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Research Article

Spring-Interseeded Winter Rye Seeding Rates Influence Weed Control and Organic Soybean Yield

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Field research in 2002 and 2003 evaluated spring-interseeded winter rye (*Secale cereale* L.) at 67, 134, or 200 kg ha^{-1} at two soybean (*Glycine max* (L.) Merr.) row spacings (19- and 76-cm) on weed control, yield, and gross margins. Based on regression analysis, wide-row (76-cm) soybean grain yield and gross margins were greatest when winter rye was interseeded at 114 and 106 kg ha^{-1}, respectively. Yields and gross margins for wide-row soybean were 8 to 55% greater than narrow-row (19-cm) soybean seeded at 494,000 or 742,000 seeds ha^{-1} which was probably due to flexibility for implementing cultivation. As interseeded rye rates increased from 67 to 200 kg ha^{-1}, yields and gross margins for narrow-rows decreased. Soybean row spacing had minimal impacts on specific weed species and total weed biomass or density. The use of wide-row soybean and spring-interseeded rye at 67 kg ha^{-1} was more cost-effective compared to narrow rows.

1. Introduction

Demand for organic crop production in the USA has increased, resulting in over 4.2 million certified organic crop production hectares in 2005 [1]. In 2005, more than 55% of the organic field crop production hectares in Missouri were soybean, while Missouri ranked 23rd in the USA for the number of certified organic producers in 2007 [1]. Missouri farmers have noted increased profit margins with organic versus conventional crop production systems in mid-west states [2, 3] and are more likely to consider using land previously set aside in the conservation reserve program for organic crop production [4]. Claypan soils in Missouri enrolled in the conservation reserve program generally are highly erodible. Using preplant primary tillage followed by two or three rotary hoeings and at least two in-crop cultivations has been an acceptable method of controlling weeds in organic soybeans [4–6]. Long-term research indicated that tillage-intensive, organic systems had greater soil benefits than conventional no-till on drought-prone, erodible soils [7]. However, the intensity of labor and tillage required for organic crop production has limited the widespread adoption of organic soybean production, especially on highly erodible soils.

Weed interference has affected soybean yields more in organic production systems than in conventional systems [8, 9], especially in narrow rows [10]. Weed control using companion crops such as winter rye seeded and narrow-row soybean was described in the 1950s [11]. Winter rye was preferred as a companion crop over wheat (*Triticum aestivum* L.). Cover crops such as winter rye have been used to suppress weeds, reduce soil erosion, reduce surface water runoff, increase organic carbon, and increase beneficial microbial populations [8, 12–14]. Typically, winter rye is seeded in the fall and desiccated with herbicides or incorporated with tillage to suppress winter annual weeds in row-crops [12, 15–17]. Winter rye residue suppresses weeds physically through interference and chemically with allelopathic compounds that delay weed emergence [18–20]. However, winter rye residue cannot provide full-season weed suppression [16, 17, 21, 22]. When used in an organic production system, winter rye has suppressed weeds through physical interference as a living mulch, but this system may also decrease crop grain yields [6, 11, 23]. Management of rye

Table 1: Field information and selected management practices in 2002 and 2003.

Field information and management practices	2002	2003
Tillage		
Fall tillage	Chisel plow	Moldboard plow
Spring disk-harrow	—[a]	1x
Spring field cultivated	3x	3x
Soybean planting date	June 5	May 29
Cultivar	Big Bubba	Big Bubba
Winter rye planting date	June 5	May 29
Cultivar	Forage Master	Forage Master
Rotary hoed[b]	June 17, June 22	June 9, June 16
Stage of soybean development[c]	VC, V1	VC, V1
Row cultivated[d]	June 25, July 3, July 18	June 23, July 2, July 20
Stage of soybean development	V3, V5, V7	V3, V4, V6
Harvest date	October 10	October 12

[a]No treatment was applied.
[b]All treatments except the weedy check.
[c]As described in Fehr and Caviness [24].
[d]All 76-cm wide-row plots except the weedy check.

using cultivation was necessary to minimize yield reductions, particularly in dry years, because no alternative methods exist to control rye in organic soybean.

