No-Tillage Corn and Grain Sorghum Response to Cover Crop and Nitrogen Fertilization

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ABSTRACT

No-tillage cropping systems may benefit from the addition of winter annual cover crops through decreased soil erosion, accumulation of biologically fixed N, or increased crop yield. The objectives of this research were to assess the amount of cover provided by winter annual legumes and oat (*Avena sativa* L.) to quantify the fertilizer N equivalent value of each cover crop system and the effect of cover crop and N rate on corn (*Zea mays* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] grain yield. Two experiments, one in corn and one in sorghum, were conducted in 1997, 1998, and 1999. In each experiment, the main-plot effect was cover crop treatment while the subplot effect was spring N rates of 0, 56, 112, and 168 kg ha^{-1}. The addition of oat to the legume cover crop treatments increased fall ground cover but decreased total spring dry matter yield. Maximum spring dry matter yield was greatest in the hairy vetch (*Vicia villosa* Roth)-alone treatment. Hairy vetch alone also produced the greatest mean fertilizer N equivalent value in the corn and sorghum experiments, 43.6 and 56.9 kg N ha^{-1}, respectfully. These values, however, were variable among years. Corn and sorghum grain yield were greatest in the Austrian winter pea (*Pisum sativum* L.) and hairy vetch full seeding rate treatments, 5.19 and 7.06 Mg ha^{-1}, respectfully. Our results indicate that winter annual cover crops provide several distinct benefits to no-tillage corn and sorghum production systems and that cover crops should be selected based on specific grower needs.

The advantages of including cover crops into corn and sorghum production systems are well documented for the southeastern region of the United States; however, fewer experiments have quantified the impact of these systems in the Central Great Plains region (Decker et al., 1994; McVay et al., 1989; Holderbaum et al., 1990; Oyer and Touchton, 1990; Torbert et al., 1996; Wagger, 1989). Estimates of N contribution associated with winter annual legume cover crops range from 0 to 159 kg N ha^{-1}, depending upon year, location, and legume cover crop (Hesterman et al., 1992; Oyer and Touchton, 1990). McVay et al. (1989), Hargrove (1986), and Touchton et al. (1982) reported that legume cover crops may provide the total N requirements for sorghum and could replace a substantial portion of the N needed to maximize corn yield. Hesterman et al. (1992) reported that N accumulation in the soil was directly related to legume cover crop dry matter yield. Holderbaum et al. (1990) found that winter annual legumes such as hairy vetch may contribute up to 2 kg N ha^{-1} d^{-1} to the system when measured from spring growth initiation to chemically induced senescence at corn planting.

Benefits attributed to winter annual cover crops are not limited to N contribution alone (Blevins et al., 1990). Decker et al. (1994) indicated that legume cover crops killed before corn planting provided N and increased soil water content for the subsequent corn crop. Cover crops may also increase grain yield by increasing water infiltration and reducing evaporation, thus conserving water in the cropping system (Corak et al., 1991; Dabney, 1998). Furthermore, McVay et al. (1989) reported that hairy vetch replaced fertilizer N, improved soil water infiltration, and increased the aggregate stability of the soil.

Winter annual cover crops also benefit the cropping system by supplying additional soil residue cover. Crop residue cover is a critical component in limiting soil loss, especially on frozen soil or landscapes with steep inclinations (Cruse et al., 2001). In addition to decreased soil loss, crop residue cover may increase soil water content, reduce evaporation, and increase crop yield (Dormaar and Carefoot, 1996; Power et al., 1998; Schoenau and Campbell, 1996; Wilhelm et al., 1986).

Interseeding mixtures of winter annual legumes and winter wheat (*Triticum aestivum* L.) tends to decrease grain yield when compared with pure legume covers (Decker et al., 1994; Holderbaum et al., 1990). This may be due to N immobilization and delayed N release caused by an increase in the C/N ratio (Hargrove, 1986; Wagger, 1989). Wagger (1989) reported that N was released more quickly from hairy vetch than from rye (*Secale cereale* L.) due to a faster rate of cover crop decomposition. Kuo et al. (1997) also reported that the C/N ratio in both above- and belowground biomass was greater in cereal crops such as cereal rye and annual ryegrass (*Lolium multiflorum* Lamarck) than in legume crops such as Austrian winter pea and hairy vetch.

