Spring-Planted Winter Rye (Secale cereale) as a Living Mulch to Control Weeds in Soybean (Glycine max)

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Source: *Weed Technology*, Vol. 10, No. 2 (Apr. - Jun., 1996), pp. 347-353
Published by: Cambridge University Press on behalf of the Weed Science Society of America
Stable URL: https://www.jstor.org/stable/3988068

Spring-Planted Winter Rye (*Secale cereale*) as a Living Mulch to Control Weeds in Soybean (*Glycine max*)[1]

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Abstract. The effects of rye planting time, rye seeding rate, and rye/weed management systems on weed control and soybean yield were determined in field experiments near Arlington, WI from 1992 to 1994. Insufficient precipitation in 1992 resulted in limited soil moisture, less ground cover, less weed control, and lower soybean yields than in 1993 and 1994. The higher rye seeding rate provided more ground cover and better weed control than the lower rate in all years; however, it reduced soybean vigor. The optimum rye seeding rate was 112 kg/ha. The rye-only system reduced weed shoot biomass by 90, 82, and 60%, in 1992, 1993, and 1994, respectively, relative to the no-rye weedy check treatment. Killing rye 45 d after planting soybean gave optimum weed control. In 1993, rye alone suppressed the weeds without decreasing crop yield, but in 1994 crop yield was decreased due to inadequate weed control by rye. The results indicate that the rye living mulch technique can adequately control weeds without causing soybean yield reduction if weed pressure is low, ground cover and soil moisture are adequate and rye interference is minimal. **Nomenclature:** Rye, *Secale cereale* L.; soybean, *Glycine max* (L.) Merr.
Additional index words: Alternative control, cover crop.

INTRODUCTION

Herbicides in surface and groundwater (23), weeds resistant to herbicides (14), emergence of new weed problems (11), and regulations on herbicide development and use (18) have encouraged research on alternative weed management systems. Living mulches may be a potential non-chemical technique to reduce reliance on herbicides. Living mulches can control erosion, increase soil nutrients, or suppress weeds. Several grass and leguminous species have been evaluated as living mulches (1, 8).

Rye is considered an important cover crop in a variety of cropping systems because it contributes organic matter, reduces soil erosion, inhibits weeds, and enhances water penetration and retention (4, 5). Rye germinates in untilled soils and at low temperatures, tolerates many soil moisture levels, and develops an extensive root system (25). Rye acts as a physical barrier to weeds, competes with weeds, and releases toxic substances that prevent some weeds from growing. Fall-planted rye suppresses germination of weed species in crops but also competes with the interseeded soybean (7) or corn (*Zea mays* L.) (6, 21) and reduces the crop stand and yield (19). Weed suppression and subsequent soybean yield depend on soil moisture and the time elapsed between killing the rye and seeding soybean (29).

Evidence for allelopathy by spring-planted rye has been shown by Barnes and Putnam (2). A living cover of spring-planted rye seeded at 140 kg/ha reduced early season biomass of common lambsquarters (*Chenopodium album* L.) by 98%, large crabgrass [*Digitaria sanguinalis* (L.) Scop.] by 42%, and common ragweed (*Ambrosia artemisiifolia* L.) by 90% compared to no-rye controls (3). However, spring-planted rye may reduce soybean yield due to rye interference (28). Spring-planted winter rye is characterized by leafy shoots with tender stems and remains vegetative, thus may be easier to manage than fall-planted rye with rapid elongation and flowering the following spring.

The greatest challenge is to manage the living mulch to obtain benefits with minimal risk to the crop (9, 10, 13). Controlling living mulches has been a persistent obstacle to widespread acceptance of this practice (22). When soil moisture is limiting, rye must be suppressed to reduce water depletion (2). Living mulches can be suppressed by herbicides (20), mowing (12), and natural infection by fungal diseases (24). Grubinger and Minotti (12) compared rototilling and mowing to suppress a living mulch of white clover (*Trifolium repens* L.) and observed that yields from the rototilled treatments were similar not only to those of

[1]Received for publication July 27, 1995 and in revised form Jan. 14, 1996.
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the mowed treatments but to the clean-cultivated check treatments as well.

