybean planting density and interseeded rye	2000	2001	2002
seeds ha^{-1}		kg ha^{-1}	
444 600	2 553	947	2 661
889 200	2 936	1 592	2 983
1 333 800	2 984	1 908	2 963
LSD	188	235	215
No interseeded rye	2 780	1 673	3 124
Interseeded rye	2 871	1 297	2 600
LSD	NS	161	146

RESULTS AND DISCUSSION

Drill-Planted System

Interseeded winter cereal rye had a significant effect on soybean yield and early- and late-season soybean biomass in both 2001 and 2002 (Table 1). Evaluation of the main effects (Table 2) shows that the presence of interseeded rye reduced soybean yield by 22 and 17% in 2001 and 2002, respectively, when averaged across the three levels of soybean planting densities. However, the presence of rye did not affect soybean plant density at harvest. In 2000, the interseeded rye did not affect soybean yield or biomass; however, increasing soybean planting population did reduce late-season rye biomass. This may be associated with the higher precipitation levels during the 2000 growing season (Table 3), which may have diminished the competitive effect of the interseeded rye. This result suggests that in years with normal to below-normal precipitation levels, competition from interseeded rye in a drill-planted soybean system may reduce the grain yield potential of soybean despite the limited effect on soybean plant density at harvest. This is consistent with the findings of Ateh and Doll (1996), who reported reduced soybean vigor when

Table 3. Annual precipitation levels at the W.K. Kellogg Biological Station compared with 30-yr means (1971–2000).

	2000	2001	2002	30-yr.
		mm		
Jan	19.4	19.5	24.8	56.4
Feb.	23.4	97.5	38.5	44.7
Mar.	37.4	17.0	53.8	62.0
Apr.	91.4	82.8	55.4	88.9
May	192.1	155.0	98.2	89.9
June	67.6	94.5	32.8	93.5
July	78.8	34.3	111.3	96.5
Aug.	125.8	137.3	134.3	97.8
Sept.	109.0	114.3	37.1	104.1
Oct.	52.2	170.7	62.9	74.4
Nov.	82.0	69.5	44.2	74.9
Dec.	36.1	40.4	38.9	67.1
Total	915.2	1032.8	732.2	950.2

Table 4. Early- and late-season biomass, plant density at harvest, and grain yield of soybean in a drill-planted (19-cm) system, as affected by soybean planting density and interseeded winter rye.

Year	Rye	Planting density	Early-season biomass			Late-season biomass			Harvest plant density	Grain yield
			Soybean	Rye	Weeds	Soybean	Rye	Weeds		
	kg ha^{-1}	seed ha^{-1}	kg ha^{-1}						plants ha^{-1}	kg ha^{-1}
2000	125	444 600				4 201	3 655	39	331 185	2 573
	125	889 200				5 149	242	26	548 053	3 024
	125	1 333 800				4 882	161	0	727 936	3 017
	0	444 600				3 926	0	301	258 898	2 540
	0	889 200				5 692	0	18	506 026	2 849
	0	1 333 800				5 074	0	7	704 400	2 950
		lsd				1 659	136	277	131 481	349
2001	125	444 600	179	773	117	783	1 264	72	289 388	826
	125	889 200	313	899	26	1 429	1 030	114	583 723	1 344
	125	1 333 800	489	777	64	2 180	796	45	706 156	1 720
	0	444 600	209	0	144	2 365	0	1 335	251 051	1 068
	0	889 200	460	0	82	3 638	0	605	560 226	1 848
	0	1 333 800	909	0	99	3 256	0	381	742 020	2 102
		lsd	452	208	NS	907	493	950	167 671	430
2002	125	444 600	694	416	38	7 671	1	328	441 132	2 365
	125	889 200	875	474	7	6 951	0	40	591 763	2 681
	125	1 333 800	657	418	11	7 385	0	631	790 810	2 768
	0	444 600	1 169	0	211	8 699	0	732	408 854	2 929
	0	889 200	1 406	0	70	9 866	0	84	640 180	3 286
	0	1 333 800	1 605	0	12	8 850	0	167	946 820	3 151
		lsd	507	349	NS	3 022	NS	NS	302 778	390

interseeded with rye. These results also support the concept proposed by Stanislaus and Cheng (2002), who reported on the utility of a cover crop that self-destructs in response to an environmental cue. This type of cover crop self-destruction trait could eliminate the competitive effect of the cover crop yet still maintain the advantages associated with less tillage and low inputs of an organically farmed system.

Soybean planting density did not affect early-season weed biomass and affected late-season weed biomass in only year 2000 of the study (Table 1). Even though the soybean planting density effect on weed biomass was statistically significant in 1 out of 3 yr, treatment effects shown in Table 4 indicate a trend for decreased weed biomass at higher soybean plant populations. Soybean planting density, however, significantly affected grain yield in all 3 yr of the study. Increased soybean planting density consistently resulted in higher grain yield (Table 4). The two soybean planting density levels of 889 200 and 1 333 800 plants ha^{-1} are greater than those generally recommended for conventional herbicide-based management systems (Ennin and Clegg, 2001). However, the favorable yield response to high soybean planting density levels in this study is consistent with results reported by Holshouser and Whittaker (2002). They found a soybean plant density of only 208 000 plants ha^{-1}, adequate for maximum yield at a site subjected to a brief stress period. However, a soybean plant density of more than 600 000 plants ha^{-1} was required for maximum yield when the site was subjected to more severe drought stress. These results demonstrate that under conditions of high plant competitiveness, such as the system evaluated in this experiment utilizing narrow-row organic production and interseeded rye, a high soybean planting density is required to maximize yield.