Currently, little research exists that quantifies the effect of interseeding oat with winter annual legumes in the fall. However, Johnson et al. (1998) documented the effect of seeding oat alone as a winter cover crop. They reported that oat interseeded into soybean before leaf drop significantly increased surface residue cover when compared with the no-cover control. Oat also produced as much fall growth as rye and did not decrease the subsequent corn grain yield. The objectives of this research were to assess the amount of cover provided by winter annual legumes and oat to quantify the fertilizer N equivalent value of each cover crop system and the effect of cover crop and N rate on corn and sorghum yield.

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MATERIALS AND METHODS

Site Description and Experimental Design

Two experiments, one in corn and one in sorghum, were conducted in 1997, 1998, and 1999 at the University of Missouri Bradford Research and Extension Center located near Columbia, MO. The soil type was a Mexico silt loam (fine, smectic, mesic Aeric Vertic Epiaqualfs) with 26.0 g kg^{-1} organic matter and pH 5.9. For each crop, the experimental design was a randomized complete block in a split-plot arrangement with four replications. The main-plot effect was cover crop treatments consisting of: oat alone (102 kg ha^{-1}), hairy vetch full rate (34 kg ha^{-1}), hairy vetch reduced rate (22 kg ha^{-1}), Austrian winter pea full rate (67 kg ha^{-1}), Austrian winter pea reduced rate (45 kg ha^{-1}), hairy vetch full rate plus oat, hairy vetch reduced rate plus oat, Austrian winter pea full rate plus oat, Austrian winter pea reduced rate plus oat, and a no cover crop control. The full seeding rate of each cover crop treatment was based on the recommended forage seeding rate for that crop. The reduced seeding rate for each legume cover crop treatment was two-thirds of the full seeding rate. The oat seeding rate was 102 kg ha^{-1} in each treatment. The whole plot area was 30.0 by 6.1 m. The subplot effect consisted of spring N (NH_4NO_3) rates of 0, 56, 112, and 168 kg ha^{-1}. The N rates were based on expected yield goal estimates for corn and sorghum. The subplot area was 3.0 by 6.1 m.

Field Procedures and Data Collection

In each year, cover crops were established by overseeding into soybean before leaf drop (R7 soybean) (Ritchie et al., 1997) in September. The cover crops were seeded by hand using a spinner seeder on 12 Sept. 1996, 10 Sept. 1997, and 8 Sept. 1998. The soybean crop was harvested using a plot combine with a 1.5-m head. The combine was adjusted to evenly distribute the soybean residue across each subplot.

Following cover crop establishment, percentage ground cover was estimated using the line transect method described by Shelton (1992). Percentage total soybean residue cover, cover crop ground cover, and total fall ground cover (sum of cover crop and soybean residue) were calculated in each subplot. Percentage ground cover was determined each fall at 13 wk after planting. In each spring, cover crop biomass was harvested from the center 0.25 m^2 of each subplot at cover crop anthesis. This occurred on 23 May 1997, 22 May 1998, and 24 May 1999. The remaining cover crop biomass was killed using a flail chopper on the same date in each year. Cover crop biomass was dried in a forced-air oven at 50°C for 3 d.

Pioneer 'Brand 33A14' field corn and Pioneer 'Brand 8500' sorghum were planted no-tillage in rows spaced 76 cm apart at 76 000 and 270 000 seeds ha^{-1}, respectively, in each year. Corn and sorghum were planted on 24 May 1997, 23 May 1998, and 25 May 1999. Weeds were controlled in each crop with a pre-emergence application of atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.7 kg a.i. ha^{-1} and metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide)-1,3,5-triazine-2,4diamine] at 1.12 kg a.i. ha^{-1}. Phosphorus and K were applied according to soil test recommendations provided by the University of Missouri Soil and Plant Testing Laboratory. Fertilizer N treatments were surface-applied before crop emergence.

