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Cover Crops

Self-Seeded Cereal Cover Crop Effects on Interspecific Competition with Corn

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ABSTRACT

Perpetuating cereal cover crops through self-seeding may increase adoption by reducing risk and cost. Winter rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), and triticale (× *Triticosecale* Wittmack) were used to develop self-seeding cover crop systems in a soybean [*Glycine max* (L.) Merr.]–corn (*Zea mays* L.) rotation. Cereal cover crops were planted in varying row spacing configurations and managed chemically and mechanically to achieve different levels of resource utilization in time and space. The objective of this study was to quantify interspecific competition of self-seeded winter cereal cover crops growing concurrently with corn. Total weed density responded more to environment than cover crop treatment, with 12.0 and 2.2 weeds m^{-2} in 2005 and 2006. Averaged across species, cover crop treatments lowered corn grain yield 5 to 22% compared with a no cover crop check. The most promising treatment lowered corn grain yield 7 and 11%, which is in the range for previously reported yield reduction using rye cover crops when rye was killed at or immediately after planting in a corn–soybean rotation. Cover crop regrowth intercepted <9% of photosynthetically active radiation (PAR) during early growth of corn. Combinations of lower corn plant population density and kernel density in cover crop treatments appear most responsible for the yield reduction. Additional research should focus on reducing interspecific competition during vegetative growth in corn when sink size is being determined.

Cover crops provide important environmental functions that include reducing soil erosion (Zhu et al., 1989; Kaspar et al., 2001) and nitrate leaching (Kladivko et al., 2004; Strock et al., 2004; Kaspar et al., 2007). Nevertheless, cover crop adoption in agronomic farming systems is low. Singer et al. (2007a) reported 11% of producers in the U.S. Corn Belt used cover crops between 2001 and 2005 and reasons for not using cover crops included too much time involved (34.8%) and too costly (27.4%). Innovative approaches that address producers' reasons for not using cover crops may increase their adoption in agronomic farming systems and enhance their environmental benefits. However, sufficient evidence exists that highlights the importance of management in preserving the yield potential of agronomic crops in systems incorporating cover crops.

Eckert (1988) chemically desiccated rye immediately after corn was planted using no-tillage and observed a reduction in corn stands in the rye compared to the no rye treatment and concluded that the planter pressed rye into the seed furrow and resulted in poor seed-to-soil contact and seedling rot, which reduced corn density. He further hypothesized that the reduction in corn stand density reduced yield because in years that corn densities were similar, no differences in corn yield were observed. Johnson et al. (1998) also chemically dessicated rye at corn planting and reported 1.6 Mg ha^{-1} lower grain yield in the rye compared to the no rye treatment. They hypothesized that the corn yield reduction might have occurred because of lower soil temperature, reduced nutrient availability, or increased allelopathic effects, but not because of differences in soil water content. Tollenaar et al. (1993) compared the effect of one wheat and four rye cultivars on corn growth and development. They quantified a corn dry matter yield reduction of 2 to 16% with cover crops compared to the no cover crop check, but there was no correlation between corn dry matter yield and cover crop shoot biomass before corn planting.

Teasdale (1996) concluded cover crop residue can provide early season weed control but not full season weed control and cropping systems using cover crops can reduce herbicide inputs if early season weed control is sufficient to shift to a postemergence only herbicide system. Allowing the cover crop to continue living in the interrow could extend weed control, while still maintaining lower herbicide inputs. Furthermore, self-seeding cover crop systems could eliminate the risk and cost of annually seeding cover crops post-harvest. Before these systems can be recommended to producers, the effect of overlapping growth of the cover crop and cash crop must be determined. The objective of this study was to quantify interspecific competition of self-seeded winter cereal cover crops growing concurrently with corn.

MATERIALS AND METHODS

Field studies were conducted at the Agricultural Engineering Research Center in Boone County, Iowa (42°01′ N, 93°45′ W; 341 m asl) during the 2005 and 2006 growing seasons. The current study was a continuation of the original research that

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Abbreviations: PAR, photosynthetically active radiation; DOY, day of year.

was published after the soybean phase was completed (Singer et al., 2007b). This research followed the original cover crop treatments that were planted in the fall before the soybean production years of 2004 and 2005 and after the original cover crops self-seeded following soybean in the fall of 2004 and 2005. The field site was managed in a soybean–corn sequence using no-tillage. The soil was a Spillville loam (fine-loamy, mixed, superactive, mesic, Cumulic Hapludolls). Soil test levels in the surface 20 cm in 2004 were 17 mg kg^{-1} P, 80 mg kg^{-1} K, and a pH of 6.6 and in 2005 were 20 mg kg^{-1} P, 115 mg kg^{-1} K, and a pH of 6.5. Nitrogen, P, and K were surface applied on 2 Apr. 2005 and 17 Apr. 2006 at a rate of 35, 39, and 74 kg ha^{-1}, respectively.