Winter rye requires a vernalization period before jointing and flowering, and it commonly dies under summer stress [11, 21]. Interseeding winter rye in spring may promote a synergistic relationship with soybean, while restricting rye to vegetative growth. In this condition, rye may serve as a living mulch that suppresses weeds and minimizes soil erosion, while exerting minimal competition with soybean. Using winter rye in narrow-row soybean may allow farmers to increase production efficiency by reducing the time allotted to cultivation. In separate experiments, spring-interseeded winter rye at 125 kg ha^{-1} in wide (76-cm) and narrow (19-cm) rows reduced soybean yield by 17 to 27% in two of three years in the narrow-row experiment and in all three years in the wide-row experiment [6]. No known research has evaluated rates of rye or compared the cost-effectiveness of rye interseeded in wide- and narrow-row soybean. The objective of this research was to evaluate spring-seeded winter rye seeding rates on control of weeds, crop response, and gross margins of organic soybean in different row spacings.

2. Materials and Methods

Field research was conducted at the University of Missouri Greenley Research Center at Novelty (40°01′N, 92°11′W) in 2002 and 2003. Research was arranged in a split-plot design with four replications in 2002 and three replications in 2003. The main plot was soybean row spacing [76-cm wide row spacing seeded at 346,000 seeds ha^{-1} (wide-row), 19-cm wide row spacing seeded at 494,000 seeds ha^{-1} (NRL = Narrow-row with low seeding rate), and 19-cm wide row spacing seeded at 741,000 seeds ha^{-1} (NRH = Narrow-row with high seeding rate)], and the subplot was winter rye seeding rate (67, 134, and 200 kg ha^{-1}, weedy check with no winter rye, and weed-free check with no winter rye). Subplots were 3 by 15.2 m. A planter (John Deere 7000, Deere and Co., 501 River Drive, Moline, IL 61265-1100) and drill (Great Plains Solid Stand 10, Great Plains Manufacturing Inc., P.O. Box 218, Assaria, KS 67416) seeded “Big Bubba” soybean in wide- (76-cm) and narrow-rows (19-cm), respectively. The seeding rate in 19-cm rows was greater than the rate in wide rows, because higher seeding rates are recommended for narrow-row drill seeded soybean [25]. Two seeding rates were used in narrow-row soybean to evaluate the cost-effectiveness of a higher seeding rate. “Forage Master” winter rye was broadcast seeded with a hand spreader immediately following soybean seeding. Winter rye emergence in the spring was excellent in both years (visual observation).

The soil was a Putnam silt loam (fine, montmorillonitic, mesic Mollic Albaqualf) with pH 6.7 and 2.9% organic matter in both years. Soil texture was 13% sand, 62% silt, and 25% clay. Soil test values for P and K at this site [26] were in the medium to very-high range, based on Missouri soil test interpretations [27] and required no additional fertilizer inputs for these experiments. Field information and selected management practices are listed in Table 1. Wide-row soy bean was rotary hoed twice and cultivated three times, while narrow-row soybean was rotary hoed twice. The site had been in an organic corn soybean rotation for five years before this research. Weed species in the field included jimsonweed (*Datura stramonium* L.), common waterhemp (*Amaranthus rudis* Sauer), common cocklebur (*Xanthium strumarium* L.), common lambsquarters (*Chenopodium album* L.), giant foxtail (*Setaria faberi* Herrm.), and ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.). Weather conditions for the two study years were previously reported [28]. Precipitation from seeding until 1 October was 232 mm in 2002 and

Table 2: Effect of winter rye seeding rate on soybean, winter rye, jimsonweed, and total weed fresh weight biomass at physiological maturity in 2002 and 2003. Data were combined over years and row spacings unless denoted otherwise.

	Soybean		Winter rye			Total weed
Rye seeding rate	2002	2003	2002	2003	Jimsonweed	Biomass
(kg ha^{-1})			kg ha^{-1}			
Weedy check	1,430	800	0	0	870	8,100
67	1,660	3,100	100	0	1,250	2,400
134	1,670	2,600	120	0	640	2,500
200	1,040	2,800	400	0	130	4,100
Weed-free	2,450	3,800	0	0	0	0
LSD (P = .05)	610	830	320	NS[a]	850	3,100

[a] Abbreviations: NS: nonsignificant.