A living mulch system is more complex than conventional, clean-tilled systems, and is not suited to all situations (22). It is thus necessary to evaluate this technique in different settings. The overall objective of this study was to evaluate spring-planted winter rye as a weed control method in soybean in the upper midwest. The specific objectives were to: 1) determine the rye planting date and seeding rate to achieve adequate weed suppression, 2) determine the effects of living mulch on soybean growth and yield, and 3) evaluate different rye and weed management practices within the living mulch system on weed control and soybean yield.

MATERIALS AND METHODS

General and planting information. Research was conducted at the University of Wisconsin Agricultural Research Station, near Arlington, WI, from 1992 to 1994. The soil was a Plano silt loam soil (fine-silty, mixed, mesic, typic Arguidoll) with 6.8 pH, 4.4% organic matter, 67 ppm P, and 254 ppm K in 1992, and a pH of 6.2, 3.5% organic matter, 45 ppm P, and 204 ppm K in 1993. Soil analysis was not done in 1994 because the experiment was in the same field as both previous years. Each year, the previous crop was corn harvested for grain. Field preparation consisted of chisel plowing in fall followed by field cultivation and cultimulching in spring.

Design and treatment description. The experimental design for 1992 and 1993 was a randomized complete block in a split-split plot with four replications. The main plots were rye planting times: (a) rye planted 10 or 11 days before planting soybean (DBPS)[3], and (b) rye and soybean planted the same day (1992) or soybean planted a day after rye, (1993). The subplots were rye seeding rates of 56, 112, and 168 kg/ha. The sub-sub plots were rye/weed management systems: (a) rye without additional management; (b) rye with rotary hoeing; (c) rye with selective herbicides, and (d) rye killed with herbicide.

Planting rye without additional management allowed us to quantify the level of weed suppression by rye in soybean. Rye was supplemented with rotary hoeing 7 days after planting soybean (DAPS)[3] to control small weeds that may have emerged before rye produced enough ground cover to suppress the weeds. We hoped the rye would survive rotary hoeing and remain as a living mulch the rest of the season. At rotary hoeing, rye height was 7 and 9 cm for the early and late planted rye, respectively, and soybean was at the emergence stage (VE). The speed of the rotary hoe was approximately 13 km/h.

The rye supplemented with herbicide system included herbicides to control weeds that emerged with the rye. The weeds were identified, and appropriate, selective herbicides were applied. Broadleaf weeds 2 to 7 cm tall were treated with 0.004 kg ai/ha of thifensulfuron {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]-amino]sulfonyl]-2-thiophenecarboxylic acid} plus 0.83 kg ai/ha of bentazon [3(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] plus 28% urea ammonia nitrate and a nonionic surfactant[4] at 4%, v/v and 0.125%, v/v, respectively. Herbicides were applied with a CO_2 backpack sprayer fitted with 11002 flat fan nozzles[5] which delivered 200 L/ha at 166 kPa. Giant foxtail (*Setaria faberi* Herrm.) and green foxtail [*Setaria viridis* (L.) Beauv.] were controlled when 2 to 4 cm tall with sethoxydim {2[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} at 0.17 kg ai/ha plus crop oil concentrate[6] at 1.25%, v/v. The application was as described above but with a spray volume of 221 L/ha.

In the rye-killed management system, rye (10 to 15 cm tall; 4 to 5 tillers) was killed 45 DAPS with fluazifop-P {(R)-2-[4-[[5-trifluoromethyl)-2-pyridinyl]oxy]phenoxy] propanoic acid} at 0.17 kg ai/ha plus crop oil concentrate (1%, v/v,) in a spray volume of 221 L/ha. Soybean was at the V1 stage and ground cover by soybean and rye was greater than 70%. The rye should have suppressed weeds up to this time and the herbicide ended any further rye competition with soybean.