The experimental design was a randomized complete block with treatments arranged in a split-plot with four replicates. Species main plots were wheat ('Karl 92'), rye ('Rymin'), and triticale ('Décor' in 2004 and 'Kitaro' in 2005) that self-seeded through seed shatter after maturity and the physical disturbance caused by combining soybean on 29 Sept. 2004 and 3 Oct. 2005. Subplots were 3.8 m wide and 18.2 m long in 2005 and 24.3 m long in 2006. Treatments were the residual of the previous cover crop management systems and a no cover crop check. Residual treatments following soybean in 2004 and 2005 were four rows with early (4REB) and late (4RLB) applications of spring glyphosate [N-(phosphonomethyl)glycine] to eliminate two 0.19-m rows and mechanical control, four 0.19-m rows with mechanical control (4RNB) only, two rows with mechanical control (2RB), and two rows with no mechanical control (2RBNC). Cover crops were originally planted at 2,470,000 seeds ha^{-1} on 25 Sept. 2003 and 9 Oct. 2004 using a grain drill with 0.19-m row widths. The primary difference between the mechanical (before soybean) and self-seeding (before corn) cover crop systems is that the self-seeded cover crops were not in rows. The plant distribution was random. Additional information about the cover crop management systems can be found in Singer et al. (2007b).

Chemical control of cover crops was performed on 15 Apr. 2005 and 22 Apr. 2006 using glyphosate in a 0.25-m band over the future or already planted corn row at an application rate of 1.1 kg a.i. ha^{-1}. Dekalb brand 'DKC 53–33' corn was planted on 18 Apr. 2005 and 20 Apr. 2006 using a no-tillage planter equipped with row cleaners at a population of 86, 487 seeds ha^{-1} using a 0.76-m row spacing. Each subplot consisted of five 0.76 m wide rows. Mechanical control of cover crops was conducted using a Buffalo[1] rolling stalk chopper (Fleischer Manufacturing Inc., Columbus, NE) with one pass in the corn interrow on 23 May 2005 and 19 May 2006. Broadleaf chemical control occurred in November 2004 by using dicamba (3,6-dichloro-O-anisic acid) and 2,4-D amine (2,4-dichlorophenoxyacetic acid) at application rates of 0.28 kg a.i. ha^{-1} and 0.27 kg a.i. ha^{-1}, respectively. Additionally, chemical control of broadleaf weeds was performed on 31 May 2005 and 2006 using bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at an application rate of 0.42 kg a.i. ha^{-1}. Check plots were maintained weed-free. Nitrogen was injected as urea ammonium nitrate at 212 kg N ha^{-1} on 13 June 2005 and 24 May 2006 at V5 (Ritchie et al., 1992) and V2 in corn, respectively.

At Feekes growth stage 11.4 (Zadoks et al., 1974) cover crop shoot biomass was obtained in a 0.76 m^2 area in each subplot. Winter wheat, triticale, and rye matured on 10, 13, and 28 July in 2005 and 13, 31, and 31 July in 2006, respectively. These maturity dates are later than normal because the rolling/chopping the cover crops resulted in new tiller recruitment that delayed maturity. Cover crop shoot biomass was dried in a forced-air oven at 70°C, ground to pass a 1-mm sieve and analyzed for total N concentration using the Dumas combustion method (AOAC International, 2000).

Interception of PAR was measured weekly from 10 May to 22 June 2005 and 16 May to 26 June 2006 in full sun conditions between 1100 and 1400 h using a PAR-80 ceptometer (Decagon Devices, Pullman, WA) until corn height exceeded cover crop height. Each subplot had one incident reading, four below the cover crop canopy, and four at the top of the corn canopy to determine cover crop and corn PAR transmission. The instrument was placed diagonally across one corn row to measure transmitted PAR. Light interception was calculated as the difference between incident and transmitted light divided by incident light. Weed species composition and population density at R1 in corn was measured in one 0.76 m^2 quadrat in each subplot on 18 July 2005 and 17 July 2006.