Row-Planted System

In the 76-cm-row plant system, the interseeded rye adversely affected soybean yield in all 3 yr of the study (Table 1). In 2001 and 2002, the interseeded rye significantly reduced early-season soybean biomass. However, the interseeded rye only reduced late-season soybean biomass in 2001. This result may also be attributed to rainfall patterns. During the 2002 growing season, 111 mm of rainfall was recorded during the month of July compared with 34 mm in July 2001. The additional rainfall in July of 2002 may have facilitated soybean plant recovery from the initial rye competition. The initial competition in 2002, however, was severe enough to reduce soybean yield. Yields were greater than those recorded in 2001 when less than one-third of the 2002 rainfall was recorded (Table 5). Similar to the drill-planted system, the interseeded rye did not affect soybean plant density at harvest.

Cultivation in the row-planted system improved soybean yield in 2001 and 2002 but did not affect yield in 2000 (Table 6). This result may be attributable to the higher precipitation levels during the 2000 growing season when there was adequate moisture to minimize competition from interseeded rye and weeds. The yield benefit from cultivation was more pronounced in 2001, which as stated previously was characterized by a very dry mid–growing (July) season. During 2001, cultivation significantly increased late-season soybean biomass and reduced late-season biomass of interseeded rye and weeds. In 2002, when low rainfall in June was followed by adequate precipitation in July, cultivation significantly increased early-season soybean biomass and decreased early-season rye and weed biomass. The competitive advantage of soybean over rye was apparent during the dry month of June 2002. Cultivation was associated with greater soybean biomass early in the 2002 growing season. With the above-normal July 2002 rainfall, however, regrowth of rye and late-emerging weeds negated the early-season competitive advantage from cultivation. The early-season effect of cultivation was sufficient to improve soybean yield over plots where no mechanical weed control was used.

The significant rye × cultivation interaction for late-season rye biomass in 2001 (Table 1) may be attributed

Table 5. Early- and late-season biomass, plant density at harvest, and grain yield of soybean in a row-planted (76-cm) system, as affected by mechanical cultivation and interseeded winter cereal rye.

			Early-season biomass			Late-season biomass				
Year	Rye	Cultivation	Soybean	Rye	Weeds	Soybean	Rye	Weeds	Harvest plant density	Grain yield
	kg ha^{-1}		kg ha^{-1}						plants ha^{-1}	kg ha^{-1}
2000	125	no								2 513
	125	yes								2 029
	0	yes								3 279
	0	no								2 856
		lsd								867
2001	125	no	168	881	45	1 208	1 240	310	274 170	847
	125	yes	152	739	68	2 632	486	20	302 266	1 989
	0	yes	288	0	88	4 155	0	6	281 271	2 399
	0	no	308	0	113	2 976	0	1 883	299 796	1 498
		lsd	88	165	NS	823	447	438	19 192	457
2002	125	no	422	473	109	5 152	62	1 627	171 048	1 774
	125	yes	486	208	3	5 787	0	1 267	156 228	2 520
	0	yes	999	0	31	7 069	0	6	172 900	3 171
	0	no	802	0	533	5 426	0	1 996	143 260	2 392
		lsd	180	130	473	NS	NS	NS	NS	847

to the increased competitiveness of the rye that year, which resulted in greater rye biomass in the uncultivated plots. Similarly, because the rye was very competitive to both weeds and soybean in 2001, the significant rye × cultivation interaction for late-season weed biomass is a result of the compounded effect of the interseeded rye plus cultivation. In the absence of either practice, weed biomass was very high, reflecting the lack of competition from rye, and conversely, in the presence of cultivation and rye, late-season weed biomass was reduced.

CONCLUSIONS

Interseeded winter cereal rye decreased soybean yield in 2 of 3 yr in a 19-cm drill-planted system and in all 3 yr of the 76-cm row-planted organic soybean system. In the year that the interseeded winter cereal rye did not reduce soybean yield in the drill-planted system (2000), above-average precipitation was recorded during the growing season, suggesting that moisture stress was a predominant factor in the observed soybean grain yield reduction in 2001 and 2002. In 2000, increasing soybean planting populations were inversely correlated with late-season rye biomass. However, during the drier years of 2001 and 2002, increasing soybean planting density did not significantly reduce late-season rye biomass. The interseeded rye reduced late-season weed biomass in both the drill-planted and row systems in 2001. Removal of the interseeded rye with mechanical cultivation in the row system resulted in an increase in soybean yield.

Table 6. Soybean yield as affected by mechanical cultivation and interseeded winter cereal rye planting density in the 76-cm row-planted system. Effect of cultivation is averaged across rye treatments, and effect of interseeded winter cereal rye is averaged across cultivation treatments.

Cultivation/interseeded rye	2000	2001	2002
	kg ha^{-1}		
Cultivation	2654	2197	2842
No cultivation	2684	1169	2083
LSD	NS	235	410
No interseeded rye	3279	1949	2782
Interseeded rye	2506	1418	2150
LSD	383	235	477

This result suggests that some means of terminating the interseeded rye is necessary for effective management across a range of precipitation levels. In 76-cm-row organic soybean production systems, mechanical cultivation would be an approved practice for terminating rye growth. However, in 19-cm drill-planted systems, new technology that meets the regulatory criteria for organic production is needed to effectively terminate the interseeded rye and alleviate moisture stress–related concerns.

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