Two management systems without rye were included in each main plot within a replication and served as the controls: (a) no weed control, and (b) chemical weed control to maintain the plots weed-free. The PRE herbicide treatment was metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] (2.3 kg ai/ha) and metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] (0.5 kg ai/ha) applied in 166 L/ha of spray solution on the day soybean was planted. The PRE herbicides failed to control weeds adequately so POST herbicides, thifensul-

[3]Abbreviations: DBPS, days before planting soybean; DAPS, days after planting soybean.
[4]X-77, Chevron Chemical Co., 575 Market St., San Francisco, CA 94119.
[5]Spraying Systems, Wheaton, IL 60188.
[6]Prime Oil, Riverside/Terra Corp., Terra Center, 600 Fourth St., Sioux City, IA 51101.

furon (0.004 kg/ha) and bentazon (0.83 kg/ha), were applied 21 DAPS, and fluazifop (0.17 kg/ha) was applied 45 DAPS as described above.

The size of each experimental unit (sub-sub plot) was 3.5 by 7.6 m. The main plots were separated by 7.3-m wide alleys. The rye variety in 1992 was 'Ryman' and in 1993 and 1994, 'Hancock.' Secondary tillage and cultimulching the field preceded rye planted zero and one DBPS. A standard International[7] grain drill with 18-cm row spacing and single furrow openers was used to plant rye. Soybean was planted with the International drill in 1992 and a John Deere[8] no-till drill in 18-cm rows in 1993 and 1994. The soybean variety was 'Dairyland DSR 206' each year. Soybean seeds were planted at 120 kg/ha after inoculation with a bacterium species, *Rhizobium japonicum,* to enhance soybean nodulation.

In 1994, the experimental design was a randomized complete block in a split plot arrangement. The main plots were rye seeding rates (56 or 112 kg/ha), and the subplots were rye/weed management systems (rye without additional management or rye killed with herbicide). The control treatments were as described for 1992 and 1993. Rye and soybean were planted the same day.

Variables measured. Gravimetric soil moisture was determined every 2 wk in 1992 so as to determine if soil moisture was a limiting factor in the rye living mulch system. Three soil samples per plot were randomly collected from 0 to 15-cm and 15 to 30-cm depths with a soil probe. Samples were weighed, dried in an oven at 105 C for 24 h, then reweighed. In 1993, excessive precipitation precluded the frequent determination of soil moisture content as in 1992. Soil moisture content was determined only twice in 1993: when soybean plants were at the V1 and V6 growth stages during periods without precipitation. In 1994, precipitation was abundant during the growing season so soil moisture content was not determined. Ground cover by rye and soybean was determined weekly by the Laflen et al. (17) method until herbicides were applied to kill rye in the rye-killed treatments. At this stage, the mean ground cover by rye and soybean for each rye treatment was greater than 75%. Shoot biomass of rye, weed, and soybean, weed control, weed density, and soybean vigor were determined at 30, 60, 90 DAPS and at harvest.

Weed biomass was visually rated as a percentage of weediness of the plot, where 0% represented no weeds and 100% represented weed density in the no-rye weedy check. Weed biomass was also determined by hand-clipping shoots from three random 0.09-m^2 quadrats per plot then dried in a forced air drier until constant weight was obtained. Prior to biomass harvest the predominant weeds were identified and counted in these quadrats.

Soybean vigor was visually rated (0 to 100) where 0 represents plant death and 100 represents healthy, vigorous plants. Soybean biomass was determined using the same technique as for weed biomass described above. All biomass measurements were in the outer 0.5 m of each plot and soybeans were harvested with a combine from the center 2.5 m and yield adjusted to 13% moisture. Marginal returns for each treatment were computed by subtracting the cost of weed control from the value of the crop at harvest. Soybean price at harvest averaged over years was $0.18/kg. Mechanical weeding costs were determined by using a Machinery Costs Worksheet prepared by Schuler and Frank (26).

Analyses of variance were conducted on all data using the Statistical Analysis System[9]. Logarithmic transformations of data were made to stabilize error variance before analysis. Year by treatment interactions were significant when data from 1992 and 1993 were combined. Therefore, data from the two years were analyzed separately. Treatment means were separated by Fisher's Protected LSD method at the 5% probability level.