At R6 in corn, whole plant biomass was collected from one 0.76 m^2 quadrat in each subplot on 21 Sept. 2005 and 15 Sept. 2006 to determine shoot dry matter, kernel density, 1000-kernel weight, and harvest index. Harvest index was calculated as the ratio of grain weight to total shoot weight. Grain moisture for 1000-kernel weight is presented on a dry matter basis (ASAE, 2003). Corn density was determined by counting all plants in 6.1 m of three interior rows at harvest. Corn stalk segments were collected for basal stalk nitrate determination 2 wk after R6. Six stalk segments 0.20 m in length were collected 0.15 m above the soil surface in each subplot. Stalks were dried at 60°C for 5 d, ground to pass a 1-mm sieve, and analyzed for nitrate N by leaching 0.25 g of ground sample with 50 mL of 2 *M* KCl solution, creating a 200-fold dilution. Nitrate concentration in the leachate was determined using a Lachat autoanalyzer (Lachat Instruments, Milwaukee, WI; Method 12-107-04-1-B). Grain yield was measured by combining three interior rows from each subplot on 21 Oct. 2005 and 27 Sept. 2006. The combine had an electronic scale that measured moisture and mass. Corn yield was corrected to 155 g kg^{-1} water content.

Daily rainfall and air temperature were recorded at a weather station approximately 2 km from the experimental site (Table 1). Statistical analysis was conducted using PROC MIXED (SAS Institute, 2002) with block and block by species as random variables and year, cereal species, and treatment as fixed variables. Initially, a model including year was run to determine the year effect. If year, year by species or year by treatment interactions were significant, a separate model was run for each year. A Fisher's protected LSD (alpha = 0.05) was used for mean separation. All results were considered significant in $P \leq 0.05$.

[1] Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

RESULTS AND DISCUSSION

Light Interception

Cover crops intercepted up to 40% of incident PAR until mechanical control was conducted on 23 May 2005 (Day of year, DOY 143) and 19 May (DOY 139) 2006 (Fig. 1).

Table 1. Mean monthly air temperature and rainfall near Ames, IA.† Thirty year mean is from 1977 to 2006.

	Air temperature			Rainfall		
Month	2005	2006	30-yr mean	2005	2006	30-yr mean
	°C			mm		
Apr.	12.8	13.3	10.5	82	109	89
May	15.6	16.7	16.4	111	55	112
June	23.3	22.2	21.4	124	21	118
July	24.4	24.4	23.4	104	141	119
Aug.	22.2	22.2	22.0	172	157	122
Sept.	20.6	16.1	18.2	111	191	84

† National weather service cooperative observer program site Ames 8WSW.

Although corn emerged on 9 May 2005 and 5 May 2006, mechanical control of the cover crops was delayed to promote cover crop regrowth after mechanical control for new tiller recruitment and seed production. On 10 May (DOY 130) 2005, a species by treatment interaction was detected. In rye, 2RB, 4REB, 4RLB, 4RNB, and the check had similar PAR interception (7%), while 2RBNC was higher at 27%. In triticale, all treatments except 2RBNC had similar PAR interception (6%), which was higher at 17%. In wheat, 2RBNC and 2RB had similar PAR interception (24%), while 4REB, 4RLB, and 4RNB intercepted 17% incident PAR and the check intercepted 2%. A species by treatment interaction also occurred on 19 May 2005. In rye and triticale, all treatments were intercepting <10% PAR except 2RBNC, which was intercepting 27% in rye and 11% in triticale. In wheat, most of the cover crop management treatments had similar PAR interception (23%), which were all greater than the check.

Starting with the 23 May 2005 measurement (DOY 143), PAR interception by the cover crops was subtracted from the total PAR interception to compare corn PAR interception. After mechanical control, only a cover crop management treatment effect was detected. Pooled across species, corn in the 2RBNC intercepted 6% of PAR, which was higher than other treatments and the check. On 6 June (DOY 157) corn in all cover crop treatments had higher intercepted PAR (9%) compared to the check (5%). By 17 June (DOY 168) corn PAR interception ranged from 22 to 31% and was similar among management treatments. On 21 June (DOY 172) only rye treatments were measured because rye height exceeded corn height. Corn PAR interception among rye treatments was not different and ranged from 42 to 54%.

On 16 May 2006 (DOY 136) a species by treatment interaction occurred (Fig. 1). In rye, the check, 4REB, 4RLB, 4RNB, and 2RB had similar PAR interception (0%), while 2RBNC was higher (40%). In triticale, 2RBNC and 4REB had the highest PAR interception (30%) and the check had the lowest (0%). In wheat, 4RLB had the highest PAR interception (32%), although all treatments were higher than the check (0%). A species by treatment interaction also was detected on 24 May (DOY 144). In rye, the same response was detected as on 16 May, except the PAR interception in 2RBNC declined from 40% to 15%