574 mm in 2003 with an average precipitation of 527 mm from 1 May to 1 October during the past decade (2000–2009). Individual weed species and soybean were harvested, counted, separated, and weighed on 3 September 2002, and 12 September 2003, from two randomly placed 30 by 76 cm quadrats near physiological maturity. Total weed fresh weight biomass or density was the sum of individual weeds present in the quadrats. Two rows of wide-row soybean and a 1.5-m width of the narrow-row soybean were harvested from the entire plot length with a small-plot combine (Kincaid Equipment Manufacturing, P.O. Box 400, Haven, KS 47543) and moisture adjusted to 13%.

We performed an economic analysis to evaluate gross margins for spring-seeded winter rye rates in wide- and narrow-row soybean. The gross margin was the difference between gross receipts and weed-management costs [29, 30]. Gross receipts were the product of crop yield and an assumed market price of \$37.05 ha^{-1} [31]. Weed management costs were the sum of planting [\$25.94 ha^{-1} for drill (19-cm rows) and \$25.19 ha^{-1} for planter (76-cm rows) seeded in conventionally tilled soil], soybean seed (\$0.72 kg^{-1} adjusted to the seeding rate and 5730 seeds kg^{-1}), cultivation (\$15.61 ha^{-1} for a row cultivator and \$11.01 ha^{-1} for rotary hoeing), and broadcasted winter rye seed (\$0.41 kg^{-1} plus broadcast application at \$12.35 ha^{-1}) [32, 33]. In addition, we tested the economic benefit of using different row spacings with spring-seeded winter rye at 67 kg ha^{-1} similar to other research [34, 35]. We performed the test using the weed management costs above for different soybean seeding costs from \$0.72 to \$2.16 kg^{-1} (\$0.33 to \$0.98 lb^{-1}) and soybean grain receipt scenarios from \$0.55 to \$1.65 kg^{-1} (\$15 to \$45 bu^{-1}) to include current and possible price increases in the organic market [1].

An analysis of variance was conducted using the general linear model procedure (PROC GLM) [36]. Data were combined over years and main effects of row spacing or winter rye seeding rate presented when interactions were not observed. Mean separation for individual treatment differences was performed using Fisher's Protected LSD at P = .05. Total weed density main effects were subjected to *F-Max* test for homogeneity of variance and combined over years [37]. Regression analysis was performed using best fit analysis determined with SigmaPlot (Version 10.0). Standard errors of the yield and gross margin means were determined using SAS [36].

3. Results and Discussion

In both years, rye seeding rate influenced both biomass (Table 2) and density (Table 3) of soybean and weeds. Winter rye emergence was excellent and remained vegetative in 2002, but died in the summer of 2003 as reported in other research [6]. Due to the persistence of winter rye during the summer of 2002, it may act as a weed during a drier year and reduce yields. The main effects for winter rye seeding rate on plant biomass and density are reported since there was no interaction with row spacing except for common waterhemp density, which related primarily to weed density differences in the weedy check. Interactions between years were observed for soybean and winter rye data, since rainfall in 2002 was 295 mm below normal and in 2003 (47 mm above normal) was uniformly distributed throughout the growing season [28]. As winter rye seeding rate increased, soybean fresh weight (Table 2), and density (Table 3) decreased compared to the weed-free control. Our finding of a reduction in soybean growth under low precipitation conditions in 2002 was consistent with reports by other researchers [6, 11] and likely reflects competition between rye and soybean for available moisture.

Reductions in weed biomass and density also were strongly influenced by the presence of rye plus mechanical weed removal compared to the weedy check (Tables 2 and 3). At a rye seeding rate up to 200 kg ha^{-1}, total weed biomass and weed density were lower compared to the weedy check. Winter rye interseeded at 67 kg ha^{-1} had 99% greater jimsonweed fresh weights than higher seeding rates (200 kg ha^{-1}). However, there was no significant difference among winter rye seeding rates on the biomass of common waterhemp, common cocklebur, common lambsquarters, giant foxtail, or ivyleaf morningglory fresh weights (data not presented). Similarly, there was no significant effect of winter rye seeding rates on common waterhemp, common cocklebur, common lambsquarters, jimsonweed, giant foxtail density (data not presented), or common waterhemp (Table 3). The interaction between rye seeding rate and soybean row spacing on common waterhemp density was due primarily

Table 3: Effect of winter rye seeding rate on soybean, winter rye, common waterhemp, ivyleaf morningglory, and total weed density in 2002 and 2003. Data were combined over years and row spacings unless denoted otherwise.