RESULTS AND DISCUSSION

Soil moisture. The rainfall in 1992 and 1993 growing seasons was notably lower and higher, respectively, compared to the 20-yr average (Table 1). The period of May through August in 1992 was especially dry. Soybean emergence was erratic in 1992. Soil moisture content was lower in the medium and high rye seeding rates than for the low rate (Table 2). The soil moisture content during 1993 growing season was 30% and was not affected by rye density and management.

The low soil moisture content in the living mulch and rotary hoed systems in 1992 was probably due to greater soil water depletion by the living rye. Unlike the supplemental herbicide and rye-killed systems in which rye was suppressed, the rye-only and the rotary hoed systems had living rye throughout the growing season. Soil moisture was about 13 and 29% higher in the no-rye weedy check and no-rye weed-free check, respectively, compared to the rye-based systems. Thus, water depletion was greatest

[7]J. I. Case, Racine, WI 53404.
[8]Deere and Company, Moline, IL 61265.
[9]SAS Institute Inc., Cary, NC 27511.

Table 1. Monthly rainfall during the growing season at the Arlington Research Station for 1992, 1993, and 1994.

Month	1992	1993	1994	20-yr avg
	mm			
April	101	179	58	84
May	31	115	51	77
June	30	155	201	90
July	50	239	154	98
August	49	81	102	105
September	189	107	118	102
Total	450	876	684	556

when both rye and weeds were present. This confirms earlier results that water, in addition to nitrogen, is the most limiting factor in intercropped systems (16).

Ground cover. The lack of rainfall early in 1992 resulted in sparse and less vigorous rye and soybean, and therefore less ground cover early in the season compared to 1993 (data not presented). In 1992, ground cover at 45 DAPS increased as rye seeding rate increased. In 1993, however, ground cover was greatest at the lowest rye seeding rate (Table 2) and this was probably due to greater tillering at the lower rye seeding rate, favored by adequate soil moisture. Percent ground cover in the rye based systems in 1992 and 1993 was two and three times, respectively, greater than in the no-rye systems. Rye and weed management systems had no consistent effect on ground cover.

Weed control. The principal weeds each year were common lambsquarters, velvetleaf (*Abutilon theophrasti* Medicus #[10] ABUTH), and giant foxtail. In 1993, Pennsylvania smartweed (*Polygonum pensylvanicum* L. # POLPY) was also present. In 1992, weed control improved as rye seeding rate increased (Table 3). Adequate ground

[10]Letters followed by this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

Table 2. The effect of rye seeding rate and management system on soil moisture and ground cover[a].

	Soil moisture	Ground cover	
	60 DAPS[b]	45 DAPS[b]	
Treatment	1992	1992	1993
	%		
Rye seedling rate (kg/ha)			
56	15.2 a	62.4 b	88.8 a
112	14.7 b	70.1 ab	74.3 b
168	14.5 b	78.6 a	78.3 b
Management system			
Living mulch	14.5 b	69.9 bc	73.5 a
Herbicide	15.1 a	74.5 a	75.7 a
Rotary hoeing	14.5 b	70.5 b	69.8 b
Rye kill	15.1 a	66.3 c	73.5 a
No-rye systems			
Weedy check	16.7 b	23.3 a	18.5 a
Weed-free	19.1 a	25.6 a	14.4 b

[a]Means within columns and blocks followed by the same letter are not significantly different according to Fisher's Protected LSD Test (P = 0.05).

[b]DAPS, days after planting soybean.

Table 3. The effect of rye seeding rate and management system on weed shoot biomass and weed control in soybean[a].

	Weed shoot biomass			Weed control		
	60 DAPS[b]			60 DAPS[b]		
Treatment	1992	1993	1994	1992	1993	1994
	kg/ha			%		
Rye seedling rate (kg/ha)						
56	380 a	121 a	897 a	29 a	12 a	25 a
112	232 b	118 a	691 a	25 b	12 ab	13 b
168	80 c	117 a	—	19 c	10 b	—
Management system						
Living mulch	286 ab	135 a	762 a	31 a	15 a	19 a
Herbicide	13 c	46 b	—	11 c	5 b	—
Rotary hoeing	238 b	124 a	—	27 b	13 a	—
Rye kill	388 a	171 a	825 a	27 b	13 a	18 a
No-rye systems						
Weedy check	2652 a	766 a	2259 a	98 a	88 a	100 a
Weed-free	182 b	87 b	0 b	10 b	1 b	0 b

[a]Means within columns and blocks followed by the same letter are not significantly different according to Fisher's Protected LSD test (P = 0.05).