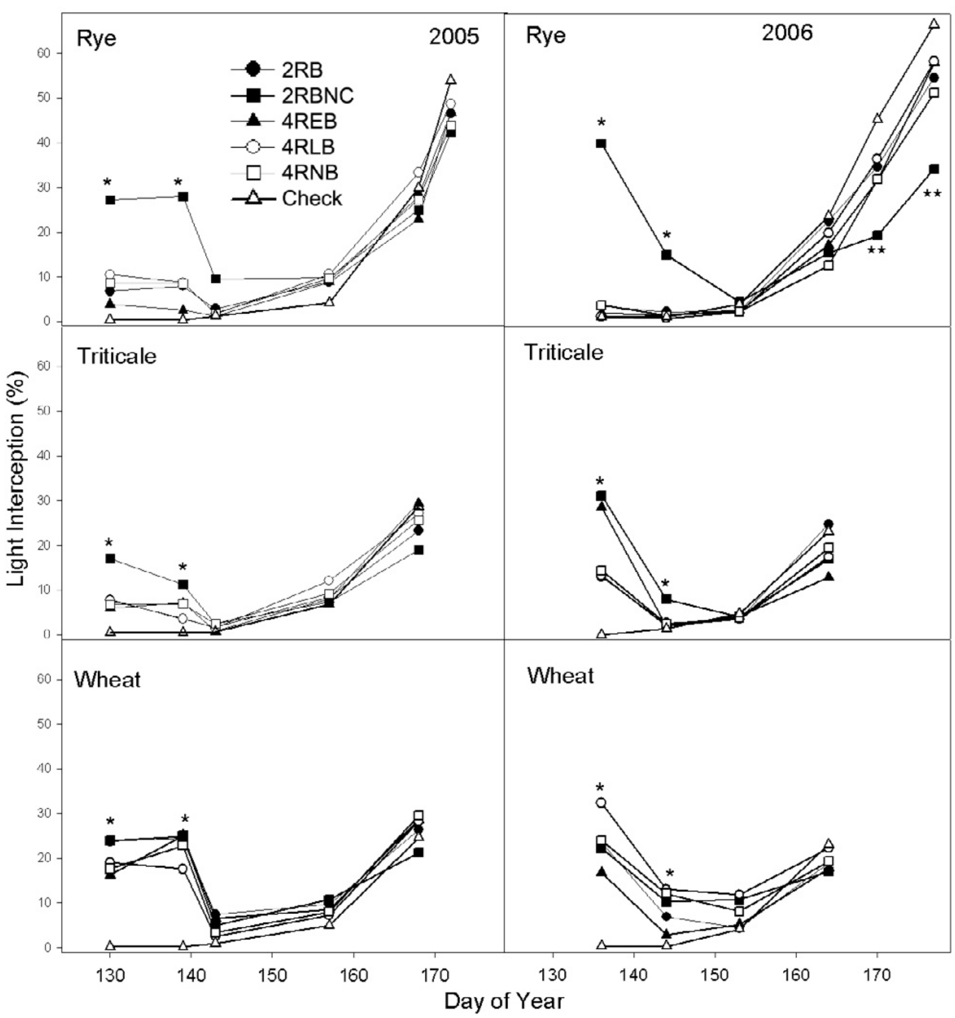

Fig. 1. Photosynthetically active radiation (PAR) interception in 2005 and 2006 for cover crop species and management systems. Residual treatments in soybean in 2004 and 2005 were four rows with early (4REB) and late (4RLB) spring glyphosate to eliminate two 0.19-m rows and mechanical control, four 0.19-m rows with mechanical control (4RNB) only, two rows with mechanical control (2RB), and two rows with no mechanical control (2RBNC). All cover crop treatments received mechanical control using a rolling stalk chopper on 23 May 2005 (day of year 143) and 19 May 2006 (day of year 139). Photosynthetically active radiation interception by the cover crops was subtracted from the total PAR interception starting with the measurement on DOY 143 in 2005 and DOY 153 in 2006 to compare corn PAR interception. *Indicates a significant (*P* < 0.05) species by treatment interaction. ** Indicates a management treatment difference (*P* < 0.05) for rye in 2006 at the last two sampling dates.

because this measurement occurred a day after mechanical control. In triticale, 2RBNC intercepted 8% PAR and was higher than the other treatments. In wheat, 4RLB intercepted 12% PAR and was higher than the check.

Starting at the 2 June (DOY 153) measurement, PAR interception by the cover crops was subtracted from the total PAR interception to compare corn PAR interception. On 2 June, corn PAR interception among cover crop species was significant. Averaged across treatment, corn in wheat had the highest intercepted PAR at 7%, while corn in rye and triticale were similar (4%). On 13 June (DOY 164) management treatments were significant. Averaged across species, the check intercepted 23% PAR, while corn in the 4REB and 2RBNC treatments had the least PAR interception (17%).