	Soybean		Winter rye		Common waterhemp			Ivyleaf	Total weed
Rye seeding rate	2002	2003	2002	2003[b]	Wide-row	Narrow-row low	Narrow-row high	morningglory	density
(kg ha^{-1})						No. m^{-2}			
Weedy check	32	17	0	0	82	36	55	5	86
67	35	39	4	0	1	10	3	0	20
134	33	32	9	0	1	5	6	1	21
200	27	32	22	0	0	3	1	5	30
Weed-free	33	37	0	0	0	0	0	0	0
LSD (P = .05)	NS	8	1	NS[a]		19		4	17

[a] Abbreviations: NS: nonsignificant.
[b] Winter rye emerged in the spring and died over the summer as in other research [6].

Table 4: Effect of soybean row spacing and narrow-row (19-cm) seeding rate on soybean and common lambsquarters fresh weights in 2002 and 2003. Data were combined over years and winter rye seeding rates unless denoted otherwise.

		Soybean		Common
Row spacing	Seeding rate	2002	2003	lambsquarters
(cm)	(seeds ha^{-1})		kg ha^{-1}	
76	346,000	1,400	3,200	50
19	494,000	1,850	1,700	420
19	741,000	1,700	3,000	20
LSD (P = .05)		NS	960	240

to differences in the weedy check compared to interseeded rye treatments. Ivyleaf morningglory density increased as winter rye seeding rate increased from 67 to 200 kg ha^{-1} which was probably due to late germination of this large-seeded broadleaf weed, but no differences in biomass were detected (P = .15). Winter rye biomass (Table 2) and density (Table 3) increased as seeding rate increased compared to the weedy check in a dry year (2002), while winter rye did not survive during the summer months in a year with higher rainfall (2003) due to increased competition of soybean.

The effect of soybean row spacing on plant fresh weight biomass and density was similar; therefore, we present only biomass data (Table 4). Soybean fresh weights were not affected by row spacing in 2002, but fresh weights were 43 to 47% lower in NRL soybean in 2003. Common lambsquarters fresh weight was 88 to 95% greater in NRL than NRH seeding rates. However, we found no significant effect of row spacing on giant foxtail (P = .41), common cocklebur (P = .40), jimsonweed (P = .16), ivyleaf morningglory (P = .45), common waterhemp (P = .32), winter rye (P = .88), and total weed biomass (P = .24) (data not presented).

Yields in the weedy check were ranked NRH (1130 kg ha^{-1}) $\geq$ NRL (1000 kg ha^{-1}) = wide rows (790 kg ha^{-1}) (Figure 1). Yields were similar between row spacings in weed-free plots in the absence of rye. Based on the yield regression equation, the optimal spring rye seeding rate for wide rows was 114 kg ha^{-1}. Winter rye interseeded at 67 kg ha^{-1} in narrow-row soybean reduced