Corn grain was harvested from the center two rows by 4.6 m on 7 Oct. 1997, 7 Oct. 1998, and 7 Oct. 1999. Sorghum grain was harvested from the center two rows by 4.6 m on 7 Oct. 1997, 7 Oct. 1998, and 21 Oct. 1999. The moisture content of corn and sorghum grain was adjusted to 155 and 140 g kg^{-1}, respectively. Precipitation and average monthly air temperatures in 1996, 1997, 1998, and 1999 are reported in Table 1.

Table 1. Precipitation and average monthly air temperatures in 1996, 1997, 1998, and 1999 at the University of Missouri Bradford Research and Extension Center located near Columbia, MO.

	Precipitation					Temperature				
Month	1996	1997	1998	1999	30 yr	1996	1997	1998	1999	30 yr
	mm					°C				
Jan.	46.2	39.6	27.7	35.6	36.8	−5.0	−5.1	0.8	−2.7	−2.5
Feb.	9.7	115.8	81.5	73.4	46.7	−1.0	2.1	5.2	5.6	0.1
Mar.	48.3	47.8	92.2	31.2	80.5	0.9	7.7	4.3	5.9	6.2
Apr.	98.8	63.8	127.0	96.5	97.3	8.6	9.4	12.2	14.7	12.6
May	133.4	137.9	34.3	110.7	127.3	16.9	15.1	20.8	17.7	17.6
June	69.3	145.3	152.4	111.5	109.7	21.5	22.1	23.4	22.0	22.2
July	100.8	18.8	144.3	80.3	93.2	23.1	25.4	25.7	26.6	25.2
Aug.	36.1	97.8	21.6	33.0	83.3	23.3	23.5	25.5	24.6	24.0
Sept.	80.0	65.3	103.1	47.0	98.0	17.1	20.4	21.6	18.1	19.9
Oct.	73.7	59.4	37.3	30.7	81.8	13.0	13.6	14.7	13.6	13.6
Nov.	51.1	54.9	29.5	18.8	74.4	3.0	4.6	8.3	12.2	6.7
Dec.	19.8	36.1	17.5	69.9	62.7	0.0	2.3	1.8	2.5	−0.1

Analysis of variance was performed using the PROC MIXED procedure of SAS (SAS Inst., Cary, NC). The mixed-model procedure provides Type III *F* values but does not provide mean square values for each element within the analysis or the error terms. All effects except replication were considered fixed. Year was treated as a fixed effect to determine interactions involving year. Mean separation was evaluated through a series of pairwise contrasts among all treatments (Saxton, 1998). Main effects and all interactions were considered significant when $P \leq 0.05$.

Regression analysis was used to describe the relationship among corn or sorghum yield and fertilizer N rate for each cover crop treatment. Regression slopes and *y* intercepts between years were compared using *t* ratios (Draper and Smith, 1998, p. 15–76, 135–169, and 505–553). Following regression analysis, fertilizer N equivalent value was calculated from each regression equation according to the procedure described by Oyer and Touchton (1990). The fertilizer N equivalent value was estimated by substituting the mean crop yield at the zero N rate for each cover crop treatment into the N response equation for the no cover crop control.

RESULTS AND DISCUSSION

Fall Ground Cover

In the corn and sorghum experiments, year × cover crop interactions were significant for percentage total soybean residue, cover crop ground cover, and total fall ground cover ($P \leq 0.001$); therefore, data were reported separately for each year (Tables 2 and 3). In both experiments, soybean residue alone provided considerable (>80%) fall ground cover in 1996 and 1997; however, a lack of precipitation in May, coupled with substantial precipitation in June and July, affected soybean growth and limited the amount of fall residue cover provide by the soybean crop in 1998.

In both experiments, oat alone and in conjunction with the hairy vetch and Austrian winter pea treatments provided greater ground cover than the legume cover crops alone in 1996 and 1997. In 1998, the hairy vetch full rate plus oat and both Austrian winter pea plus oat treatments produced the greatest fall cover.

In the corn experiment, total percentage ground cover

Table 2. Percentage soybean residue, cover crop (CC) ground cover, and total fall ground cover 13 wk after CC seeding in the corn experiment (1996–1998).