On 19 (DOY 170) and 26 June (DOY 177) only corn in rye was measured for PAR interception because rye height still exceeded corn height, while corn had already surpassed wheat and triticale. On 19 June, the check had the greatest intercepted PAR at 45%, while corn in 4REB, 4RLB, 4RNB, and 2RB were similar at 34% and 2RBNC was the lowest at 19%. On 26 June, the check intercepted 67% PAR, while corn in 4REB, 4RLB, 4RNB, and 2RB were lower at 56% and 2RBNC was the lowest at 34%.

Averaged across species, 2RBNC intercepted greater total PAR (data not presented) because of higher cover crop biomass (McDonald et al., 2008). This was most evident in rye both years. Averaged across species in 2005 and 2006, cover crop shoot biomass above corn intercepted up to 5 and 9% PAR (data not presented). Consequently, interspecific competition for PAR under similar crop management probably is not a dominant process that affects corn dry matter accumulation and grain yield.

Table 2. Mean annual grass, annual broadleaf, perennial, and total weed density at anthesis in corn, near Ames, IA, for cover crop species and management treatments in 2005 and 2006.

Treatment	Annual grass	Annual broadleaf	Perennial	Total
	no. m^{-2}			
2005				
Wheat	1.7	8.6	0.7	11.0
Rye	1.4	10.7	0.6	12.7
Triticale	2.5	9.1	0.9	12.5
LSD (0.05)	NS†	NS	NS	NS
4REB‡	0.5	10.4	0.7	11.6
4RLB	0.9	8.2	0.7	9.8
4RNB	4.4	10.5	0.9	15.8
2RBNC	2.4	6.6	0.9	9.9
2RB	1.1	11.7	0.4	13.3
LSD (0.05)	NS	NS	NS	NS
2006				
Wheat	0.7	1.3	0.4	2.3
Rye	0.9	0.8	0.1	1.8
Triticale	1.1	0.7	0.7	2.6
LSD (0.05)	NS	NS	NS	NS
4REB	0.5	1.1	1.0	2.6
4RLB	0.8	0.7	0.1	1.5
4RNB	0.8	1.0	0.2	2.0
2RBNC	0.7	1.3	0.3	2.3
2RB	1.6	0.5	0.4	2.6
LSD (0.05)	NS	NS	NS	NS

† NS, not significant. Total weed density may not be cumulative because of rounding.

‡ Residual treatments in soybean in 2004 and 2005 were four rows with early (4REB) and late (4RLB) spring glyphosate to eliminate two 19-cm rows and mechanical control, four 19-cm rows with mechanical control (4RNB) only, two rows with mechanical control (2RB), and two rows with no mechanical control (2RBNC).

Weed Abundance and Composition

Year was significant for annual broadleaf and perennial weeds, but not annual grasses. Significance was not detected for annual grass weeds primarily because densities were low (Table 2). Annual grasses were predominantly *Setaria* spp. Perennial weed densities both years were also low and *Taraxacum officinale* Weber in Wiggers was the predominant perennial weed. In 2006, a species by treatment interaction was detected for annual broadleaf weeds. In rye, the 2RBNC and 4RLB had similar weed densities (1.3 plants m^{-2}), which were greater than the 4REB and 4RNB, which had 0.3 and 0.0 plants m^{-2}. In triticale, 2RBNC had highest weed density (2.0 plants m^{-2}) compared to other treatments (0.4 plants m^{-2}). In wheat, the 4REB and 4RNB had similar densities (2.5 plants m^{-2}), which were higher than the other treatments (0.4 plants m^{-2}). Annual broadleaf weeds were dominated by *Chenopodium album* L., *Polygonum pensylvanicum* L., and *Amaranthus* spp.

Averaged across species and treatment, weed densities were 12.0 plants m^{-2} in 2005 compared to 2.2 plants m^{-2} in 2006. Chemical control for broadleaf weeds occurred on 31 May both years. June and July of both years had above normal air temperatures, but June 2006 only had 21 mm rainfall compared to 124 mm in 2005. The below normal rainfall probably had the greatest impact on weed emergence and density in 2006 because cover crop shoot biomass (Table 3) for most species by treatment combinations were higher in 2005 than 2006.

Westgate et al. (2005) reported no effect of mechanical control at second node, boot, or anthesis in rye on total weed density measured during reproductive growth in soybean. Weed density was similar during both years of their study under mechanical control and annual broadleaf weeds also generally contributed the most to the total weed density. Both the Westgate et al. (2005) findings using mechanical control and this study were perpetuating a self-seeded cereal cover crop. Shoot biomass of the cover crop may not be as critical for weed suppression in self-seeded cover crop systems because cover crop regrowth may alter the light environment enough to lower phytochrome-mediated weed responses and also extend the period of effective weed control.