[b]DAPS, days after planting soybean.

Table 4. The effect of management system on density of giant foxtail (SETFA), common lambsquaters (CHEAL), Pennsylvania smartweed (POLPY), velvetleaf (ABUTH), and total weeds 60 DAPS[a] in 1993[b].

Treatments	Weed species				
	SETFA	CHEAL	POLPY	ABUTH	Total weeds
	No./m²				
Management system					
Living mulch	40 a	20 ab	41 b	4 b	110 c
Herbicide	3 b	11 c	10 c	5 b	35 d
Rotary hoeing	39 a	25 b	51 b	5 b	124 bc
Rye kill	5 b	46 a	93 a	12 a	163 a
No-rye systems					
Weedy check	128 a	134 a	45 a	7 a	320 a
Weed-free check	24 b	10 b	10 b	3 b	54 b

[a]DAPS, days after planting soybean.

[b]Means within columns and blocks followed by the same letter are not significantly different according to Fisher's Protected LSD Test (P = 0.05).

cover was obtained in 1993 by soybean and rye at the lowest seeding rate resulting in weed control that was comparable to that with rye at the medium seeding rate.

Supplementing the living mulch system with rotary hoeing did not reduce weed shoot biomass (Table 3). Weed density was actually higher in the rotary hoed system than in the living mulch system (Table 4). Earlier reports indicate that although rotary hoeing controls the initial flush of weeds (15), more weeds grow later (27).

Rye provided an excellent ground cover that suppressed weed germination and growth. The rye-only system reduced weed shoot biomass by 90, 82, and 60%, in 1992, 1993, and 1994, respectively, compared to the no-rye weedy check (Table 3). This shows rye's ability to suppress weeds and confirms earlier observations (8, 25, 28). The variation between years was probably due to climatic differences. In 1992, the living mulch system reduced the density of common lambsquarters by 85%, Pennsylvania smartweed by 9%, velvetleaf by 43%, foxtail by 69%, and total weeds by 66% compared to the no-rye weedy system (Table 4). Herbicide applied 45 DAPS to kill rye favored the establishment of late season broadleaf weeds by allowing weed seedlings that were hitherto suppressed by the rye and soybean canopy to grow.

Soybean. In 1992, a relatively shallow seeding depth coupled with the low precipitation after planting resulted in desiccation of some soybean seeds and seedlings. Soybean density for 1992 was not determined but was certainly less than for 1993 and 1994 with 550,000 plants/ha. Nevertheless, the 1992 yields in the no-rye weed-free plots were 75% of the soybean yields for this region of Wisconsin (30).

Rye planting time had no effect on soybean vigor in 1992 and 1993 (data not shown). Increasing rye seeding rate decreased soybean yield in 1992 (Table 5) as a result of increased rye competition. On the other hand, rye seeding rate had no effect on soybean vigor in 1993 (Table 5) and 1994 (Table 6) when rainfall was adequate. The effect of management system on soybean vigor was inconsistent in the three years (Tables 5 and 6). In 1992 and 1993, the living mulch and rotary hoeing systems decreased soybean vigor because these systems didn't suppress rye enough, resulting in more rye competition. The failure by the rye-killed system to increase soybean vigor in 1994 was prob-

Table 5. The effect of rye seeding rate and management system on soybean vigor 60 DAPS[a], yield, and marginal return[b].