	1996‡			1997			1998		
CC treatment†	Soybean	CC	Total	Soybean	CC	Total	Soybean	CC	Total
	Ground cover, %								
Untreated	83.1 a§	0.0 c	83.1 d	88.8 a	0.0 c	88.8 bc	47.5 a	0.0 d	47.5 b
Oat	15.6 c	80.6 a	96.2 ab	27.5 c	66.3 a	93.8 ab	17.5 bcd	78.8 bc	96.3 a
Hairy vetch FR¶	74.4 ab	16.9 b	91.3 abc	63.8 b	27.5 b	91.3 abc	16.9 bcd	80.0 bc	96.9 a
Hairy vetch RR#	77.5 ab	14.4 b	91.9 abc	76.3 ab	11.9 c	88.2 c	19.4 bc	76.9 bc	96.3 a
Austrian winter pea FR	75.0 ab	15.0 b	90.0 bc	79.4 a	11.9 c	91.3 abc	9.4 bcd	86.3 ab	95.7 a
Austrian winter pea RR	71.9 b	14.4 b	86.3 cd	81.3 a	11.3 c	92.6 abc	25.0 b	68.8 c	93.8 a
Hairy vetch FR + oat	22.5 c	70.6 a	93.1 ab	16.9 c	76.3 a	93.2 abc	6.9 cd	92.5 a	99.4 a
Hairy vetch RR + oat	15.0 c	79.4 a	94.4 ab	15.6 c	79.4 a	95.0 a	10.0 bcd	87.5 ab	97.5 a
Austrian winter pea FR + oat	16.9 c	80.0 a	96.9 a	26.9 c	66.3 a	93.2 abc	6.3 cd	93.1 a	99.4 a
Austrian winter pea RR + oat	21.3 c	73.8 a	95.1 ab	22.5 c	72.5 a	95.0 a	3.1 d	96.3 a	99.4 a

† Cover crop seeding rates: hairy vetch full rate (34 kg ha^{-1}), hairy vetch reduced rate (22 kg ha^{-1}), Austrian winter pea full rate (67 kg ha^{-1}), Austrian winter pea reduced rate (45 kg ha^{-1}), and oat (102 kg ha^{-1}).
‡ Year × cover crop interactions were significant for percentage soybean, cover crop, and total fall ground cover ($P \leq 0.001$); therefore, data were reported separately for each year.
§ Treatment means within the same column and followed by the same letter were not considered different at $P \geq 0.05$.
¶ FR, full rate.
# RR, reduced rate.

in 1996 was greater in all treatments except the Austrian winter pea reduced seeding rate when compared with the no cover crop treatment. In 1997, percentage cover was greater in the hairy vetch reduced rate plus oat and the Austrian winter pea reduced rate plus oat treatment than in the no cover crop treatment. In 1998, percentage ground cover was greater in all cover crop treatments than in the no cover crop treatment.

In the sorghum experiment, total percentage ground cover in 1996 was greater in the hairy vetch full rate plus oat treatment than in the no cover crop treatment. In 1997, total percentage ground cover was greater in all treatments except in the hairy vetch full rate, Austrian winter pea full rate, and hairy vetch full rate plus oat treatment when compared with the no cover crop treatment. In 1998, percentage ground cover was greater in all cover crop treatments than in the no cover crop treatment.

Our results suggest that the addition of oat to legume cover crops increased fall cover. These results were similar to those reported by Johnson et al. (1998). Though substantial (>80%) ground cover was provided by soybean residue in 1996 and 1997, the addition of oat as a fall cover may be warranted when environmental conditions limit soybean crop growth such as in 1998. These results also indicate that if legume cover crops are seeded onto erodable landscapes, the addition of oat in the fall may significantly increase fall ground cover and decrease the potential for soil movement during legume establishment.

Spring Dry Matter Yield of Legume Cover Crops

Oat winter-killed during the winter in each year; therefore, spring dry matter yield consisted only of the legume cover crop biomass. Therefore, in each experiment, the no-cover control and the oat-alone treatments were removed before statistical analysis. In the corn experiment, year × cover crop interactions were not significant for spring dry matter yield ($P \geq 0.22$); therefore, data were pooled (Table 4). Dry matter yield was greatest in the hairy vetch full-rate treatment. The addition of oat decreased total dry weight in both the hairy vetch full-rate and the hairy vetch reduced-rate treatments.