Cover Crop Biomass

A species by treatment interaction occurred in 2005 for cover crop shoot biomass ($P = 0.012$)(Table 3). In wheat and triticale, no differences occurred among treatments and averaged 71.6 and 30.7 g biomass m^{-2}, respectively. In rye, 2RBNC had similar biomass compared to 4RLB and 4RNB and greater biomass than 4REB and 2RB. In 2006, cover crop biomass had a species effect ($P = 0.006$), although treatment ($P = 0.100$) and the species by treatment interaction ($P = 0.123$) were not significant. Wheat and triticale and triticale and rye had similar biomass, while wheat had higher biomass compared to rye. Rye biomass was markedly lower than the same treatment in

Table 3. Cover crop species and management treatment effect on cover crop shoot biomass and N uptake at maturity in 2005 and 2006 near Ames, IA.

Treatment	Shoot biomass			N uptake		
	2005	2006	Mean	2005	2006	Mean
	$g\ m^{-2}$			$kg\ ha^{-1}$		
Wheat	71.6	61.2	66.4	13.2	11.8	11.6
Rye	22.5	17.3	19.9	4.3	3.1	4.6
Triticale	30.7	45.2	38.0	6.0	7.7	6.4
LSD (0.05)	34.5	31.8				3.0
4REB†	37.7	21.7	29.7	7.4	4.7	5.9
4RLB	36.9	55.5	46.2	7.4	9.7	8.4
4RNB	39.7	33.5	36.6	7.1	6.2	6.5
2RBNC	52.9	63.6	58.3	9.3	11.4	10.2
2RB	40.8	31.8	36.3	7.8	5.7	6.6
LSD (0.05)	NS‡	NS				1.6
Wheat 4REB	66.7	23.9	45.3	12.6	7.0	8.8
Wheat 4RLB	62.8	72.1	67.5	11.7	13.5	11.7
Wheat 4RNB	67.3	77.1	72.2	12.3	14.6	12.5
Wheat 2RBNC	66.6	52.8	60.1	11.8	9.7	9.8
Wheat 2RB	94.6	79.7	87.2	17.5	14.4	15.0
Rye 4REB	0.0	0.8	0.4	0.4	0.1	1.2
Rye 4RLB	21.4	6.0	13.7	4.8	1.2	3.9
Rye 4RNB	32.1	2.2	33.2	5.4	0.4	3.8
Rye 2RBNC	56.2	77.0	66.6	9.3	13.8	12.5
Rye 2RB	4.7	0.4	2.6	1.5	0.0	1.7
Triticale 4REB	48.3	40.5	44.4	9.1	3.2	7.6
Triticale 4RLB	26.5	88.4	57.5	5.8	4.6	9.8
Triticale 4RNB	19.7	21.1	20.4	3.7	3.7	3.1
Triticale 2RBNC	35.9	60.9	48.4	6.8	3.2	8.3
Triticale 2RB	22.9	15.3	19.1	4.3	3.2	3.1
LSD (0.05)§	40.4	NS				5.4
LSD (0.05)¶	47.2	NS				5.5

† Residual treatments in soybean in 2004 and 2005 were four rows with early (4REB) and late (4RLB) spring glyphosate to eliminate two 19-cm rows and mechanical control, four 19-cm rows with mechanical control (4RNB) only, two rows with mechanical control (2RB), and two rows with no mechanical control (2RBNC).

‡ NS, not significant.

§ LSD (0.05) for comparing treatment means within species.

¶ LSD (0.05) for comparing treatment means across species.

either wheat or triticale, except in the 2RBNC treatment. It remains unclear if rye can be managed effectively to balance interspecific competition and seed production. Singer et al. (2007b) reported that rye had similar seed production in 1 yr and lower seed production a second year compared to wheat, yet self-seeding was lower both years. Tiller recruitment the following spring could not compensate for the lower plant densities (McDonald et al., 2008).

Cover Crop Nitrogen Uptake

Year and year interactions were not significant for cover crop N uptake, although a species by treatment interaction was detected ($P = 0.001$)(Table 3). In wheat, treatment 4REB had the lowest N accumulation at 8.8 kg ha^{-1}, but was only different than 2RB. In rye, 4REB, 4RLB, 4RNB, and 2RB had similar N uptake (2.7 kg ha^{-1}), which were lower than 2RBNC. In triticale, 4RNB and 2RB had the lowest N uptake, but were only different than 4RLB. Cover crop N uptake ranged from 1.2 to 15.0 kg ha^{-1}, which is low compared to corn N uptake. Singer et al. (2007c) reported no-tillage corn N uptake from 240 to 330 kg ha^{-1}. Actual N uptake by the cover crops in the current study was greater than the N uptake reported only

Table 4. Cover crop species and management treatment effect on corn stalk nitrate in 2005 and 2006 near Ames, IA.