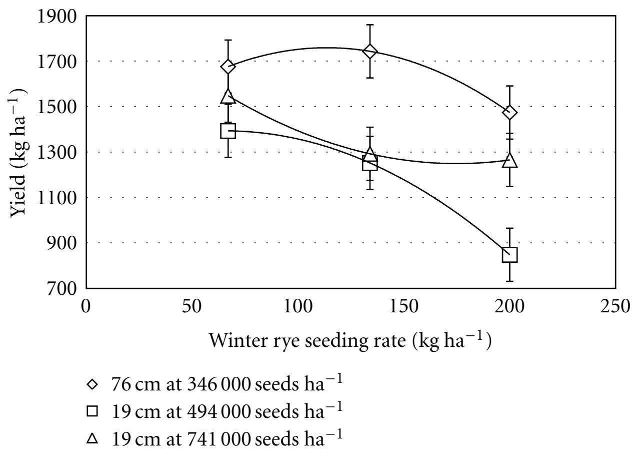

Figure 1: Effect of spring-interseeded winter rye rate on wide- (76-cm) and narrow-row (19-cm) soybean grain yield. Fitted lines are for wide rows (open diamonds, $y = -0.0382x^2 + 8.6867x + 1265.3$, $R^2 = 0.99$), narrow rows at 494,000 seeds ha^{-1} (NRL, open squares, $y = -0.0301x^2 + 3.949x + 1263.8$, $R^2 = 0.99$), and narrow rows at 741,000 seeds ha^{-1} (NRH, open triangles, $y = 0.0256x^2 - 8.9692x + 2033.8$, $R^2 = 0.99$). The vertical bars represent the standard errors of the means. The weedy check grain yields were 790, 1000, and 1130 kg ha^{-1} in wide-row, NRL, and NRH systems, respectively. Weed-free grain yields were 1900, 1740, and 1910 kg ha^{-1} in wide-row, NRL, and NRH systems, respectively. LSD (P = .05) was 300 kg ha^{-1}.

yield 360 to 380 kg ha^{-1} compared to the weed-free control. As the seeding rate of rye increased from 67 to 200 kg ha^{-1}, soybean yield decreased in narrow rows likely due to higher total weed biomass (Table 2) and density (Table 3) as the rye seeding rate increased. Soybean yield increased in narrow rows when the soybean seeding rate increased from 494,000 to 741,000 seeds ha^{-1} (Figure 1). This was similar to other research in which the optimal seeding rate in narrow-row (19-cm) organic soybean was approximately 889,200 seeds ha^{-1} in 2 of 3 years [6]. Winter rye at 67 kg ha^{-1} resulted in the highest yield of narrow-row soybean seeded at either rate. This was similar to observations and a single site-year evaluating winter rye seeding rates in Minnesota [11].

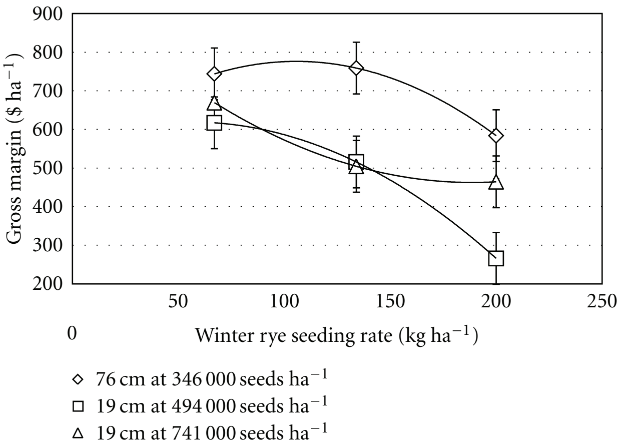

Figure 2: Gross margins for spring-interseeded winter rye rates for wide (76-cm) and narrow-row (19-cm) soybean. The gross margin was calculated as the difference between gross receipts and weed management costs. Fitted lines describing seeding rates are for wide rows (open diamonds, $y = -0.0216x^2 + 4.5697x + 534.71$, $R^2 = 0.99$), narrow-row low (NRL, open squares, $y = -0.0171x^2 + 1.9141x + 565.4$, $R^2 = 0.99$), and narrow-row high (NRH, open triangles, $y = 0.0139x^2 - 5.2651x + 959.5$, $R^2 = 0.99$). The vertical bars represent the standard errors of the means. The weedy check gross margin was \$367.04 ha^{-1}, \$461.84 ha^{-1}, and \$502.45 ha^{-1} for wide-row, NRL, and NRH systems, respectively. LSD ($P = .05$) was \$175 ha^{-1}.