Table 3. Percentage soybean residue, cover crop (CC) ground cover, and total fall ground cover 13 wk after CC seeding in the sorghum experiment (1996–1998).

	1996‡			1997			1998		
CC treatment†	Soybean	CC	Total	Soybean	CC	Total	Soybean	CC	Total
	Ground cover, %								
Untreated	87.5 a§	0.0 c	87.5 bc	85.6 a	0.0 d	85.6 e	52.5 a	0.0 d	52.5 b
Oat	28.8 b	65.6 a	94.4 ab	33.1 de	65.0 a	98.1 a	20.6 bc	78.8 ab	99.4 a
Hairy vetch FR¶	77.5 a	12.5 b	90.0 abc	60.6 c	28.8 b	89.4 cde	20.6 bc	78.2 ab	98.8 a
Hairy vetch RR#	76.3 a	13.8 b	90.1 abc	80.0 ab	15.0 bc	95.0 abcd	35.0 ab	56.9 c	91.9 a
Austrian winter pea FR	79.4 a	8.8 bc	88.2 abc	68.1 bc	21.9 bc	90.0 bcde	17.5 bc	78.1 ab	95.6 a
Austrian winter pea RR	76.3 a	8.1 bc	84.4 c	81.9 ab	11.3 cd	93.2 abcd	25.0 bc	66.3 bc	91.3 a
Hairy vetch FR + oat	29.4 b	66.3 a	95.7 a	18.1 e	70.6 a	88.7 de	5.6 c	92.5 a	98.1 a
Hairy vetch RR + oat	25.0 b	69.4 a	94.4 ab	30.6 de	66.3 a	96.9 ab	15.0 bc	81.3 ab	96.3 a
Austrian winter pea FR + oat	21.3 b	73.8 a	95.1 ab	38.1 d	58.1 a	96.2 ab	6.9 c	91.9 a	98.8 a
Austrian winter pea RR + oat	21.9 b	71.9 a	93.8 ab	34.3 d	60.6 a	94.9 abcd	10.6 c	89.4 a	100.0 a

† Cover crop seeding rates: hairy vetch full rate (34 kg ha^{-1}), hairy vetch reduced rate (22 kg ha^{-1}), Austrian winter pea full rate (67 kg ha^{-1}), Austrian winter pea reduced rate (45 kg ha^{-1}), and oat (102 kg ha^{-1}).
‡ Year × cover crop interactions were significant for percentage soybean, cover crop, and total fall ground cover ($P \leq 0.001$); therefore, data were reported separately for each year.
§ Treatment means within the same column and followed by the same letter were not considered different at $P \geq 0.05$.
¶ FR, full rate.
# RR, reduced rate.

Table 4. Spring dry matter yield of winter cover crops before corn establishment (1997–1999).

Cover crop†	Total dry weight‡
	Mg ha^{-1}
Hairy vetch full rate	1.96 a§
Hairy vetch reduced rate	1.63 ab
Austrian winter pea full rate	0.80 de
Austrian winter pea reduced rate	0.85 de
Hairy vetch full rate plus oat	1.34 bc
Hairy vetch reduced rate plus oat	1.19 cd
Austrian winter pea full rate plus oat	0.55 e
Austrian winter pea reduced rate plus oat	0.54 e

† Treatment seeding rates: hairy vetch full rate (34 kg ha^{-1}), hairy vetch reduced rate (22 kg ha^{-1}), Austrian winter pea full rate (67 kg ha^{-1}), Austrian winter pea reduced rate (45 kg ha^{-1}), and oat (102 kg ha^{-1}).
‡ Year × cover crop interaction was not significant ($P \geq 0.22$); therefore, data were pooled among years.
§ Treatment means within the same column and followed by the same letter were not considered different at $P \geq 0.05$.