Treatment	Stalk nitrate	
	2005	2006
	$mg\ kg^{-1}$	
Wheat	2360	2087
Rye	3228	1934
Triticale	2392	2082
LSD (0.05)	546	NS†
Check	3350	1580
4REB‡	2692	1926
4RLB	2863	2213
4RNB	2269	2089
2RBNC	2229	2558
2RB	2557	1843
LSD (0.05)	636	570

† NS, not significant.

‡ Residual treatments in soybean in 2004 and 2005 were four rows with early (4REB) and late (4RLB) spring glyphosate to eliminate two 19-cm rows and mechanical control, four 19-cm rows with mechanical control (4RNB) only, two rows with mechanical control (2RB), and two rows with no mechanical control (2RBNC).

at this sampling because shoot material was chopped in the spring before corn planting that had already accumulated N. McDonald et al. (2008) reported maximum N uptake by the cover crops at 21 to 35 kg ha^{-1} combining spring and maturity uptake.

Corn stalk nitrate concentration at harvest is a diagnostic tool to determine plant N status and helps refine fertilizer N recommendations. Binford et al. (1992) concluded that between 700 and 2000 mg NO_3–N kg^{-1} is the optimal range for stalk nitrate at the end of the growing season. Most of the species and treatments exceeded or were at the upper limit of the optimal range for stalk nitrate (Table 4). Nitrogen was sidedressed at 212 kg ha^{-1} to provide non-N limiting conditions for corn growth. These results indicate that the sidedress N rate can probably be lowered because corn accumulated excess N and the cover crops probably will not accumulate enough N to lead to corn N deficiency.

Corn Grain Yield

Grain yield was affected by treatment ($P < 0.001$) in 2005 but not species ($P = 0.936$). The check produced the highest yield, while 4REB, 4RLB, and 2RB had similar yield that was 10.4% lower than the check (Table 5). The lowest grain yield was recorded in 4RNB and 2RBNC, which was 20% lower than the check. In 2006, species ($P < 0.001$) and treatment ($P = 0.001$) were significant for grain yield. Averaged across treatment, rye had greater yield than wheat or triticale, which had similar yield. Averaged across species, the check had similar yield to 4REB, 4RNB, and 2RB. Similarly to 2005, 2RBNC had the lowest grain yield. The 2RBNC treatment in rye had the greatest and was among treatments that had the greatest quantify of biomass in wheat and triticale in the spring (McDonald et al., 2008) and at cover crop maturity, which competed with corn for PAR during early growth. Furthermore, 2RBNC also consistently had lower corn plant populations than most of the other treatments and the check (Table 5 and 6). Eckert (1988) reported a reduction in corn plant densities when a rye cover crop was used and concluded poor seed to soil contact and seedling rot reduced corn density.

Table 5. Cover crop species and management treatment effect on corn plant population (PP), kernel density, dry 1000-kernel weight, stover biomass, and grain yield at harvest in 2005 near Ames, IA.

Treatment	Corn PP	Kernel density	1000-kernel wt.	Stover biomass	Grain yield
	——no. m^{-2}——		g	——Mg ha^{-1}——	
Wheat	6.83	3076	265	6.67	9.15
Rye	7.24	2904	283	7.43	9.09
Triticale	6.75	2780	273	7.46	9.16
LSD (0.05)	NS†	NS	NS	NS	NS
Check	7.49	3639	266	7.91	10.37
4REB‡	6.60	2845	274	7.00	9.27
4RLB	7.26	2998	276	7.44	9.45
4RNB	6.79	2690	271	6.85	8.52
2RBNC	6.35	2616	277	6.98	8.05
2RB	7.16	2732	280	6.95	9.16
LSD (0.05)	0.61	NS	NS	NS	0.62

† NS, not significant.

‡ Residual treatments in soybean in 2004 and 2005 were four rows with early (4REB) and late (4RLB) spring glyphosate to eliminate two 19-cm rows and mechanical control, four 19-cm rows with mechanical control (4RNB) only, two rows with mechanical control (2RB), and two rows with no mechanical control (2RBNC).

Table 6. Cover crop species and management treatment effect on corn plant population (PP), kernel density, dry 1000-kernel weight, stover biomass, and grain yield at harvest in 2006 near Ames, IA.

Treatment	Corn PP	Kernel density	1000-kernel wt.	Stover biomass	Grain yield
	——no. m^{-2}——		g	——Mg ha^{-1}——	
Wheat	6.21	3469	220	5.09	7.72
Rye	7.10	4552	230	5.85	9.11
Triticale	6.69	3300	235	5.51	8.16
LSD (0.05)	NS†	NS	NS	NS	0.76
Check	7.17	4245	214	5.45	9.12
4REB‡	6.77	4057	215	5.38	8.50
4RLB	6.80	3529	240	5.59	8.06
4RNB	6.91	3866	220	5.67	8.69
2RBNC	5.64	3080	259	5.58	7.18
2RB	6.70	3865	221	5.22	8.41
LSD (0.05)	0.51	713	25	NS	0.89

† NS, not significant.