Treatment	Soybean vigor		Soybean yield		Marginal return	
	1992	1993	1992	1993	1992	1993
			kg/ha		$/ha	
Rye seedling rate (kg/ha)						
56	68 a	80 a	1198 a	2391 a	170 a	437 a
112	58 b	78 a	1035 b	2556 a	126 b	442 a
168	50 c	78 a	781 c	2563 a	70 c	458 a
Management system						
Living mulch	54 c	78 ab	797 b	2801 ab	111 b	463 a
Herbicide	60 ab	80 a	1238 a	3006 a	106 b	407 b
Rotary hoeing	58 b	78 b	879 b	2603 b	120 b	445 ab
Rye kill	62 a	78 ab	1105 a	2837 ab	150 a	469 a
No-rye systems						
Weedy check	50 b	52 b	274 b	2279 a	52 b	415 a
Weed-free	98 a	98 a	1670 a	3010 a	159 a	371 b

[a]DAPS, days after planting soybean.

[b]Means within columns and blocks followed by the same letter are not significantly different according to Fisher's Protected LSD Test (P = 0.05).

Table 6. The effect of rye seeding rate and management system on soybean vigor 60 DAPS[a], yield, and marginal return in 1994[b].

Management system	Seeding rate	Soybean vigor	Soybean yield	Marginal returns
	kg/ha	%	kg/ha	$/ha
Living mulch	56	58 b	1311 c	206 c
Rye kill	56	66 b	2003 bc	314 bc
Living mulch	112	68 b	1599 c	247 bc
Rye kill	112	68 b	2470 b	377 b
Weedy check	None	40 c	602 c	108 c
Weed-free	None	100 a	3748 a	514 a

[a]DAPS, days after planting soybean.

[b]Means within columns and blocks followed by the same letter are not significantly different according to Fisher's Protected LSD Test (P = 0.05).

ably due to competition from weeds that had emerged prior to rye kill but could not grow through the rye canopy.

In 1992, soybean matured later in the rye-only and rotary hoed systems compared to the other systems because rye and weeds delayed soybean drying and defoliation. The living mulch system and the non-rye weedy check reduced soybean yield by 40 and 84%, respectively, in 1992 (Table 5) compared to the no-rye weed-free check, and reduced soybean yield by 68 and 90%, respectively, in 1994 (Table 6). These yield reductions were lower in 1993 due to less competition by weeds than in 1992 and 1994.

The relatively high soybean yield and low purchased input level at the low rye seeding rate in 1992 resulted in the highest marginal return (Table 5). However, the medium rye seeding rate resulted in better weed control than the low seeding rate, especially in the dry year, 1992 (Table 3). In 1993 (Table 5) and 1994 (Table 6), marginal returns were not affected by rye seeding rate.

The effect of management systems on marginal returns was inconsistent in 1992 and 1993. In 1992, the highest marginal return was from the rye-killed system (Table 5). Although the supplemental herbicide system had a high soybean yield in 1992 and 1993 (Table 5), this did not result in high marginal returns due to the high input costs in the system. In 1993, the rye-only and the rye-killed systems had similar marginal returns.

Conditions for soybean growth were favorable in 1993, and yield differences between management systems were insignificant (Table 5). In 1994 (Table 6), the rye-killed system had a higher marginal return than the rye-only system. This is similar to the 1992 results where the rye-killed system had higher soybean yields than the rye-only system. Although soybean yield from the weed-free check treatment in 1993 was higher than in the weedy check, high variable costs due to herbicide application in the former reduced its marginal return. This indicates that both yield and cost are necessary to determine the feasibility of a weed control technique.

It is very difficult to control weeds without herbicides and cultivation. With increasing concerns of herbicide use causing environmental problems and resistant weeds, more innovative ways to address weed problems are needed (11). Though living mulch systems are used in some horticultural crops (22) for weed control, there is less potential to adapt this system to field crops.

Soil moisture, weed pressure, and competition from the rye are critical to the success of the living mulch system. The rye living mulch by itself might not be adequate for weed control. Suppressing rye might improve the management system but might result in future weed problems. However, if the living mulch technique is well integrated with other weed management techniques like herbicides and mechanical practices, a sustainable integrated weed management system could be attained.

ACKNOWLEDGMENTS

The authors thank D. Stoltenberg and J. Lauer for their critical reviews of the manuscript. Technical assistance was provided by Dwight Mueller, Kevin Beaty, Steve Kraak, John Quimbe, Tim Anthon, and John Albright.

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