In the sorghum experiment, year × cover crop interactions were significant for spring dry matter yield ($P \leq 0.001$); therefore, data were analyzed separately by year (Table 5). In 1997, dry matter yield was greatest in the hairy vetch full-rate treatment. The addition of oat decreased dry matter yield in both Austrian winter pea treatments and in the hairy vetch full-rate treatment. In 1998, dry matter yield was greater in the hairy vetch full-rate treatment than in the Austrian winter pea reduced-rate treatment, the Austrian winter pea plus oat treatments, and the hairy vetch reduced rate plus oat treatment. In 1999, dry matter yield was greater in the hairy vetch treatments than in the Austrian winter pea treatments.

These results indicated that total dry matter yield among cover crop treatments was variable; however, in each year, total dry matter yield was greatest in the hairy vetch full-rate treatment. Our results were similar to those reported by Blevins et al. (1990), McVay et al. (1989), and Stute and Posner (1993). McVay et al. (1989) reported that hairy vetch and crimson clover (*Trifolium incarnatum* L.) produced larger amounts of dry matter than Austrian winter pea, whereas Blevins et al. (1990) reported that hairy vetch produced greater dry matter yield than either big flower vetch (*Vicia grandiflora* W. Koch var. *kitailbeliana*) or rye. Furthermore, Stute and Posner (1993) reported that hairy vetch produced greater dry matter yield than red clover (*Trifolium pratense* L.), alsike clover (*Trifolium hybridum* L.), ladino clover (*Trifolium repens* L.), and sweetclover [*Melilotus officinalis* (L.) Lam.].

Table 5. Spring dry matter yield of winter cover crops before sorghum establishment (1997–1999).

Cover crop†	Year 1997‡	1998	1999
	– Total dry weight, Mg ha^{-1} –		
Hairy vetch full rate	2.18 a§	1.49 a	2.11 a
Hairy vetch reduced rate	1.51 b	1.14 abc	2.42 a
Austrian winter pea full rate	1.52 b	0.82 abc	0.73 b
Austrian winter pea reduced rate	1.47 b	0.52 c	0.64 b
Hairy vetch full rate plus oat	1.50 b	1.45 ab	1.85 a
Hairy vetch reduced rate plus oat	0.97 bc	0.61 bc	2.27 a
Austrian winter pea full rate plus oat	0.80 c	0.51 c	0.52 b
Austrian winter pea reduced rate plus oat	0.70 c	0.54 c	0.23 b

† Treatment seeding rates: hairy vetch full rate (34 kg ha^{-1}), hairy vetch reduced rate (22 kg ha^{-1}), Austrian winter pea full rate (67 kg ha^{-1}), Austrian winter pea reduced rate (45 kg ha^{-1}), and oat (102 kg ha^{-1}).
‡ Year × cover crop interaction was significant ($P \leq 0.001$); therefore, data were reported separately for each year.
§ Treatment means within the same column and followed by the same letter were not considered different at $P \geq 0.05$.

Table 6. Estimated fertilizer N equivalent value provided to corn by fall cover crop.

Cover crop†	Year 1997	1998	1999	Mean
	kg ha^{-1}			
Oat	−74.5	13.2	−21.1	−27.5
Hairy vetch FR‡	41.2	61.5	23.0	41.9
Hairy vetch RR§	7.5	46.2	82.0	45.2
Austrian winter pea FR	10.3	26.8	52.1	29.7
Austrian winter pea RR	34.8	23.1	55.4	37.8
Hairy vetch FR + oat	−13.2	44.3	64.8	32.0
Hairy vetch RR + oat	−49.4	34.1	78.0	20.9
Austrian winter pea FR + oat	−53.8	−3.1	−24.6	−27.2
Austrian winter pea RR + oat	−54.3	4.5	−7.0	−18.9

† Treatment seeding rates: hairy vetch full rate (34 kg ha^{-1}), hairy vetch reduced rate (22 kg ha^{-1}), Austrian winter pea full rate (67 kg ha^{-1}), Austrian winter pea reduced rate (45 kg ha^{-1}), and oat (102 kg ha^{-1}).
‡ FR, full rate.
§ RR, reduced rate.