‡ Residual treatments in soybean in 2004 and 2005 were four rows with early (4REB) and late (4RLB) spring glyphosate to eliminate two 19-cm rows and mechanical control, four 19-cm rows with mechanical control (4RNB) only, two rows with mechanical control (2RB), and two rows with no mechanical control (2RBNC).

Several factors may be responsible for the observed grain yield reduction we detected in these cover crop treatments. First, as Eckert (1988) reported, physical impedance of the cover crop may impact corn seed placement and corn plant populations. Second, Opoku and Vyn (1997) reported corn grain yield reduction in one of 2 yr from wheat residue under no-tillage and more importantly, Barnes and Putnam (1983) reported that rye residues contributed allelopathy to control weeds and that rye root leachate reduced tomato (*Lycopersicon esculentum* L.) dry weight, which they stated is additional evidence that rye is allelopathic to other plant species. Third, competition for light and water at different periods during the growing season may have impeded corn growth and development.

Hall et al. (1992) reported that the critical period of weed control in corn is highly variable and begins between the 3rd and 14th leaf stage, although the end of the critical period is less variable and ends on average at the 14th leaf stage. They stated that the beginning of the critical period appeared to be influenced by differences in weed density and environmental conditions to a greater extent than the end of the critical period. In self-seeded cover crop systems, the primary period of resource competition occurs until the secondary cover crop tillers complete spike elongation. Cover crops did not mature until between 10 and 28 July in 2005 and 13 and 31 July in 2006. On average, silking occurred for most treatments on 17 July 2005 and 18 July 2006, which indicates that cover crops were growing during the entire critical period of weed control according to Hall et al. (1992). Nevertheless, the most promising treatment in this study (4REB) had 7 and 11% yield reductions for corn growing concurrently with cereal cover crops, which are higher (3% yield reduction, Eckert, 1988) and lower (17% yield reduction, Johnson et al., 1998) than those reported for a rye cover crop that was killed immediately after or at corn planting in a corn–soybean rotation.

Yield Components

In 2005, species ($P = 0.501$) and treatment ($P = 0.063$) were not significant for kernel density. In 2006, species was not significant ($P = 0.080$) and treatment was significant ($P = 0.024$) for kernel density. Averaged across species, the check had greater kernel density than 4RLB and 2RBNC (Table 6). In 2005, a species by treatment interaction was detected for 1000-kernel weight. Wheat treatments had similar 1000-kernel weight, which averaged 274 g. Rye 4REB, 4RLB, 4RNB, 2RBNC, and 2RB were similar at 290 g 1000-kernels^{-1}, while the check had the lowest 1000-kernel weight (246 g). In triticale, 4RNB had lower 1000-kernel weight (256 g) than 2RB (292 g), which had the greatest weight among treatments. In 2006, a treatment effect occurred for 1000-kernel weight (Table 6). Treatments 4REB, 4RNB, 2RB, and the check were similar at 218 g 1000-kernels^{-1}, while 4RLB was greater than the check and 4REB and 2RBNC was greater than all treatments except 4RLB. Generally, 1000-kernel weight increased to compensate for lower kernel density.

Corn stover biomass was not significant for species ($P = 0.409$) or treatment ($P = 0.196$) in 2005 and averaged 7.19 Mg ha^{-1} (Table 5). In 2006, neither species ($P = 0.064$) nor treatment ($P = 0.925$) were significant and stover biomass averaged 5.48 Mg ha^{-1} (Table 6). Harvest index (data not presented) also had no species or treatment effects and averaged 0.45 in 2005 (treatment range 0.44–0.46) and 0.55 in 2006 (treatment range 0.53–0.57, $P = 0.105$). Results from yield component data suggest interspecific competition occurred during corn vegetative growth when kernel number was being determined because visual inspection of the ears at harvest did not indicate kernel abortion adjusted for source constraints.

CONCLUSIONS

Perpetuating a cover crop through self-seeding may increase the environmental benefits to soil and water conservation because the cover crop continues to grow during the spring when the soil is vulnerable to erosion. The most promising cover crop treatment in this study lowered corn grain yield 7 and 11%, which is in the range for previously reported yield reduction using rye cover crops when rye was killed at or immediately after planting. Cover crop regrowth intercepted <9% PAR during early growth of corn, which indicates light interception by corn is probably not a major limiting in this system. Additional research should focus on reducing interspecific water competition during vegetative growth in corn when sink size is being determined.

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