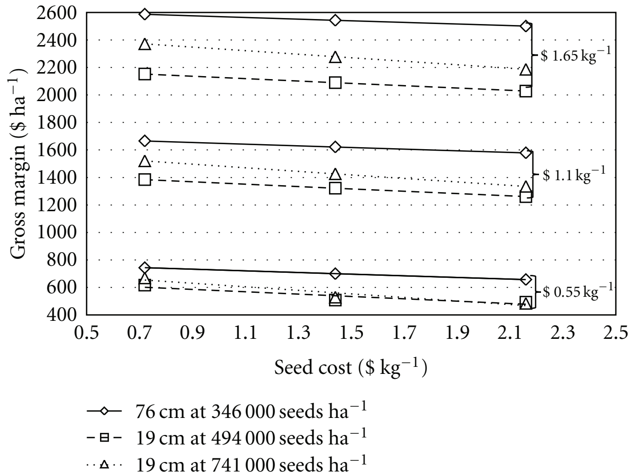

Figure 3: Gross margins for spring-interseeded winter rye at 67 kg ha^{-1} into wide- (76-cm) and narrow (19-cm) soybean rows for different soybean seed costs from \$0.72 to \$2.16 kg^{-1} (\$0.33 to \$0.98 lb^{-1}) scenarios and returns for soybean (\$0.55, \$1.10, and \$1.65 kg^{-1}) (\$15 to \$45 bu^{-1}).

Thelen et al. [6] reported that rye interseeded at 125 kg ha^{-1} consistently reduced yield compared to soybean without winter rye, which was similar to our results with a seeding rate of 134 kg ha^{-1}. However, the use of cultivation reduced the competitive impact by winter rye in wide rows. Yield differences between wide- and narrow-row organic soybean with winter rye were not as great as other research evaluating row spacings in the absence of winter rye [10].

Although soybean yield is important, profitability also depends upon minimizing crop inputs. Based on gross margins, the optimal winter rye seeding rate was 106 kg ha^{-1} for wide rows (Figure 2), while the highest gross margins came from rye at 67 kg ha^{-1} for narrow-row soybean seeded at either rate. Since spring-seeded winter rye at 67 kg ha^{-1} was nearly the optimal seeding rate for both wide- and narrow-row organic soybean yields (Figures 1 and 2), we performed additional economic analysis to evaluate the impact of various seed cost and soybean return scenarios (Figure 3) similar to other research [30, 34, 35]. As seed cost increased from \$0.72 to \$2.16 kg^{-1}, gross margins decreased from \$85 to \$185 ha^{-1} depending upon the row spacing. Although wide-row soybean had additional costs associated within row cultivation, gross margins were \$75 to \$470 ha^{-1} greater than narrow-row soybean, regardless of seeding rate. While increased seed costs were realized with NRH compared to NRL soybean, gross margins were \$20 to 220 ha^{-1} greater when soybean were seeded in the NRH system. The only exception was when soybean seed costs were \$2.16 kg^{-1} and returns were \$0.55 kg^{-1}, and NRL had gross margins that were \$10 ha^{-1} greater than NRH.

Wide-row soybean grain yields and gross margins at all interseeded rye rates were 8 to 55% greater than NRL or NRH. Based on yield and gross margins, the optimal winter rye interseeding rate in wide-row soybean was 106 to 114 kg ha^{-1} for the rye rates evaluated in our research, though other research found that a higher interseeded rye rate (125 kg ha^{-1}) consistently reduced soybean yield [6]. None of the narrow-row treatments in this research resulted in grain yields equivalent to wide-row soybean, which was probably due to flexibility for implementing cultivation in wide rows. The utilization of winter rye in narrow-row, organic soybean production did not provide adequate grain yields or gross margins to justify conversion from wide- to narrow-row production. Risk associated with narrow-row soybean and spring-interseeded rye as a weed management system preclude the adoption of narrow-row soybean in an organic soybean production system since narrow-row soybean rules out using mechanical weed control. In North Carolina, soybean seeding rates up to 556,000 seeds ha^{-1} in organic soybean production systems increased grain yields and profitability in 76-cm rows [38], while delayed seeding of rye after soybean were established maximized yields compared to seeding at the time soybeans were planted [23]. Seeding a companion crop up to 18 d before soybean planting was not recommended for effective weed control [11]. Additional research is needed to discover whether it is possible to increase soybean yield and consistency of this weed management system. A logical next step would be to look at integrating increased soybean seeding rates with interseeded rye at rates less than 110 kg ha^{-1} in wide-row soybean and delayed spreading of interseeded rye in wide or narrow rows.

Abbreviations

NRL: 19-cm wide rows seeded at 494,000 seeds ha^{-1}

NRH: 19-cm wide rows seeded at 742,000 seeds ha^{-1}.

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