In our experiment, the addition of oat to either hairy vetch or Austrian winter pea tended to decrease total dry matter yield of the legume. This may be due to decreased legume cover crop establishment (plants m^{-2}) or decreased fall growth caused by oat competition for light or moisture. Fall biomass or stand counts data were not collected to verify these effects. Our results indicated that maximum dry matter yield was obtained when hairy vetch was planted alone at the full seeding rate.

Fertilizer Nitrogen Equivalent Value

Regression analysis indicated that the relationship between corn or grain sorghum yield and fertilizer N rate for each cover crop treatment differed among years for both slope ($P \leq 0.001$) and y intercept ($P \leq 0.001$); therefore, data were analyzed separately. Since N rates were based on expected yield goal estimates, we were unable to develop a linear N rate plateau (data not presented). In each year, corn or grain sorghum yield increased linearly as fertilizer N rate increased. Based on these regression equations, the fertilizer N equivalent value provided by each cover crop was estimated in each year (Tables 6 and 7).

The fertilizer N equivalent value contributed by each cover crop was greater on average in the sorghum experiment than in the corn experiment. This suggests that sorghum may be more efficient at utilizing N from legume residue or that released N was available at a more critical time for sorghum utilization. These results differ from those presented by McVay et al. (1989) where estimates for replaced fertilizer N were greater for corn than sorghum. McVay et al. (1989) hypothesized that the difference was due to the higher N requirement and yield potential of corn; however, in our experiment, sorghum grain yield was greater than corn.

In both the corn and sorghum experiments, the mean estimated fertilizer N equivalent value was highest in

Table 7. Estimated fertilizer N equivalent value provided to sorghum by fall cover crop.

Cover crop†	Year 1997	1998	1999	Mean
	kg ha^{-1}			
Oat	−40.4	−25.9	52.1	−4.7
Hairy vetch FR‡	27.0	64.5	93.3	61.6
Hairy vetch RR§	66.5	−0.4	90.6	52.2
Austrian winter pea FR	−6.2	41.0	83.3	39.4
Austrian winter pea RR	−6.0	13.0	14.9	7.3
Hairy vetch FR + oat	−15.9	62.5	91.0	45.9
Hairy vetch RR + oat	−37.7	−7.0	118.0	24.4
Austrian winter pea FR + oat	1.0	4.4	44.9	16.8
Austrian winter pea RR + oat	−28.5	13.8	2.5	−4.1

† Treatment seeding rates: hairy vetch full rate (34 kg ha^{-1}), hairy vetch reduced rate (22 kg ha^{-1}), Austrian winter pea full rate (67 kg ha^{-1}), Austrian winter pea reduced rate (45 kg ha^{-1}), and oat (102 kg ha^{-1}).
‡ FR, full rate.
§ RR, reduced rate.

the hairy vetch-alone treatments. The addition of oat to either hairy vetch or Austrian winter pea reduced the amount of N available to corn and sorghum in each experiment. The fertilizer N equivalent value provided by oat alone was negative. Our results were similar to those reported by Wagger (1989) where the fertilizer N equivalent values for hairy vetch and rye were 40 and −25 kg N ha^{-1}, respectively.

Our results indicated that hairy vetch contributed the greatest amount of available N and that the addition of oat reduced the yield of the succeeding cash crop. Our results also indicated that the mean fertilizer N equivalent value was similar between the reduced and full seeding rate of hairy vetch in both the corn and sorghum experiments. Among years however, substantial variability was evident between the full and reduced seeding rates of each legume cover crop. This suggests that there may be increased risk associated with the reduced seeding rates of these winter annual legumes and that it may be beneficial for growers to plant the recommended forage seeding rate when establishing these cover crops.

Table 8. Cover crop influence on corn and sorghum grain yield (1997–1999).

Cover crop†	Corn yield	Sorghum yield
	Mg ha^{-1}‡	
Untreated	4.83 abcd§	6.59 b
Oat	4.56 cd	6.57 b
Hairy vetch FR¶	5.06 ab	7.33 a
Hairy vetch RR#	4.98 abc	7.00 ab
Austrian winter pea FR	5.19 a	7.06 ab
Austrian winter pea RR	4.88 abcd	6.89 ab
Hairy vetch FR + oat	4.88 abcd	6.94 ab
Hairy vetch RR + oat	4.70 bcd	6.82 ab
Austrian winter pea FR + oat	4.47 d	6.64 b
Austrian winter pea RR + oat	4.80 abcd	6.78 b

† Treatment seeding rates: hairy vetch full rate (34 kg ha^{-1}), hairy vetch reduced rate (22 kg ha^{-1}), Austrian winter pea full rate (67 kg ha^{-1}), Austrian winter pea reduced rate (45 kg ha^{-1}), and oat (102 kg ha^{-1}).
‡ Year × cover crop interactions were not significant in either the corn ($P \geq 0.88$) or sorghum experiments ($P \geq 0.72$); therefore, data were pooled.
§ Treatment means within the same column and followed by the same letter were not considered different at $P \geq 0.05$.
¶ FR, full rate.
# RR, reduced rate.

Table 9. Nitrogen influence on corn and sorghum grain yield (1997–1999).

N rate	Corn yield 1997†	Corn yield 1998	Corn yield 1999	Sorghum yield 1997	Sorghum yield 1998	Sorghum yield 1999
kg ha^{-1}	Mg ha^{-1}					
0	5.36 d‡	1.65 d	4.27 b	6.04 c	4.75 d	5.66 c
56	6.19 c	2.29 c	5.35 a	7.05 b	6.06 c	7.18 b
112	7.42 b	2.78 b	5.51 a	7.68 a	6.97 b	7.46 ab
168	8.10 a	3.43 a	5.68 a	7.97 a	7.75 a	7.71 a

† Year × N interactions were significant for grain yield in both the corn ($P \leq 0.0001$) and sorghum experiments ($P \leq 0.0001$); therefore, data were separated by year.
‡ Treatment means within the same column and followed by the same letter were not considered different at $P \geq 0.05$.

Grain Yield Response to Cover Crop and Nitrogen Fertilizer

Year × cover crop × N and cover crop × N interactions were not significant for grain yield in either the corn ($P \geq 0.13$; $P \geq 0.08$) or sorghum ($P \geq 0.38$; $P \geq 0.35$) experiments, respectively. Year × cover crop interactions were also not significant for grain yield in either the corn ($P \geq 0.88$) or sorghum experiment ($P \geq 0.72$); therefore, data were pooled (Table 8). In the corn experiment, yield was greater in the Austrian winter pea full-rate treatment when compared with the oat alone, hairy vetch reduced rate plus oat, and the Austrian winter pea full rate plus oat treatments. In the sorghum experiment, yield was greater in the hairy vetch full-rate treatment when compared with the untreated control, oat alone, or the Austrian winter pea plus oat treatments.

Year × N interactions were significant for yield in both the corn ($P \leq 0.0001$) and sorghum experiments ($P \leq 0.0001$); therefore, data were separated by year (Table 9). In each experiment, yield increased as N rate increased. Though a direct statistical comparison is not valid, yield was greater on average in the sorghum experiment than in the corn experiment. This observation was more apparent in 1998 and 1999 when moisture was a limiting factor (Table 1).

Our results suggest that fall seeding of a winter annual legume crop into soybean may increase crop yield; however, seeding oat alone or in combination with a winter annual legume cover crop may negate any beneficial affects of the winter annual legume cover crop on grain yield. Our results also suggest that sorghum may prove to be a more economically viable crop than corn, especially in soils where water limitations exist.

CONCLUSIONS

The addition of oat to each legume cover crop did increase percentage fall ground cover but also decreased total spring dry matter yield. The reduction in dry matter by oat limited the fertilizer N equivalent value contributed by each legume cover crop. Though the mean fertilizer N equivalent value was similar between the reduced and full seeding rates in hairy vetch, there was substantial variability among years. This indicates that the full rate of hairy vetch may prove most beneficial to growers. Our results also indicated that hairy vetch contributed the most N to the subsequent grain crop and that winter annual legume cover crops may increase crop grain yield. These results indicate that winter annual cover crops may prove beneficial to both no-tillage corn and sorghum production systems.

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